GENETIC AND ENVIRONMENTAL EFFECTS ON KERNEL NUMBER AND EAR LENGTH IN CORN
(*ZEA MAYS* L.)

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ABSTRACT

A 6-entry diallel set involving 3 temperate and 3 tropical corn inbreds was planted monthly in Hawaii during a 21-month period from August, 1977 to May, 1979 to study the effects of seasonal change in climatic factors on kernel number and ear length and the stability of these characters. Another 10-entry diallel set involving 5 temperate and 5 tropical corn inbreds was evaluated at different locations in temperate and tropical regions to study the effects of geographically diverse environments on kernel number and ear length and their relationships to grain yield. Also, generation mean analysis based on 6 crosses among 2 temperate and 2 tropical corn inbreds was carried out to study the genetics of kernel number and ear length.

Under seasonal environments where cyclic changes in climatic conditions influence corn growth, the days to maturity of the corn plants were mainly determined by temperature and the vegetative growth of the corn plants was a function of the solar radiation available to the corn plants before silking. Corn plants were more sensitive to slight climatic changes during winter months than during summer months. Fifteen corn hybrids among 6 inbred lines did not differ significantly for almost all ear characters when seasonal environments were favorable for corn growth, but showed significant differences under unfavorable conditions. General combining ability (GCA) and specific combining ability (SCA) mean squares and GCA x month interaction mean squares were significant indicating that both additive and non-additive genes contributed to the genetic variation in ear characters with a significant contribution by the additive x month interaction.

Kernels per row, kernels per ear, cob length, filled ear length and grain yield followed the cyclical change in solar radiation, while floret number and row number were quite stable in seasonal environments. Average daily solar radiation during the 3rd month of the corn plant's growth explained 65 % of the variation in kernel number, ear length and grain yield. A non-linear asymptotic regression line showed that the expression of ear characters and grain yield was greatly influenced by a small change in solar radiation under unfavorable environments. Lower temperature during the winter season extended the growing period of the corn plants and compensated for the low irradiance, thus maintaining a grain yield higher than predictions based on solar radiation levels alone. The stable number of florets per row over season indicated that sink strength or limitations at the source rather than a limited sink size was responsible for lower grain yield in unfalorable seasonal environments.

The stability of 15 hybrids, as estimated by regression analysis, was found to be different for kernels per row and filled ear length but not for grain yield. Additive genes were responsible for the stability of the corn hybrids. The relative stability of a hybrid could be predicted by the regression coefficients of combining ability effects. The response of GCA effects to environments was basically a response to the cyclical change in solar radiation in seasonal environments. Therefore, it would be possible to identify genotypes tolerant to light stress by testing a large number of genotypes and selecting genotypes with high stability in seasonal environments where solar radiation is a major limiting factor for corn growth.

Under different geographic environments, growth of corn was influenced by temperature, daylength and daylength sensitivity of the genotypes. Average number of days to mid-silking of 45 hybrids ranged from 50 at Waimanalo, Hawaii to more than 80 at Kamuela, Hawaii and at the temperate areas of Ames, Iowa, and Suweon, Korea. Additive and non-additive genes contributed to the genetic variation of the ear characters with significant effects of additive x location interaction as in seasonal environments. The high GCA/SCA ratio for all ear characters and grain yield indicated that GCA was more important than SCA for all characters. In general, the temperate inbreds CI21E, Mo17 and Oh545 were good combiners for kernels per row and filled ear length, while the tropical inbreds CM105 and Tx601 were good combiners for kernels per ear with a high row number. Partial correlation coefficients indicated that kernel number was the most important determinant of grain yield at all locations.

Hybrids among tropical inbreds had a high stability for kernels per row and filled ear length, while hybrids among temperate inbreds responded better to favorable environments. Several hybrids between temperate and tropical inbreds showed higher stability as well as higher kernel number, longer ear length and higher grain yield than hybrids among tropical or temperate inbreds alone. Regression analysis of GCA effects showed that all tropical inbreds contributed to high stability in their hybrids. The hybrid x location interaction was mainly due to the linear response of GCA effects to different locations while SCA effects appeared to be stable from location to location.

Generation mean analysis of 6 crosses among 4 inbreds showed that the dominance gene effects were the most important contributors to the inheritance of floret number, kernels per row, cob length and filled ear length. Additive gene effects were of minor importance in 6 crosses studied. Genetic variances were smaller than environmental variance for all characters. Average narrow sense heritability estimates were 39 % for floret number and 22 to 27 % for other characters. The minimum number of genetic factors was 3 for floret number and 5 to 8 for other three characters.

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1. INTRODUCTION

Corn yields under subtropical or tropical conditions are usually lower than those of temperate regions, especially during typical monsoon seasons when low solar radiation consistently results in minimal grain yields. Evidence from tropical yield trials suggests that solar radiation is one of the most important limiting factors for corn production (Brewbaker, 1974; Milbourn, 1977; Lee, 1978). The association of low yield with low irradiance in the tropics not only prompts studies on physiological responses, but also a search for corn genotypes with improved responses to low light. By finding gene source tolerant to the stress of low solar radiation, it might be possible to increase tropical corn yields.

The storage capacity of the corn plant is known to be a limiting factor for higher grain yields in the tropics (Goldsworthy, 1975, and Yamaguchi, 1974). One way of increasing storage capacity for higher grain yield is to increase the number of kernels per plant or per unit area. Ear length is closely related to both kernel number and size and has been recognized as an important selection criterion for higher grain yierds since the early days of corn breeding. Information relating the response of kernel number and kernel size to the seasonal fluctuation of radiation level in the tropics is limited.

Genotype-environment interactions provide a major deterrent to selection advance in breeding programs. The understanding of such interactions is indispensable when breeding materials are tested under conditions involving temporal and/or spatial differences.

Several studies were initiated to obtain the essential information regarding these problems at the University of Hawaii Agricultural Research Station at Waimanalo. Single crosses of a diallel set involving temperate and tropical inbreds were planted monthly to study the effects of seasonal environments on kernel number and ear length and to identify any genetic difference in response to the seasonal environments. Another set of diallel crosses was tested under tropical and temperate locations to study the effects of geographic environments on kernel number and ear length and their contribution to grain yield under different locations. At the same time a study on the genetics of kernel number and ear length was carried out to provide information on the potential and actual capacity of assimilate storage in terms of kernel number in corn plant.

2. LITERATURE REVIEW

2.1 Kernel number and ear length

2.1.1 Relating corn yield to its components

The objectives of increasing grain yield has encouraged interest in plant and ear characters that are correlated with yield. Esterhaty (1887) and Davenport (1897) were among the earliest workers who studied on the association among various characters in corn. Woodworth (1931) emphasized that yield might be increased in grains by selecting for the components of yield, and that parental varieties should be selected on the basis of their component attributes. However, morphological yield components have not been used extensively as selection criteria by plant breeders for improvement of yield itself. Frey (1971) gave three reasons for this lack of interest: 1) the relationship between yield and the yield components is often multiplicative and thus non-linear, 2) the environment affects the relationship between yield and its components, and 3) the collection of yield component data may be more expensive than collecting yield data.

Much progress has been made in hybrid corn improvement based on empirical tests, without clear-cut genetic information on the inheritance of grain-yielding ability nor understanding of the basic physiological processes being manipulated (Leng, 1963; Adams et al., 1975). However, new genetic and physiological information should lead to increased efficiency in selection programs and help breeders raise maximal yield levels. There have been different views on the values of yield components in the interpretation of the hereditary control of yield variations. Williams (1959, 1960) and Grafius (1959, 1960) have taken the position that because yield components posses a multiplicative relationship to yield, much of the non-additive variability in yield can be explained in terms of additive yield component variation. Grafius (1964) concluded that all plants follow a rhythm of development and yield components are directly related to the growth stage. Therefore, yield components are largely separated in time and consquently may be subject to entirely stresses in a given environment. All changes in the yield components need not to be expressed in changes in yield but all changes in yield may be accompanied by changes in one or more of the components.

On the other hand, Hayman (1960^{a}) and Moll et al. (1962) insisted that yield is inherited as an overall character, and that component analysis is not helpful and even confusing in attempts to clarify genetic control. The primary effects of genes are biochemical in nature and,therefore, it is more reasonable to think of yield as some function of the total energy minus the amount used for structural growth and chemical energy. Further, they (ibid) argued that any advantage of the yield component approach is less than the disadvantage of accumulation of errors in a joint interpretation of multiplicative components; however, the yield components can be measured with much less error than yield and can be useful as an aid to yield improvement.

Leng (1963) re-analyzed the yield and yield components' data from experiments conducted during the years 1945 - 1950 in Illinois to clarify the above arguments. He concluded that analysis of phenotypic components would not provide a satisfactory appraisal of the genetic basis for heterosis of the inheritance of corn grain yield. Also the statistical-genetic studies of total grain yield have not led to reliable estimates of the type of gene action involved. He stressed the need for a new approach of effective coordination of present technique for investigation of grain yield inheritance in corn.

Recently, Thomas and Grafius (1976) tested a 14-entry diallel set in Colombia to study the correlated sequential yield components of corn. They concluded that the true relative genetic variance of corn as measured by the loss in variation of the second and subsquent in the sequence caused by the influence of previous traits of corn was high and this indicated that the yield components are not bound tightly together either physiologically or genetically. They suggested the possibility for construction of hybrids with high values for each component without worrying about inter-component compensation.

Ear length and diameter were the first characters recognized to be significantly related to grain yield of corn (Ewing, 1910; Love, 1911, 1912; Emerson and East, 1913; Love and Wentz, 1917; Collins, 1916; Jenkins, 1929). Other characters such as number of kernels per row, kernel weight, number of ears per plant and number of rows per ear were studied more recently in relation to the grain yield (Robinson et al., 1955; Leng, 1963; Moll et al., 1962; Compton, 1964; Singh, 1966).

Leng (1951) listed six major components of grain yield in corn and separated these six components into two groups as primary and secondary components. Number of ears per plant, kernel weight, row number and number of kernels per row, which cannot be readily further subdivided, were regarded as primary components, while, weight of grain per ear and number of kernels per ear were regarded as secondary or complex components since they are the products of two or more of the primary components. Kovács et al. (1970) listed ear length, number of kernel rows, number of kernels per row, kernel depth and kernel weight as five basic yield components of the grain yield of corn. Herczegh (1970) included cob weight, cob diameter, ear diameter, ear weight and shelling percentage in his study of yield components as well as Kovács et al.'s (1970) five basic yield components.

Since ear length is the only component which is able to induce a joint increase in both number and weight of the kernel, i.e. the two most important yield components, it has been natural that the corn breeders have devoted so much attention to the ear length. Recently, Russell and Machado (1978) confirmed that ear length was the most important component of yield, and encouraged breeders to give close attention to this trait in development of inbred lines. However, Sinha and Khanna (1975) considered number of ears per plant, number of kernels per ear, and kernel weight to be the main components. They stated that yield of corn is determined principally by the number of rows, the number of kernels per row, and the kernel weight.

2.1.2 Source and sink as limiting factors of corn yield

Plant physiologists have disagreed the limitation to higher grain yield of corn in terms of source, the assimilate produced by the plant, and sink, the number and size of kernels to store the products of photosynthesis (Evans, 1975; Tollenaar, 1977; Shannon, 1978). Published results on the relative importance of the post-anthesis photosynthate supply and the capacity of the grain to accumulate photosynthate are predominantly in the direction of a sink limitation in corn (Tollenaar and Daynard, 1978^{a}). Goldsworthy et al. (1974) compared highland and lowland corns in Mexico and concluded that the source (assimilate supply) was not limiting for higher yield, but that more storage capacity in kernels was needed. Yamaguchi (1974) also concluded that high grain yield of corn was attributable primarily to the large number of kernels per unit area and that sink size is possibly the dominant factor controlling the grain yield in lowland Mexico.

The role of photosynthesis of a corn plant tends to remain relatively constant over time assuming the absence of climatic change (Sayer, 1948; Chandler, 1960). The photosynthate used for kernel growth comes both from current photosynthesis and from labile carbohydrates accumulated earlier in stalk, leaf sheath, and roots. Transfer of carbohydrates can take place from stalks and leaf sheath to kernels under extreme conditions (Hume and Campbell, 1972). Results of defoliation studies in Rhodesia showed that a relatively large amount of dry matter in the stem could be translocated to the grain. This also indicates a sink limitation (Allison and Watson, 1966; Allison et al., 1975).

These results suggested the possibility of increasing corn yied by increasing kernel number and size. This may be accomplished through increase of number of kernels per row and/or kernel row number. Since the kernel number is determined within the limited space on ear, it is important to increase ear length or increase number of ears per plant (Herczegh, 1970; Goldsworthy and Colegrove, 1974; Goldsworthy et al., 1974).

The decrease that occurs in stem weight in the latter part of the grain-filling period in Canada was interpreted as indicating that source may be limiting grain yield (Daynard et al., 1969). Tollenaar and Daynard (1978^{b}) reported that grain yield was affected more by alteration in assimilate supply during the grain-filling period than the period of silking. These results indicated a predominant source limitation for grain yield in the corn hybrids grown in short growing-season environments like Canada. When the source is identified as the limiting factor for grain yield, grain yield may be increased by increasing leaf area, extending leaf area duration after silking, and/or increasing net assimilation rate (Tollenaar, 1977).

In his review, Tollenaar (1977) summarized that reproductive sink capacity is commonly a limiting factor for grain yield of corn in temperate and sub-tropical regions, and source is a limitation for grain yield in short-season, cold temperate regions. Sinha and Khanna (1975) pointed out, however, that there is no detailed information on the potential kernel number in inbred parents and their hybrids in corn. It is quite possible that reported results underestimated potential sink capacity and interactions with environmental variations.

