Stability analysis of single-cross hybrids of maize

(<u>Zea</u> <u>mays</u> L.) produced from selected and

unselected inbred lines

by

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INTRODUCTION

Much of the evidence confirms the viewpoint that the individual cannot be considered out of the context of its environment. The problem of inconsistency of performance of crop varieties has been long recognized by plant breeders. There is rather general agreement among plant breeders that interactions between genotype and environment have an important bearing on the breeding of better varieties.

Although plant breeders have been aware of important genotypic differences in stability, they have been unable to exploit them fully in breeding programs. Studies on the effect of environment upon animals and plants by Mather (1953), Lerner (1954), Dobzhansky and Levene (1955), Lewontin (1957), and others provided some basic knowledge about the nature and significance of adaptability or stability of production. The results from their data and conclusions, however, were of little value to applied genetics and plant breeding.

The maize breeders have struggled continuously to develop high yielding hybrids, and, therefore, must be concerned with the relative large variation in yield potential that occurs among the many environments in which a hybrid will be grown. The development of hybrids that have a stable performance over a range of environmental conditions would allow a given hybrid to be useful and productive in a larger region. Extensive testing, therefore, has been required to identify the genotypes

that possess the greatest stability of performance over vary-
ing environments.

In an attempt to bridge this gap, procedures have been
proposed recently which describe the mean of a variety in
terms of estimated stability parameters. Some studies have
been conducted by Finlay and Wilkinson (1963), Eberhart and
Russell (1966), and others to illustrate the use of these
techniques; they have been shown to be of greater value in
evaluating the relative stability of varieties and hybrids.

The objective of this study was to examine the relative
performance for grain yield among groups of maize (Zea mays
L.) hybrids that were produced from selected and unselected
inbred lines to determine which group of hybrids was more
productive and stable over a range of environments.

REVIEW OF LITERATURE

Lack of basic information about the genetics of plant populations has meant that plant breeding is largely empirical. The importance of genotypic differences in adaptability of some crop species has long been appreciated by plant breeders. Many approaches to the estimation of the various stability parameters for maize and other agronomic species have been and are being proposed. The literature on genotype x environmental interactions is extensive. An extensive review of the literature pertaining to a consideration of the buffering capacity of plant species against variations of the environment comprises two categories of papers. Some are directed toward the theoretical explanation involving the genotype behavior over the range of environments that occur in different locations or seasons, and others which characterize the presentation and interpretation of results from planned experiments. I will be first concerned with the reviews which deal largely with the theoretical aspects, followed by those reports which present the results of field experiments with maize and other crop species.

According to Mather (1953) and others, lack of stability is the term used to describe variation which is not genetic in origin and which has no observed environmental cause. Since the cause is unknown the variation appears to be random in direction. Bradshaw (1965) pointed out that there is

considerable amount of evidence favoring stability being under genetic control. He considers stability and adaptation as being correlated and suggests that the condition where there is lack of plasticity is included in the term stability. He describes the concept of plasticity when the expression of the genotype is altered by environmental influences and suggests that morphological and physiological plasticity are closely interrelated. The stability of performance aimed by plant breeders may be due to inherent stability of the crop species and plasticity of the components of final yield. He presents evidence of varying population densities with different plant species to emphasize and substantiate his discussion of plasticity and stability.

Lerner (1954) has discussed the evidence for the hypothesis that control of homeostasis in cross-fertilized organisms may be vested to a considerable degree in heterozygosity. He favors the superiority of fitness of heterozygotes as compared to homozygotes; he suggests that this buffering action must be a function of some type of self-controlling model whereby alternate developmental pathways are available to the organism with their use dependent upon genetic and environmental influences. Selection is responsible for the preservation of genetic variability and consequently in maintaining heterozygosity in the population. He has cited Schmalhausen (1949) who defined stabilizing selection as the rejection by natural selection of the extreme deviates of the

population. Differential reproduction of individuals thus promotes both a high degree of individual homeostasis and heterozygote superiority.

Lewontin (1957), in his paper, has described two types of adaptation: adaptation within a population and adaptation of a population. The former is defined by him as the relative ability of individuals of a particular genotype to contribute offspring to successive generations; the latter as the ability of that population relative to others to leave offspring to succeeding generations. These two definitions are the specification of fitness or adaptative value of genotypes to a given environment. He further points out that a population possesses a greater general adaptation than another if it is adapted to a greater number of environments. Hence, a population which can adjust its genotypic or phenotypic composition to allow its survival and reproduction in different environments is called a homeostatic population. It should, however, be emphasized that homeostasis and adaptation are not identical, although they are closely related. Lewontin (1957) also considers that there are two types of mechanisms to control homeostasis: the genotypic composition of the population and second the individuals themselves.

Simmonds (1962) has examined the concept of adaptation and defined it as the property of a genotype which permits its survival under selection. He considers four types of adaptation: (1) specific genotypic, (2) general genotypic,

(3) specific population, and (4) general population adaptation. Specific genotypic adaptation is defined as the close adaptation of the corresponding phenotype to a limited environment. For example, tomatoes (_Lycopersicon esculentum_) for hothouse production are an inbred annual species adapted for high performance in a specific environment. General genotypic adaptation is defined as the capacity of a genotype to produce a range of phenotypes adapted to a variety of environments. This is exemplified by several plant species which show a wide adaptation of certain lines or clones. Specific population adaptation is defined as the specific adaptation of a heterogeneous population that is attributable to interactions among components, rather than to adaptation of the components themselves. Examples of these types of populations are those composed of a mixture of genotypes where superior performance of the composed population is compared to the weighted mean of the components. The definition of general population adaptation is analogous to general genotypic adaptation; i.e., the capacity of a heterogeneous population to adapt to a variety of environments. Simmonds (1962) considers capacity as stability of performance and thus should be measured in terms of variance of error.

Allard and Bradshaw (1964) have discussed the two mechanisms which promote stability in productivity over varying environments. They defined a well-buffered variety, which is equivalent to homeostatic term used by Lewontin (1957),

as the one which can adjust its genotypic or phenotypic state in response to transient fluctuations in environment in such ways that it gives high and stable economic return for the place and year. They used the terms individual and populational buffering as descriptive for the two stabilizing mechanisms. Individual buffering is defined as the capacity of individual members of a population to exhibit a stable performance over environments as a result of buffering within the individual itself. Population buffering refers to buffering above and beyond that of individual constituents of the populations. In self-pollinated species there is evidence that buffering can be a property of specific genotypes not associated with heterozygosity. They also pointed out that the idea of genetic diversity associated with heterozygosity has been widely recognized and utilized in crossbreeding species. They suggest that population buffering is real and often important, even though there have been few conscious attempts to utilize it and little is known of its underlying mechanisms. The use of single- and double-cross hybrids in maize is cited as one example of widespread utilization of population buffering. They also described some of the possible advantages and disadvantages of the use of mixtures or blends in crop species where uniformity of the product is an important factor and in which for some crop species the blends would meet the ideal requirements for uniformity.

Thoday (1955) gave two possible explanations to account

for superior homeostasis or buffering in heterozygous individuals. The first one he attributes a special property to heterozygosity that promotes versatility in development beyond that possible in homozygotes. In the second one, he attributes no special property to heterozygosity except the classic one of promoting segregation, which leads to superior buffering in hybrids by virtue of the heterozygous balance achieved in outbreeding species by natural selection.

Plaisted and Peterson (1959) developed a statistical technique for evaluating the ability of selections for consistency of yield in different locations or seasons. Their technique consists of calculating a combined analysis of variance for all potato (Solanum tuberosum) varieties evaluated in different locations in a given year. If the variety by location mean square was significant they proceeded to compute the combined analysis of variance for all combinations of pairs of varieties at all locations per year, in such a way that if there are n varieties, there will be n(n-1)/2 analysis. The observed mean squares were equated to the expected mean squares and solved to obtain an estimate of σ^2_{vl} from the analysis of each pair of varieties. The arithmetic mean of the estimates σ^2_{vl} is obtained for all pairs of varieties having one common number, thus there will be n-1 estimates in each mean. This is the relative contribution of the common variety to the variety by location interaction obtained in the combined analysis of variance using all

varieties. Finally, a variety with better adaptation should be the one that gives low contribution to the variety by location interaction.

Scott (1967) presented a study to determine if one can select for yield stability and attempted to verify these selection differences by subsequent testing. He defined a stable hybrid as one that exhibits the least yield variation over all environments. This hybrid would be high yielding at low yield levels and would have a relatively low yield potential. Further, he defines another type of stable hybrid as one that does not change its relative performance with other entries tested in many environments. Such a hybrid would yield as expected relative to the other entries at each of many environments. Its regression value on the environmental index would be approximately 1.0 when analyzed by the methods of Finlay and Wilkinson (1963) and Eberhart and Russell (1966). He suggests that selection for one type of stability automatically selects against the other type; and concluded that selection for stability of yield was effective in most cases and this strongly suggests that this character is under genetic control. Both types of stability, as defined, have merit for selection in a desirable maize hybrid; however, these two types tend to be mutually exclusive.

Baker and Kosmolak (1977) studied the effects of genotype x environment interaction of two composite samples of 20 to 30 wheat (Triticum aestivum) lines by mixing equal

amounts of seeds and grown at two to four locations for two years in western Canada. They used three parameters, the mean, the variance, and the correlation to assess the importance of genotype x environmental interaction of eight traits related to milling and baking quality in hard red spring wheat. Differences between environments were significant for all traits studied. The variances among lines within environments differed significantly, indicating the presence of genotype x environment interaction. Correlation between lines grown at different environments varied from a low value of -0.40, indicating that lines selected in one environment would not necessarily have acceptable quality in another, to a high value of 0.96. Also, relatively high correlations were found for four traits suggesting relative insensitivity to genotype x environment interaction.

Sprague and Federer (1951) attempted to estimate the relative magnitude of the variety x location and variety x year components of variance to the error variance component. From these estimates they obtained information for conducting yield trials. A series of topcross, single-cross, and double-cross hybrid maize were grown in randomized complete block design for eight years at several locations in Iowa. Data from these yield experiments showed that the existence of either variety by location or variety by year interaction is the cause of the small increase in the average genetic advance for the comparisons involving two or more replications.

They also suggested that the optimum distribution of a given number of plots would be one replication per location with an increase in number of locations and years.

Rojas and Sprague (1952) worked with two groups of experiments of maize yield trials. The first included 55 single crosses grown at three locations for three years. The second involved 45 single crosses grown at two locations for a three-year period. They found the variance components for the interactions involving specific combining ability and either locations or years were consistently larger than the corresponding estimates involving general combining ability. This suggests that the variance of specific combining ability included not only the nonadditive deviations due to dominance and epistasis but also a considerable portion of the genotype x environment interaction.

Sentz et al. (1954) developed five levels of heterozygosis for each of two populations of maize utilizing inbred lines and their F_1, F_2, and backcross generations. A split-plot design was employed with six to 25 replications per trial. The material was grown in five locations for four years. The magnitude of the heterozygosis levels by environment interaction variance indicated greater importance of genotype x year than genotype x location interaction for most characters studied. Variability in heterozygosis-performance relationships under various environmental conditions demonstrated the importance of genotype x environment

interactions in establishing principles of quantitative inheritance.

In comparing yields of 317 single and 483 double crosses of maize, Jones (1958) observed that average yields of the two groups did not differ. The single crosses displayed a bi-modal frequency distribution and a greater range in yield, however, than did the double crosses, whose frequency was more nearly normal. Double crosses were consistently greater yielding and more desirable in other respects than the single crosses. He attributed the more consistent and stable per-formance of double crosses to their more genetically variable composition and suggested that hybrid mixtures may be equally as valuable for naturally self-fertilized species as crosses of inbred strains have been for cross-fertilized species.

Adams and Shank (1959), working with eight groups of hybrids of maize with differing levels of heterozygosity, studied the relationship of heterozygosity to homeostasis. Hybrids belonging to the same level of heterozygosity group frequently manifested significantly different buffering properties. Hence, heterozygosity per se was not the only hypothesis required to account for homeostasis. Homeostasis in those maize hybrids was highly related to the expected levels of heterozygosity of the hybrid groups. Also, the relationship of homeostasis to heterozygosity was analogous to the relationship of heterosis to heterozygosity; both phenomena might result from a common fundamental geometry of

enumeration and measurement.

Shank and Adams (1960) studied the environmental effects within inbred lines and single crosses of maize. Ten long-time inbred lines and five F_1 hybrids obtained from these inbreds were grown in five randomized block designs for two years. The heterozygous hybrids, as a group, were found to be better buffered, as measured by the lower coefficient of variation, than the homozygous parents for the five plant and ear traits studied. There appeared to be no significant differences in buffering among the hybrids for ear weight; the inbred parents, however, differed significantly among themselves in buffering for all traits. The proposal of systems of alternative biosynthetic pathway which function under different environmental optimum is discussed and these systems seem to be controlled in maize heterozygotes by alternative alleles of a single gene or by nonalleles of two or more loci. They emphasized that in maize homozygotes the systems are controlled by nonalleles.

Finlay (1963), working with F_2 seed of 45 barley (Hordeum vulgare) hybrids and their 10 parent varieties over a three-year period, found that hybrids showed both an increase in comparison with parental lines for yield over all environments and an extraordinary increase in phenotypic stability. Most of the hybrids were observed to display above average stability while most of the parents exhibited below average stability. The marked superiority of hybrids in the unfavor-

able environments accounted for much of the phenotypic stability of the heterozygous populations. He also found that the superior performance of hybrids in all environments resulted in enhanced mean yield over all environments.

An investigation on phenotypic stability was conducted by Rowe and Andrew (1965) in five inbred dent lines of maize, ten F_1 hybrids, F_2, F_3, BC_1 and BC_2, grown at two locations with two treatments per location for a two-year period. They considered six genotypic groups in accordance with the level of heterozygosity. Stability was measured by estimating the environment and variety by environment components of variance and by calculating deviations from regression. Stability, as measured by environmental variance components decreased with increasing heterozygosity for grain yield. Phenotypic stability decreased as mean performance increased. The genotype by environment components of variance were larger for the nonsegregating inbred and F_1 groups than for the genetically diverse segregating groups. These results suggested that differences in stability among genotypic groups were associated with differences in ability to exploit favorable environments. A regression analysis showed that the segregating groups were more stable in performance than the inbred or F_1 groups, since their means for each environment deviated less from regression. Variances for deviation from regression and estimated variety by environment components of variance indicated that the superior stability of the

genetically diverse segregating populations may be due to compensating interactions of individuals within varieties of these groups. No evidence was found for superior F_1 stability.

Byth and Weber (1968) conducted experiments with soybeans (Glycine max) across three environments and found that heterogeneous and homozygous populations performed equally. They observed greater phenotypic stability for seven traits in the F_2 derived lines than in the F_5 derived lines. They believed the greater stability was attributable to the greater heterogeneity within the F_2 derived lines, and the genotypic uniformity within the F_5 derived lines resulted in larger genotype by environment interactions for all characters studied. The heterogeneous F_2 derived populations had lower variance and this was attributed to the homeostatic effects due to heterogeneity within lines.

Bhatt and Derera (1975) investigated genotype by environment interactions, heritabilities, and correlations among nine quality traits in three sets of hard spring wheat at six different environments. The material was grown in a randomized complete block design with four replications. Significant genotype by environment interaction was found for all the quality traits. Significant positive correlations existed between protein content and baking traits, grain protein and flour protein, and baking score and baking volume. They concluded that evaluation of breeding lines over several

environments will give a more accurate estimate of their quality traits.

Finlay and Wilkinson (1963) made a study of analysis of adaptation in plant breeding programs. They developed a statistical technique for comparing the performance of a set of barley varieties grown at several environments in south Australia. The statistical technique consists of measuring yield on a logarithmic scale and regressing individual yield of each variety on the mean yield of all varieties at each environment. The mean yield of all varieties at each site and for each season provided a numerical grading of sites and seasons and is utilized for comparative evaluation of the environment. In this way they could identify varieties adapted to either high or low yielding environments and those showing good general adaptability. Two parameters were used in their analysis of adaptation, the regression coefficient and the variety mean yield over all environments. Average stability is indicated when the regression coefficient approximates 1.0. When this is associated with high mean yield, varieties have general adaptability; on the other hand, when associated with low mean yield, varieties are poorly adapted to all environments. Regression values above 1.0 mean varieties with increasing sensitivity to environmental change (below average stability) and, therefore, increasing specificity of adaptability to high yielding environments. Regression values below 1.0

indicate a greater resistance to environmental change (above average stability) and show increasing specificity of adaptability to low yielding environments. The second parameter, the variety mean yield over all environments, gives information to compare measure of performance of the individual varieties. By plotting the two parameters as coordinates in a two-dimensional scatter diagram, this provides a wider interpretation about them.

Finlay and Wilkinson (1963) evaluated 277 varieties in several locations and found wide variation in both mean yield and regression coefficients. Because the individual variety yields were plotted against the mean of all the variety yields for each environment, the population mean has a regression coefficient of 1.0. The varieties which presented general adaptability for their environments all possessed slightly above average phenotypic stability, with "b" values around 0.8. The low yielding varieties had "b" values ranging from 0.14 to 2.13. They consider an ideal variety the one which has high yield potential in the most favorable environment and with high phenotypic stability. Varieties with high phenotypic stability had low mean yield and were so stable that they were unable to utilize high yielding environments. Also, they found some varieties with low mean yields and high regression coefficients indicating high sensitivity to environmental changes.

Yates and Cochran (1938) applied a similar statistical

technique on barley yield data collected from six experiment
stations over a two-year period. They computed the regres-
sion coefficients of the difference between the mean yield of
each variety and the mean of all other varieties on the mean
yield of each experiment. The main purpose of their work
was to show the relationships between general fertility and
varietal differences; therefore, they suggested that this
procedure could be used to relate varietal differences with
fertilizer applications or other treatments.