The capacity to translocate assimilates from source to sink was listed as one of possible factors limiting grain yield (Evans, 1975). Shannon (1978) redefined the term "sink strength" as the efficiency with which the developing kernel imports assimilates and utilizes them in the production of dry matter. He mentioned that kernel sink strength may be limited by the rate of sugar movement from the phloem to the endosperm cells and sugar utilization in starch synthesis. No detailed results have been reported on the limitation of translocation for higher grain production. Tollenaar and Daynard (1977) indicated that sink strength may be a limiting factor for growth of tip kernels.

2.1.3 Relationships among yield, kernel number, and ear length

Relationships between yield and yield components are expressed in terms of correlation coefficients, multiple correlations or pathway coefficients. There are a wide range of values depending on the materials used, researchers and/or environments tested. Kovàcs et al. (1970) and Herczegh (1970) studied the relationships among phenotypic yield components of Hungarian hybrids and found high correlation between yield and kernel number per row (r = 0.8443). Camacho (1962) used genotypic correlations to calculate pathway coefficients and pointed out that the direct effect of number of kernel rows on grain yield was higher than that of number of kernels per row. Satovic (1975), Yamaguchi (1974^b) and Tollenaar and Daynard (1977) reported that the number of kernels per row was the most important component of grain yield. Positive direct and indirect effects through average kernel weight surpassed 60 per cent (Satovic, 1975)

The number of kernels per ear is greatly influenced by the number of rows per ear, diameter of ear and ear length. Grain yield was much more influenced by the number of kernels per plant in inbreds than hybrids (Schuster et al.,1979). Based on regression analysis between yield and yield components, Herczegh (1970) stated that a long ear is 75 to 80 % effective in increasing kernel number and 20 to 25 %

effective in improving kernel weight. Ottaviano et al. (1975) also reported that ear length was associated with two common factors acting during the first part of vegetative growth and a factor which is mainly related to ear size (kernels per row and row number).

Many investigations showed a positive and significant correlation between ear length and grain yield of corn (Montgomery,1909; Love, 1912; Biggar, 1919; Wolfe, 1924; Johnson and Hayes, 1936; Hayes and Johnson, 1939; Singh, 1966; Hallauer and Wright, 1967; Sharman and Dhawan, 1968). Low or poor correlations between the two characters (range 0.277 to 0.877) was reported by others (Williams and Welton, 1915; Cunningham, 1916; Love and Wentz, 1918; Robinson et al., 1955). Phenotypic and genotypic correlations between grain yield and ear length reported by Robinson et al. (1955) and Sharman and Dhawan (1968) ranged from 0.188 to 1.05. El-Lakany and Russell (1971) obtained high phenotypic correlation between yield and ear length at high plant densities among test crosses of 20 inbreds in Iowa.

Ear length shows a high relationship with number of kernels per row. More than 90 percent of the effect of ear length on yield was due to the increase of number of kernels per row (Herczegh, 1970), since number of kernels per row was influenced by the available space on ear (Kovàcs et al., 1970). Pavilicic (1974) also reported a high and positive correlation between ear length and kernels per ear. On the other hand, ear length generally was negatively correlated with number of kernel rows (Kempton, 1924; Kyle and Stoneberg, 1925; Hallauer and Wright, 1967). Jorgenson and Brewbaker (1927) reported a multiple correlation of 0.607 with yield of F_1 as the dependent variable and five characters viz., ear length, number of kernel rows, ear diameter, plant height and grains per plant as independent variables.

2.1.4 Genetics of kernel number and ear length

Genetic studies of kernel number, and other yield components provide information on heritability, heterosis, additivity of variances and gene number. Heritability is low for kernel number and ear length. The heritability of most yield components has been 30 to 40 %, while kernel row number shows higher values (52 to 70 %). Ear length is highly correlated with kernel number and has 26 to 32 % heritability (Robinson et al., 1949; Warner, 1952; Williams, 1959; Camacho, 1962; Leng, 1963; Herczegh, 1970; Daniel, 1971; Dhillon and Singh, 1979).

Heterosis values for yield components range 40 to 100 %. Number of kernels per row showed the highest heterosis (60 to 100 %), while kernel row number had the lowest heterosis (14 to 50 %) (Leng, 1954; Kovács et al., 1970). Leng (1963) reported that number of kernels per row was the only primary component which gave wide and consistent superiority of hybrids over their better parents. The number of kernels per row of the hybrids was 142 percent that of the better parents. The degree of heterosis expressed in this component varies in the different hybrids, being to somewhat related to the number of kernels per row of the inbred lines. The short-ear x short-ear hybrids exhibited the highest relative amount of heterosis, while long-ear x short-ear hybrids showed the least heterosis. No overdominance in the control of number of kernels was noticed (Leng, 1954). The primary components of yield most affected by heterosis are those which require the longest time for their expression to be finally fixed, and in which, consquently, heterotic stimulation can be operative over the longest period.

Studies of Burdick (1948) indicated that there are two dominant genes with complementary action for control of row number. Emerson and Smith (1950) showed evidence of the existence of heterotic effects on row number in studies of hybrids between 12-row inbred lines. It was postulated that more than one genetic system was operative in the control of kernel row number (Leng, 1954). Gamble (1962) concluded that additive, dominant and epistatic gene effects appear to contribute more or less equally to the inheritance of kernel row number.

Partial to complete dominance was indicated for controlling ear length, ear number and ear diameter (Robinson et al., 1949). Shin (1972) also concluded that dominance gene effects were more important than additive effect for ear length in sweet corn. On the other hand, Robinson et al. (1955) and Eberhart et al. (1966) reported that additive genetic variance appeared to account the largest proportion of total genetic variance in the inheritance of ear length, ear diameter and ear number in open pollinated varieties. Epistasis was also reported to be involved in the inheritance of ear length and ear diameter (Gorsline, 1961; Eberhart, 1966; Eberhart and Gardner, 1966). In a recent report, Cortez-Mendoza and Hallauer (1979) suggested that the long ear length was dominant to short ear length. Selection for long ear was not effective for increasing yield, because a significant decrease in kernel depth coupled with selection for long ear caused the lack of yield response.

Johnson (1973) examined a set of 15 single cross and 30 three-way cross hybrids derived from a group of 6 commercially adapted, essentailly homozygous inbred lines and concluded that yield response to non-additive effects were maximized by crosses among lines that, on the basis of additive effect, exhibited high row numbers and kernel weights. However, he concluded that the additive effect estimates of yield components provide no more information concerning yield than did the additive effect estimates of yield itself. The dominance variance in kernels per row was primarily responsible for the dominance variability in yield.

Selection for yield components may be effective during inbred development. If such inbreds had greater general combining ability for yield, yield components would be useful selection criteria (Kuhn and Stucker, 1976). Geadelman and Peterson (1974) and Ferris and Geadelman (1978) increased ear length of several Minnesota inbreds through conversion and this resulted in increase of yield by 10 % comparing to the counterparts of the modified lines. From a backcross conversion program which increased the expression of number of ears per plant, ear length and kernel depth in five corn inbreds, Kuhn and Stucker (1976) concluded that average yields of single crosses involving the modified inbreds were significantly improved over the average yields of the normal by normal crosses in two sets of hybrids. However, Johnson (1973) pointed out that yield component data collected on inbred lines themselves would not be any more useful than inbred yields in predicting hybrid performance.

2.2 Effects of some environmental factors on ear development

2.2.1 Developmental morphology of corn ear

It is important to understand how kernel number is determined and how ears are developed in relation to possible environmental influences. The number of kernels per ear is determined by the number of kernel rows and the number of kernels per row. Kernel row number ranges from 4 in distichous types to 30 or more in fasciated types. Most commercial hybrids have about 16 to 18 rows of kernels (Bonnett, 1954). According to Anderson and Brown (1948) row number is affected by the degree of condensation or telescoping of the successive internodes. As the condensation index increases, there is an increase in the kernel row number. It is thought that types with a kernel row number of 16 or less do not carry condensation factors. The mature ear varies in size from 2.5 cm long in prehistoric corn up to 50 cm in the best ears of some hybrids, but it is usually 8 - 42 cm long and 3 - 7.5 cm in diameter, with 300 - 1,000 kernels in temperate regions (Aldrich et al., 1975; Purseglove, 1972).

Kernel row number is the first ear character to be determined when the spikelet-forming branch primordia are initiated at the base of the ear shoot primordium (Bonnett, 1954). This occurs within 35 to 40 days after planting when grown under normal Corn Belt conditions (Leng, 1951). The number of kernels per row is determined by the growth of the ear shoot, with spikelet-forming branch primordia produced beneath the apex of the shoot (Bonnett, 1954).

The potential kernel number of a corn plant is determined by the rate and duration of spikelet initiation. Ears are developed from the upper one or more axillary shoots of the stem (Bonnett, 1966). Spikelet primordia are produced in acropetal succession along the ear. Each spikelet has two floret primordia but usually only one floret is functional. The kernels are produced from a fertile floret. Siemer et al. (1969) reported that spikelet initiation continues until approximately 1 to 2 weeks prior to silking. Spikelet initiation is stopped on the lower ears first. Therefore, the topmost ear has the longest duration of spikelet initiation.

All florets do not undergo subsequent development after initiation. Some ovules are aborted and some florets fail to enlarge fully. Therefore, considerable number of potential kernels fail to mature. Daynard and Duncan (1969) reported in Canada that some florets on the tip of ears were fertilized but aborted and small apical kernels had ceased to develop at an early stage of development. The three week period following silking marks the transition from embryo development to starch deposition. The size and number of kernels that will fill are determined at this stage (Deihl, 1969). Brown and Robinson (1955) and Wilson (1978) observed that through the first 15 days following fertilization, the endosperm cell walls form and growth is largely by cell division.

Cessation of growth of tip kernels occurs at the onset of linear dry matter accumulation of the kernels but cessation was not directly related to the available carbohydrate assimilates for grain growth. Soluble carbohydrates usually continue to accumulate in stem until 2 to 3 weeks after silking (Campbell, 1964; Williams et al., 1968) and kernel enlargement ceased despite a relative high soluble sugar

Concentration in both stem and kernels during the early post-silking period (Tollenaar and Daynard, 1978[a,b]). The maximum expression of the number of kernels per row is fixed after fertilization of the ovules has been completed, approximately 75 days after planting under Illinois conditions (Leng, 1951) or 60 days in Hawaii (Brewbaker, 1974). The final limits on kernel weight are not set until the grain reaches physiological maturity, at about 105 to 115 days after planting in temperate areas.

2.2.2 Kernel development and environmental effects

Environmental factors such as solar radiation, photoperiod, temperature, moisture and mineral nutrition are known to influence the ear development from planting to silking (Kiesselbach, 1950; Robins and Domingo, 1953; Sass and Loeffel, 1959; Moss and Stinson, 1961; Hanway, 1962[a,b]; Du Plessis and Dijkhuis, 1967; Earley et al., 1967; Moss and Downey, 1971; Peaslee et al., 1971; Prine, 1973; Bonaparte, 1975; Coligado and Brown, 1975). Few studies include data on the effects of environment on the development of ear components. It is not known whether environmental factors affect the number of initiated kernels or the number of spikelets which fail to develop into mature kernels. Tollenaar (1977) concluded that vegetative development can be profoundly affected by environmental factors in the period from plant emergence to the cessation of spikelet initiation, while reproductive development is less sensitive to environmental variation.

Reduction of irradiance did not decrease ear length or spikelet number per ear in studies of Sass and Loeffel (1959) and of Nishikawa and Kudo (1973). In his study of East-European genotypes ranging early to late maturity, Fuchs (1968) concluded that the assimilation surface at tassel initiation determined the number of kernel initials rather than the duration of kernel initiation. On the other hand, Siemer et al. (1969) reported that hybrids produce more kernels per row because of their longer duration of the spikelet initiation than inbreds.

Cessation of ear growth during the flowering period may be caused by low amount of irradiance per plant (Moss and Stinson, 1961; Earley et al., 1967; Prine, 1971; Iwata, 1975), incomplete fertilization due to the time lag from pollen shed to silking under high plant densities or moisture stress (Wooley et al., 1962; Du Plessis and Dijkhuis, 1967; El-Lakany and Russell, 1971), or intra-plant competition for photosynthate during flowering period between ear shoots, tassel, stem and roots (Hanway, 1962[a]).

Number of florets per row of the ear at the time of flowering decreased slightly with increase in population. Number of kernels per row and per ear decreased with time after flowering especially in higher population (Wilson and Allison, 1978). Some abortion of kernels apparently occurs soon after flowering, when plant is producing considerably more assimilate than the kernels require and labile dry matter accumulates in the stem (Daynard et al., 1969). The lateral expansion of kernels in corn may be limited by the area available per kernel on the surface of the rachis (Wilson and Allison, 1978).

Potential size of kernels was evidently fixed soon after flowering. In rice the maximum size to which kernels can grow depends on the space within the rigid outer and inner glumes (Murata and Matsushima, 1975).

In wheat, Wardlaw (1970) suggested that potential size of kernels might be influenced by the number of endosperm cells formed during the early part of grain growth and thus, an upper limit of kernel size was set fairly soon after flowering. Wilson and Allison (1978) found that the removal of alternate plant in the corn field had little effect on weight per kernel of the remaining plants when it was done more than 2 - 3 weeks after plants had silked, but increased final kernel weight when done close to the time of silking.

2.2.3 Solar radiation

Effect of light on the growth of corn plants would be classified into two aspects, i.e. the effect of duration of light or photoperiod on reproductive development and the effect of amount of radiation on the growth of corn plants. Reported results show that increased daylength reduced grain yield of corn. McClelland (1928) observed that increasing the daylength from normal (11 hours) to 15 hours in Puerto Rico reduced the number of kernels per plant and resulted in the reduction of final grain yield. In later studies, Ragland et al. (1966) reported that supplemental light increased roughly one row number and the kernels initiated per row by 10 % for the April planting and 7.5 % for the June planting in Kentucky. However, there were fewer kernels per row at maturity under supplemental light because a fairly large numbers of the initiated kernels failed to develop into mature kernels. Also, weight per kernel was reduced by 10 %. Fewer kernels and reduced kernel size resulted in lower grain yield per plant which received supplementary illumination.

Lee (1978) observed changes in several yield components of corn under extended daylength in Hawaii. Cob length was increased under extended daylength of 4 hour period. No difference in filled ear length was noticed among the insensitive genotypes but filled ear length was increased among the intermediate genotypes. Both kernels per row and 100 kernel weight were decreased slightly in both genotypes. Row number was relatively unaffected by photoperiod. Kernel initials per row were increased by long days and with increasing sensitivity to photoperiod of genotypes. On the whole, sensitive genotypes showed drastia yield reduction under extended daylength with decreased cob length, filled ear length, kernels per row, 100 kernel weight and kernel depth.

Corn plants under long day conditions had prolonged vegetative growth and tassel initiation, delayed silking, taller plant and ear height and more leaf number (McClelland, 1928; Urano et al., 1959; Chaudhry, 1968; Francis, 1970; Francis et al., 1970; Hunter et al., 1974;Coligado and Brown, 1975; Faungfupong, 1976; Lee, 1978). Under increased daylength, Spencer (1974) reported that grain/stover ratios decreased in photoperiod sensitive cultivars, but photoperiod insensitive cultivars were not affected because increased daylength increased both grain and stover yields. Hunter et al. (1977) also observed that longer photoperiod resulted in higher final dry weight which was attributed to a higher leaf area per plant.

The effect of level of radiation on the growth of corn has been studied by means of shading, reflector or high planting density (Lang et al., 1956; Hageman et al., 1961; Knipmeyer et al., 1962; Stickler, 1964; Earley, 1965; Pendleton, 1965; Colville, 1966; Earley et al., 1966, 1967, 1974; Pendleton et al., 1966, 1967; Rutger and Crowder, 1967; Giesbrecht, 1969). Earley et al. (1966) stated that reducing light to 70 % of normal sunlight decreased kernel number per plant by 22 % for the prolific hybrid Illinois 972A, while the kernel number of the nonprolific hybrid WF9 x C103 decreased only 4 % under the same condition. The greater reduction of kernel number per plant for the prolific hybrid was due to the failure of development of the second ear. In the continued studies, Earley et al. (1967, 1974) noticed that shading during vegetative growth caused a greater reduction in number of kernels per plant. The 70, 80 and 90 % shade treatments drastically reduced kernel initiation and development of the first ear. They concluded that the kernel and ear initiation and development are directly depend on the rate of metabolites flow from the leaves.

However, in a recent study on shading in tropics, artificial shading had no significant effect on grain number per plant (IITA,1977). It was concluded that while radiation environment of the ear does not directly influence ear development, the environment of the leaf canopy immediate to the ear is very important. It apparently produces the additional assimilates that was used in grain development and probably provided some type of hormonal stimulus to ensure that grain survival rather than grain abortion occurred.

Pendleton et al. (1966, 1967) used a white reflective ground cover to study the effect of reflected light on corn yield. They observed consistent corn yield increases of 7 to 26 % over the uncovered ground. Based on multiple regression analysis of monthly planting data of corn hybrids in Hawaii, Lee (1978) concluded that the solar radiation on the 3rd month of the plant's growth, corresponding to grain filling period, was more important than the effects of solar radiation of the earlier two months in contributing to grain yield. Light intensity also influences the length of the growing period. A reduction in light intensity of 30 to 40 % was found to cause a delay in maturity of 5 to 6 days. Later varieties were the most susceptible to reduced light intensity (Barbat and Puja, 1957).

Nitrate reductase activity was known to be closely related with tolerance of corn plants to light conditions. Hageman et al. (1961) and Knipmeyer et al. (1962) reported that nitrate reductase activity of corn decreased proportionately with the reduction in light intensity in the experiments of shading and different planting densities. Hybrids tolerant to high planting density had a higher level of nitrate reductase activity than the intolerant hybrids at all light level. They suggested that grain production of tolerant hybrids at low light intensity was more closely related to their ability to reduce nitrate than to a lack of carbohydrate reserve under low light conditions.

Both grain number and weight of rice plants are influenced significantly by the solar radiation level during the ripening period. Based on the monthly plantings of two rice varieties in Thailand, Osada et al. (1973) concluded that the changes in yield were mainly due to the differences in the solar radiation during the ripening period. Changes in numbers of panicles and spikelets were not associated with various environmental factors, while percentage of ripened grain and 1,000 grain weight were influenced by the solar radiation level. They also noticed that the relationship between solar radiation and grain yield was confounded by the temperature effects. Murata and Togari (1972) reported that a considerable part of the local differences of rice yield in Japan is attributable to the influence of solar radiation and temperature not only on reproductive but also on the vegetative stage. Moomaw et al. (1967) and De Datta and Zarate (1970) also observed significant correlation between solar radiation during ripening period of rice and grain yield. Murata (1964) and Hanyu et al. (1966) reported a linear and positive effect of solar radiation on grain yield at different locations in Japan, while Munakawa et al. (1967) reported a hyperbolic effect of solar radiation on rice yield with saturating point of the effect at about 500 $cal{\cdot}cm^{-2}{\cdot}day^{-1}$.

Spikelet number per square meter was not influenced significantly by shading from 75 to 25 % of the sunlight during vegetative stage of rice, while shading during the reproductive stage reduced spikelet number per square meter. Shading during the ripening period considerably reduced grain yield, largely because it reduced the percentage of filled grain (IRRI, 1974). The utilization of sunlight varied among rice varieties (IRRI, 1966). Taichung #1 and Milfor were more efficient during cloudy weather than other varieties. Taichung #1 produced about 6.5 T/ha in the dry season and about 5.0 T/ha in the wet season, but the yield per unit sunshine was greater in the cloudy wet season.

2.2.4 Temperature

The rate of development of corn from planting to anthesis is a function of temperature experienced by the growing point over the period rather than of photosynthesis (Duncan, 1975). Wilson et al. (1973) and Hunter et al. (1977) obtained the higher grain yield and dry weight of corn plants under lower temperature. The lower temperature induced the higher leaf area indices and greater leaf area duration after silking and increased the length of grain filling period and proportion of the post-anthesis dry matter allocated to the grain. Goldsworthy (1975) reported the similar results in location experiments of corn in Mexico.

One of the disadvantages of high night temperatures in the lowland tropics has been considered as greater respiration loss which might be responsible for reduced grain yield (Milbourn, 1977). Aldrich et al. (1975) also indicated that respiration loss is excessive when the night temperatures are high, thereby resulting in lower yield in the U.S. Corn Belt. However, reports of Semikhatova (1970) and Beevers (1970) suggested that any effect of temperature on respiration would have only minor effect on the net photosynthate per day available for plant metabolism. Goldsworthy (1975) also pointed out that the reduction of grain yields in the lowland tropics is not due to the limiting effect of high night respiration losses on crop growth rate. Corn in the humid tropical environments is a conservative plant with respect to carbon consumption for respiration and, thus, corn yield differences between the temperate zone and the humid tropics cannot be attributed to high night respiration losses (IITA, 1977). Similar conclusions for rice in the tropics were obtained by Tanaka et al. (1966).

Kernel number and ear length and subsequent yield are similarly affected by temperature. Hunter et al. (1977) observed the marked different kernel number between the 20° C and 30° C treatments. The sharp decline in kernel number at 30° C relative to 20° C was due to faster kernel development at 30° C. However, there were a photoperiod x temperature interactions. Kernel number during the period of rapid grain growth did not differ between 30° C treatment and the 20° C with 10 hour photoperiod treatment, there was significant difference in kernel number between 30° C and 20° C treatments with 20 hour photoperiod. Friend (1965) stated that a long head with many soikelets were formed at low temperatures because of the long period of slow growth of the developing inflorescence but temperature had relatively little effect on the length of the developing ear at the stage of anther development in wheat. Temperature changed spikelet number in wheat mainly by affecting the rate and duration of the appearance of primordia after flower initiation (Halse and Weir, 1974).

It would be expected that the greater corn growth would result in environment having leaf temperatures of 30 - 33° C during the day and cool nights. Such conditions are characteristic of locations in regions that are arid or at high elevations. Conversely, warm humid environments at low elevations usually have less diurnal variation and might be expected to produce less total growth (Duncan, 1975).

2.2.4 Altitude and latitude

Corn in high altitude tropical locations develops very slowly due to low temperature and this results in higher grain yields. Unless the low temperature causes damage to the corn plant, the long growing period results in high yields associated with long ears which have more kernels per ear (Cuany et al., 1969). When yields were converted to yield per day, however, high altitude had no advantage. In studies on lowland tropical corn, Goldsworthy and Colegrove (1974) and Goldsworthy et al. (1974) concluded that the higher yields at high elevation were due to better development of grain sink capacity (more ears per unit area and more grains per ear) which were results of the longer period of growth before flowering.

Eberhart et al. (1973) and Darrah and Penny (1974) reported that average increase of grain yield of corn was about 1.5 T/ha and average increase of days to tasseling was about 27 days per km increase in altitude in Kenya. Because the variation in daylength is small near equator, temperature was the main factor in the altitude response for corn yield. Bhargava and Utkhede (1978) observed the same result in study of response of corn varieties to altitude in India.

On the other hand, Wilson et al. (1973) noticed that increase in altitude decreased the capacity of the grain to accommodate dry matter in relation to the supply of dry matter from the photosynthetic system after flowering. Grain dry weight per cent of the dry matter accumulated after flowering and the kernel number per plant decreased with increase in altitude. In green-house experiments with corn races, Duncan and Hesketh (1968) observed that high altitude races had relatively higher leaf growth rates and dry weight at harvest at low temperatures while they showed lower net photosynthetic rates at high temperature. Darrah and Penny (1974) and Wilson et al. (1973) also noticed that varieties which had been selected at or obtained components from high elevation showed higher response to altitudes.

Responses of corn yield and yield components to latitude were tested in Nigeria in a range of latitude from 6° to 11° N. The grain production per plant decreased with decreasing latitude, due mainly to small number of kernels per row with a smaller decrease in number of rows per ear. A small increase in grain size (possibly due to less space competition on the cob) at lower latitude could not compensate for the big reduction in kernel number. The reduction of total plant dry matter and yield was mainly response to radiation level (IITA, 1977). Cross and Zuber (1973) tested seven single crosses and their topcross progenies to Zapalote Chico and Super Stiff Synthetic at 20 different locations ranging from 21° N in Mexico to 49° N in Canada. They reported that the relationships between plant height, number of leaves and flowering date were very low in the range of environments tested, because of probable environment-genotype interaction. They presented no information on yield and yield components.

2.2.6 Growth of corn in the tropics

Within tropical latitudes, temperature variations with season and altitude are more important in determination of the growing period for a given variety than variation in daylength. Effects of temperature and altitude were discussed in the previous sections. A quite different problems exists in the wet forest zones in the tropics where yields are reduced by a lack of solar radiation due to continually cloudy conditions and the increased incidence of pests and disease that are inevitable in wet humid conditions (Milbourn, 1977). Kassam et al. (1975) showed yield advantages which resulted from a increase in solar radiation in the savanna areas north of the forest zone. Trials in West Africa showed that one short season crop fitted to the single rainy season in the savanna latitudes can outyield double cropping of corn in the forest zone where there are two rainy seasons per year. Villanueva (1971), Watanabe (1976) and Lee (1978) reported that grain yields of corn reduced by 40 to 70 % in winter months when solar radiation is reduced to half that of summer in Hawaii.

Yamaguchi (1974) tested tropical corn varieties at tropical lowland locations in various seasons and at highland locations in Mexico. He reported that the tropical varieties grown at the lowland locations in summer was characterized by (1) a high growth rate and a short growth duration, (2) a small leaf area duration during maturity, (3) a great loss of dry weight at late maturity, (4) a low harvest index, and (5) a small number of kernels formed per unit field area. The predominant cause of the former two characters appear to be environmental and that of the latter three characters are due to genetic difference. At high location or in winter at the lowland, the longer growth period and the longer leaf area duration resulted in a longer dry matter production after silking and a higher grain yield, which are apparently resulted in by lower temperature.

Allison (1969) pointed out that improved varieties benefitted from an extension in leaf area duration after flowering in the tropics. Voldeng and Blackman (1973) suggested that wide separation of leaves up the stem may lead to a higher net assimilation rate with better light interception. However, there may be scope to produce a short-stemmed corn, as has been developed for temperate regions, which enables more efficient partition of dry matter to the ear in the tropics. Brewbaker (1974) reported that most tropical races are unnecessarily tall and late in maturity for modern corn management, silking 65 to 75 days, while much of the excellent Corn Belt germplasm mature too early in the tropical conditions for maximal yield, silking between 40 to 50 days in Hawaii. Vegetative growth and yield are greatly affected by the reduction in light, but maturity appears unaffected. Brewbaker et al. (1966) also reported that sweet corns were harvestable about 13 days earlier in Hawaii than in the mainland U.S.A.

2.3 Genotype-environment interactions and yield stability

The expression of phenotype is a result of the interplay of both genetic and non-genetic factors. The existence of interactions between genotype and environments has long been recognized. Because of these interactions, the tests in a single environments are not sufficient to provide adequate information for evaluation of genotypes. An extensive literature is available on the studies of genotype-environment interactions. Byth (1977) classified these works into three main areas, viz. physiological-genetic aspects comprising the detection and characterization of genotype response differences, the influence of environmental factors, and biometrical genetic aspects involving analyses of the genetic basis of genotype-environment interactions. Based on studies of genotype-environment interactions, the concept of genotype stability has been developed (Finlay and Wilkinson, 1963;

Eberhart and Russell, 1966).

2.2.1 Statistical methods of genotype-environment interaction analysis

Partitioning of variances, regression analysis, multivariate analysis and combination of these methods have been used in genotype-environment interaction studies. Freeman (1973), Moll and Stuber (1974), Hill (1975) and Byth (1977) reviewed various statistical methods of the analysis of genotype-environment interactions, their significance in quantitative genetics and plant breeding, and basic assumptions underlying the analyses. Mather and Jinks (1971) discussed biometrical-genetic aspects of genotype-environment interactions in detail.