Johnson et al. (1968) employed a technique similar to
that of Finlay and Wilkinson (1963) to study the yield poten-
tial and performance stability of selected hard red winter
wheat varieties. They used data from 12 varieties grown in
two regions: Southern, comprising nine sites and 283 trials
for a 24-year period; and Northern, involving ten sites and
44 trials within a three-year period. Linear regression
coefficients were computed from yields of individual varie-
ties on nursery mean yields at each location in each year.
The regressions permitted comparisons of predicted varietal
performance over a range of environments. Substantial
progress in developing varieties with improved stability of
performance and high yield potential in both regions could be
shown by the predicted yields of varieties based on their
linear regression. Some varieties whose mean yields in
regional tests were nearly equal exhibited sharply different
yields when the levels of productivity (environments) were

specified.

Breese (1969) studied the measurement and significance of genotype by environment interactions in five populations of cocksfoot (Dactylis glomerata), grown in two different locations over two years. The character studied was weight in grams of fresh material harvested. By applying the model proposed by Finlay and Wilkinson (1963), they found the major part of the population by environment variance was explained by differences between the slopes of linear regression. The deviation mean square was significantly greater than the replication error item so that there were deviations from linearity which could not be explained in terms of yield error. Since the linear regression represented very definite and measurable response to environment, they considered more profitable the model described by Eberhart and Russell (1966) than the one by Finlay and Wilkinson (1963). They concluded for the five grass populations that the yield responses measured were linear, and differences between populations could be largely explained by differences between the slopes of their linear regression.

Knight (1970) reviewed the research of Mitchell and Lucas, 1962, and Breese (1969) where the regression analysis developed by Finlay and Wilkinson (1963) was applied. He found the present alternative of plotting the yield of a genotype as a linear function of the environment,when the environment is measured as the mean yield of several genotypes, was a

valuable technique for the plant breeder. However, it is essential to realize that the technique uses a transformation to make linear an average genotypic response. Also, he emphasized when making a biological interpretation that: (1) if the environmental variation in one factor ranges both below and above the optimum, then sub- and superoptimum mean yields of equal value are juxtaposed; (2) different limiting factors result in equally low mean yields (genotypes are unlikely to be similarly ranked under these factors but those differences in ranking are not readily detected by the existing regression technique); and (3) the interpretation will be greatly affected by the scale in the analysis. It is possible that no one scale will be appropriate for all genotypes in a trial. If those possibilities are recognized, the procedure of plotting the yield of a variety as a regression on the mean yields of many varieties will continue to aid the plant breeder in his task of selecting genotypes with various responses to the environment.

Johnson and Whittington (1977) studied the effects of genotype by environment interaction for 16 F_1 barley hybrids. Sixteen genotypes grown in 16 environments were employed, comprising eight treatments in each of two seasons. The breakthrough in the analysis of genotype by environment effects was credited to Finlay and Wilkinson (1963) without the log transformation. They defined a stable genotype as one which does not interact with its environment. The regres-

sion coefficients ranged from 0.68 to 1.33, but no remarkable

stable (low b-value) or unstable (high b-value) genotypes

showed up. Generally, the hybrids had slightly higher b-

values than the male parents, but not significantly so. They

also compared each genotype by its individual mean over the

environments and by its regression coefficient. All of the

hybrids showed regression coefficients greater than 1.0, al-

though none was significant. The overall analysis of vari-

ance for most of the genotypes did not have a significant

interaction term. Hybrid stabilities in terms of yield re-

sponse to changing environments were found to be very similar

to those of the parents.

Eberhart and Russell (1966) have presented a model,

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij} \quad ,$$

which defines stability parameters which may be used to de-

scribe the performance of a variety over a series of environ-

ments. Y_{ij} represents the variety mean of the ith variety

at the jth environment, μ_i symbolizes the ith variety mean

over all environments, β_i is the regression coefficient that

measures the response of the ith variety to varying environ-

ments, δ_{ij} is the deviation from the regression of the ith

variety at the jth environment, and I_j is the environmental

index. They suggested that an index independent of the

experimental varieties obtained from environmental factors

such as rainfall, temperature, and soil fertility would be

desirable. However, until more precise knowledge of the

relationship of these factors with yield to permit the cal-
culation of environmental indices on this basis, the average
yield of the varieties in a particular environment must
suffice. The varieties must be grown in an adequate number of
environments covering the full range of all possible environ-
mental conditions in order to provide useful information.
With this procedure, three stability parameters were obtained,
the regression coefficient, the deviations from regression,
and the mean yield of all varieties. Also, this model per-
mits a partitioning of the genotype by environment interac-
tion of each variety into two parts: (1) variation attributa-
ble to the response of a variety to the different environment-
al indices; and (2) the unexplainable deviations from the
regression on the environmental index. They defined a stable
variety as one which has a regression coefficient of 1.0 and
deviation from the regression approaching 0.0.

By applying the model to single and three-way crosses of
maize, they found genetic differences among hybrids were
indicated for the regression of the hybrids on the environ-
mental index, with no evidence of nonadditive gene action.
The estimates of the deviations from regression for the dif-
ferent hybrids ranged from 0.0 to extremely large values.
Because the variety by environment (linear) sum of squares
did not account for a very large proportion of the variety
by environment interaction, they point out that deviation
from regression seems to be very important. Since the dis-

tribution of rainfall is a major environmental factor, early and late plantings can be used to obtain an extra environmentment at each location. Also, they suggest that low and high plant densities and varying rates of fertilizers could be used to increase the number of environments and provide a greater range of environmental conditions.

Smith et al. (1967), using Eberhart and Russell's (1966) model for evaluating the phenotypic stability in soybeans, found heterogenous-homozygous soybean lines responded less radically to environmental changes than did corresponding homogeneous-homozygous lines. Their stable genotype was defined as one which has a regression coefficient of 1.0 and deviations from regression of 0.0. They found that genotypes with low deviations from the regression tended to be associated with regression coefficients with below average values. Also, genotypes which expressed above average stability were influenced less by changing environmental conditions than were those that expressed below average stability. A positive correlation was observed between the mean performance of homogeneous daughter lines and heterogeneous maternal lines.

Russell and Eberhart (1968) reported results obtained from two experiments with one and two ear types of Corn Belt maize inbreds. They used ten single-ear and ten two-ear inbred lines in testcross with a one-ear single cross and a two-ear single cross to compare stability of yield performance. The first experiment was tested in 12 environments, four locations

for three years; the second, with 24 environments, four plant densities in two locations for three years. They applied the method described by Eberhart and Russell (1966) to the grain yield data in the two series of experiments.

Stability parameters were similar for the four groups of hybrids in the two experiments. The analysis showed there was less genotype by environment interaction within the (2x2)x2 group than within the (1x1)x1 group. When the relative performances of the single-ear and two-ear genotypes were compared, the (1x1)x1 group had lower average yields in the low-yield environments and higher average yields in the high-yield environments, and the reverse situation happened for the (2x2)x2 group. The (1x1)x1 group had greater deviations from the regression values than the (2x2)x2 group. On the basis of two stability parameters, mean yield and regression, the (1x2)x2 group closely satisfied the definition of a stable variety, but it was intermediate between the (1x1)x1 and (2x2)x2 groups for the parameter, deviations from the regression.

In 1969, Eberhart and Russell presented a study to compare the stability of 45 single-cross and 45 double-cross hybrids grown in 21 locations throughout the U.S. Corn Belt for two years. They gave a general model

$$Y_{KK'} = m + g_K + g_{K'} + s_{KK'} \quad ,$$

where g_K is the general effect and $s_{KK'}$ is the specific effect. With this model the variation among the hybrids can be

partitioned into general and specific sum of squares and the
residual due to epistatic effects. The means from both
single crosses and double crosses were used to estimate the
g_K and s_{KK}, effects and the corresponding mean squares due to
these effects. The residual variation due to epistatic ef-
fects can be partitioned further by removing the portion due
to the difference between the mean of the single crosses and
the mean of the balanced set of double crosses. The stability
parameters, as suggested by Eberhart and Russell (1966), were
estimated to compare the stability of the single and double
crosses.

They found a significant environment (linear) by general
mean square indicating that the inbred lines did differ in
their response to environments. Two single crosses were found
to be as stable as any of the double crosses. Even though the
double crosses showed, on the average, smaller deviation mean
squares than the single crosses, there were some high yielding
single crosses that were as stable as the average double
cross. The stability parameter, deviation mean square, was
the most important for stability of single- and double-cross
hybrids. Also, they realized that all types of gene action
seemed involved, but they emphasized that potentially useful
single crosses must be evaluated over a wide range of environ-
mental conditions to identify stable, high yielding single
crosses.

Joppa et al. (1971) used the regression analysis on yield

data of 11 selected spring wheat cultivars grown at 15 to 20

locations in the North Central U.S. and Canada for a 10-year

period. They applied the model suggested by Eberhart and

Russell (1966). The regression of cultivar yield on the

average yield of the nursery (b) and the mean square devia-

tion from the regression (sd^2) were calculated for each culti-

var in each of the years. Each cultivar had its own charac-

teristic value for b and sd^2. The magnitude of sd^2 was an

excellent indicator of specific genotype by environment inter-

actions. Also, they showed that the use of regression analy-

sis on data from uniform regional nurseries could materially

assist the plant breeder in making decisions regarding culti-

var release.

The stability parameters proposed by Eberhart and Russell

(1966) were computed by Frey (1972) for 12 midseason and 12

early oat isolines. The material was grown at four loca-

tions in Iowa for four years, using randomized block designs

with three replications. For grain yield, three isolines in

the early group and four in the midseason group produced

grain yields significantly different from the respective

recurrent parents. Among the midseason isolines, the b values

ranged from 0.76 to 1.41 and in the early group the range

was from 0.88 to 1.23. The regression values for the

recurrent parent was significantly different from 1.0, but

four early and five midseason isolines had b-values signifi-

cantly different from unity. Among the midseason isolines,

only two had nonsignificant s^2d values, and four early iso-
lines showed nonsignificant s^2d values.

Paccuci and Frey (1972) presented a study involving two
experiments, each with a series of oat lines grown in several
environments. The stability of grain yield in selected mutant
oat lines was calculated via the model given by Eberhart and
Russell (1966). They found a positive relation between grain
yields and b-values, thus decreasing the grain yield decreased
the regression coefficient values. The mutant lines selected
for normal seed weight or height did not carry many obvious
mutations for yield and stability traits, but the shorter and
large and small seed lines carried mutations that depressed
yield and b-values. Estimates of s^2d, deviations from the
regression, were very sporadic, but there was a slight tendency
for lines from untreated populations to have greater s^2d
values. For yield, they also found the variety by environment
(linear) sum of squares was 1/3 and 1/2 the magnitude of the
variety by environment interaction in experiments 1 and 2,
respectively.

Fatunla and Frey (1974) analyzed the stability index
for several traits of irradiated and nonirradiated oat (Avena
sativa) genotypes propagated in bulk populations. Data of
each trait were subjected to a regression analysis to esti-
mate the stability indices, linear regression, and deviations
from the regression in accordance with Eberhart and Russell
(1966) and Freeman and Perkins (1971). The pooled mean square

for deviations from regression, when significant, was used to
test the significance of the mean squares for environment
(linear) by population and the environment (linear) by geno-
type/population mean squares, and the pooled within-environ-
ment error mean square was used to test the significance of
the mean squares for pooled deviations from regression. They
found a significant environment (linear) by population mean
square, indicating that the generation means of regression for
grain yield were variable over environments. Mean regression
stability indexes for grain yield decreased from 1.17 to 1.02
in the nonirradiated lines and increased from 0.82 to 1.04
in the irradiated lines of descent over time. The pooled
deviation mean squares for grain yield was significant in all
generations of the irradiated lines, which shows that those
oat genotypes fitted the linear model better than did those
from the nonirradiated lines. The regression of the relative
values for grain yield upon generation numbers indicates that
there were consistent expansions in the genotype by environment
interaction variances within generations. Correlation coeffi-
cients also were computed between regression stability in-
dexes and means for grain yield per generation; correlations
were significantly positive.

Russell and Prior (1975) evaluated the stability of yield
performance of prolific and nonprolific maize hybrids. The
material included four types of maize single crosses with
seven crosses per type. The types were: (1) elite, non-

prolific; (2) first cycle, prolific; (3) second cycle or elite, prolific; and (4) crosses of elite, nonprolific with first cycle, prolific inbred lines. The material was evaluated at six plant densities in eight environments. A stability analysis was computed following the model defined by Eberhart and Russell (1966) for each density in the eight environments, for average yields over all densities in eight environments, and for 48 density-environment combinations. In the three lower plant densities, type 3 had the highest linear yield response to high yield environments; but in the three higher plant densities, the types did not differ significantly. For the average yields over all plant densities, type 3 had the highest linear response, and the other types did not differ. For the 48 environments, type 1 had the highest linear response, probably because low plant densities were usually low yield environments in which type 1 had relatively low yields, but type 3 had relative high yields. Types 2, 3, and 4 were similar for deviations from linear response for all plant densities. Type 1 had the lowest deviations in the lowest plant densities, but the deviations increased as densities increased and were the highest in the highest plant densities.

Freeman and Perkins (1971) presented a study to explain the relationship between genotypes grown in different environments and a measure of these environments. They suggested a new approach, based on biometrical interpretations, to

measure the phenotypic stability of genotypes. Their model

is represented by $\bar{y}_{ij} = \mu + d_i + \bar{\beta}Z_j + \bar{\delta}_j + \beta d_i Z_j + \delta d_{ij}$:

μ is the grand mean over all replications, genotypes, and

environments; d_i is the additive genetic contribution of the

i^{th} genotype; $\bar{\beta}$ is the combined regression slope; Z_j is the

independent assessment of the environment; $\bar{\delta}_j$ is the devia-

tion of $\bar{y}_i$ from the combined regression line; and δd_{ij} is the

deviation of the ith lines from its linear regression on Z_j in

the jth environment less $\bar{\delta}_j$. They gave an example with a

fungus from a trial containing two replications of 36 geno-

types grown in eight different environments. Their results

showed that most of the interaction was accounted for by the

heterogeneity of regressions. The values of "b" for regres-

sion of the 36 genotypes on the control ranged from 0.54 to

1.33; the mean value "b" being 0.92 $\pm$ 0.046. However, these

data did not contradict the hypothesis $\bar{\beta} = 1$, but $\bar{\delta}$ is not

negligible. A plot of the regression of the mean of the 36

genotypes on the control does not suggest any particular

curvature, merely a high degree of scatter. The use of

further controls could possibly reduce this overall scatter,

but the genotypes in this situation had different phenotypic

stability in the sense of Eberhart and Russell (1966) and

Breese (1969).

MATERIALS AND METHODS

Plant Materials

I used for this study the plant materials derived from
the two-eared maize populations Pioneer Two-ear Composite and
the Iowa Two-ear Synthetic. Pioneer Two-ear Composite (PHPRC)
was developed by W. L. Brown of Pioneer Hi-Bred International,
Inc. by crossing Caribbean and Southern United States germ-
plasm with Corn Belt inbred lines; Iowa Two-ear Synthetic
(BSTE) was developed by W. A. Russell of the Iowa Agriculture
and Home Economics Experiment Station by recombining 10 inbred
lines that expressed a prolific tendency in the corn breeding
nursery.

Hallauer (1967) and Lonnquist and Williams (1967) pro-
posed a technique for developing and testing single cross
maize hybrids by use of plants that produced seed on two ears.
The method involves the use of two prolific populations from
which single-cross hybrid development and population improve-
ment can efficiently be achieved. The so-called "full-sib
reciprocal recurrent selection method" is described in some
detail by Hallauer (1967, 1973), Hallauer and Eberhart (1970),
and Obilana (1977).

A brief description of the breeding scheme will be pre-
sented, as illustrated by Hallauer (1973). The two breeding
populations are planted in alternate rows to make the pollina-
tions. Split pollinations were used by crossing on second

ears the first day and selfing on the top ears the second day to produce the hybrid full sib seed (S_0xS_0) and selfed seed (S_1) for future inbredding and crossing. The interpopulation full-sib (S_0xS_0) progenies are yield tested in replicated experiments in several environments the following season. In the same season, the pairs of S_1 rows, corresponding to each full-sib progeny in yield test, are grown in the breeding nursery. Inbreeding to produce S_2 progenies and crossing to produce S_1xS_1 crosses usually are continued for three to five pairs of plants within each selected pair of S_1 progenies. Selection and pollinations are completed for the pairs of S_1 progenies before the yield tests of the S_0xS_0 progenies are available. After the yield tests are harvested and summarized, final selections are made for pairs of S_2 progenies included in the breeding nursery and S_1xS_1 crosses included in the yield tests the following season. Selfing and crossing as well as yield testing the derived plant-to-plant crosses are continued for five to seven generations until the lines approach homozygosity.

In the summer of 1963, Hallauer (1967) initiated the reciprocal full-sib selection program using the BSTE and PHPRC populations. He obtained selfed (S_1) seed for line maintenance and recombination, and enough hybrid (S_0xS_0) seed for yield trials from 144 pairs of S_0 plants. For the purpose of this study, two types of lines were subsequently developed: (1) selected lines from BSTE and from PHPRC, and

(2) unselected lines from BSTE and from PHPRC. Both groups
of lines originated from the selfed progeny of the 144 pairs
of S_0 plants in the C_0 populations.

The unselected lines were developed by selfing unselected
plants in each generation from the original 144 S_0 pairs,
where each one came from a different S_0 plant. No inten-
tional selection was done in selfing and maintaining these
lines. Selected lines, however, were chosen on the basis of
superior cross performance in the S_0xS_0 through the S_4xS_4
yield tests. The 24 selected lines from each population
represent eight S_0 plants of each original population. All
lines were maintained by single seed descent until the S_7
generation.