Partitioning of variances has been used to detect and consolidate the genotype-environment interactions by means of statistical techniques. This method was first suggested by means of factorial experimentation (Fisher and Mackenzie, 1926). Immer et al. (1934) used this method to study yield trials of wheat varieties which were planted at different locations and different years. Later, Sprague and Federer (1951), Comstock and Robinson (1952), Hanson et al. (1956), Miller et al. (1959) and Comstock and Moll (1963) developed the method to partition total variation in multi-environment experiments into components due to effects of genotypes, environments and their interactions. Genetic variance components could be further subdivided into additive, non-additive, and their interaction components with appropriate experimental designs (Moll and Stuber, 1974).

However, in these procedures, interaction is regarded as a statistical confounding factor rather than as an expression of genetic and partly heritable differences in environmental responses (Freeman, 1973; Hill, 1975; Byth, 1977). Interaction is characterized in general terms only and no information on the responses of individual genotype or the effects of particular environments can be obtained. Although, Plaisted and Peterson (1959) suggested the use of an arithmatic mean of the genotype-environment variances of each genotype as a stability estimate, it is almost impractical method as number of genotypes tested increased.

Results from numerous experiments with corn indicate that estimates of genotype-environment interaction variance components are significant for most traits evaluated and are relatively large when compared with estimates of genetic variances (Gardner, 1963; Moll and Robinson, 1967; Stuber and Moll, 1971). Both additive and non-additive effects show significant interactions with environments. In general, second-order interactions (genotype-year-location) tend to be much greater than either genotype-year or genotype-location effects. Studies with corn by Otsuka et al. (1972) and Stuber et al. (1973) indicated that genotype-environmental interaction effects produced greater biases than epistatic effects when predictions were made from data obtained in a single environment. When several environments were used for prediction, biases from the two types of effects were nearly equal.

Regression models have been used to characterize responses of genotypes in varying environmental conditions. This method was suggested by Yates and Cochran (1938) and developed by Finlay and Wilkinson (1963), Eberhart and Russell (1966) and Perkins and Jinks

(1968). These regression models are based on regression of performance or of genotype-environmental interaction effect on an environmental idex which is estimated by mean performance of all genotypes at an environment. This index is not quite an independent measure of environment (Freeman and Perkins, 1971; Moll and Stuber, 1974; Freeman, 1973) and several other methods estimating environmental index were proposed (Bucio Alanis and Hill, 1966; Knight, 1970; Tai, 1971; Hardwick and Wood, 1972). Various physical factors such as climatic factors, soil fertility, altitude index, and drought index were used as a way of estimating independent measure of environment (Dowker, 1963; Corsi and Shaw, 1971; Perkins, 1972; Eberhart et al., 1973; Sopher et al., 1973).

Genotype response to complex agricultural environments involves diverse, simultaneous and separate responses to a number of environmental factors. Therefore, an index estimated by mean performance of genotypes are considered to be effective and appropriate (Breese, 1969; Moll and Stuber, 1974). Hardwick and Wood (1972) stated that, provided that a large number of genotypes are included in the experiment and the environmental range is such that the between environments mean square is significantly greater than the error mean square, any bias which results from regression methods should not prove serious in practice from a plant breeding point of view.

Based on regression models, genotypic and phenotypic stability parameters have been suggested to measure the degree of stable performance of any genotype in a range of environments tested (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Tai, 1971).

A regression coefficient of unity indicates average stability, greater than unity indicates below average stability and less than unity indicates above average stability (Finlay and Wilkinson, 1963). Eberhart and Russell (1966) suggested two empirical parameters for stability measure, the slope of the regression line and the deviations from the regression line. The stable genotype was defined to be one with a regression coefficient of unity (b = 1.0) and with a minimum deviation from the regression line ($s_d^2 = 0$). Eberhart (1969) indicated that the deviation mean square is a more important parameter for corn single cross stability measure.

Multivariate analyses are used recently to summarize data in terms of the relationships between patterns of genotypic responses. Applications of cluster analysis were reported by Mungomery et al. (1974), Lin and Thompson (1975) and Byth et al. (1976), and of principal component analysis by Perkins (1972) and Freeman and Dowker (1973). Mungomery et al. (1974) and Byth et al. (1976) reported the results of cluster analyses for soybean and wheat yield trials, respectively. Cluster analyses were effective to delineate groups of genotypes which differed in mean performance and/or in the form of environmental responses, and within which genotypes were relatively homogeneous for mean performance and response. The group structure provided an efficient partition of the genotype-environment interaction sums of squares and accounted for almost all of the genotype-environment interaction (Lin and Thompson, 1975). Eismann et al. (1977) stated that cluster analysis is more powerful and flexible than regression analysis to characterize and summarize the patterns of genotypic response and genotype-environment interactions over environments. Their conclusion also implied that regression analysis give efficient information to describe response patterns when deviation from linearity was not large.

Although principal component analysis is useful to indicate the major direction of variation among the tested genotypes, it does not provide different groups of response types. The components are mathematical artifacts without any obvious direct relationship to environmental condition and information about the relationships of genotypes to environment can not be obtained (Lin and Thompson, 1975; Byth, 1977). Nor and Cady (1979) proposed the beta response method which combined principal component analysis and regression analysis. An environmental index based on physical measurement of the environment affecting crop yield was estimated by multivariate regression. This procedure is followed by usual regression method to estimate the stability of any genotype. Their result on corn yield data in New York areas showed, in general, good agreement with result of regression analysis. However, there is not enough information yet to confirm the practical advantage of this method.

Several models were developed to relate the regression parameters of the genotype-environment interaction to the appropriate genetic parameters. Thus, the genetic components and their interactions with environments could be examined simultaneously. Hinkelmann (1974) suggested an analysis in which the sum of squares for heterogeneity of slopes was partitioned into general and specific combining ability components to investigate whether heterogeneity of slope can be attributed to interactions between environments and additive or non-additive gene action. Moav et al. (1975) regarded each slope as being the sum of two components (one proportional to the corresponding intercept and the other equal to the remainder) which they obtained by regressing the slopes on the intercepts. The two components of the slopes and the intercepts were then analysed separately to investigate each genotype. Lin et al. (1977) developed a model in which Griffing's (1956) combining ability model and regression analysis are combined for the genotype-environment interaction study. This model assumed that one genetic system (general combining ability and specific combining ability) controlls both genetic effects and heterogeneity of slope.

2.3.2 Stability of grain yield in corn

Corn breeders have given considerable amount of efforts on breeding genotypes which will provide stable high yields in a wide range of environments. If genotypes that perform well over a broad spectrum of environments were desired, small genotype-environmental interactions and/or well buffered genotypes are needed. However, if genotypes that specific in advance, then large interactions may be allowed and buffering may be of little value (Moll and Stuber, 1974).

Allard and Bradshaw (1964) suggested that heterozygous and heterogeneous populations offer the best opportunity to produce varieties which show small genotype-environment interactions. They used term "individual buffering" and "population buffering". A homozygous or heterozygous genotypes must depend largely on individual buffering to achieve stability over a range of environments, whereas a heterogeneous population may use individual and population buffering to adapt to a somewhat different range of environments. Lerner (1954) used the term "genetic homeostasis" to describe the ability of a population to maintain a gene frequency for optimum fitness. Uniformity over a range of environments is assumed to be associated with heterozygosity for outbreeding organisms. Terms such as broad adaptability or general adaptability and specific adaptability were also used in relation to crop stability (Byth, 1977; Dhillon and Singh, 1978).

Phenotypic stability appears to increase with heterozygosity in corn (Adams and Shank, 1959). Sprague and Federer (1951) presented evidence that double crosses interact with environments less than single crosses. The data obtained over many environments suggested that double crosses are superior to single crosses for stability of performance. Eberhart et al. (1964) reported that when the two types of crosses were compared in the same environment "hybrid x year" interactions were significantly greater for single crosses than for the three-way crosses. Rowe and Andrew (1964) found that the variance component caused by the variety-environment interactions for yield, ear height and plant height for inbreds and their F_1 entries was much greater than for the segregating entries derived from these lines.

Jones (1958) suggested that if additional genetic diversity for stability and consistency of performance is necessary, blending of individual hybrids would be a more efficient way of obtaining this diversity than the use of synthetic varieties or multiple hybrids. Funk and Anderson (1964) reported that blending of corn hybrids was found to increase yield stability with a decrease in the entry-location interaction. However, it is possible that some single crosses may show more phenotypic stability than the most stable three-way or double crosses. Because the variance of a mean is less than the variance of an individual, the average genotype-environment interaction of a mixture may be expected to be less than the interaction for a single genotype (Eberhart et al., 1964).

Prolificacy is also recognized as an important character contributing to stability of grain yield in corn. Collins and Russell (1965) proposed second ear development as a mechanism by which corn can exhibit developmental homeostasis. Russell and Eberhart (1968) demonstrated that two-eared types have more stability on the average than single-eared types. Zuber et al. (1960) found prolific-type corn in Missouri to have more consistent yields than single-ear types regardless of planting rate. Josephson (1957) in Tennessee found that hybrids capable of producing more than one ear per plant can better adjust to soil fertility and available moisture, which permits higher yields from thinner stands than is possible with single-ear hybrids. The capacity of prolific hybrids to produce one good ear on each plant at high rates of planting appeared to be the greatest advantage of prolific hybrids (Josephson, 1961). Freeman (1955) pointed out that the prolific tendency in hybrids in the South gave varieties adaptability to wide fluctuations in soil fertility and plant population. Prolific hybrids were found to be flexible in adapting to changing environmental conditions (Baumann, 1960). Collins et al. (1965) also pointed out that two-ear type corn yielded more consistently than one-ear types when population levels were changed in Iowa.

Results of Shank and Adams (1960), Scott (1967) and Eberhart and Russell (1969) indicated that stability of corn yield is under genetic control. Apparent genetic differences among inbred lines as well as single crosses were noticed by these authors. Scott (1967) reported that selection based on F_2 topcross results and F_3 crosses was effective for selection of yield stability in corn. Additive genes appear to be responsible for the stability of hybrid performance in different environments. Eberhart and Russell (1966) and Eberhart(1969) pointed out that additive gene action was the main variation among single crosses for regression coefficient and to a lesser extent in the deviation mean squares. Dhillon and Singh (1978) concluded that the differences in linear response of genotypes to environments were primarily due to general combining ability, while both specific and general combining abilities were equally important in expression of deviation from the regressions for corn grain yield. The 20 varieties and their 190 crosses were divided into two clusters of which one combined high specific combining ability effects for grain yield and regression coefficients and the other one had low specific combining ability estimates for regression and above average specific combining ability for grain yield.

In general, there is trend of positive association between mean performance and linear response (Finlay and Wilkinson, 1963; Eberhart and Russell, 1969; Eberhart, 1969). On the other hand, Dhillon and Singh (1978) noticed no association between mean yield and linear response to environments at the parental as well as the general combining ability level. This suggested that it is possible to produce genotypes which combined high yield and stability. However, extensive evaluation trials over a wide range of environments are necessary to obtain hybrids showing small deviations from the expected regretsion on the environmental index (Eberhart and Russell, 1969).

3. MATERIALS AND METHODS

Four experiments were conducted to study the genetic and environmental effects on kernel number and ear length in corn. Materials and methods are described separately for each experiment in this chapter. Common procedures described in the earlier sections were used for all other experiments unless otherwise stated. Statistical methods were modified to fit to these experimental materials and methods and brief descriptions are given in the last section.

3.1 Preliminary experiments on ear development

3.1.1 Ear development study

H610 (Hi25 x Ant.2), a University of Hawaii hybrid, was planted to obtain information on ear development at the Waimanalo Research Station on July 26, 1977. The research Station is located at 21° N on Oahu, Hawaii, and it has a Typic Haplustoll subgroup soil type. The soil is silty clay with pH of 6.5. Plant spacing used was 76 cm between rows and 22 cm between plants within a row. Three seeds were sown per hill and thinned down to one plant per hill 4 weeks after emergence to give a population of about 60,000 plants per hectare. A preplant fertilizer application equivalent to N - P_2O_5 - K_2O = 130 - 130 - 100 kg/ha was made and corn plants were sidedressed with 70 kg/ha of nitrogen after thinning. A herbicide, Sutan^R, was applied to control weeds after field preparation. Overhead sprinkler irrigation was used on a 5- to 6-day schedule. Unless otherwise stated, all field experiments carried out at the Waimanalo

Research Station followed the same management.

Samples of 10 plants were taken every 3 days, beginning 15 days after emergence, until silking to observe the timing of ear shoot development. After silking, ear samples were taken every 5 days until maturity for the subsequent observations. Length of ear shoot, number of florets, row number, flowering date and filled ear length were measured for the 1st, 2nd and 3rd ears of each plant sampled.

3.1.2 Shading experiment

To study the effects of shading on ear shoot development, H610 was planted at the Waimanalo Research Station on August 31, 1978 following the general procedures described in 3.1.1. Wooden frames covered with saran cloth (Figure 1) were used to apply 30, 47 and 73 % shading on corn plants. The frames were 75 cm x 150 cm x 150 cm in size. The shading treatments were applied for 10 days beginning at 20, 30, 40 and 50 days after emergence. Each plot consisted of three rows with 15 plants in a row. Only the middle 7 plants were covered by the wooden frames. A randomized complete block design with 2 replications was used.

Five ears were sampled from the middle row of each plot one week after the final treatment, i.e. 67 days after emergence. Data were taken on row number, floret number per row, floret number per ear and cob length.

Figure 1. Wooden frames used for shading treatments (From left to right, 73, 30 and 47 % shading, respectively)

3.2 Effects of seasonal environments on kernel number and ear length

A 6-entry diallel cross involving temperate and tropical inbreds was used to study the effects of seasonal environments on kernel number and ear length. Temperate inbreds B37, B68 and Oh545 and tropical inbreds Hi27, Mp68:616 and Tx601 were used. All inbreds were converted to Mv gene for resistance to *Peregrinus maidis* transmitted maize mosaic virus, Rp_1^d gene for resistance to *Puccinia sorghi* and Ht_1 gene for resistance to *Helminthosporium turcicum* at the University of Hawaii (Brewbaker, 1974).

Fifteen single crosses of the 6-entry diallel were planted monthly beginning August, 1977 for a period of 21 months. Plantings were made in the first week of each month. Several plantings were delayed several days due to rain (Table 1). Therefore, plantings in November and December, 1978 and January, 1979 are referred to as December, 1978 and January, and February, 1979 plantings hereafter, respectively.

Each experimental plot consisted of 25 hills planted with 2 seeds per hill which were thinned to one plant after 4 weeks. Planting distance was 76 cm between rows and 22 cm within a row. A drip irrigation system was used at least twice a week except during winter season when it rained frequently. Two border rows of H610 were planted around each planting. A randomized complete block design with two replications was used for each planting.

Five ears were sampled from one side of each plot at about 2

Table 1. Planting and harvest dates of monthly plantings

Planting number	Plantings referred	Planting date	Harvest date
1	August	August 2, 1977	November 17, 1977
2	September	September 3, 1977	December 24, 1977
3	October	October 6, 1977	January 24, 1978
4	November	November 3, 1977	February 26, 1978
5	December	December 1, 1977	March 26, 1978
6	January	January 5, 1978	April 27, 1978
7	February	February 4, 1978	June 1, 1978
8	March	March 16, 1978	June 26, 1978
9	April	April 6, 1978	July 26, 1978
10	May	May 10, 1978	August 26, 1978
11	June	June 8, 1978	September 26, 1978
12	July	July 5, 1978	October 24, 1978
13	August	August 5, 1978	November 28, 1978
14	September	September 7, 1978	December 29, 1978
15	October	October 3, 1978	January 27, 1979
16	December	November 21, 1978	March 22, 1979
17	January	December 31, 1978	April 27, 1979
18	February	January 27, 1979	May 24, 1979
19	March	March 3, 1979	June 28, 1979
20	April	April 10, 1979	July 31, 1979
21	May	May 22, 1979	September 2, 1979

weeks after silking to collect data on floret number. Other data were collected from centred 10 plants of each plot. The plant and ear characters were measured as follows: 1) floret number, as the number of fertile florets of a randomly selected row for each sampled ear; 2) days to mid-silking, as the time in days from planting to the day when a half of the plants in a plot had emerged silks; 3) plant height, as the height in cm from ground to the tip of the central axis of the tassel; 4) ear height, as the height in cm from the ground to the base of the topmost ear; 5) cob length, as the length in cm of ear from the tip of the cob to the butt; 6) filled ear length, as the length in cm of ear containing fully developed kernels; 7) row number; as the number of kernel rows at the middle of ear; 8) kernels per row, at the number of fully developed kernels of a randomly selected row from each ear; 9) kernels per ear, as the total number of kernels per ear computed by multipling row number with kernels per row; 10) 100 kernel weight, as the weight in grams of 100 randomly selected fully developed kernels; and 11) grain yield, as the grain weight in metric tons per hectare adjusted to 15.5 % moisture.

Solar radiation, temperature and rainfall data recorded at the Waimanalo Research Station were used to relate climatic factors and corn yield and yield components. Solar irradiance was measured by a pyranometer (Model Lambda Integrator LI-500 with LI200S pyranometer sensor) and continuously recorded and integrated throughout the daylight hours. Analyses of variance for all characters for each planting and combined data of all plantings, combining ability analyses

(Griffing, 1956) for both individual and combined plantings, stability analyses (Eberhart and Russell, 1966) and joint combining ability and regression analyses (Lin et al., 1977) were carried out for data on yield and yield components. Detailed methods of analysis are discussed in section 3.5.

3.3 Effects of geographic environments on kernel number and ear length

A 10-entry diallel cross involving temperate and tropical inbreds was set up to study the effects of geographic environments on kernel number and ear length in corn. Five inbreds from temperate germplasm - B37, B68, CI21E, Mo17 and Oh545 - and 5 inbreds from tropical materials - Hi27, CM105, CM111, Mp68:616 and Tx601 - were used to produce 45 hybrids. All inbreds used were previously converted to Mv, Rp_1^d and Ht_1 genes at the University of Hawaii. Seeds were produced in summer, 1977 without reciprocals. This 10-entry diallel set included the 6-entry diallel set of monthly plantings. Therefore, the information obtained in both experiments could be used for the comparative analysis of the results.

The 45 entries were planted once at 5 locations and three times at Waimanalo. The locations, altitudes, latitudes, planting date and planting densities are given in Table 2. The locations ranged from CIAT, Cali, Colombia at 3° N to Ames, Iowa at 42° N, and from Waimanalo, Hawaii at just above sea level to CIAT at 1,000 m above sea level. Corn was planted following the standard methods of each experiment station or institution to provide the maximum variation in

Table 2. Experimental locations, latitudes, altitudes, planting date and planting densities

Locations	Latitudes	Altitudes (m)	Planting date	Planting densities
				(plts/ha)
Waimanalo-1, Hawaii	21° N	30	July 26, 1977	60,000
Waimanalo-2, Hawaii			Nov. 26, 1977	60,000
Waimanalo-3, Hawaii			May 15, 1979	60,000
Kamuela, Hawaii	19° N	850	Aug. 4, 1977	60,000
Kapaa, Hawaii	22° N	200	Aug. 25, 1977	60,000
Ames, Iowa	42° N	150	May 1, 1978	39,000
CIAT, Cali, Colombia	3° N	1,000	March 31,1978	53,000
Suweon, Korea	37° N	35	May 29, 1978	45,000

environmental conditions.

Ear samples were taken 2 weeks after silking from the Waimanalo-2 and -3, Ames and Suweon plantings. The following characters were evaluated for all plantings except Suweon and CIAT plantings; days to mid-silking, plant height, ear height, cob length, filled ear length, row number, kernels per row, kernels per ear, 100 kernel weight and grain yield. Measurements for the characters have been described in section 3.2. Data were all expressed on plot mean basis and all grain weight measurements were adjusted to 15.5 % moisture.

Analyses of variance, combining ability analyses and regression analyses following the methods described in section 3.5 were carried out for individual and combined experiments. A 6-entry diallel set extracted from the above 10-entry diallel set was used for additional analysis.

3.4 Generation mean analysis

The four inbreds, B37, Mo17, Hi27 and Tx601 were selected for generation mean analysis based on the results of 10-entry diallel experiments in 1977 at the Waimanalo Research Station. The 6 sets of crosses among the four parents included the generations of parents (P_1 and P_2), F_1, F_2, and the backcrosses (B_1 and B_2). Twenty-eight populations, consisting of 4 parents, 6 F_1's, 6 F_2's, 6 B_1's and 6 B_2's, were planted on March 15, 1979 at the Waimanalo Research Station. In the field, 1 row each of P_1, P_2 and F_1, 3 rows of B_1 and B_2 and 6 rows of F_2 were planted for each set of crosses. Each row had 25 hills which were planted 2 seeds per hill and thinned to leave one plant per hill after 4 weeks of emergence. A randomized complete block design with 3 replications was used for each set of crosses.

Ten ear samples were taken to count floret number from a half of each row two weeks after silking. Ten ears were harvested at maturity from the remained half of each plot. Number of florets per row, kernels per row, cob length and filled ear length were measured for the statistical analysis. All the data were measured on individual basis.

Genetic effects of a three parameter model and a six parameter model were estimated following Hayman's (1958) method using Gamble's (1962) notation. Estimates of additive, dominant and environmental variances were calculated to compute heritabilities following Mather and Jinks (1971, 1977). Least square method of generation mean analysis is described in section 3.5.

3.5 Statistical methods

Statistical methods used for the analyses of data of experiments on the effects of seasonal and geographic environments on kernel number and ear length and generation mean analysis were adapted from Eberhart and Russell (1966), Lin et al. (1977) and Hayman (1958). The statistical models, analysis of variance table and procedures are briefly discussed.

3.5.1 Stability analysis

Estimates of the stability parameters were computed from the mean values of hybrids over all replications for each experiment (Table 3). The two stability parameters b_i and $s_{d_i}^2$ for individual

Table 3. Analysis of variance to partition genotype-environment interaction into sums of squares due to regression on the environmental index and deviation from regression

Source	df[a]	Sums of squares
Total	gk - 1	$\sum_i\sum_j Y^2_{ij}$ - CF
Hybrids (G)	g - 1	$\sum_i Y^2_{i.}/k$ - CF
Environment + (G x E)	g(k - 1)	$\sum_i\sum_j Y^2_{ij} - \sum_i Y^2_{i.}/k$
Regression on environment (linear)	1	$(\sum_j Y_{.j}I_j)^2/g\sum_j I^2_j$
G x E (linear)	g - 1	$\sum_i\{(\sum_j Y_{ij}I_j)^2/\sum_j I^2_j\}$ - E(linear)
Pooled deviation	g(k - 2)	$\sum_i\sum_j d^2_{ij}$
Hybrid 1	k - 2	$\sum_j d^2_{1j}$
Hybrid 2	k - 2	$\sum_j d^2_{2j}$
.	"	.
.	"	.
Hybrid g	k - 2	$\sum_j d^2_{gj}$
Pooled error	k(r-1)(g-1)	σ^2_e

[a] g = number of hybrids, k = number of environments, and r = number of replications.

cross (i = 1, 2, 3, ... g) were estimated on the basis of the following regression model (Eberhart and Russell, 1966):

$$Y_{ij} = m + b_i I_j + d_{ij}$$

where, Y_{ij} is the mean value of the i-th hybrid at the j-th environment; m is the mean of the i-th hybrid over all environments; b_i is the regression coefficient that measures the response of the i-th hybrid to the varying environmental indices; d_{ij} is the deviation from the regression of the i-th hybrid at the j-th environment; and I_j is the environmental index at the j-th environment and is obtained as the mean of all hybrids at the j-th environment minus the grand mean (environmental index), or as the mean solar radiation of the j-th planting minus overall mean solar radiation (radiation index). Analysis of variance based on the regression model was computed to partition the genotype-environment interaction into sum of squares due to regression and deviations from the regression. The analyses of variance and methods of calculating sums of squares are given in Table 3. Phenotypic index, defined as a deviation of mean of each genotype from overall mean, is calculated following Ram et al. (1970).

3.5.2 Combining ability and regression analysis

A combined analysis of Griffing's (1956) diallel cross and regression analysis for genotype-environment interaction study (Lin et al., 1977) was modified for the analysis of data (Table 4). Let Y_{ijk} be the observed value of the ij-th genotype (the progeny of the cross between the i-th and the j-th parental lines) at the k-th environment. The genotype-environment interaction can be expressed as a linear

Table 4. Analysis of variance for genotype-environment interaction study with Griffing's Method 4 (Modified from Lin et al.'s, 1977)

Source	df	Sums of squares	
Environment (E)	(k-1)	$2\sum_{k} Y^2_{..k}/p(p-1) - CF$	$=S_1$
Genotype (G)	{p(p-2)/2}-1	$\sum_{i<j}\sum Y^2_{ij.}/k - CF$	$=S_2$
GCA (g_i)	(p-1)	$\sum_{i} Y^2_{i..}/(p-2)k - 2CF$	$=S_3$
SCA (s_{ij})	p(p-3)/2	$S_2 - S_3$	$=S_4$
G x E	p(p-2)(k-1)/2	$\sum_{k}\sum_{i<j}\sum Y^2_{ijk} - CF - S_1 - S_2$	$=S_5$
g_i x E	(p-1)(k-1)	$\sum_{k}\sum_{i} Y^2_{i.k}/(p-2) - 4\sum_{k} Y^2_{..k}/p(p-2)$	
		$- \sum_{i} Y^2_{i..}/(p-2)k + 2CF$	$=S_6$
Slope of g_i	(p-1)	$(p-2)\sum_{i}\{(\sum_{k}\hat{g}_{ik}I_k)^2/\sum_{k}I^2_k\}$	$=S_7$
Residual	k(p-1)	$S_6 - S_7$	$=S_8$
s_{ij} x E	p(p-3)(k-1)/2	$S_5 - S_6$	$=S_9$
Slope of s_{ij}	p(p-3)/2	$\sum_{i<j}\sum\{(\sum_{k}\hat{s}_{ijk}I_k)^2/\sum_{k}I^2_k\}$	$=S_{10}$
Residual	p(p-3)(k-2)/2	$S_9 - S_{10}$	$=S_{11}$
Pooled error		$S_8 + S_{11}$	
Total	kp(p-1)2-1		

Where, $CF = 2Y^2_{...}/p(p-1)k$,

p = number of parental lines, and

k = number of environments.

function of the environmental indices and the two-way classification model can be written as follow:

$$Y_{ijk} = m + g_{ij} + e_k + b_{ij}I_k + d_{ijk}$$

where, g_{ij} is the genetic effect, e_k is the environmental effect, b_{ij} is the coefficient of regression on I_k of the ij-th genotype, I_k is the environmental index obtained by subtracting the overall mean ($\bar{Y}_{...}$) from each environmental mean ($\bar{Y}_{..k}$), and d_{ijk} is the deviation of the ij-th genotype in the k-th environment.

Since genetic effects can be written in terms of general combining ability (GCA) and specific combining ability (SCA), the interaction between the genetic components (GCA and SCA) and environment can be expressed as a linear funation of I_k. The above model, then, can be expressed as follows:

$$Y_{ijk} = m + g_i + g_j + s_{ij} + e_k + (b_{g_i} + b_{g_j} + b_{s_{ij}})I_k + d_{ijk}$$

where, b_{g_i}, b_{g_j}, and $b_{s_{ij}}$ are the regression coefficients of g_i, g_j and s_{ij} on I_k, respectively.