For the purpose of this study, 24 pairs of selected lines
and 24 pairs of unselected lines were used. The lines were
divided into six sets, each set containing four selected and
four unselected pairs. No two lines in a set were derived
from the same S_0 plant. Single crosses were performed within
and between each group of each set as shown in Table 1.

By applying the Comstock and Moll (1952) Design II
mating design, 16 crosses are possible between the two popula-
tions. Using the diallel mating system, six crosses are
possible within each population. The 16 Design II crosses
plus 12 diallel crosses make a total of 28 crosses from each
four pairs of lines. Thereafter, the 56 crosses derived from
four selected pairs and four unselected pairs will be

Table 1. Structure of mating patterns used in developing the crosses for this study

	1	2	3	4		1'	2'	3'	4'
1					1	1x1'	1x2'	1x3'	1x4'
2	1x2		PHPRC		2	2x1'	2x2'	2x3'	2x4'
3	1x3	2x3			3	3x1'	3x2'	3x3'	3x4'
4	1x4	2x4	3x4		4	4x1'	4x2'	4x3'	4x4'

	1'	2'	3'	4'
1'		2'x1'	3'x1'	4'x1'
2'			3'x2'	4'x2'
3'		BSTE		4'x3'
4'				

considered as a set. Six sets of 336 single crosses were made for use in this study.

Field Procedures

The 56 crosses of each set made up the entries for the experiment. Entries were arranged in a 7x8 simple rectangular lattice trial with two replications at each testing site. The six lattice trials were grown in three locations for a three-year period. The locations, years, row spacings, plant spacings within the row, and stand densities assigned for the

nine environments are shown in Table 2.

Table 2. Location, year, row width, spacing, and stand density for each experiment

Location	Year	Row width	Spacing in row	Stand density plants/ha
		--------cm--------		
Ames	1971	101.6	25.4	38,734
	1972	101.6	25.4	38,734
	1973	101.6	25.4	38,734
Ankeny	1971	91.4	24.1	45,305
	1972	91.4	24.1	45,305
	1973	96.5	24.1	42,919
Martinsburg	1971	96.5	24.1	42,919
	1972	96.5	24.1	42,919
	1973	96.5	24.1	42,919

The plots in all environments were seeded with a funnel planter and thinned when the plants were 30 to 40 cm tall to attain stands of one 17-plant row. Data were taken on the first 10 competitive plants per plot. For plots that included fewer than 10 competitive plants, data were taken on all competitive plants remaining. The experiments were hand-harvested and dried to uniform moisture level in forced air dryers.

Collection of Data

The first 10 competitive plants were harvested for grain yield. Grain yields to the nearest gram were obtained by

weighing the dry, shelled grain from each plot on a Toledo balance. Those measurements were subsequently converted to quintals per hectare.

Statistical Analysis

Analysis of variance

The data analyzed also were used by Hoegemeyer (1974). He analyzed the data for several characters using different statistical models. From those models he had computed simple and combined analyses of variance (see Tables A1 to A4 in the Appendix). For my studies I will use his analysis of variance as a basis for my analysis. Because evaluation for stability seems more relevant for total grain yield than the other plant and ear traits, only the total mean grain yield data will be used.

I analyzed the data first for hybrid mean yields by use of the following descriptive linear model:

$$Y_{ijk} = m + A_i + B_j + C_k + AB_{ij} + AC_{ik} + BC_{jk} + ABC_{ijk} \quad ,$$

where

Y_{ijk} = observed yield value of the ijk^{th} plot;

m = overall experiment mean;

A_i = effect of the ith hybrid, $i=1,\ldots,56$;

B_j = effect of the jth year, $j=1,2,3$;

C_k = effect of the kth location, $k=1,2,3$;

AB_{ij} = effect of hybrid x year interaction;

AC_{ik} = effect of hybrid x location interaction;

BC_{jk} = effect of location x year interaction; and

ABC_{ijk} = effect of hybrid x year x location interaction.

From this model, individual analysis of variance for each of the six sets and the combined analysis of variance pooled across the six sets were computed. The sources of variation with their respective degree of freedom are shown in Table 3.

In the individual and combined analysis of variance, the mean square for hybrid x year x locations interaction was tested against the pooled error mean square. If the hybrid x year x location interaction mean square was significant, it was used to test the mean squares for the other six sources of variation.

Stability analysis

The procedures described by Eberhart and Russell (1966) were followed for the stability analysis of the data, hybrid mean yields, and the calculation of the stability parameters. The stability parameters were estimated by the regression of each hybrid in an environmental index and a function of the squared deviations from this regression. The descriptive model defining the stability parameters is as follows:

$$Y_{ij} = \mu_i + \beta_i I_j + \delta_{ij} \quad ,$$

where

Y_{ij} = the hybrid mean of the ith hybrid at the jth

Table 3. Analysis of variance for the statistical model used for each set (X) and combined across sets (Y) for entry means

Source of variation	Degrees of freedom[a]		E(MS) for X
	X	Y	
Locations (L)	$(c-1)$	$(c-1)s$	
Years (Y)	$(b-1)$	$(b-1)s$	
Hybrids (H)	$(a-1)$	$(a-1)s$	$\sigma^2 + r\sigma^2_{HYL} + rb\sigma^2_{HL} + rc\sigma^2_{HY} + rbc\sigma^2_{H}$
H x Y	$(a-1)(b-1)$	$(a-1)(b-1)s$	$\sigma^2 + r\sigma^2_{HYL} + rc\sigma^2_{HY}$
H x L	$(a-1)(c-1)$	$(a-1)(c-1)s$	$\sigma^2 + r\sigma^2_{HYL} + rb\sigma^2_{HL}$
Y x L	$(b-1)(c-1)$	$(b-1)(c-1)s$	$\sigma^2 + r\sigma^2_{HYL} + ra\sigma^2_{YL}$
H x Y x L	$(a-1)(b-1)(c-1)$	$(a-1)(b-1)(c-1)s$	$\sigma^2 + r\sigma^2_{HYL}$
Pooled error	$(r-1)(a-1)bc$	$(r-1)(a-1)bcs$	σ^2

[a] a = hybrids, b = years, c = locations, and s = sets.

environment;

μ_i = the mean of the jth hybrid over all environments;

β_i = the regression coefficient that measures the response of the ith hybrid to varying environments;

I_j = the environmental index obtained as the mean of all hybrids at the jth environment minus the grand mean; and

δ_{ij} = the deviation from the regression of the ith hybrid at the jth environment, where

i = 1,2,...,v and

j = 1,2,...,n   .

The environmental indices were computed by using the following formula:

$$I_j = (\Sigma Y_{ij}/v) - (\Sigma \Sigma Y_{ij}/vn), \text{ where } \Sigma I_j = 0 \quad .$$

The regression coefficients were calculated in the usual manner; i.e.,

$$b_i = \Sigma Y_{ij} I_j / \Sigma I_j^2 \quad .$$

For the analysis of variance estimating the stability parameters, the sums of squares due to environments and hybrid x environments were partitioned into environments (linear), hybrids by environments (linear), and deviations from the regression.

The grain yield data were analyzed by performing the generalized stability analysis program for the following

situations: (a) each of the six sets, (b) combined over all sets, (c) selected and unselected groups of hybrids, and (d) combined selected and unselected. The appropriate values necessary for the stability analysis of variance were extracted from these analyses as shown in Tables 4 and 5.

A desirable hybrid was considered, in this study, as one with mean yield greater than the overall mean yield, regression coefficient equal to 1.0, and deviations from the regression near 0.0. The hypothesis that the difference among hybrid means was significant ($H_0 = \mu_1 = \mu_2 = \ldots = \mu_{336}$) was tested by dividing the mean square associated with hybrids by the mean square associated with the pooled deviations (Table 4). The significance of hybrids (selected and unselected) x environment interaction mean squares was tested against the pooled error mean squares. The calculated F-values were compared with the tabulated F-values for the appropriate degrees of freedom.

Significance of no genetic differences among entries for their regression upon the environmental indexes ($H_0 = \beta_1 = \beta_2 = \ldots = \beta_{336}$) was tested by F-ratio by dividing the mean square associated with entries by environment (linear) by the mean square associated with the pooled deviations. The comparable F-ratio was calculated for each of the six sets. Also, I have tested this interaction by dividing its mean squares by the mean square associated with the residual

Table 4. Stability analysis of variance for each set (X) and combined over all sets (Y)

Source of variation	Degrees of freedom[a]	
	X	Y
Hybrids (H)	$(h-1)$	$(h-1)s$
Environments (E)	$(e-1)$	$(e-1)s$
H x E	$(h-1)(e-1)$	$(h-1)(e-1)s$
Environment (linear)	1	s
H x E (linear)	$(h-1)$	$(h-1)s$
Pooled deviations	$h(e-2)$	$h(e-2)s$
Pooled error	$e(r-1)(h-1)$	$e(r-1)(h-1)s$

[a] h = hybrids, e = environments, r = replications, and s = sets.

experimental error as considered by Freeman (1973).

To test the hypothesis that each regression coefficient was not different from unity, the following t-test, as outlined by Snedecor and Cochran (1967), was applied:

$$t = (b-\beta)/\sqrt{s^2_{Y.x}/\Sigma x^2} \quad,$$

where β = 1 and df = n-2 .

An approximate F-test also was made to test whether the deviations from the regressions for each entry were significantly greater than the pooled error from the combined analysis of variance for all entries in all experiments; i.e.,

Table 5. Stability analysis of variance of each selected and unselected group of each set (X) and combined over all sets (Y)

Source of variation	Degrees of freedom[a]	
	X	Y
Selected hybrids (Hs)	(c-1)	(c-1)s
Environments (E)	(e-1)	(e-1)s
Hs x E	(c-1)(e-1)	(c-1)(e-1)s
Environment (linear)	1	s
Hs x E (linear)	(c-1)	(c-1)s
Pooled deviations	c(e-2)	c(e-2)s
Unselected hybrids (Hu)	(u-1)	(u-1)s
Environments (E)	(e-1)	(e-1)s
Hu x E (linear)	(u-1)	(u-1)s
Pooled deviations	u(e-2)	u(e-2)s
Selected x unselected	1	s

[a]c = selected hybrids, e = environment, u = unselected hybrids, and s = sets.

$$F \approx (\sum_{j} \hat{\delta}^2_{ij}/n\text{-}2)/\text{pooled error}.$$

Correlation

Simple product-moment correlation coefficients were computed for the following four situations:

(a) Yield means between locations;

(b) Yield means between years;

(c) Between mean yields and regression coefficients; and

(d) Between mean yields and deviations from the
regression.

The formula used to calculate these correlation coeffi-cients was given by Steel and Torrie (1960).

EXPERIMENTAL RESULTS

All the results to be presented were obtained from data
collected from the nine environments described previously.
Significant variation in grain yield was observed for all
sets and environments used in this study (Tables 6 to 11).
Mean yields for the different hybrids in the different environ-
ments ranged from 65.2 to 105.0, 63.4 to 108.2, 57.5 to 104.2,
52.8 to 105.9, 53.2 to 99.2 and 52.7 to 105.8 q/ha for sets
1 to 6, respectively. Mean yield of hybrids averaged over all
sets ranged from 52.8 to 108.2 q/ha (Tables 6 to 11).

The conventional analysis of variance for the grain yield
mean data for each set and combined across sets are presented
in Table 12. In each set the mean square for mean yield due
to the hybrid effects were highly significant at the 1% level.
This indicates significant differences in yield among hybrids
in each set across the nine environments. Years and locations
mean squares were highly significant at the 1% level in each of
the sets, except in set 6 where the mean square for year effect
was not significant. Different results were found for the
three first-order interactions (hybrids x years, hybrids x lo-
cations, and years x locations) for the six sets. The analyses
of variance for the crosses can be summarized as follows:
(a) mean squares for hybrids and hybrids by years interaction
were highly significant at the 1% level in each set but set 2.
This indicates that some hybrids yielded relatively better in

Table 6. Stability parameters and average yields over all
environments for each selected single cross in set 1

Pedigree	Means (q/ha)	B-values[a]	Deviations MS[b]
S22-2x21-11467x1463	99.17	1.50	42.56
S22-2x29-21456x1464	74.48	1.05	20.93
S22-2x51-31467x1465	85.42	0.95	39.07
S22-2x55-11467x1466	83.41	1.47	74.19**
S30-1x21-11473x1469	89.10	0.63	70.61**
S30-1x29-21473x1470	81.16	0.94	33.25
S30-1x51-31473x1471	80.20	1.14	38.87
S30-1x55-11473x1472	92.53	0.72	67.87**
S52-3x21-11479x1475	104.97	1.31	52.05
S52-3x29-21479x1476	77.19	0.97	22.22
S52-3x51-31479x1477	93.81	0.96	36.16
S52-3x55-11479x1478	69.26	1.12	68.59**
S54-2x21-11485x1481	83.52	1.45	77.87**
S54-2x29-21485x1482	75.36	1.09	33.50
S54-2x51-31485x1483	77.88	0.53	66.04**
S54-2x55-11485x1484	86.81	0.73	27.74
S21-1x29-2551x552	95.19	0.84	62.29*
S21-1x51-3553x554	97.92	1.61*	14.57
S21-1x55-1555x556	102.64	1.50	64.99**
S29-2x51-3557x558	76.17	0.42*	9.27
S29-2x55-1559x560	87.11	0.87	26.39
S51-3x55-1561x562	90.37	0.86	62.33*
S22-2x30-1563x564	84.34	0.59	53.13*
S22-2x52-3565x566	76.94	1.88*	34.09
S22-2x54-2567x568	66.71	0.81	41.52
S30-1x52-3569x570	84.57	0.52	67.82**
S30-1x54-2571x572	79.06	1.05	115.28**
S52-3x54-2573x574	73.47	0.86	35.88
Overall mean	84.60	0.26[c]	
LSD (.05)	6.80		

[a]Linear regression of hybrid yield on environmental index
in this and subsequent tables.

[b]Deviation mean square from linear regression in this and
subsequent tables.

[c]Standard error in this and subsequent tables.

*,**Significant at the 5% and 1% level, respectively, in
this and subsequent tables.

Table 7. Stability parameters and average yields over all environments for each selected single cross in set 2

Pedigree	Means (q/ha)	B-values	Deviations MS
S22-2x21-11491x1487	88.50	0.82	5.99
S22-2x51-31491x1488	85.47	1.35	54.69**
S22-2x97-101491x1487	87.50	0.84	31.24
S33-2x67-91491x1490	90.48	1.60	50.22**
S53-3x21-11497x1493	96.49	1.08	24.41
S53-3x51-31497x1494	92.96	0.99	26.47
S53-3x97-101497x1495	96.70	2.39*	78.62**
S53-3x67-91497x1496	89.90	1.85*	24.29
S98-10x21-11503x1499	93.44	0.93	17.37
S98-10x51-31503x1400	90.64	0.80	59.06**
S98-10x97-101503x150	96.89	0.84	30.00
S98-10x67-91503x1502	96.58	1.08	52.76**
S66-7x21-11509x1505	83.96	0.52*	6.26
S66-7x51-31509x1506	81.20	1.09	61.68**
S66-7x97-101509x1507	90.16	0.60	70.67**
S66-7x67-91509x1508	82.93	0.54	30.41
S21-1x51-3575x576	82.77	0.60	24.02
S21-1x97-10577x578	83.58	1.00	13.76
S21-1x67-9579x580	79.32	0.75	22.74
S51-3x97-10581.x582	76.79	0.94	36.04
S51-3x67-9583x584	77.19	0.62	15.78
S97-10x67-9585x586	88.60	1.00	21.87
S22-2x52-3587x588	87.67	1.17	30.15
S22-2x98-10589x590	78.71	0.70	29.28
S22-2x66-7591x592	85.38	0.99	52.58**
S52-3x98-10593x594	94.57	0.43	35.02
S52-3x66-7595x596	90.49	1.33	167.22**
S98-10x66-7597x598	84.40	1.12	68.44**
Overall mean	87.61	0.33	
LSD (.05)	6.20		

Table 7. (Continued) Unselected single cross in set 2

Pedigree	Means (q/ha)	B-values	Deviations MS
U97-1x96-31059x1055	79.11	1.01	71.86**
U97-1x218-31059x1056	83.57	1.47	101.39**
U97-1x200-91059x1057	91.37	0.81	83.06**
U97-1x212-51059x1058	82.63	0.03*	58.15**
U7-6x96-31065x1061	72.57	0.80	95.28**
U7-6x218-31065x1062	89.63	1.36	28.63
U7-6x200-91065x1063	87.47	0.95	19.60
U7-6x212-51065x1064	76.69	0.92	28.23
U209-6x96-31071x1067	84.47	1.80*	37.99
U209-6x218-31071x106	97.07	1.57	62.38**
U209-6x200-91071x106	108.17	1.27	16.22
U209-6x212-51071x107	86.22	0.87	59.36**
U213-8x96-31077x1073	73.97	0.94	33.46
U213-8x218-31077x107	90.82	1.70	72.86**
U213-8x200-91077x107	92.43	1.67*	29.16
U213-8x212-51077x107	83.08	0.60	33.72
U96-3x218-3719x720	70.12	0.90	37.44
U96-3x200-9721x722	65.96	1.49	25.99
U96-3x212-5723x724	63.43	1.35	18.47
U218-3x200-9725x726	91.99	1.39	39.55
U218-3x212-5725x728	81.23	0.79	22.83
U200-9x212-5729x730	79.43	0.79	33.20
U97-1x7-6731x732	68.34	0.21*	36.87
U97-1x209-6733x734	77.01	0.57	20.44
U97-1x213-8735x736	72.39	0.81	14.69
U7-6x209-6737x738	79.71	0.97	40.85*
U7-6x213-8739x740	74.62	0.31*	22.20
U209-6x213-8741x742	72.99	0.67	16.15
Overall mean	81.30	0.30	
LSD (.05)	6.20		