3.5.3 Generation mean analysis

The generation mean analysis of Hayman (1958) was applied to estimate genetic parameters. Gamble's (1962) notation was used in defining parameters since the meaning is more readily apparent. Two models were fit by least squares independently: Model 1 consisting of m, a, and d; and Model 2 consisting of m, a, d, aa, ad, and dd. Notations m, a, d, aa, ad, and dd refer to gene effects of mean, additive, dominance, additive x additive, additive x dominance, and dominance x dominance, respectively.

In matrix notation the parameters are related to generations as follows:

$$\begin{bmatrix} P_1 \\ P_2 \\ F_1 \\ F_2 \\ B_1 \\ B_2 \end{bmatrix} = \begin{bmatrix} 1 & 1 & -0.5 & 1 & -1 & 0.25 \\ 1 & -1 & -0.5 & 1 & 1 & 0.25 \\ 1 & 0 & 0.5 & 1 & 1 & 0.25 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0.5 & 0 & 0.25 & 0 & 0 \\ 1 & -0.5 & 0 & 0.25 & 0 & 0 \end{bmatrix} \begin{bmatrix} m \\ a \\ d \\ aa \\ ad \\ dd \end{bmatrix}$$

This may be designated as $Y = X\beta$, where Y is the vector of generation mean, X is the matrix of coefficients, and β represents the vector parameters. Therefore, Model 1 consists of the first three columns of the coefficient matrix, and m, a, and d of the parameter vector, while Model 2 is as above. The normal equations were obtained as $X'Y = X'X\,\beta$, and the solution as $\hat{\beta} = (X'X)^{-1}X'Y$. The inversion matrices for both models are shown below:

Model 1:

$$(X'X)^{-1} = \begin{bmatrix} 0.17646 & 0 & 0.11764 \\ 0 & 0.4 & 0 \\ 0.11764 & 0 & 1.41176 \end{bmatrix}$$

Model 2:

$$(X'X)^{-1} = \begin{bmatrix} 1 & 0 & -4 & -4 & 0 & 4 \\ 0 & 2 & 0 & 0 & 2 & 0 \\ -4 & 0 & 25.5 & 24 & 0 & -31 \\ -4 & 0 & 24 & 24 & 0 & -32 \\ -4 & 2 & 0 & 0 & 2.5 & 0 \\ 4 & 0 & -31 & -32 & 0 & 54 \end{bmatrix}$$

The sum of squares due to regression (SSR) is $\hat{\beta}X'Y$ and the total uncorrected sum of squares equals $Y'Y$. A residual is obtained as $Y'Y - \hat{\beta}X'X$. The reduction due to mean, R(m), is subtracted from the SSR and total sum of squares in the analysis is presented in Table 5.

Table 5. Analysis of variance by Model 1 for a given cross

Source	df	Sum of squares
a,d	2	$\hat{\beta}\,'X'Y - R(m) = R(a,d)$
Residual	3	$Y'Y - \hat{\beta}X'X$
Total	5	$Y'Y - R(m)$

R(m) is the usual correction factor for the mean. Predicted values are calculated as $\hat{Y} = X\hat{\beta}$ for each model. However, Model 2 does not involve the error variance and there is no way to test the estimates.

Estimates of additive, dominance and environmental variances (Mather and Jinks, 1971, 1977) were calculated based on the assumption that there were no epistasis and no linkage involved. Estimates of the six population variances were obtained by pooling the within row sum of squares over replications in the analysis of variance. Narrow sense heritability was calculated following Warner's (1952) formula and broad sense heritability was computed in the conventional way. The Castle-Wright formula (Frey, 1949) and another formula attributed to Sewall Wright (Burton, 1957) were used to estimate minimum number of genetic factors.

4. RESULTS AND DISCUSSION

4.1 Preliminary experiments on ear development

4.1.1 Time relationship in ear development

This experiment was conducted to determine sampling time for floret number counting in other experiments. Plants of H610 (Hi25 x Ant.2) were sampled at 2- or 3-day intervals starting 2 weeks after planting through silking, and then every 5 days until maturity. Patterns of ear shoot (cob) elongation and increase in floret number per row of the top three ears are presented in Figure 2. The first ear shoot was initiated (shoot length about 2 mm) about 26 days after planting. The elongation of the first ear shoot occurred gradually until tasseling (about 45 days after planting). Then, rapid growth followed until 2 weeks after silking. The elongation of the second ear shoot followed the same pattern but was delayed about 2 days compared to the first ear shoot. The elongation of the second ear shoot ceased at about 1 week after silking of the first ear. The growth rate of the third ear shoot slowed at about 1 week before tasseling and no more growth was observed. The second and third ear shoots failed to silk for all plants observed. The average maximum cob length of the first ear shoot at 2 weeks after silking reached 23.0 cm but this decreased to 17.5 cm at harvest due to moisture loss.

The pattern of increase of floret number per row was the same as that of ear shoot length, but occurred about one week earlier. The number of frorets for all ear shoots increased rapidly between 35 and 45 days after planting and stopped increasing afterward. Sixty

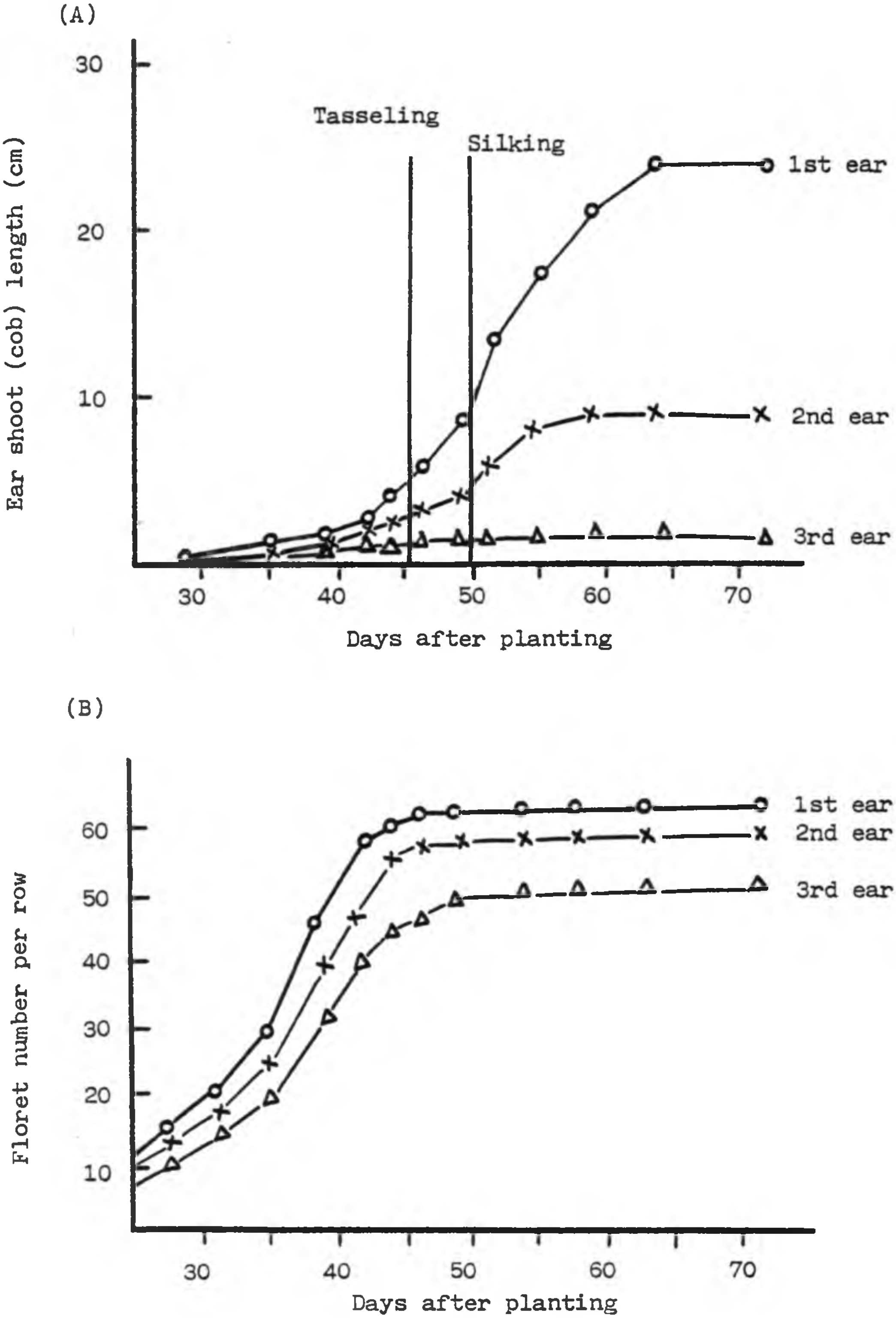

Figure 2. Increase of cob length (A) and floret number per row (B) during growth of the ear shoots

visible florets per row were noted at this stage developing at a rate of increase of 3 florets per row per day. The difference in floret development between the first and the second ear shoots was very small (less than 5 at any time of the growth stage). Comparing the very short ear shoot, the third ear had floret number per row not much less than the first or second ear shoots. The time pattern of development was the same for all three ear shoots. The maximum number of florets per row was reached 2 or 3 days before tasseling.

After silking, which occurred about 50 days after planting, the tip florets were found to be nonfunctional and no more growth was noticed. The remaining florets were fertilized and grew in volume. However, some of the fertilized florets ceased to increase in size during the early grain filling period. By the time of maturity only 37 kernels per row, that is, only 62 % of florets per row, were counted. Based on this result it was decided to take ear samples 10 to 15 days after silking to count floret number per row in other experiments. At this stage cobs reach maximum length and it is possible to distinguish fertilized and unfertilized florets.

4.1.2 Shading experiment

This experiment was conducted to obtain information on adequate shading level and time in screening experiment of genotypes tolerant to light stress. The same hybrid H610 was planted to test the effect of shading on ear development at different growing stages. Four shading treatments (0, 30, 47 and 73 % shading of daylight) were applied for 10 days at 20, 30, 40 and 50 days after emergence.

Corn plants tasseled and silked at 47 and 53 days after emergence, respectively. Shading treatments applied at 20 days after emergence were before the initiation of ear shoot. When shading treatments started, ear shoots grew 0.4, 3.4 and 10.0 cm in length and had 14, 49 and 57 florets per row at 30, 40 and 50 days after emergence, respectively.

The mean values of various treatments and results of analyses of variance are given in Table 6 and 7, respectively. Florets per row and florets per ear, which were computed by multiplying florets per row and row number, showed no significant differences among treatments. The level of shading and stages of treatment and their interaction were highly significant for cob length, while only growing stages and shading x stage interaction were significant for row number. However, the significant effects of growing stages and interaction on row number have no biological meaning, since row number is determined shortly after ear initiation.

Cob length was reduced significantly by higher shading levels and by shading later at developmental stages. In general, the results showed that shading for 10 days at 40 days after emergence was most effective in reducing cob length. Shading for 10 days at 20 days after emergence did not reduce cob length, however, 73 % shading treatment reduced cob length dramatically even though the stage was not a period of rapid cob elongation (Figure 3). This dramatic reduction was probably due partly to the effect of competition with adjacent rows, and not solely to treatment effect. Cob length for the 50 day treatment was longer than other at the 73 % shading level. Since samples were taken about 10 days after treatment, it was possible

Table 6. Mean values of cob length, floret number per row, row number and floret number per ear in shading experiment

			Shade (%)			
Characters	Control	DAE[a]	30	47	73	Mean
Cob length (cm)	19.8	20	21.5	16.6	11.1	16.4
		30	17.7	15.5	13.1	15.4
		40	16.5	13.1	11.8	13.8
		50	15.2	14.5	14.2	14.6
		Mean	17.7	14.9	12.6	15.1
		BLSD (0.05) = 1.2				
Floret number per row	53.1	20	53.9	50.8	53.0	52.6
		30	49.5	47.1	46.2	47.6
		40	49.5	51.3	47.5	49.4
		50	49.9	50.4	49.3	50.0
		Mean	50.7	49.9	49.3	50.0
		BLSD (0.05) = 6.9				
Row number	14.0	20	13.4	13.4	11.9	12.9
		30	13.0	13.6	13.8	13.5
		40	14.4	14.0	14.0	14.1
		50	15.0	14.0	14.0	14.3
		Mean	14.0	13.6	13.4	13.7
		BLSD (0.05) = 0.83				
Floret number per ear	744	20	723	681	635	680
		30	645	639	656	646
		40	711	689	666	689
		50	748	706	745	733
		Mean	707	679	675	687
		BLSD (0.05) = 102				

[a] DAE = Days after emergence when shading treatments started for a 10 day period.

Table 7. Analysis of variance of effects of shading at different growing stages on ear characters

		Mean squares			
Source	df	Cob length	Florets per row	Row number	Florets per ear
Replications	1	48.25	3.12	1.67	508.66
Treatments	12	1804.71**	10.92	1.28**	3201.47
Check vs. shading	1	4327.71**	18.32	0.12	5466.79
Shading (S)	2	4853.17**	4.22	0.27	1824.04
Growing stages (G)	3	927.17**	25.40	2.20**	6224.61
S x G	6	806.83**	4.69	1.36**	1771.49
Error	12	92.88	16.28	0.28	3534.40

** Significant at 1 % level.

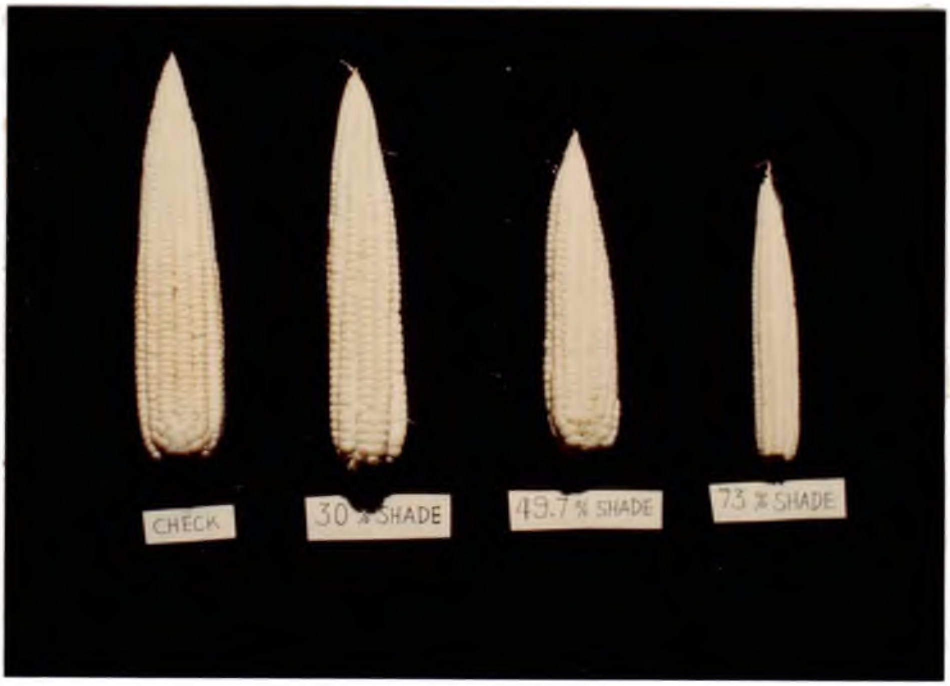

Figure 3. Ear samples taken one week after silking from shading treatments at 40 days after emergence for a 10 day period

that growth was compensated for the 50-day treatment.