Table 8. Stability parameters and average yields over all
environments for each selected single cross in set 3

Pedigree	Means (q/ha)	B-values	Deviations MS
S22-2x21-11515x1511	92.33	0.70	37.79
S22-2x51-31515x1512	88.77	1.57	29.23
S22-2x97-101515x1513	80.40	0.44	39.82
S22-2x67-91515x1514	87.11	0.93	37.23
S52-3x21-11521x1517	99.98	1.04	120.35**
S52-3x51-31521x1518	91.40	1.17	80.21**
S52-3x97-101521x1519	90.01	0.50	38.43
S52-3x67-91521x1520	86.23	0.43	34.90
S98-10x21-11527x1520	97.12	1.74*	41.49
S98-10x51-31527x1520	94.54	0.73	57.45
S98-10x97-101527x1520	95.39	1.28	128.23**
S98-10x67-91527x1520	90.80	0.71	35.80
S66-7x21-11533x1529	87.21	0.99	67.39**
S66-7x51-31533x1530	85.19	1.10	33.17
S66-7x97-101533x1530	79.74	1.16	29.97
S66-7x67-91533x1532	82.31	0.49	43.63
S21-1x51-3599x600	91.73	1.44	30.76
S21-1x97-10601x602	87.91	1.29	62.61**
S21-1x67-9603x604	90.13	1.28	32.12
S51-3x97-10605x606	78.70	0.84	22.65
S51-3x67-9607x608	78.13	0.74	22.04
S97-10x67-9609x610	82.28	1.24	40.75
S22-2x52-3611x612	81.30	0.93	47.88*
S22-2x98-10613x614	77.00	1.10	13.64
S22-2x66-7615x616	78.24	0.93	27.12
S52-3x98-10617x618	79.46	0.32	78.03**
S52-3x66-7619x620	83.60	1.27	97.81**
S98-10x66-7621x622	84.12	1.59	66.62**
Overall mean	86.47	0.28	
LSD (.05)	6.50		

Table 8. (Continued) Unselected single cross in set 3

Pedigree	Means (q/ha)	B-values	Deviations MS
U81-10x14-101083x107	77.83	0.54	80.13**
U81-10x10-101083x108	90.14	0.55	76.14**
U81-10x54-31083x1081	104.27	0.34	158.88**
U81-10x92-61083x1082	84.04	0.68	68.66**
U9-8x14-101089x1085	70.10	1.02	41.12
U9-8x10-101089x1086	71.78	1.21	19.61
U9-8x54-31089x1087	93.07	1.63	104.54**
U9-8x92-61089x1088	81.74	1.83*	32.32
U53-1x14-101095x1091	74.34	0.95	113.80**
U53-1x10-101095x1092	81.73	1.30	74.51**
U53-1x54-31095x1093	90.63	0.53*	216.34**
U53-1x92-61095x1094	82.79	0.96	56.73**
U91-7x14-101101x1097	72.46	1.60	45.93
U91-7x10-101101x1098	74.04	0.77	20.17
U91-7x54-31101x1099	94.80	1.66	181.81**
U91-7x92-61101x1100	77.66	0.85	38.74
U14-10x10-10743x744	58.68	0.54	82.89**
U14-10x54-3745x746	77.47	0.85	38.74
U14-10x92-6747x748	61.12	1.02	71.58**
U10-10x54-3749x750	80.66	0.47	52.41*
U10-10x92-6751x752	72.29	0.80	29.59
U54-3x92-6753x754	81.76	1.16	67.88**
U81-10x9-8755x756	79.30	0.78	19.73
U81-10x53-1757x758	87.10	0.67	87.03**
U81-10x91-7759x760	57.47	1.53	42.00
U9-8x53-1761x762	79.12	1.23	81.50**
U9-8x91-7763x764	77.02	2.01	142.25**
U53-1x91-7765x766	74.31	0.76	154.08**
Overall mean	78.85	0.42	
LSD (.05)	6.50		

Table 9. Stability parameters and average yields over all
environments for each selected single cross in set 4

Pedigree	Means (q/ha)	B-values	Deviations MS
S21-1x22-21539x1535	87.48	1.34*	9.17
S21-1x52-31539x1536	89.51	0.56	59.51**
S21-1x98-101539x1537	83.87	0.97	40.54
S21-1x66-71539x1538	76.71	0.76	100.00**
S51-3x22-21545x1541	90.43	0.83	15.35
S51-3x52-31545x1542	94.46	1.46	105.95**
S51-3x98-101545x1543	89.03	0.75	15.09
S51-3x66-71545x1544	90.53	1.28	74.05**
S97-10x22-21551x1547	84.72	1.31	26.93
S97-10x52-31551x1548	94.23	1.28	160.31**
S97-10x98-101551x154	100.83	1.55	110.46**
S97-10x66-71551x1550	88.88	1.50	24.94
S67-9x22-21557x1553	90.77	0.95	76.13**
S67-9x52-31557x1554	105.93	0.95	90.00**
S67-9x98-101557x1555	102.84	0.92	34.60
S67-9x66-71557x1556	100.01	1.06	213.32**
S22-2x52-3623x624	83.80	0.84	56.43*
S22-2x98-10625x626	71.86	0.66	40.65
S22-2x66-7627x628	80.21	0.66	68.67**
S52-3x98-10629x630	85.06	0.90	141.98**
S52-3x66-7631x632	87.33	0.71	39.32
S98-10x66-7633x634	75.27	0.61	70.78**
S21-1x51-3635x636	85.02	0.52	45.21
S21-1x97-10637x638	81.09	1.63	38.14
S21-1x67-9639x640	80.37	0.43	81.15**
S51-3x97-10641x642	89.09	1.45	33.53
S51-3x67-9643x644	93.89	0.78	57.49*
S97-10x67-9645x646	93.93	1.33	27.03
Overall mean	88.47	0.33	
LSD (.05)	6.60		

Table 9.   (Continued)   Unselected single cross in set 4

Pedigree	Means (q/ha)	B-values	Deviations MS
U23-2x24-51179x1175	80.18	0.37	28.95
U23-2x26-31179x1176	80.60	1.52	58.45*
U23-2x26-61179x1177	83.57	1.19	100.72**
U23-2x28-51179x1178	86.63	1.56	38.25
U25-1x24-51185x1181	67.77	0.70	50.54*
U25-1x26-31185x1182	66.38	0.98	56.68*
U25-1x26-61185x1183	77.79	0.82	53.51*
U25-1x28-51185x1184	84.02	1.29	23.14
U25-2x24-51191x1187	74.92	0.05*	131.97**
U25-2x26-31191x1188	69.99	0.91	25.64
U25-2x26-61191x1189	79.89	1.19	65.66**
U25-2x28-51191x1190	78.88	1.23	41.36
U27-1x24-51197x1193	63.14	0.97	35.49
U27-1x26-31197x1194	69.31	1.72*	22.34
U27-1x26-61197x1195	79.63	0.53	44.67
U27-1x28-51197x1196	69.11	0.45	37.79
U24-5x26-3767x768	52.80	0.74	58.65*
U24-5x26-6769x770	60.57	0.88	17.84
U24-5x28-5771x772	60.66	0.87	50.05*
U26-3x26-6773x774	56.96	0.74	39.34
U26-3x28-5775x776	61.29	1.08	19.29
U26-6x28-5777x778	68.70	1.23	27.17
U23-2x25-1779x780	83.19	1.62	124.23**
U23-2x25-2781x782	80.73	0.88	19.62
U23-2x27-1783x784	71.72	0.78	14.67
U25-1x25-2784x786	76.18	1.56	83.70**
U25-1x27-1787x788	75.37	1.37	67.47**
U25-2x27-1789x790	78.90	0.74	24.32
Overall mean	72.82	0.32	
LSD (.05)	6.60		

Table 10. Stability parameters and average yields over all
environments for each selected single cross in
set 5

Pedigree	Means (q/ha)	B-values	Deviations MS
S21-1x22-21563x1559	77.34	0.26	97.20**
S21-1x52-31563x1560	90.57	0.98	85.85**
S21-1x98-101564x1561	86.01	1.05	58.26**
S21-1x66-71565x1562	74.26	0.46	65.91**
S51-3x22-21569x1565	86.94	1.48	76.59**
S51-3x52-31569x1566	88.53	1.02	24.38
S51-3x98-101569x1567	79.20	1.20	117.84**
S51-3x66-71569x1568	75.37	1.40	31.27
S97-10x22-21575x1571	80.52	0.83	41.42
S97-10x52-31575x1572	91.38	1.21	63.39**
S97-10x98-101575x1573	94.19	1.66	30.65
S97-10x66-71575x1574	80.10	1.19	40.55*
S67-9x22-21581x1577	88.12	0.47	56.76**
S67-9x52-31581x1578	99.24	1.06	46.81*
S67-9x98-101581x1579	96.70	1.07	35.75
S67-9x66-71581x1580	96.01	1.31	99.73**
S22-2x52-3647x648	81.91	0.88	40.41*
S22-2x98-10649x650	73.37	0.91	17.83
S22-2x66-7651x652	73.39	0.21	109.06**
S52-3x98-10653x654	90.37	1.25	128.06**
S52-3x66-7655x656	77.30	1.70	65.91**
S98-10x66-7657x658	73.70	0.75	31.63
S21-1x51-3659x660	80.97	0.90	60.06**
S21-1x97-10661x662	82.24	0.77	59.75**
S21-1x67-9663x664	85.62	0.54	49.43**
S51-3x97-10665x666	88.00	1.23	57.25**
S51-3x67-9667x668	98.47	1.28	25.46
S97-10x67-9669x670	84.12	0.57	25.24
Overall mean	84.78	0.33	
LSD (.05)	6.30		

Table 10.　(Continued)　Unselected single cross in set 5

Pedigree	Means (q/ha)	B-values	Deviations MS
U72-1x99-21323x1319	80.13	0.82	71.99**
U72-1x73-61343x1320	83.70	0.63	28.02
U72-1x79-61323x1321	80.74	0.59*	7.17
U72-1x79-91323x1322	77.62	0.81	15.59
U72-4x99-21329x1325	75.07	0.54*	7.79
U72-4x73-61329x1326	81.01	1.03	41.69*
U72-4x79-61329x1327	78.87	1.18	59.30**
U72-4x79-91329x1328	72.18	1.55*	5.07
U78-4x99-21335x1331	66.06	0.85	23.00
U78-4x73-61335x1332	77.47	1.44	15.36
U78-4x79-61335x1333	67.10	1.01	83.72**
U78-4x79-91335x1334	71.24	0.95	48.14*
U78-8x99-21341x1337	78.02	0.49*	10.11
UM78-873-61341x1338	82.48	1.00	51.59**
U78-8x79-61341x1339	74.46	0.31	58.60**
U78-8x79-91341x1340	75.11	1.24	30.22
U72-1x72-4791x792	75.23	0.83	25.84
U72-1x78-4793x794	53.22	0.65	12.22
U72-1x78-8795x796	73.68	0.83	17.24
U72-4x78-4797x798	66.67	0.57	70.60**
U72-4x78-8799x800	65.04	0.84	13.00
U78-4x78-8801x802	60.93	1.26	44.64*
U71-1x73-6803x804	82.39	1.51	137.30**
U71-1x79-6805x806	77.38	1.19	29.47
U71-1x79-9807x808	83.26	1.93	91.25**
U73-6x79-6809x810	80.11	1.12	51.91**
U73-6x79-9811x812	76.87	1.39	26.35
U79-6x79-9813x814	71.66	1.36	23.37
Overall mean	74.56	0.28	
LSD (.05)	6.30		

Table 11. Stability parameters and average yields over all environments for each selected single cross in set 6

Pedigree	Means (q/ha)	B-values	Deviations MS
S51-1x52-31587x1583	96.77	1.96	280.73**
S51-1x98-101587x1584	89.42	0.90	51.07*
S51-1x66-71587x1585	85.42	1.29	16.35
S51-1x32-71587x1586	87.49	1.85	49.35*
S97-10x52-31593x1589	92.89	0.89	22.98
S97-10x98-101593x1590	94.39	1.60	40.65
S97-10x66-71593x1591	77.13	1.23	92.88**
S97-10x32-71593x1592	86.24	0.94	77.37**
S67-9x52-31599x1595	105.83	0.81	222.94**
S67-9x98-101599x1596	99.22	1.75	61.27**
S67-9x66-71599x1597	95.98	2.05	231.27**
S67-9x32-71599x1598	87.50	1.47	31.87
S31-4x52-31605x1601	82.50	0.30	92.98**
S31-4x98-101605x1602	76.09	0.29	37.67
S31-4x66-71605x1603	78.50	1.26	9.09
S31-4x32-71605x1604	80.36	0.12*	34.78
S52-3x98-10671x672	75.34	0.39	63.49**
S52-3x66-7673x674	79.57	0.66	46.34
S52-3x32-7675x676	77.04	0.88	37.74
S98-10x66-7677x678	76.51	0.78	47.48*
S98-10x32-7679x680	78.22	0.39	40.46
S66-7x32-7681x682	70.98	0.27*	9.80
S51-3x97-10683x684	80.41	0.85	83.83**
S51-3x67-9685x686	93.79	1.32	105.14**
S51-3x31-4687x688	87.26	0.26*	114.27**
S97-10x67-9689x690	89.21	1.81	101.96**
S97-10x31-4691x692	85.14	1.04	29.71
S67-9x31-4693x694	89.27	0.63	38.39
Overall mean	85.66	0.43	
LSD (.05)	7.10		

Table 12. Analysis of variance of yield (q/ha) for each set combined over all environments and combined across sets and environments

Source of variation	d.f.[b]	Mean squares[a] Set 1	Set 2	Set 3
Locations (L)	2	2,597.52**	4,209.24**	4,267.48**
Years (Y)	2	4,027.64**	1.833.32**	2,471.18**
Hybrids (H)	55	1,645.70**	1,414.02**	1,589.86**
H x Y	110	173.64**	111.08*	233.02**
H x L	110	109.12	78.42	142.28**
Y x L	4	6,853.06**	2,977.22**	3,304.90**
H x Y x L	220	102.46**	81.62**	90.44**
Pooled error	495	68.50	52.70	60.20

[a]Mean squares were computed on the basis of hybrid means (two replications).

[b]Degrees of freedom for each set combined across environments.

[c]Degrees of freedom for six sets combined across nine environments.

Mean squares				
Set 4	Set 5	Set 6	Combined	d.f.[c]
1,067.08**	531.42**	336.44*	2,168.20**	(12)
4,621.14**	4,777.36**	7.18	2,956.30**	(12)
2,441.86**	1,504.68**	1,665.56**	1,710.28**	(330)
167.70**	129.12**	166.06**	163.43**	(660)
133.78	102.16	136.22	116.99**	(660)
4,383.44**	4,935.30**	3,857.44**	4,385.23**	(24)
94.32**	85.58**	107.98**	93.73**	(1320)
64.30	52.50	61.80	59.83	(2970)

some years whereas others yielded less in different years.
The interaction of hybrids with years indicates that either
the relative ranking or relative yields among hybrids were
different for the different years. (b) The mean square for
hybrids by locations interaction was significant at the 1%
level only in set 3. It seems that the hybrids included
in this study did not have much variation in relative ranking
or yield at the same locations in different years. (c) Years
and locations interaction with hybrids mean squares were highly
significant at the 1% level in all sets. The mean squares
for the second-order interaction, H x Y x L, also were highly
significant at the 1% level in all sets (Table 12).

The combined analysis of variance including all six sets
in all nine environments revealed that the mean squares for
hybrids, locations, years, first-order interactions, and
second-order interaction were highly significant at the 1%
level. The significant interactions indicate instability of
yield performance for the group of hybrids studied in the
nine environments. The analyses presented thus far do not
provide for comparisons among hybrids for stability of per-
formance across locations and years.

In the preceding presentation, I have presented only the
standard analysis of variance necessary to determine whether
the hybrids included in this study were significantly differ-
ent and had different responses to varying environments,
i.e., years and locations within years. The remainder of the

results will be concerned with the analysis of variance and presentation of data for the estimation of the stability parameters, i.e., linear regression and deviations from regression.

For any study on stability analysis, the environments to be used must be significantly different and must be representative of the possible range of environmental conditions encountered for growing the hybrids; that is, the environmental indexes have to have a wide range and a good distribution within the range. The environmental mean values averaged over all 336 hybrids and the ranking for yield in each environment are given in Table 13 for each environment. Yield ranges were good with six environmental means above and three environmental means below the overall mean. The ranking for yield for the selected and unselected hybrids agrees very closely, with Ankeny, 1972, being the highest yielding environment and Ames, 1971, the lowest yielding environment. Figure 1 shows the distribution of the selected and unselected hybrids over all sets for the nine environments. For each environment, differences were present for the mean values and the 75% of the hybrid values near the mean. The results presented in Tables 12, 13, and Figure 1 indicate that the two basic requirements were fulfilled: (1) significant differences existed among hybrids in their ability to produce grain yield, and (2) significant differences among environments.

The stability analyses of variance for each of the six

Table 13. Mean yields (q/ha) over all six sets in nine environments of single cross hybrids produced from selected and unselected lines

Location	Year	Env. no.	Yield of all hybrids	Ranking for yield[a]		
				All hybrids	Sel. hybrids	Unsel. hybrids
			-------------------- q/ha -------------			
Ames	1971	1	72.9	1	1	1
Ankeny	1971	2	79.8	3	3	3
Martinsburg	1971	3	87.3	8	8	8
Ames	1972	4	84.6	6	6	7
Ankeny	1972	5	87.9	9	9	9
Martinsburg	1972	6	82.1	4	5	4
Ames	1973	7	82.2	5	4	5
Ankeny	1973	8	84.8	7	7	6
Martinsburg	1973	9	75.7	2	2	2
Average			81.9 ± 0.10			

[a]1 = lowest and 9 = highest yield.

sets and combined over all sets are given in Table 14. These analyses of variance were computed in accordance with the model described by Eberhart and Russell (1966). Selected and unselected groups of hybrids were included for these stability analyses. The F-test used to show if there were any genetic differences among the hybrids for their regression upon the environmental indexes, hybrids x environmental (linear), was

Figure 1. Distribution of selected and unselected hybrids
for the nine environments

   o = one or more outside values (these occur about
       one in 20 for normal samples)
   * = one or more detached values (these occur about
       one in 200 for normal samples)
   In the rectangule, dashed line corresponds to the
   median and "+" to the mean

62b
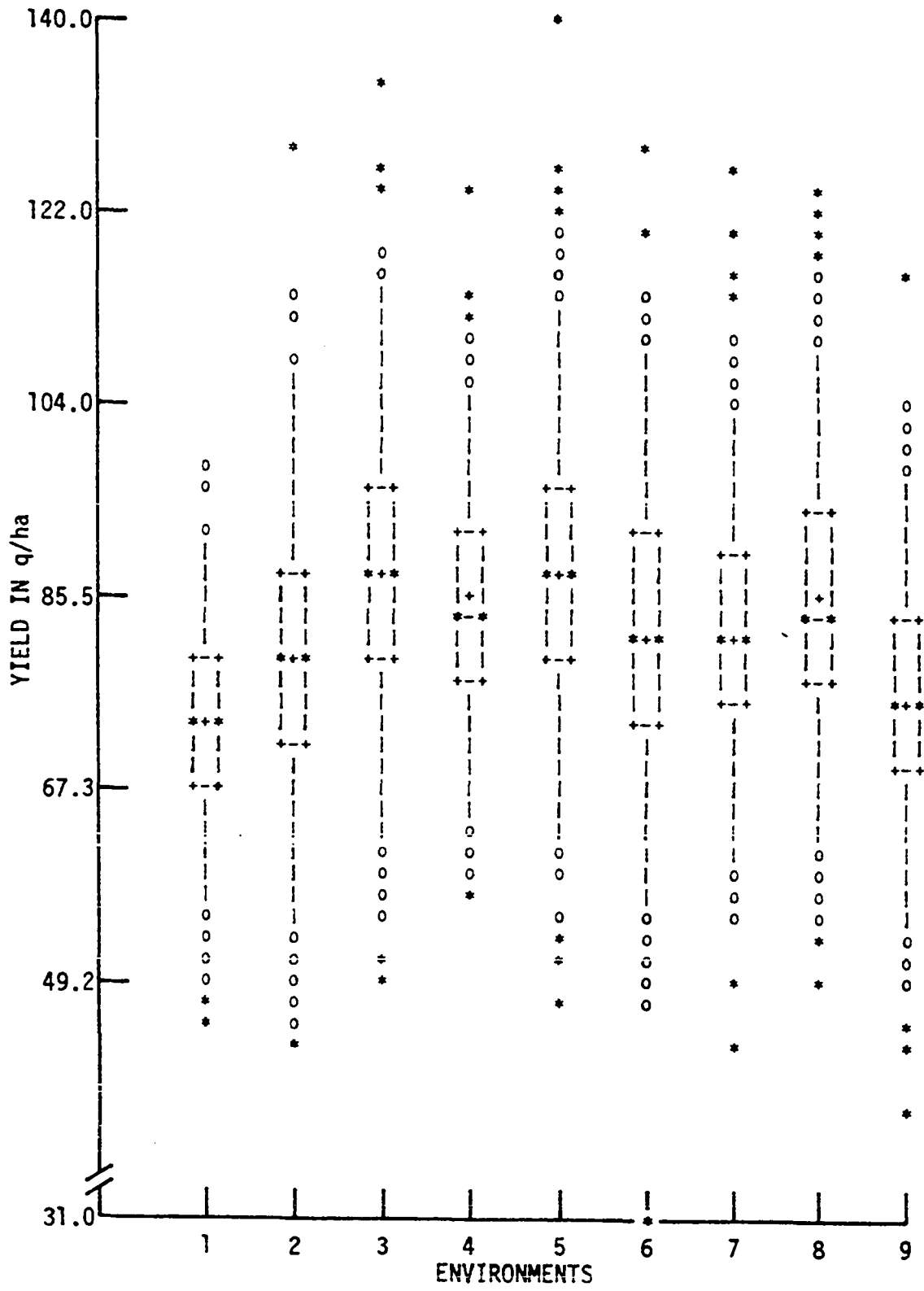
Table 14. Stability analysis of variance for grain yield
(q/ha) for each set and combined across sets

Source of variation	d.f.	MS[a]
Set 1		
Hybrids (H)	55	1,644.50**
Environments (E)	8	5,092.20**
H x E	440	122.00**
Environment (linear)	1	40,650.30**
H x E (linear)	55	163.66* (**)[b]
Pooled deviations	392	114.20**
Pooled error	397	68.5
Set 2		
Hybrids (H)	55	1,413.40**
Environments (E)	8	2,995.40**
H x E	440	88.40**
Environment (linear)	1	24,000.94**
H x E (linear)	55	88.62 (**)
Pooled deviations	392	86.69**
Pooled error	411	52.70
Set 3		
Hybrids (H)	55	1,589.30**
Environments (E)	8	3,336.10**
H x E	440	139.10**
Environment (linear)	1	26,718.50**
H x E (linear	55	110.86 (**)
Pooled deviations	392	140.50**
Pooled error	397	60.2

[a]Analyzed on the basis of hybrid means with 2 replications for each environment.

[b]( ) tested with the pooled error.

**Indicates significance at the 1% level assuming a bivariate normal distribution.

*Indicates significance at the 5% level assuming a bivariate normal distribution.

Table 14.   (Continued)

Source of variation	d.f.	MS

Set 4

Hybrids (H)	55	2,442.50**
Environments (E)	8	3,617.00**
H x E	440	122.50**
Environment (linear)	1	28.929.24**
H x E (linear)	55	93.96 (**)
Pooled deviations	392	124.10**
Pooled error	396	64.3

Set 5

Hybrids (H)	55	1,503.70**
Environments (E)	8	3,797.40**
H x E	440	100.60**
Environment (linear)	1	30,360.10**
H x E (linear)	55	89.80 (**)
Pooled deviations	392	100.16**
Pooled error	397	58.5

Set 6

Hybrids (H)	55	1,665.00**
Environments (E)	8	2,014.10**
H x E	440	129.60**
Environment (linear)	1	16,119.52**
H x E (linear)	55	127.53 (**)
Pooled deviations	392	127.56**
Pooled error	411	61.8

Combined

Hybrids (H)/sets	330	1,709.75**
Environments (E)	8	17,271.94**
Environments (E)/sets	40	716.05**
H x E/sets	2640	117.03**
Environment (linear)/sets	6	27,811.52**
H x E (linear)/sets	330	112.62 (**)
Pooled deviations/sets	2352	115.54**
Pooled error	2382	59.05

significant in only set 1. This indicates that the genetic differences among the hybrids for the stability parameter "b" were not significantly different at the 5% level for all sets except for set 1.

The combined analysis also had a nonsignificant hybrid by environment (linear) mean square. The hybrid by environment (linear) mean square was tested with the pooled deviation mean square, which was tested with the pooled error mean square. Also, the hybrid by environment (linear) mean square was tested with the pooled error mean square because the E(MS) shows that the correct denominator to use to test this interaction is the pooled error mean square. In using this second approach, the hybrid by environment (linear) mean squares were highly significant at the 1% level for all sets and combined over all sets. Except for set 1, the hybrid by environment (linear) and pooled deviations mean square were similar in magnitude. The pooled deviation mean square was highly significant at the 1% level in all instances, indicating that not all the genotype by environment interaction was accounted for by differences of linear response among hybrids. The environment (linear) mean squares were highly significant in all sets and when combined across sets.

The analyses in Table 14 included all hybrids, selected and unselected, for each set. The mean yield data for the selected and unselected hybrids also were subjected to a regression analysis to estimate the stability indexes, linear

regression, and deviations from the regression as proposed by Eberhart and Russell (1966). The results of these analyses are presented in Table 15. In these combined analyses of variance, the selected groups of hybrids had less variation due to hybrid by environment interaction in sets 1, 2, and 3, as compared to the unselected group of hybrids. For sets 4, 5, and 6, however, the unselected groups of hybrids had less variation due to hybrid by environment interaction as compared to the selected group of hybrids. For both the selected and the unselected groups of hybrids, the hybrid by environment interaction mean squares were significant at the 1% level, as indicated by the F-tests when using the pooled error mean square in the denominator. Also, in the combined analysis over all sets, the interaction mean squares for the selected and unselected groups were highly significant at the 1% level, and the selected group of hybrids had similar variation due to hybrid by environment interaction as compared to the unselected group of hybrids (114.41 vs 110.04). The environment (linear) mean squares were highly significant at the 1% level for both selected and unselected groups of hybrids in all the six sets and when combined across sets. The nonsignificance for hybrid x environment (linear) mean squares for the selected groups of hybrids in all six sets and in the combined analysis, when tested with the pooled deviation mean square, indicates that there were no genetic differences among hybrids in their response to different environments. For the

Table 15. Stability analysis of variance for grain yield (q/ha) of each selected and unselected group of hybrids for each set and combined across sets

Source of variation	d.f.	MS[a]
Set 1		
Selected hybrids (Hs)	27	1,741.97**
Environments (E)	8	2,793.49**
Hs x E	216	101.82**
Environments (linear)	1	22,360.28**
Hs x E (linear)	27	109.33 (*)[b]
Pooled deviations	196	97.08**
Unselected hybrids (Hu)	27	1,564.67**
Environments (E)	8	2,640.08**
Hu x E	216	141.42**
Environments (linear)	1	21,170.10**
Hu x E (linear)	27	264.82* (**)
Pooled deviations	196	119.11**
Hs x Hu	1	1,073.34**
Set 2		
Selected hybrids (Hs)	27	660.47**
Environments (E)	8	1,425.68**
Hs x E	216	83.16**
Environment (linear)	1	11,426.68**
Hs x E (linear)	27	72.81 ( )
Pooled deviations	196	81.50**
Unselected hybrids (Hu)	27	1,848.98**
Environments (E)	8	1,791.32**
Hu x E	216	88.42**
Environments (linear)	1	14,332.76**
Hu x E (linear)	27	105.76 (**)
Pooled deviations	196	82.86**
Hs x Hu	1	10,047.24**

[a]Analyzed on the basis of hybrid means, with 2 replications for each environment.

[b]( ) Tested with the pooled error.

**Indicates significance at 1% level assuming a bivariate normal distribution.

*Indicates significance at 5% level assuming a bivariate normal distribution.

Table 15. (Continued)

Source of variation	d.f.	MS
	Set 3	
Selected hybrids (Hs)	27	717.08**
Environments (E)	8	2,286.03**
Hs x E	216	105.68**
Environments (linear)	1	18.969.28**
Hs x E (linear)	27	95.72 (*)
Pooled deviations	196	99.80**
Unselected hybrids (Hu)	27	1,929.22**
Environments (E)	8	1,664.32**
Hu x E	216	154.84**
Environments (linear)	1	13,231.54**
Hu x E (linear)	27	97.78 (*)
Pooled deviations	196	157.60**
Hs x Hu	1	14,623.92**
	Set 4	
Selected hybrids (Hs)	27	1,200.91**
Environments (E)	8	2,241.57**
Hs x E	216	129.64**
Environments (linear)	1	17,839.94**
Hs x E (linear)	27	77.79 ( )
Pooled deviations	196	132.63**
Unselected hybrids (Hu)	27	1,484.64**
Environments (E)	8	1,920.27**
Hu x E	216	99.59**
Environments (linear)	1	15,365.46**
Hu x E (linear)	27	53.59 ( )
Pooled deviations	196	102.36**
Hs x Hu	1	61,664.22**
	Set 5	
Selected hybrids (Hs)	27	1,130.00**
Environments (E)	8	2,065.84**
Hs x E	216	116.91**
Environments (linear)	1	16,545.94**
Hs x E (linear)	27	82.93 (*)
Pooled deviations	196	117.32**
Unselected hybrids (Hu)	27	955.95**
Environments (E)	8	1,917.70**
Hu x E	216	81.05**

Table 15.   (Continued)

Source of variation	d.f.	MS
Set 5 (continued)		
Environments (linear)	1	15,353.70**
Hu x E (linear)	27	77.26 (*)
Pooled deviations	196	78.62**
Hs x Hu	1	26,309.88**
Set 6		
Selected hybrids (Hs)	27	1,278.07**
Environments (E)	8	1,491.49**
Hs x E	216	151.76**
Environments (linear)	1	11,934.36**
Hs x E (linear)	27	139.75 (**)
Pooled deviations	196	147.99**
Unselected hybrids (Hu)	27	1,133.95**
Environments (E)	8	769.88**
Hu x E	216	103.02
Environments (linear)	1	6,171.16**
Hu x E (linear)	27	111.31* (**)
Pooled deviations	196	98.14**
Hs x Hu	1	26,420.40**
Combined		
Selected hybrids (Hs)/ sets	162	1,121.67**
Environments (E)	8	10,271.98**
E x sets	40	420.31**
Hs/sets x E	1296	114.41**
Environments (linear)/sets	6	16,512.58**
Hs x E (linear)/sets	162	78.55 (**)
Pooled deviations/sets	1176	115.19**
Unselected hybrids (Hu)/sets	162	1,495.52**
Environments (E) .	8	7.475.59**
E x sets	40	646.93**
Hu/sets x E	1296	110.04**
Environments (linear)/sets	6	14,270.79**
Hu x E (linear)/sets	162	107.93 (**)
Pooled deviations/sets	1176	106.45**
Hs x Hu/sets	6	23,356.59**

unselected groups of hybrids, the interaction hybrid x
environment (linear) mean squares were significant at the 5%
level for only sets 1 and 6. This indicates that there were
some unselected hybrids which were variable in their response
over environments. The hybrid x environment (linear) mean
square in the combined analysis for the selected and unselected
groups was not significant in either instance.

When the hybrid by environment (linear) mean square was
tested with the pooled error mean square the results had dif-
ferent interpretations. In the selected groups of hybrids, the
hybrid by environment (linear) mean squares were significant
at the 5% level for sets 1, 3, and 5, and nonsignificant for
sets 2 and 4. For set 6 and in the combined analysis across
sets, the hybrid by environment (linear) mean squares were
highly significant at the 1% level. These results indicate
that there are genetic differences among hybrids in their
response to different environments for at least four groups
of selected hybrids used in this study. In the unselected
groups of hybrids the hybrid by environment (linear) mean
squares were significant at the 5% level for sets 3 and 5, and
nonsignificant for set 4. For sets 1, 2, and 6 and combined
over sets, the interaction hybrid by environment (linear) mean
squares were highly significant at the 1% level. Again, these
results showed that there were genetic differences among the
unselected hybrids in their response to different environments
for some groups of hybrids.

When comparing hybrid by environment interaction mean squares with hybrid by environment (linear) interaction mean squares, the former did not have much greater values than the latter. The selected groups of hybrids ranged from 1.1% to 1.4% and the unselected groups ranged from 1.0% to 1.8%. In the combined analysis this advantage was 1.4% and 1.0% for the selected and unselected groups, respectively. The s^2d parameter becomes important when the variety x environment (linear) sum of squares is a small portion of the total variety x environment interaction.

Mean squares for the pooled deviations were significant at the 1% level in all groups of selected and unselected hybrids for the six sets and when combined across sets. This indicates that difference in linear response among the hybrids in each group did not account for all the hybrid x environment interaction. The selected and unselected interaction mean squares were highly significant at the 1% level in all sets and combined across sets.

Some comparisons of the mean squares in the combined analysis pooled over sets (Table 15) show that the selected and unselected groups of hybrids performed similarly relative to the analyses for stability. The hybrids/sets by environments mean squares for the combined analyses were nearly the same (114.41 vs 110.04). Mean squares for hybrids by environment (linear) were nonsignificant in both instances, with the mean square for the unselected hybrids slightly greater, but not

significantly, than for the selected hybrids (78.55 vs
107.93). Pooled deviations mean squares were significant for
both groups of hybrids, but the pooled deviation mean square
was slightly smaller for the unselected group of hybrids
(115.19 vs 106.45). Although the comparison of the means
for the selected versus unselected groups of hybrids were
highly significant in each set and combined across sets, there
does not seem to be any trend for the stability analyses;
i.e., the mean squares in the stability analyses of variance
were very similar for both groups of hybrids. The selection
procedure used in developing the lines and testing in hybrids
did not enhance the stability of the hybrids for the environ-
ments used in these experiments. Lines used to produce the
unselected group of hybrids were developed in the same environ-
ments as the selected lines, but they had not been previously
tested in hybrid combinations. The selected hybrids pro-
duced from selected lines tested in hybrids, however, were no
more or no less stable in performance across environments
than the hybrids produced from unselected and untested lines.

Three stability parameters could be computed from the
analyses of variance: the yield mean, the regression coeffi-
cient, and the deviation from the regression. In this study,
an ideal stable hybrid is characterized by having a high mean
yield, the regression coefficient about 1.0, and deviations
from the regression near zero. The estimates of the three
stability parameters for each hybrid in each set are shown

in Tables 6 to 11.

Mean yield for each entry across all environments and over all sets ranged from 58.8 to 108.2 q/ha; the regression coefficient ranged from -0.03 to 2.39; and the deviation from the regression ranged from 4.85 to 280.73. Table 16 shows the frequency distributions of the selected and unselected groups of hybrids classified according to regression coefficient (b) and deviations from the regression (S^2d) for each of the six sets.