The floret number per row was not significantly affected by shading at all stages. There was an indication that treatment at 30 days reduced floret number slightly, but there were no significant differences among shading levels. Considering the results of the previous experiment on ear development, in which the floret numbers of the second and the third ears were not much less than the first ear, this is quite a significant fact, from the view of potential kernel number. The floret number appeared not to be affected by external environments, that is, the potential kernel number is quite stable. As shown in Figure 3, cob length after the 73 % shading treatment reduced greatly but number of florets per row or ear did not reduce as much as expected. Since information on difference between genotypes in response to different solar radiation levels could be obtained from monthly plantings, no further experiment was conducted.

4.2 Effects of seasonal environments on kernel number and ear length

4.2.1 Response of corn plants to seasonal environments

A 6-entry diallel set involving 3 tropical inbreds and 3 temperate inbreds was planted every month for a period of 21 months from August, 1977 to May, 1979 at the Waimanalo Research Station. A randomized complete block design with two replications was used. All plantings were made in the same part of the field. Data on solar radiation, maximum and minimum air temperatures and rainfall were recorded during the period of study. The monthly means of the climatic data are presented in Figure 4.

The highest daily mean solar radiation averaged over one month was 507 $\text{cal}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$ in May 1979, while the lowest daily mean solar radiation was recorded as 216 $\text{cal}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$ in February, 1979. The average daily mean solar radiation during the whole experimental period was 363 $\text{cal}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$. In general solar radiation from May to September was above the average and solar radiation from November to February was below the average. The cyclic change of air temperatures was similar to that of solar radiation with approximately one month difference, but the annual range was very small (about 4° C). Rainfall distribution was quite opposite to that of solar radiation, i.e. high during winter and low during summer. During the experimental period, '77 - '78 winter was rather dry, while '78 - '79 winter had unusually heavy rainfall. Since a drip-irrigation system was used, the relationship between rainfall and plant characteristics will not be discussed in this study.

As Figure 4 indicates, corn seeded in April - June grew to maturity under high solar radiation; July - September plantings grew under high irradiance during vegetative stages and progressively falling irradiance during the grain filling period; October - December plantings grew under continual low irradiance; January - March plantings grew under progressively increasing irradiance.

Correlation coefficients among climatic factors are given in Table 8. Average solar radiation was computed based on the total incident solar radiation and number of days from planting to harvest. Total solar radiation showed near perfect correlation with average

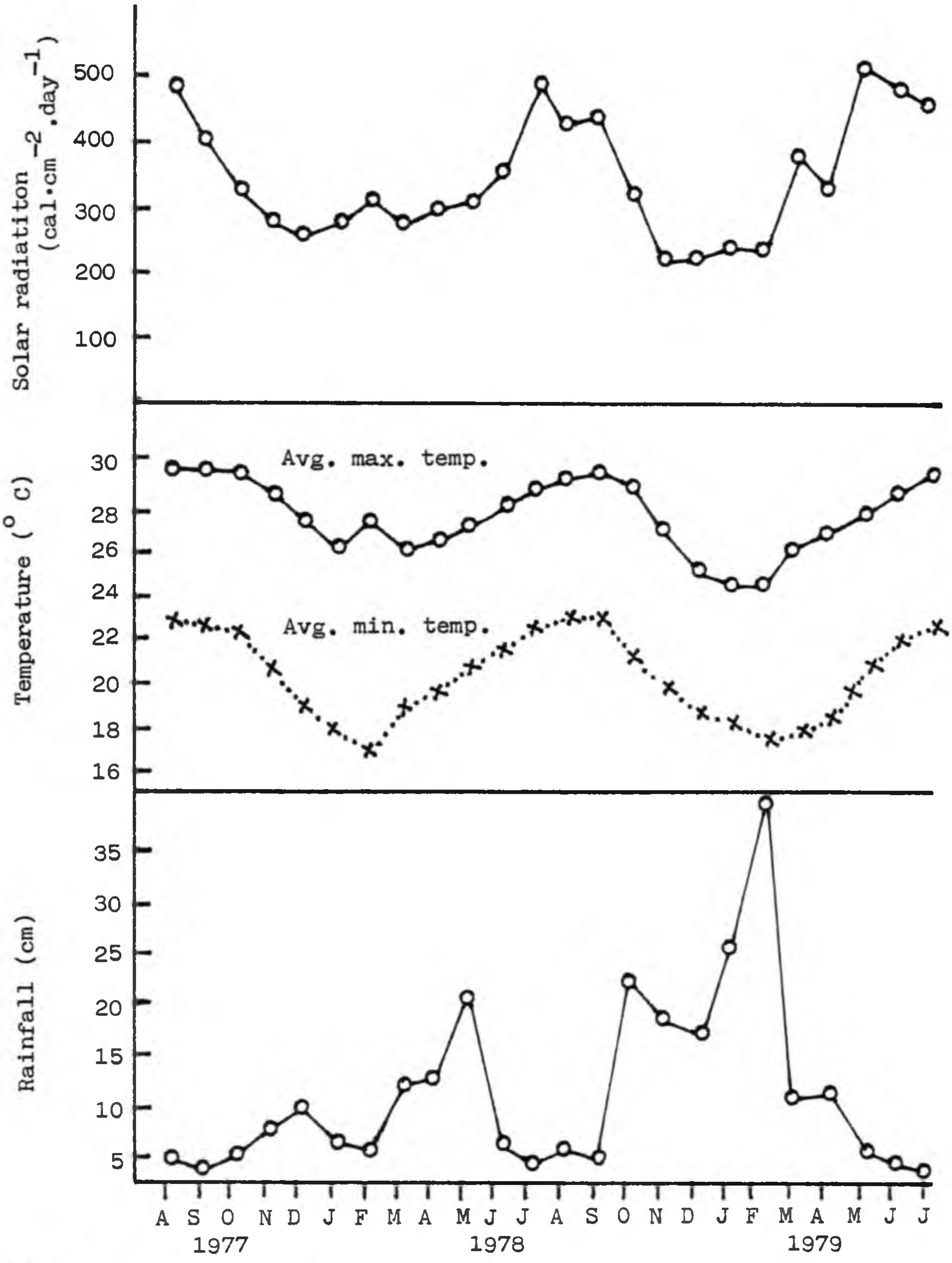

Figure 4. Monthly mean solar radiation, temperatures and rainfall from August, 1977 to July, 1979 for Waimanalo, Hawaii

daily solar radiation, as expected. At Waimanalo it takes about 4 months from planting to harvest for corn plants, i.e. 2 months from planting to flowering and 2 months from flowering to harvest. Reproductive organs are initiated and developed mostly during the second month and the third month is grain filling period. Therefore, the separation of solar radiation to monthly base approximately coincides with the growth stages of corn plants. The first and fourth month solar radiation showed lower correlation coefficients with total and average daily radiation than the second and third months. Because the solar radiation changes, either progressively increasing or decreasing during the four month period, the correlation coefficient between the first month and the fourth month was negative, even though it was not significant. The correlations between the first month and the third month and between the second month and the fourth were not significant, while correlations between any two consecutive months were highly significant.

There were highly significant correlations between solar radiation and average maximum and minimum temperatures. The correlation between average maximum and minimum temperatures was near perfect, which indicates that the two temperatures changed with the same degree during the period of experiment.

The result of analyes of variance of days to mid-silking, plant and ear heights and means of 15 hybrids for each plantings are shown in Appendix 1. The number of days to mid-silking differed significantly in all plantings, ear height was significantly different among hybrids in most plantings, and differences in plant height were not significant

Table 8. Correlation coefficients among climatic factors

Climatic factors	S_A	S_1	S_2	S_3	S_4	T_{max}	T_{min}
S_T = Total solar radiation ($kcal \cdot cm^{-2}$)	0.98**	0.46*	0.82**	0.89**	0.60**	0.62**	0.63**
S_A = Average daily solar radiation ($cal \cdot cm^{-1} \cdot day^{-2}$)		0.53*	0.86**	0.89**	0.56*	0.70**	0.72**
S_1 = 1st month solar radiation (")			0.57**	0.27	−0.29	0.80**	0.74**
S_2 = 2nd month solar radiation (")				0.60**	0.30	0.74**	0.73**
S_3 = 3rd month solar radiation (")					0.61**	0.45*	0.48*
S_4 = 4th month solar radiation (")						−0.02	0.08
T_{max} = Average maximum temperature (°F)							0.94**
T_{min} = Average minimum temperature (°F)							–

* Significant at 5 % level.

** Significant at 1 % level.

for majority of plantings. Plant heights in plantings between October 1978 and May 1979 were all significantly different among hybrids. The period was marked by the worst (October 1978 to February 1979) and the best (March 1979 to May 1979) growing conditions during the experiment.

The average number of days to mid-silking in summer plantings (May to August) was less than 55 days, and was greater than 70 days in winter plantings (December to February). Number of days to mid-silking in the winter of 1978 - 1979 was much longer than that of the 1977 - 1978 winter. The latter period was cooler and wetter than the previous winter. Average plant height of the 15 hybrids varied from over 250 cm to as short as 137 cm from summer to winter plantings. Ear height also ranged from over 100 cm under favorable environmental conditions to lower than 50 cm under poor conditions. Average numbers of days to mid-silking, plant height and ear height of 15 hybrids for 21 monthly plantings are given in Appendix 2, 3 and 4.

The number of days from planting to mid-silking, with an average of 15 hybrids for each planting, is graphed in Figure 5. When this was compared with average temperature, the variation in number of days to mid-silking showed a contrasting trend. Flowering occurred early in the long days of summer and late in the short and cool days of winter. This indicates that daylength in Hawaii is not a main factor determining flowering as shown by Lee (1978).

✓ The relationship between average temperature during the vegetative growing period of the corn plant and average number of days to mid-silking for 15 hybrids clearly indicates that temperature is the main factor controlling flowering (Figure 6). The regression coefficient

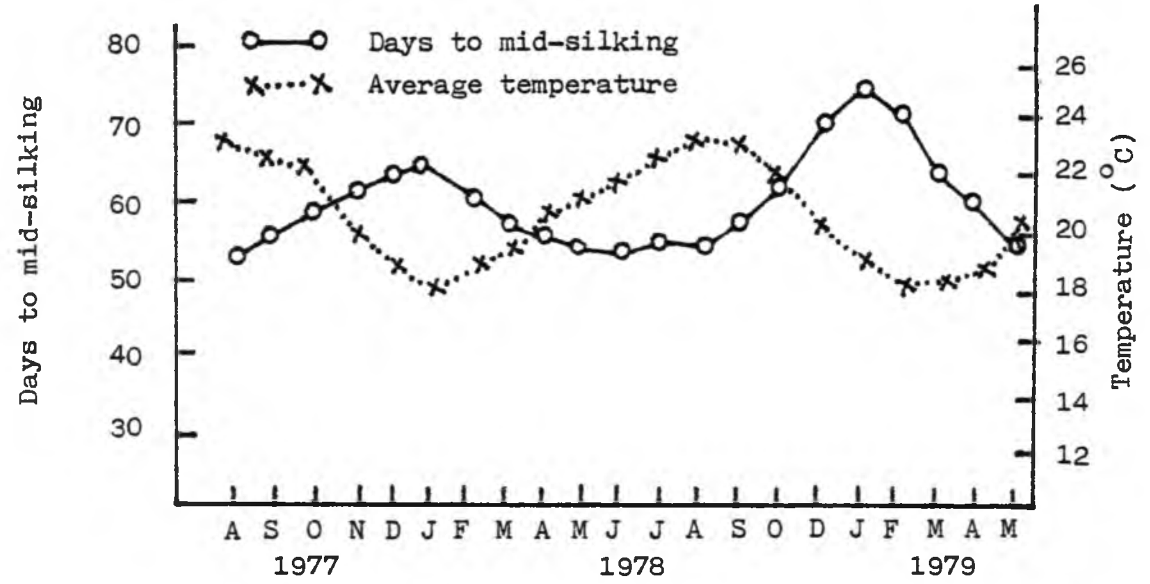

Figure 5. Number of days to mid-silking and average temperature in monthly plantings