The regression coefficient is a measure of the quantity of change in a dependent variable per unit change in the independent variable. The independent variables in this case are the environmental indexes which are obtained by subtracting the average yield of all hybrids at all locations from the average yield of all hybrids at a specific location, and the dependent variables are the mean yields of a hybrid in an individual environment. Thus, the statistic, b, is a measure of the average increase in yield of a hybrid per unit of increase in the environmental index. The deviations from regression (S^2d) are the average of the squared distances of the hybrid yield from the calculated regression line, which measures how well the line fits the average regression line. This statistic (deviations from regression) measures how well the predicted response agrees with the observed response.

The selected group of hybrids had a higher proportion of hybrids with a regression that was not significantly different

Table 16. Frequency of significant (sig.) and nonsignificant (NS) regression (b) and deviations from the regression (S^2d) stability parameters[a] for the selected and unselected hybrids in each of the six sets

Sets	NS b	Sig. b	NS S^2d	Sig. S^2d	% of stable hybrids[b]		
					1	2	3
				Selected			
1	25	3	16	12	89.3	57.1	53.6
2	25	3	18	10	89.3	53.2	42.8
3	27	1	18	10	96.4	64.3	39.3
4	27	1	13	15	96.4	46.4	57.1
5	28	0	8	20	100.0	28.6	71.4
6	25	3	13	15	89.3	46.4	60.7
Total	157	11	86	82	93.4	51.2	54.2
				Unselected			
1	22	6	15	13	78.6	53.6	57.8
2	23	5	19	9	82.1	67.8	46.4
3	26	2	10	18	92.9	35.7	67.8
4	26	2	16	12	92.9	57.1	46.4
5	24	4	16	12	85.7	57.1	57.1
6	21	7	17	11	75.0	60.7	50.0
Total	142	26	93	75	85.7	55.4	55.9

[a]Nonsignificant b and significant b means b = 1.0 and b $\neq$ 1.0, respectively. Nonsignificant S^2d and significant S^2d means S^2d = 0 and $S^2d \neq$ 0, respectively.

[b]Stable hybrid denotes b = 1.0 and S^2d = 0. 1 - only considering b values; 2 - only considering S^2d values; 3 - considering both b and S^2d values.

from one than did the unselected group of hybrids, i.e., 93.4%
for the selected group and 85.7% for the unselected group,
which indicates the selected group had a greater proportion
of stable hybrids than did the unselected group. Set 5 of
the selected hybrids was the only set that did not have a
hybrid with a regression value significantly different from
one, but sets 3 and 4 only had one. The frequency of regres-
sion values that were significantly different from one was low
in all sets of the selected groups of hybrids, ranging from
zero for set 5 to three for sets 1, 2, and 6. The frequency
of regression values significantly different from one for the
unselected hybrids ranged from two for sets 3 and 4 to seven
for set 6. The percentage of hybrids that had a stable per-
formance across environments, as measured by the regression
value, was large in all sets for both the selected and unse-
lected hybrids (Table 16). Comparisons of the regression
values significantly different from one for the two groups
of hybrids show the following comparisons: six above one and
five below one for the selected hybrids; and eight above one
and 18 below one for the unselected hybrids. Hence, there was
a tendency for the unselected hybrids to have a greater number
of regression values significantly less than one than for the
selected hybrids. The use of the regression values to deter-
mine stability for the two groups of hybrids, however, does
not show any striking differences between the selected and
unselected hybrids. The trends agree with the expected, but

the evidence is not convincing.

The proportion of hybrids with S^2d significantly different from zero in the unselected group of hybrids was slightly greater compared with the selected group; i.e., 55.4% of the unselected hybrids had deviation mean squares that were not significantly different from zero, whereas the selected hybrids had 51.2% that were not different from zero. This indicates that the unselected group had slightly more stable hybrids than did the selected group. The frequency of deviations from the regression values that were significantly different from zero were slightly lower in sets 2, 4, 5, and 6 of the unselected group of hybrids, ranging from nine for set 2 to 18 for set 3. The selected group of hybrids with frequency of deviations from the regression (S^2d) different from zero ranged from eight for set 5 to 18 for sets 2 and 3. When considering both regression (b) and deviations from regression (S^2d) parameters, however, the proportion of stable hybrids was nearly the same in the selected (54.2%) and unselected (55.9%) groups of hybrids. There were 336 hybrids assayed for this aspect of my study. One hundred and eighty-five hybrids were found to be stable for both the regression and deviations from regression stability parameters. Therefore, the frequency of stable hybrids was similar for the selected and unselected hybrids.

Comparisons for the performance of the hybrids relative to the mean yield for the selected and unselected groups in each

of the six sets are shown in Table 17. The mean yields in the
selected hybrid group for each of the sets were generally
greater than those of the unselected group. In the selected
group (68.5%) there were more hybrids superior to the overall
mean yield than for the unselected group (29.8%). The number
of means significantly different at the 5% level from the
overall mean of each selected and unselected group of hybrids
in each of the six sets is presented in Table 18. The number
of means for one LSD above the overall mean in each set was
different for the selected and unselected hybrid groups but
not for the total. For two LSD's above the overall mean, the
number of means for each set was different except for set 2;
in the total the selected had fewer number than the unselected.
Contrary to the two stability parameters, b and S^2d, therefore,
the mean yield of the two groups of hybrids indicates that
the selected hybrids were superior to the unselected hybrids.
There were seven more unselected hybrids (89 vs 82) that ex-
ceeded mean of all hybrids than selected hybrids, but the
unselected had 10 more that were greater than two LSD's below
the overall mean.

I selected the five highest and the five lowest yielding
single crosses in each set to show if there was any relation-
ship among the three stability parameters. In considering the
five highest yielding hybrids (Table 19) from each set, most
of them did not combine high yield with a regression of 1.0 and
pooled   deviations not significantly different from zero.

Table 17.   Mean yields for the selected (X) and unselected (Y) hybrids for the six sets compared with the mean yield of the nine environments

Sets	Yield > $\bar{X}$[a]		Yield < $\bar{X}$		% stable hybrid	
	X	Y	X	Y	X	Y
1	16	16	12	12	57.14	57.14
2	23	13	5	15	82.14	46.43
3	20	8	8	20	71.43	28.57
4	22	4	6	24	78.57	14.28
5	17	4	11	24	60.71	14.28
6	17	5	11	23	60.71	17.86
Total	115	50	53	118	68.45	29.76

[a]$\bar{X}$ = overall mean yield (81.9 q/ha ± 0.10).

Two of the hybrids had regression values significantly different from one and 19 had a deviation mean square greater than zero. Only five of the 30 greatest yielding hybrids, however, were from the unselected group of hybrids.

On the other hand, when considering the five lowest yielding hybrids for each set (Table 20), most of them combined low yield with regression of 1.0 and S^2d not different from zero. Only two of the lowest yielding hybrids had a b value significantly less than one and 10 had a deviation mean square greater than zero. Except for mean yield, the low-yielding hybrids had greater stability, based on estimates of

Table 18. Least significant difference for selected and unselected hybrid groups for the six sets

	Sets[a]												Total	
	1		2		3		4		5		6			
	S	U	S	U	S	U	S	U	S	U	S	U	S	U
> -2 LSD	2	3	0	3	0	3	1	2	0	2	1	1	4	14
-2 LSD	7	4	5	6	6	3	5	4	7	4	6	4	36	25
-1 LSD	7	7	8	6	8	8	8	6	8	5	7	8	46	40
+1 LSD	5	7	10	6	10	8	10	7	7	11	7	11	49	50
+2 LSD	3	5	5	5	4	3	2	8	4	6	6	4	24	31
> +2 LSD	4	2	0	2	0	3	2	1	2	0	1	0	9	8
$\bar{X}$	84.60	82.53	87.61	81.30	86.47	78.85	88.47	72.82	84.78	74.56	85.66	75.41	86.27	77.58

[a]S indicates hybrids of selected lines and U indicates hybrids of unselected lines.

Table 19. Mean yields (q/ha), regression coefficients, and deviation mean squares of the five highest yielding single-crosses in each set

Pedigree	Yield	Stability parameters	
		b-value	s^2d
Set 1			
S22-2x21-11467x1763	99.2	1.50	42.56
S52-3x21-11479x1475	105.0	1.31	52.05
S21-1x55-1555x556	102.6	1.50	64.99**
U31-3x28-8933x930	102.0	1.75	70.44**
U31-3x32-6933x932	100.9	2.08	246.34**
Set 2			
S52-3x21-11497x1493	96.5	1.08	24.41
S52-3x97-101497x1495	96.7	2.39*	78.62**
S98-10x97-101503x1501	96.9	0.84	30.00
S98-10x67-91503x1502	96.6	1.08	52.76**
U208-6x200-91071x1069	108.2	1.27	16.22
Set 3			
S52-3x21-11521x1517	100.0	1.04	120.35**
S98-10x21-11527x1523	97.1	1.74*	41.49
S98-10x97-101527x1525	95.4	1.28	128.23**
U81-10x54-31083x1081	104.2	0.34	158.88**
U91-7x54-31101x1099	94.8	1.66	181.81**
Set 4			
S51-3x52-31545x1542	94.6	1.46	105.95**
S97-10x98-101531x1549	100.8	1.55	110.46**
S67-9x52-31557x1554	105.9	0.95	90.00**
S67-9x98-101557x1555	102.9	0.92	34.60
S67-9x66-71557x1556	100.0	1.06	213.32**
Site 5			
S97-10x98-101575x1579	94.2	1.66	30.65
S67-9x52-31581x1578	99.2	1.06	46.81*
S67-9x98-101581x1579	96.7	1.07	35.75
S67-9x66-71581x1580	96.0	1.31	99.73**
S51-3x67-9667x668	98.5	1.28	25.45

Table 19.   (Continued)

Pedigree	Yield	Stability parameters	
		b-value	s^2d
Set 6			
S51-1x52-31587x1583	96.8	1.96	280.73**
S97-10x98-101593x1596	94.4	1.60	40.65
S67-9x52-31599x1595	105.8	0.81	222.94**
S67-9x98-101599x1596	99.2	1.75	61.27**
S67-9x66-71599x1597	96.0	2.05	231.27**
Average	99.2	1.38	101.29
LSD (.05)	5.0		

the regression values and the deviation mean squares. The 30 highest yielding hybrids averaged 35.30 q/ha more than the 30 lowest yielding hybrids. Only two of the 30 lowest yielding hybrids were from the selected group of hybrids.

Simple correlation coefficients of yield among locations and among years are shown in Tables 21 and 22 for all hybrids. The correlations were highly significant among locations and years at the 1% level in all instances. For locations and years, the correlation values ranged from 0.30 to 0.75 and 0.25 to 0.74, respectively. The magnitude of the correlations were similar among locations and years. The mean yields for Ames and Ankeny were more highly correlated (0.67) than for the other location combinations. Mean yields for 1972 and 1973 were more highly correlated (0.66) than 1971 with either 1972 or 1973. Although all correlations were significant,

Table 20. Mean yields (q/ha), regression coefficients and
deviation mean squares of the five lowest yielding
single crosses in each set

| Pedigree | Yield | Stability parameters | |
		b-values	s^2d
Set 1			
S52-3x55-11479x1478	69.3	1.12	68.59**
S22-2x54-2567x568	66.7	0.81	41.52
U21-7x30-7915x913	68.7	0.97	4.85
U21-7x29-8707x709	65.2	0.78	51.42
U21-7x31-10709x710	70.1	0.88	41.18
Set 2			
U96-3x218-3719x720	70.1	0.90	37.44
U96-3x200-9721x722	66.0	1.49	25.99
U96-3x212-5723x724	63.4	1.33	13.47
U97-1x7-6731x732	68.4	0.21	36.87
U97-1x213-8735x736	72.4	0.81	14.69
Set 3			
U9-8x14-101089x1085	70.1	1.02	41.12
U9-8x10-101089x1086	71.8	1.21	19.61
U17-10x92-6747x748	61.1	1.02	71.58**
U14-10x10-10743x744	58.7	0.54	82.89**
U81-10x91-7759x760	57.5	1.53	42.00
Set 4			
U24-5x26-3767x768	52.8	0.74	58.65*
U24-5x26-6769x770	60.6	0.88	17.84
U24-5x28-5771x772	60.6	0.87	50.05*
U26-3x26-6773x774	57.0	0.74	39.34
U26-3x28-5775x776	61.3	1.08	19.29
Set 5			
U78-4x99-21335x1331	66.1	0.85	23.00
U72-1x78-4793x794	53.2	0.65	12.22
U72-4x78-4797x798	66.7	0.57	70.60**
U72-4x78-8799x800	65.1	0.84	13.00
U78-4x78-8801x802	60.9	1.26	44.64*

Table 20. (Continued)

| Pedigree | Yield | Stability parameters | |
		b-value	s^2d
Set 6			
U84-2x83-21359x1357	63.7	0.05*	71.02**
U84-10x83-81365x1364	52.7	2.20	85.69**
U80-8x82-3815x816	68.2	0.45	16.28
U80-8x84-10819x820	68.2	1.68	33.11
U82-3x84-10823x824	61.7	-0.24*	68.69**
Average	63.9	0.91	40.72
LSD (.05)	5.0		

the coefficients of determination were less than 56% in most instances.

Simple correlation coefficients also were computed among mean yields, regression coefficients, and deviations from the regression as shown in Table 23. A nonsignificant negative correlation was shown between mean yield and the regression coefficient for the unselected hybrids in set 6, whereas the selected hybrids had a significantly positive correlation. In sets 1 and 5 for the selected hybrids, there was no correlation between mean yields and the regression values. For the unselected group of hybrids, the r_{yd}'s were significant at the 1% level for all sets except for set 6. All other correlations were intermediate to low in value. The correlation values for the combined over sets were significant at the 1% level and ranged from 0.21 to 0.41. Although significant, the

Table 21. Simple correlation coefficients of yield among locations computed for each set and combined over sets for all hybrids

	Sets					
	1		2		3	
Locations[a]	B	C	B	C	B	C
A	.68**	.30**	.66**	.43**	.63**	.45**
B		.46**		.60**		.63**

[a]A = Ames, B = Ankeny, and C = Martinsburg.

**Indicates significance at the 1% level with 334 d.f.

Table 22. Simple correlation coefficients of yield among years computed for each set and combined over sets for all hybrids

	Sets					
	1		2		3	
Years[a]	B	C	B	C	B	C
A	.25**	.31**	.54**	.44**	.45**	.33**
B		.69**		.63**		.66**

[a]A = 1971, B = 1972, and C = 1973.

**Indicates significance at the 1% level with 334 d.f.

Sets						Combined	
4		**5**		**6**			
B	C	B	C	B	C	B	C
.75**	.55**	.71**	.44**	.54**	.37**	.67**	.43**
	.60**		.46**		.62**		.56**

Sets						Combined	
4		**5**		**6**			
B	C	B	C	B	C	B	C
.59**	.46**	.54**	.37**	.47**	.39**	.46**	.38**
	.74**		.63**		.69**		.66**

Table 23. Simple correlation coefficients among mean yield (y), regression coeffi-
cients (b), and deviation from the regression (d), estimated for selec-
ted, unselected, and all hybrids for each set and combined over all sets.

Hybrids	r^a	Sets						Combined
		1	2	3	4	5	6	
Selected	$r_{y.b}$	.00	.81	.53**	.36**	.00	.60**	.29**
	$r_{y.d}$	.37**	.34*	.24	.16	.33*	.56**	.33**
Unselected	$r_{y.b}$	.41**	.15	.22	.22	.08	-.39	.21**
	$r_{y.d}$	.56**	.42**	.36**	.38**	.34**	.26	.41**
Combined	$r_{y.b}$	.23	.15	.10	.43**	.21	.38	
	$r_{y.d}$	.48**	.32*	.39**	.06	.30	.47**	

[a] $r_{y.b}$ = correlation coefficient between mean yield and regression coefficient;
$r_{y.d}$ = correlation coefficient between mean yield and deviation from the regression.

correlations would have poor predictive value.

For the selected group of hybrids, the r_{yb} ranged from 0.0 to 0.60 and the r_{yd} ranged from 0.16 to 0.56. The unselected group of hybrids had r_{yb} values ranging from -0.39 to 0.41 and r_{yd} values ranging from 0.26 to 0.56. For both groups of hybrids combined across sets, the r_{yd} correlations were larger than the r_{yb} correlations. Although the correlations of yield with the deviations mean squares were larger than the correlations of yield with the regression values, the coefficients of determination were small in all instances; i.e., 8.4, 10.9, 4.4, and 16.8% for r_{yb} and r_{yd} of the selected hybrids and r_{yb} and r_{yd} for the unselected hybrids, respectively.

The regression coefficients of the means of the hybrids upon the environmental indexes measures whether a given hybrid produces relatively more or less than all the hybrids in the environments. Table 24 shows the frequencies of the selected and unselected groups of hybrids related to regression coefficient for each set and combined over sets. For the selected group of hybrids, sets 1, 2, 4, and 6 had more hybrids with a b-value less than one. In set 3 the proportion of hybrids was the same for b-values less than or greater than one. Set 5 had fewer hybrids with superiority in the low-yielding environment. The unselected group of hybrids had more hybrids with superiority for low-yielding environments in sets 2, 3, and 4. Sets 1 and 5 had an equal number of hybrids that

Table 24. Frequencies of single-crosses related to the linear regression coeffi-
cient for each of the six sets and combined over sets

Type of hybrid	b-values	Sets						Combined total
		1	2	3	4	5	6	
Selected	b<1.0	16.0	16.0	14.0	17.0	13.0	16.0	92 (54.8%)
	b>1.0	12.0	12.0	14.0	11.0	15.0	12.0	76 (45.2%)
Unselected	b<1.0	14.0	17.0	17.0	16.0	14.0	11.0	87 (52.9%)
	b>1.0	14.0	11.0	11.0	12.0	14.0	17.0	79 (47.1%)

had b-values less than and greater then one. In set 6, the proportion of hybrids that had a greater response to the high-yielding environments was greater than for low-yielding environments. When combined over sets, the frequencies of hybrids with supriority for low-yielding environments were relatively greater than for high-yielding environments for both selected and unselected groups of hybrids. The frequency of b-values that was less than one or greater than one was similar for the selected and unselected hybrids.

To illustrate the yields and regression values for the six groups of selected and unselected hybrids, I plotted the yield against the environmental indexes as shown in Figures 2 and 3 for each of the six sets of selected and unselected groups of hybrids. Both the selected and unselected groups of hybrids showed similar regression values. The two groups of hybrids differed from each other in yield superiority; i.e., set 1 > set 2 > set 3 > set 6 > set 5 > set 4 for both the selected and unselected groups of hybrids. Mean yields combined over sets of selected and unselected hybrids and the environmental indexes are given in Figure 4. Similar regressions for the two groups were obtained. Although the regressions were similar the mean yields of the selected group of hybrids were superior to the mean yields of the unselected group of hybrids.

Hoegemeyer (1974) compared the diagonal versus off-diagonal crosses of the selected Design II's, to better
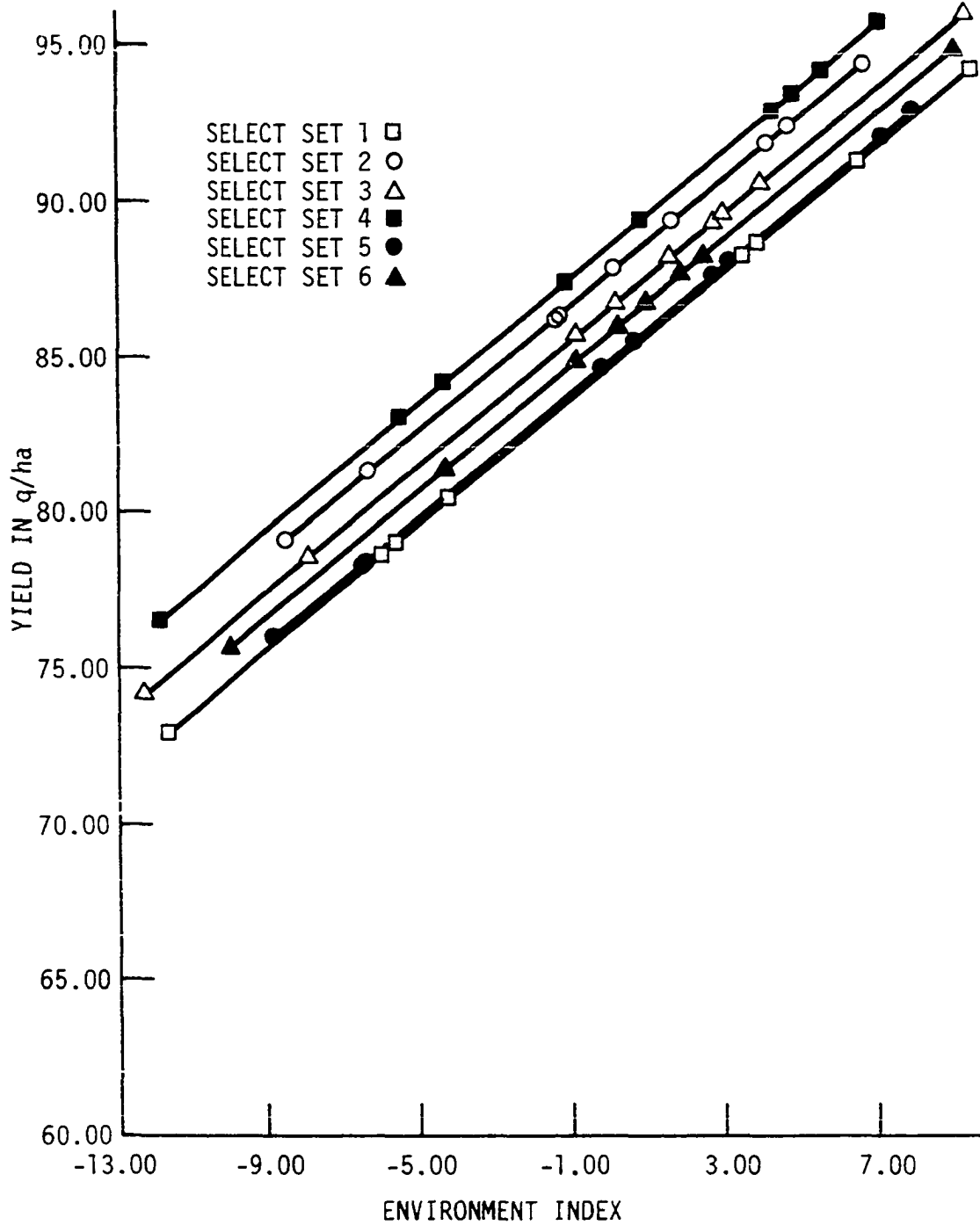
Figure 2. The average response of the selected group of hybrids to varying environments
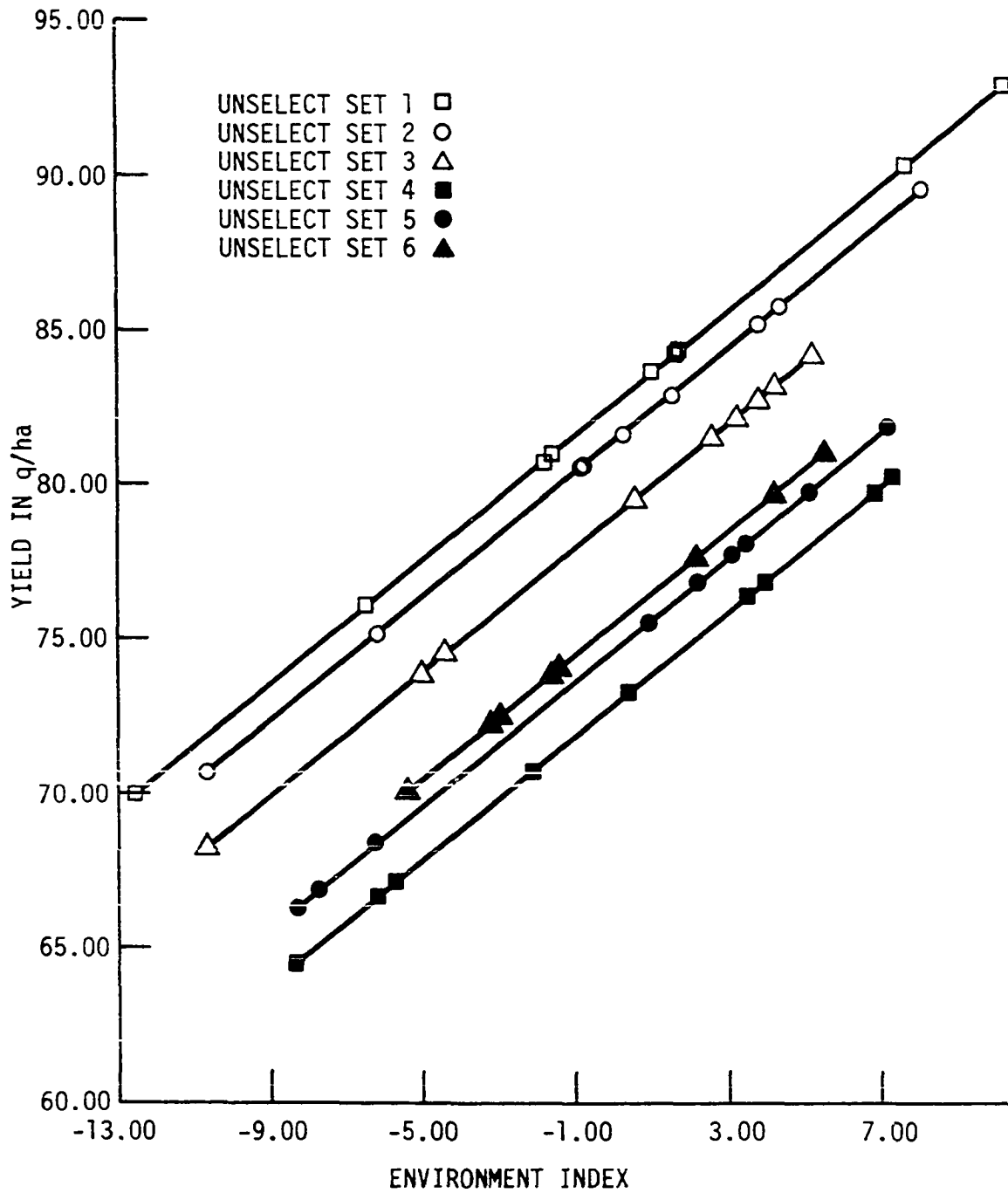
Figure 3. The average response of the unselected group of hybrids to varying environmenta
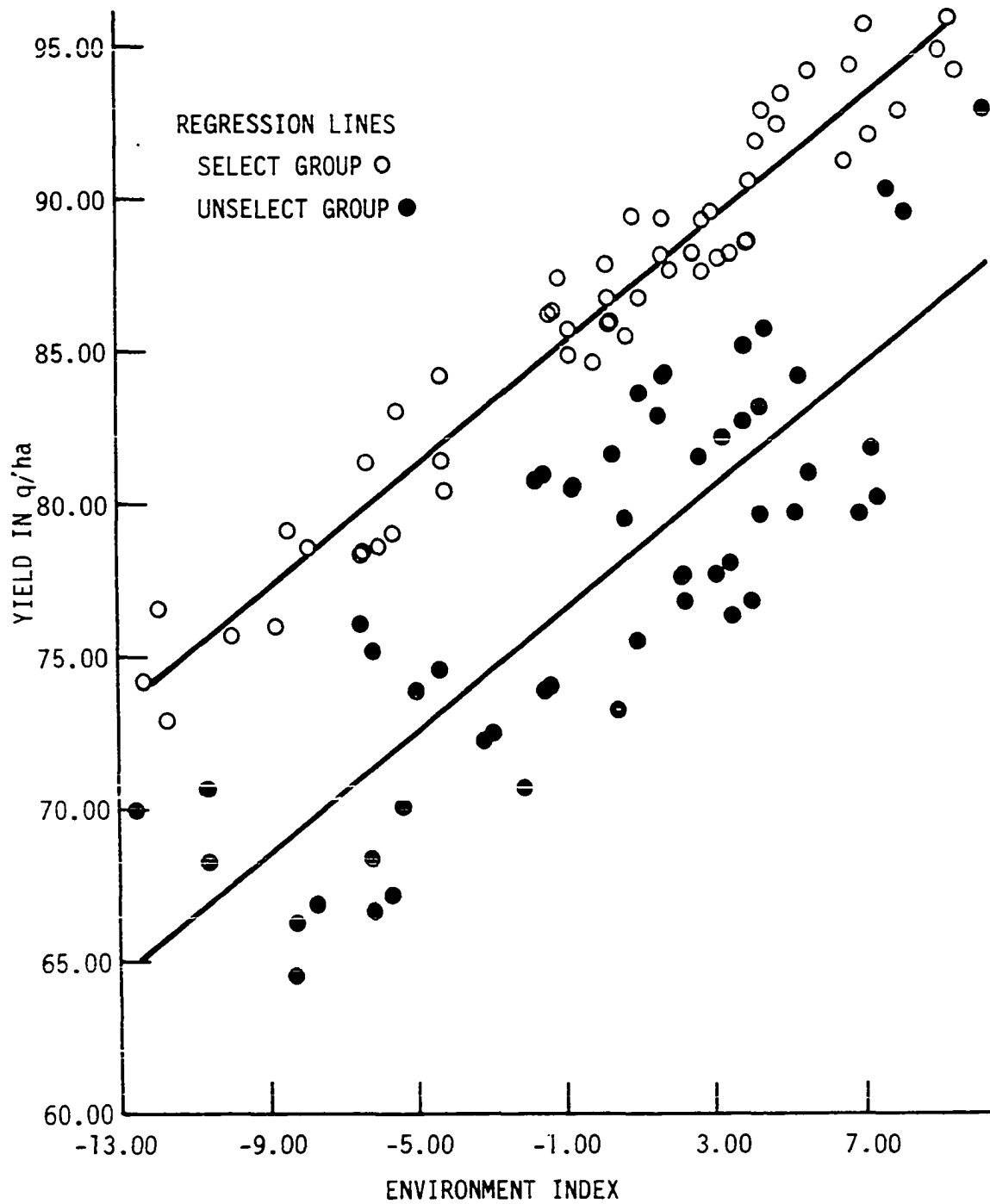
Figure 4. The average response of the selected and unselected groups of hybrids over the six sets to varying environments

visualize the effect of selection among and within full-sib
families as a method of single-cross development. The diag-
onal crosses of the selected lines represented the elite single
crosses selected by the full-sib procedure, the off-diagonal
crosses represent untested crosses of lines chosen as elite on
the basis of superior performance when crossed to their
paired lines. The diagonal crosses yielded 3.7 q/ha (4.2%)
more than off-diagonal crosses, a highly significant differ-
ence. The diagonal crosses of the unselected lines aver-
aged 1.4 q/ha less total yield than the off-diagonal crosses.
Based upon these results, I decided to determine if there is
any relationship between these relatively high yielding
(diagonal crosses) and lower yielding (diagonal crosses) and
the stability parameters. Table 25 shows the diagonal crosses
for each set with their respective stability parameters.
These diagonal crosses of the selected lines represent the
elite single crosses selected by the reciprocal full-sib
selection method (Hallauer, 1973). The number of hybrids
for the selected and unselected diagonal crosses that had re-
gression values not different from 1.0 was about the same for
all six sets. The proportion of stable hybrids over all six
sets, when considering the three parameters, mean, b-value,
and S^2d, was higher in the selected diagonal crosses than in
the unselected ones; i.e., 50 and 17%, respectively. The
comparison made between the diagonal single crosses and the
off-diagonal single crosses for the selected group of hybrids

Table 25. Stability parameters for the diagonal crosses of selected and unselected lines of Design II for each set

Pedigree	Means (q/ha)	Stability parameters	
		b-values	s^2d
Set 1			
S22-2x21-11467x1463	99.17	1.50	42.56
S30-1x29-21473x1470	81.16+	0.94	33.25
S52-3x51-31479x1477	93.81	0.96	36.16
S54-2x55-11485x1484	86.81	0.73	27.74
U21-7x20-6915x911	78.58+	-0.03*	28.45
U29-8x28-8921x918	91.22	1.37	99.98**
U31-10x30-7927x925	74.73+	0.39	98.70**
U31-3x32-6933x932	100.89	2.08	246.34**
Set 2			
S22-2x21-11491x1487	88.50	0.82	5.99
S53-3x51-31497x1494	92.96	0.99	26.47
S98-10-97-101503x150	96.89	0.84	30.00
S66-7x67-91509x1408	82.93	0.54	30.41
U97-1x96-31059x1055	79.11+	1.01	71.86**
U7-6x218-31065x1062	89.63	1.36	28.63
U209-6x200-91071x106	108.17	1.27	16.22
U213-8x212-51077x107	83.08	0.60	33.72
Set 3			
S22-2x21-11515x1511	92.33	0.70	37.79
S52-3x51-31521x1518	91.40	1.17	80.21**
S98-10x97-101527x15	94.54	0.73	57.45**
S66-7x67-91533x1532	83.31	0.49	43.63
U81-10x14-101083x107	77.83+	0.54	80.13**
U9-8x10-101089x1086	71.78+	1.21	19.61
U53-1x54-31095x1093	90.63	0.53*	216.34**
U91-7x92-61101x1100	77.66+	0.85	38.74
Set 4			
S21-1x22-21539x1535	87.48	1.34*	9.17
S51-3x52-31545x1542	94.46	1.46	105.95**
S97-10x98-101551x154	100.83	1.55	110.46**
S67-9x66-71557x1556	100.01	1.06	213.32**
U23-2x24-51179x1175	80.18	0.37	28.95
U25-1x26-31185x1182	66.38+	0.98	56.68*
U25-2x26-61191x1189	79.89+	1.19	65.66**
U27-1x26-61197x1195	79.63+	0.53	44.67

Table 25. (Continued)

Pedigree	Means (q/ha)	Stability parameters	
		b-values	s^2d
Set 5			
S21-1x22-21563x1559	77.34+	0.26	97.20**
S51-3x52-31569x1566	88.53	1.02	24.38
S97-10x98-101575x157	94.19	1.66	30.65
S67-9x66-71581-1580	96.01	1.31	99.73**
U72-1x99-21323x1319	80.13	0.82	71.99**
U72-4x73-61329x1326	81.01+	1.03	41.69*
U78-4x79-61335x1333	67.10+	1.01	83.72**
U78-8x79-91341x1340	75.11+	1.24	30.22
Set 6			
S51-1x52-31587x1583	96.77	1.96	280.73**
S97-10x98-101593x159	94.39	1.60	40.65
S67-9x66-71599x1597	95.98	2.05	231.27**
S21-4x32-71605x1604	80.36+	0.12*	34.78
U86-1x97-31347x1343	82.21	1.40	66.73**
U82-3x81-41353x1350	81.29+	1.32	32.32
U84-2x83-21359x1357	63.70+	0.05*	71.02**
U84-10x83-81365x1364	52.69+	2.20	85.69**

for the three stability parameters over all six sets (Tables 6 to 11) shows a greater frequency of stable hybrids in the selected diagonal crosses than in the off-diagonal crosses, i.e., 50% and 31%, respectively. The unselected group of hybrids, therefore, presented similar proportions of stable hybrids in the diagonal crosses and off-diagonal crosses. The proportion of b-values above 1.0 and less than 1.0 was different for the selected and unselected groups of hybrids, i.e., 1:1 and 0:3 for selected and unselected hybrids, respec-

tively. The frequency of selected and unselected hybrids over

sets for S^2d different from zero also was different with 9

and 14 for the selected and unselected hybrids, respectively.

DISCUSSION

The groups of hybrids included in my study originated from crosses between selected and unselected inbred lines developed from BSTE and PHPRC. These lines were obtained via full-sib reciprocal recurrent selection (Hallauer, 1973). For the selected groups of hybrids, the lines were identified on the basis of cross performance with a paired line during development. In the unselected groups of hybrids, however, the lines were developed by selfing without regard to performance of the original $S_0 \times S_0$ crosses. Thus, we should expect the occurrence of some high-yielding hybrids originating from the crosses of unselected lines. But the frequency of superior crosses was much greater for the selected group of hybrids.

The presence of significant hybrid x environment interaction mean square in all sets of selected and unselected groups of hybrids indicated that they differed in either rank or relative yields with environments. Although they had been selected for the same trait, they did not produce similar grain yield response to the nine test environments. Robinson and Moll (1959) and Comstock and Moll (1963) have shown that variety x locations and variety x years effects are often relatively small compared to the second-order interaction of variety x year x location. Maize genotype expression was not associated with a particular environment, i.e., location or

years. My results for individual analyses have shown that first-order interaction, hybrid x years effects, was as important as the second-order interaction. Thus, for this study, genotype x environment interaction seems more associated with years than with locations. The significant interactions found for each group of selected and unselected hybrids with environments, as shown in the combined analysis of variance, emphasized the variation that was due to genotype x environment interactions. The selected hybrid groups had significantly greater grain yields than the unselected hybrids. Systematic positive association between hybrid grain yield level and the magnitude of genotype x environment interaction was not observed. The low yielding groups of hybrids (unselected groups) did not have the lowest variance due to genotype x environment interaction as compared to the selected groups in all six sets. These results do not agree with Jowett (1972) in which low yielding varieties will be compelled to make a relative smaller contribution to the interaction sum of squares. This also suggests that the hybrids in the low yielding groups would not perform poorly relative to the other high yielding hybrids in all environments. The observed result may be explained by the occurrence of high yielding hybrids found in the unselected groups.

In each selected and unselected group of hybrids, the environment mean squares were highly significant. The selected groups had average yields which were above the overall

mean for all environments, but the unselected groups had some above and below. This indicates that the variability at a given environment was not related with the magnitude of the mean yield.

When the stability parameters were estimated it was shown clearly that there were differences among the groups of selected and unselected hybrids in each of the six sets. The regression coefficient parameter has been proposed as being very useful for studying the response of varieties to different environments (Finlay and Wilkinson, 1963). The regression parameter explains that portion of the genotype x environment interaction variation that can be accounted for in terms of linear environmental effects. In both the selected and unselected groups of hybrids, the majority of the hybrids had regression coefficient values that were not significantly different from 1.0 (P < 0.05). The regression coefficients, however, differed from each other in the selected and unselected groups of hybrids, as indicated by the hybrid x environment (linear) mean squares. When using the regression parameter to measure whether a given hybrid produces relatively more or less than all hybrids in the environments characterized by low and high yielding potential, the proportion of selected and unselected hybrids with either b < 1.0 or b > 1.0 was very similar. The difference in the responses for the selected and unselected groups of hybrids to varying environments was not due to the different responses of the hybrids as indicated by

the small hybrid x environment (linear) mean squares.

The regression coefficient and the deviations from the regression were defined to characterize stable genotypes by Eberhart and Russell (1966). Thus, a stable genotype would have regression coefficient equal to 1.0 and deviation from regression near zero. My results show that when considering these two parameters, the frequency of stable hybrids was similar for both selected and unselected groups of hybrids.

The significance of the deviation mean squares for both the selected and the unselected group of hybrids indicate that difference in linear response among the hybrids did not account for all the genotype x environment interaction.

The deviations from regression for a trait become important when the variety x environment (linear) sum of squares is a small portion of the total variety x environment interaction (Eberhart and Russell, 1966). The most reliable estimate of the deviation from regression is provided when there is a maximum number of environments and minimum replication per environment. This is because the variance of S^2d is a function of the number of environments. In my analysis, I found that the hybrid x environment (linear) sum of squares was only 11 and 25% of the magnitude of the hybrid x environment interactions in the combined selected and unselected group of hybrids, respectively.

The stability parameter for the selected and unselected hybrids were generally similar, although some exceptions were

evident, as one would expect because of the differences in environments. Relatively few of the hybrids satisfied the initial definition of a stable hybrid for all of the three stability parameters, high mean, regression near one, and deviation mean squares not different from zero.

When comparing the diagonal versus off-diagonal of selected crosses, there were more stable hybrids originated from lines selected among full-sib families than those selected within full-sib families. These stable hybrids were characterized by having mean yield above the overall mean, b-value not different from 1.0 ($P < 0.05$), and s^2d near zero ($P < 0.01$). These results indicate some relation with what was found by Hoegemeyer (1974), where he observed that diagonal crosses were better yielding than off-diagonal crosses. Thus, better yielding single crosses tend to be more stable.

Correlation among environments were highly significant, indicating that hybrids selected in one environment would be expected to have similar responses in other environments. Although the correlations were generally significant, their coefficients of determination were less than 56% in most instances. Hence, their use in predicting yields from one environment to another would not be reliable in all instances. The correlations among locations and years were similar for the selected and unselected hybrids. A high correlation between the regression values and the deviation from the regression would not be desirable because selecting for a hybrid that has

a good response to environment (b = 1.0) would not bring the same response for a deviation from regression mean square near zero. The correlations between (1) mean yield and regression and (2) mean yield and deviation from regression for the selected and unselected group of hybrids when pooled over sets were highly significant at the 1% level. If we consider the groups of hybrids in each set, the results ranged from no correlation to very high correlations. Thus, this high significant correlation between mean yield and the stability parameters make selection of their desired combination most difficult. Therefore, one should conclude that selection based upon yield only would have similar effect as utilizing "b" and "S^2d" parameters. The use of linear functions to determine hybrid stability is, of course, open to criticism. From my study, the estimation of the stability parameters did not provide any additional information that would assist the maize breeder in selecting the superior hybrids. Selection based on mean yield across environments was as effective as the estimation of stability parameters from the stability analyses. Mean yields of the selected hybrids were significantly greater than those of the unselected hybrids, but the stability parameter estimates were very similar for both groups of hybrids.

SUMMARY AND CONCLUSIONS

The objectives of my study were to determine the relative grain yield and stability of grain yield among groups of maize single-cross hybrids produced from selected and unselected inbred lines. I used the model of Eberhart and Russell (1966) to perform the stability analysis of variance and calculated the stability parameters, regression coefficient and deviations from the regression for mean grain yield of 336 single cross hybrids. The 336 single crosses were evaluated in six simple rectangular lattice experiments (7 x 8 simple rectangular design) at three Iowa locations (Ames, Ankeny and Martinsburg) in 1971, 1972, and 1973. A stable hybrid was defined as one with high mean yield, regression coefficient equal to 1.0, and deviations from the regression near zero.

The results from the conventional analysis of variance indicated that the selected and unselected groups of hybrids differed in either relative rank or relative yields with en-vironments. No consistent pattern of positive association be-tween hybrid grain yield and the magnitude of genotype x environment interaction was observed.

The stability analysis of variance showed that there were genetic differences for some groups of selected and unselected hybrids for stability parameter "b", as indicated by the hybrid x environment (linear) mean squares. The pooled devia-tions mean square, therefore, indicated that not all the

genotype x environment interaction was accounted for by differ-
ences of linear response among hybrids. The hybrid x environ-
ment (linear) mean squares were not significant, but the pooled
deviations mean squares were significant in the combined an-
alysis over sets for the selected and unselected hybrids.

The estimate of the stability parameter "b" indicated
that the majority of the selected (93.4%) and unselected
(85.7%) hybrids had regression coefficient values that were not
significantly different from 1.0. Unselected hybrids had a
greater number of b-values significantly less than 1.0 than
the selected hybrids. The proportion of hybrids with devia-
tions from the regression (S^2d) different from zero was slightly
greater for the unselected group (55.4%) than for the selected
group (51.2%) of hybrids. My results showed that the frequency
of the regression coefficient and deviations from regression
parameters were similar for the selected and unselected groups
of hybrids. Relatively few of the hybrids satisfied the
initial definition of a stable hybrid for all of the three
stability parameters, high mean, regression near 1.0, and
deviations mean square not different from zero.

When comparing the diagonal versus off-diagonal of selected
crosses, more stable hybrids originated from lines selected
among full-sib families than those selected within full-sib
families. Thus, the diagonal crosses were better yielding than
off-diagonal crosses (Hoegemeyer, 1970) and therefore tended to
be more stable.

Simple correlation coefficients of yield among locations and among years were similar in all instances. Simple correlation coefficients among mean yields, regression coefficients, and deviations from regression for the selected and unselected groups of hybrids were significant but too low to be of any predictive value. If we consider the groups of hybrids in each set, the results ranged from no correlation to very high correlations.

From this study, the estimation of the stability parameters did not provide any additional information that would assist the maize breeder in selecting the superior hybrids. Selection based only upon mean yield across environments was as effective as the estimation of the stability parameters from the stability analyses. Mean yields of the selected hybrids were significantly greater than those of the unselected hybrids, but the stability parameter estimates were very similar for both groups of hybrids.

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APPENDIX

Table A1. Analysis of variance of yield for each set combined over all environments

Source of variation	d.f.	Mean squares					
		Set 1	Set 2	Set 3	Set 4	Set 5	Set 6
Environments	8	5092.2**	2995.4**	3336.1**	3617.0***	3797.4***	2014.1**
Reps/env	9	278.7	260.4	115.7	80.9	210.4	124.0
Varieties							
Unadjusted	55	1610.7**	1380.5**	1540.1**	2397.4***	1480.1**	1675.7**
Ajusted	55	1644.5**	1413.4***	1589.3***	2442.5**	1503.7***	1665.0**
Var x env							
Unadjusted	440	120.7***	93.7***	141.1***	121.0***	99.5***	129.1**
Adjusted	440	122.0**	88.4***	139.1**	122.5**	100.6***	129.6***
Pooled error	495						
RCBD		72.8	58.1	67.6	69.9	54.2	67.1
Effective	..a	68.5	52.7	60.2	64.3	52.5	61.8
		(397)	(411)	(397)	(396)	(397)	(411)
C.V. (%)		9.9	8.6	9.4	9.9	9.0	9.6

aEffective error degrees of freedom varies with each set and is given in parentheses below mean square.

Table A2. Analysis of variance for yield combined over
environments and pooled across sets

Source	d.f.	SS	MS	F
Sets	5	18,459.84	3,691.97	5.16**
Environments	8	138,175.52	17,271.94	24.12**
Sets x env	40	28,642.17	716.05	4.02**
Reps/env & sets	54	9,630.18	178.34	
Varieties/sets				
Unadjusted	330	554,653.88	1,680.77	14.30**
Adjusted	330	564,218.47	1,709.75	14.61**
Var x env/sets				
Unadjusted	2640	310,209.69	117.50	1.81**
Adjusted	2640	308,958.84	117.03	1.95**
Pooled error				
RCBD	2970	192,863.24	64.94	
Effective	2382	142,660.17	59.89	
Total	6047	1,252,661.17		

**In this and all following tables indicates that the
calculated F-value exceeds the 1% tabled value of F.

Table A3. Orthogonal partitions of varieties sums of squares for yield in each set

Source	d.f.	Mean squares Set 1	Set 2	Set 3
Selected group	27	1,741.97**	660.47**	715.03**
Diallel vs DII	1	1.26	4,621.14**	5.319.00**
Within DII	15	1,627.22**	469.54**	612.12**
Diagonals	3	1,119.06**	649.92**	571.26**
Off-diagonals	11	1,640.06**	462.99**	668.95**
Diag vs off-diag	1	3,010.50**	0.36	109.62
Males	(3)	456.72*	1,645.26**	1,682.64**
Females	(3)	3,633.90**	393.30**	952.26**
Males x females	(9)	1,348.52**	121.04	141.92
Within diallels	11	2,056.68**	560.78**	436.79**
BSTE	5	840.85**	535.07**	148.28
GCA	3	1,332.18**	704.34**	158.52
SCA	2	103.86	281.16*	132.93
PHPRC	5	1,556.96**	369.97**	625.18**
GCA	3	2,509.92**	244.08*	943.08**
SCA	2	127.53	555.81**	148.32
BSTE vs PHPRC	1	10,634.40**	1,643.40**	937.44**
Unselected group	27	1,564.67**	1,851.25**	1.975.93**
Diallel vs DII	1	4,970.34**	16,211.34**	9,387.18**
Within DII	15	1,601.74**	1,450.40**	1,697.00**
Diagonals	3	2,586.06**	2,986.92**	1,131.72**
Off-diagonals	11	1,468.57**	1,038.42**	1,920.89**
Diag vs off-diag	1	113.58	1,372.68**	930.06*
Males	(3)	4,064.70**	4,389.18**	6,272.34**
Females	(3)	3,472.56**	2,094.36**	1,476.12**
Males x females	(9)	157.12	256.16**	245.52
Within diallels	11	1,204.53**	1,092.39**	1,682.52**
BSTE	5	430.96**	2,108.30**	1,791.97**
GCA	3	445.14*	3,406.50**	2,834.46**
SCA	2	409.68*	161.01	228.24
PHPRC	5	2,172.89**	279.83**	1,761.73**
GCA	3	3,569.22**	243.42*	1,780.74**
SCA	2	78.39	334.44*	1.733.22**
BSTE vs PHPRC	1	230.58	75.60	739.26*
Selected vs unsel	1	1.073.34**	10 047.24**	14,623.92**
Total	55			

Table A3.   (Continued)

Source	d.f.	Mean squares		
		Set 1	Set 2	Set 3
Selected group	27	1,200.91**	1,130.00**	1,278.07**
Diallel vs DII	1	7,874.82**	2,039.22**	5,332.50**
Within DII	15	1,042.44**	1,137.31**	1,316.77**
Diagonals	3	679.08**	1,265.10**	1,089.78**
Off-diagonals	11	1,109.45**	1,151.57**	1,397.86**
Diag vs off-diag	1	1,395.36**	597.06*	1,105.74**
Males	(3)	1,030.68**	1,864.92**	1,567.14**
Females	(3)	2,902.86**	2,587.92**	3 850.02**
Males x females	(9)	426.22**	411.24**	388.90**
Within diallels	11	810.28**	1,037.37**	856.72**
BSTE	5	648.61**	826.34**	158.69
GCA	3	1,006.62**	1,114.38**	65.04
SCA	2	111.60	394.29*	299.16
PHPRC	5	654.01**	723.78**	367.31*
GCA	3	956.22**	845.10**	475.56*
SCA	2	200.70	541.80**	204.93
BSTE vs PHPRC	1	2,399.94**	3,660.48**	6,793.92**
Unselected group	27	1,484.64**	955.95**	1,133.95**
Diallel vs DII	1	5,738.94**	2,110.86**	107.46
Within DII	15	917.57	479.06**	1,410.08**
Diagonals	3	929.88**	735.42**	3,693.06**
Off-diagonals	11	967.96**	450.57**	616.97**
Diag vs off-diag	1	326.34	23.40	3,285.36**
Males	(3)	1,692.42**	1,282.68**	2,248.80**
Females	(3)	1,963.08**	766.14**	1,160.40**
Males x females	(9)	310.78**	115.50	1,213.76**
Within diallels	11	1,871.17**	1,501.25**	850.73**
BSTE	5	499.57**	1,205.42**	867.13**
GCA	3	798.78**	1,185.30**	1,367.16**
SCA	2	50.76	1,235.61**	117.09
PHPRC	5	303.19*	323.24**	388.84*
GCA	3	200.46	373.08*	623.58**
SCA	2	457.29*	248.49	36.72
BSTE vs PHPRC	1	16,569.00**	8,870.40**	3,078.18**
Selected va unsel	1	61,664.22**	26,309.88**	26,420.40**
Total	55			

Table A4. Partitions of varieties sums of squares for grain
yield pooled across sets

Source	d.f.	SS	MS
Selected group/sets	162	181,614.06	1,121.07**
Diallel vs DII/sets	6	25,187.94	4,197.99**
Within DII/sets	90	93,081.06	1,034.23**
Diagonals	18	16,122.60	895.70**
Off-diagonals	66	70.739.82	1,071.82**
Diag vs off-diag	6	6,218.64	1,036.44**
Males	18	24,742.08	1 374.56**
Females	18	42 798.78	2,377.71**
Males x females	54	25,540.56	472.97**
Within diallels/sets	66	63.344.88	959.77**
BSTE	30	15,789.24	526.31**
GCA	18	13,143.24	730.18*
SCA	12	2,646.06	220.50**
PHPRC	30	21,486.06	716.20**
GCA	18	17.921.88	995.66*
SCA	12	3,564.18	297.02**
BSTE vs PHPRC	6	26,069.58	4 344.93**
Unselected group/sets	162	242.107.44	1,494.49**
Diallel vs DII/sets	6	38.526.12	6,421.02**
Within DII/sets	90	113.337.90	1,259.31**
Diagonals	18	36,189.18	2,010.51**
Off-diagonals	66	71,097.30	1,077.23**
Diag vs off-diag	6	6,051.42	1,008.57**
Males	18	59,850.36	3,325.02**
Females	18	32.797.98	1,882.11**
Males x females	54	20,689.56	369.46**
Within diallels/sets	66	90.228.42	1,367.10**
BSTE	30	34,516.80	1,150.56**
GCA	18	30,112.02	1,672.89*
SCA	12	4,404.78	367.07**
PHPRC	30	26,148.60	871.62**
GCA	18	20,317.50	1,128.75*
SCA	12	5,777.10	481.43**
BSTE vs PHPRC	6	29,563.02	4,927.17**
Selected vs unselected/sets	6	140,139.54	23,356.59**
Total varieties/sets	330	1,252,661.17	