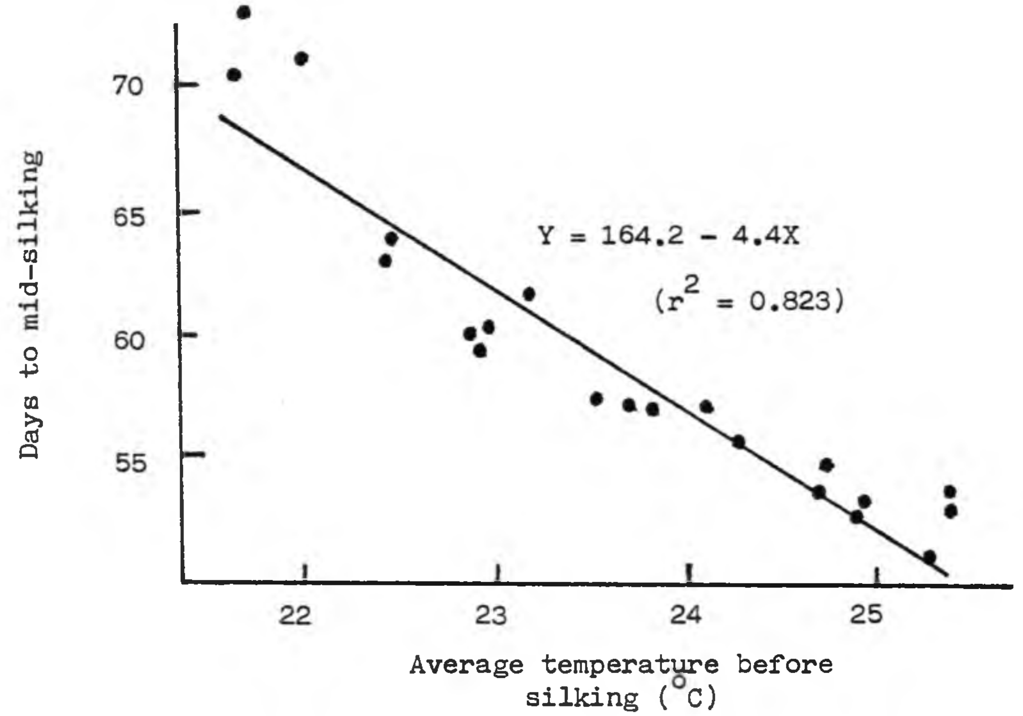

Figure 6. Relationship between days to mid-silking and average temperature during the vegetative growing period

shows that as average temperature during the growing period of the corn plants decrease 1° C, the number of days to mid-silking increases 4.4 days. Based on temperature difference of 4° C between summer and winter, it was expected that there would be about 17 day difference in the number of days to mid-silking between summer and winter plantings. The observed difference agreed well with the predicted values.

Correlation coefficients between plant characters and climatic factors, i.e. solar radiation and average minimum and maximum temperatures, during the growing period of corn plants are presented in Table 9. Corn plant performance is broken down into "poorer" months (September - December) and "better" months (January - August) depending on performance vis-a-vis the overall average. Number of days to mid-silking, plant and ear heights showed highly significant correlations with average daily solar radiation and average minimum and maximum temperatures during the vegetative growing period. However, correlation coefficients based on the two groups (better and poorer months) showed interesting relationships between plant characters and climatic factors. Number of days to mid-silking had similar correlation coefficients with average solar radiation and temperatures in all cases. On the other hand, the correlation coefficients between plant and ear heights and climatic factors for better months were not significant, although there were highly significant correlations between those characters and solar radiation and temperatures in poorer months. This indicates that the growth of corn plants was more sensitive to external environments when the season is unfavorable to corn growth.

A combined analyses of variance was carried out for the plant

Table 9. Correlation coefficients between plant characters and climatic factors during the vegetative growing period

Climatic factors	No. of days to mid-silking	Plant height	Ear height
Over all months (n = 21)			
Avg. solar radiation ($cal\cdot cm^{-2}\cdot day^{-1}$)	-0.688**	0.721**	0.721**
Avg. max. temp. (°F)	-0.874**	0.646**	0.765**
Avg. min. temp. (°F)	-0.818**	0.533*	0.653**
Better months (n = 13)			
Avg. solar radiation ($cal\cdot cm^{-2}\cdot day^{-1}$)	-0.600*	0.537	0.480
Avg. max. temp. (°F)	-0.798**	0.325	0.539
Avg. min. temp. (°F)	-0.833**	0.323	0.484
Poorer months (n = 8)			
Avg. solar radiation ($cal\cdot cm^{-2}\cdot day^{-1}$)	-0.785*	0.833*	0.944**
Avg. max. temp. (°F)	-0.937**	0.893**	0.976**
Avg. min. temp. (°F)	-0.804*	0.759*	0.893**

* Significant at 5 % level.

** significant at 1 % level.

characteristics (Table 10). Highly significant differences were found among months and hybrids. The hybrid x month interaction was highly significant for days to mid-silking and ear height and non-significant for plant height. This indicated that the various hybrids had different responses to changing climatic conditions for days to mid-silking and ear height, but had similar responses for plant height.

In summary, days to mid-silking, which includes the period of initiation and development of potential yield components, was mainly determined by temperatures. Also, the quantitative growth of the corn plant expressed as plant height and ear height was a function of available solar radiation before flowering. Corn plants were more sensitive to climatic changes under unfavorable environmental conditions.

4.2.2 Combining ability of kernel number and ear length

Analysis of variance was conduated for all ear characters that determine kernel number, ear length and grain yield over 21 monthly plantings (Appendix tables 6 - 27). The results of individual analysis of variance are summarized in Appendix 5. Hybrids were significantly different in nearly all months for cob length, floret number per row, filled ear length, kernels per row and kernels per ear, while kernel row number was not significantly different among hybrids in the majority of plantings. Although there were several exceptions, the characters which were not significantly different among hybrids generally showed differences when climatic conditions were not favorable for corn growth, i. e. in winter. Characters such

Table 10. Analysis of variance of days to mid-silking, plant and ear heights for 15 hybrids over the 21 monthly plantings

Source	df	Days to mid-silking	Plant height	Ear height
Month (M)	20	1271.50**	267.27**	99.28**
Reps. in M	21	4.00	7.09	2.91
Hybrids (H)	14	203.57**	35.20**	37.67**
H x M	280	3.29**	1.91	0.91**
Error (b)	294	1.94	1.64	0.62

** Significant at 1 % level.

as cob length, filled ear length, kernels per row and kernels per ear showed significant differences among hybrids. Hybrids did not differ significantly with regard to the above characters when corn plants were subjected to high solar radiation and high temperature, i.e. favorable growing conditions.

A combined analysis of variance of the twenty-one plantings was carried out for all the characters studied (Table 11). Highly significant differences were found for months and hybrids. The hybrid x month interaction was either significant or highly significant for all the characters studied except row number. This indicated that the hybrids had a different response to different growing conditions. The significant interactions were probably due to the different response of hybrids to those unfavorable growing conditions. Homogeneity tests of variances for all the characters were conducted and the results are presented in Appendix 6. Chi-square values for all the ear characters were not significant at the 5 % level. Therefore, the combined analysis created no problems in the interpretation of the results.

Combining ability analysis (Griffing, 1956) was carried out over 21 plantings for all the ear characters studied. Results of the combined analysis are given in Table 12. General combining ability (GCA) and specific combining ability (SCA) mean squares were highly significant for all the characters. This indicated that additive and non-additive genes contributed to the genetic variation of cob length, filled ear length, floret number per row, kernels per row, kernels per ear and row number regardless of planting time. In the combined

Table 11. Analysis of variance of ear characters for 15 hybrids over 21 monthly plantings

Source	df	Floret number per row	Cob length	Filled ear length	Row number	Kernels per row	Kernels per ear
Month (M)	20	78.9**	153.4**	170.3**	11.2**	890.3**	2509.8**
Reps in M	21	11.2	2.1	2.8	1.2	13.4	55.3
Hybrids(H)	14	469.4**	45.2**	48.8**	11.3**	406.4**	1005.1**
H x M	280	10.3**	1.6*	2.0*	0.8	10.9*	29.3*
Error (b)	294	6.9	1.2	1.5	0.7	8.7	23.1

* Significant at 5 % level.

** Significant at 1 % level.

analysis, the GCA x month interactions were highly significant for all characters except row number. The SCA x month interaction was significant only for floret number. This would suggest that additive genes generally were not stable in their expression under different growing environments. However, additive genes controlling row number were stable within the range of experimental environments. Non-additive genes were not much influenced by environmental variations for all ear characters studied except floret number, however, expression of these genes was not consistent from month to month in contribution to floret number per row.

Estimates of GCA effects over 21 plantings were computed for all the ear characters studied (Appendices from 17 to 24). B37 and Hi27 had negative GCA effect and Oh545 had positive GCA effect for cob length in all 21 plantings. This suggested that B37 and Hi27 were poor combiners for cob length, while Oh545 was a good combiner at all times. Tx601 was a good combiner with positive GCA effect during the winter plantings but was a poor combiner during the summer plantings. Similar GCA effects were obtained for filled ear length. B68 showed negative GCA effects for filled ear length. Most of the GCA effects for cob length were positive for B68.

For floret number per row, Oh545 and Tx601 showed highly significant GCA effects indicating they were good combiners for floret number per row. On the other hand Hi27 and Mp68:616 were poor combiners with negative GCA effects for this trait. The majority of GCA effects were positive for inbreds B37 and B68, but their GCA effects were rather low when compared to other inbreds. For kernels

Table 12. Analysis of combining ability of ear characters for 15 hybrids over 21 plantings

		Mean squares					
Source	df	Floret number per row	Cob length	Filled ear length	Row number	Kernels per row	Kernels per ear
GCA	5	629.0**	60.1**	60.9**	14.7**	510.2**	1262.2**
SCA	9	19.4**	2.0**	4.3**	0.8*	34.3**	83.9**
Month (M)	20	41.3**	76.3**	85.2**	5.7**	446.0**	1256.4**
GCA x M	100	5.5**	1.1**	1.5**	0.4	8.1**	18.6**
SCA x M	180	4.9*	0.6	0.7	0.4	3.9	12.4
Error	194	3.5	0.6	0.8	0.3	4.3	11.5

* Significant at 5 % level.

** Significant at 1 % level.

Table 13. Estimates of general combining ability effect of 6 inbreds on ear characters from combined analysis

Inbreds	Floret number per row	Cob length	Filled ear length	Row number	Kernels per row	Kernels per ear
B37	0.72	-0.97	-1.07	-0.36	-2.21	-50.9
B68	1.13	0.39	-0.21	0.06	-2.28	-30.6
Hi27	-3.75	-0.77	-0.77	0.44	-2.17	-17.5
Mp68:616	-3.15	0.05	0.59	0.16	2.61	42.3
Oh545	2.30	1.35	1.18	-0.35	2.10	18.4
Tx601	2.74	-0.04	0.29	0.32	1.96	38.4
SE(g_i - g_j)	0.29	0.12	0.13	0.09	0.32	5.2

per row B37, B68 and Hi27 were, with few exceptions, poor combiners for all plantings. Mp68:616, Oh545 and Tx601 were good combiners for kernels per row. Oh545 showed lower GCA effects for winter plantings, while Tx601 showed high GCA effects for winter plantings and opposite effects for summer plantings.

Again, B37 had all negative GCA effects for row number in all 21 plantings. In the majority of plantings, B68 and Oh545 showed negative GCA effects for row number. Hi27 and Tx601 were good combiners for all plantings except in several cases when GCA effects were not significantly different from zero. These GCA effects of 6 parental lines for different characters were reflected in estimates of GCA effects for kernels per ear. B37, B68 and Hi27 had negative GCA effects for kernels per ear with a few exceptions where GCA effects were not significantly different from zero. On the other hand, Oh545 and Tx601 showed positive GCA effects for kernels per ear again with one or two exceptions. Mp68:616 was not a good combiner for cob length and floret number, but was found to be a good combiner for kernels per row and kernels per ear. B68, however, was a good combiner for cob length and floret number per row, but was found to be a poor combiner for filled ear length and kernels per row. Both B37 and Hi27 were poor combiners for all ear characters except for row number in the case of Hi27.

GCA effects estimated from the combined analysis of 21 plantings are presented in Table 13. As already discussed in the individual analyses, B37, B68 and Hi27 did not combine as well as Mp68:616, Oh545 and Tx601 for ear length, kernels per row and kernels per ear.

Although Hi27 and B37 were not good combiners for kernel number and ear length, B37 showed positive GCA effect for floret number per row and Hi27 was a good combiner for row number. Oh545 appeared to be a good combiner for ear length and kernels per row but not for row number. Mp68:616 and Tx601 were found to be good combiners for filled ear length and kernels per row in general.

Hybrid and parental means of floret number, kernels per row, cob length, filled ear length, row number and kernels per ear for 21 monthly plantings are presented in Tables 14, 15 and 16. Hybrids B68 x Oh545, Oh545 x Tx601 and B37 x Tx601 had higher floret number per row than other hybrids. Hybrids with more kernels per row were Mp68:616 x Oh545, Mp68:616 x Tx601 and Oh545 x Tx601. Hybrids Hi27 x Mp68:616 showed the lowest floret number per row, and B37 x Hi27, B68 x Hi27 and B37 x B68 had the lowest kernel number per row. Parental means of B37, B68, Oh545 and Tx601 were higher than those of Hi27 and Mp68:616 for floret number per row. On the other hand, inbreds B37, B68 and Hi27 had lower parental means for kernels per row than Mp68:616, Oh545 and Tx601.

Hybrids B68 x Oh545, Mp68:616 x Oh545 and Oh545 x Tx601 had the longest cob length, while B37 x Hi27 showed the shortest cob length. B68 x Oh545 and Oh545 x Tx601 had the longest filled ear length with B37 x Hi27, B37 x B68 and B68 x Hi27 showing the shortest filled ear length. The parental means of Oh545 showed expected high values for cob and filled ear length as predicted by GCA effects fot this inbred on both characters. Inbred B37 showed the shortest cob and filled ear length among parental means.

Table 14. Floret number per row and kernels per row of 15 hybrids over 21 monthly plantings

	B68	Hi27	Mp68:616	Oh545	Tx601	Array mean
B37	55.8[a]	56.0	51.6	56.4	57.9	55.5
	26.5	25.9	32.4	31.5	32.5	29.7
B68		50.3	52.9	59.0	56.2	54.8
		25.5	33.2	31.7	31.3	29.6
Hi27			46.9	52.5	54.0	51.9
			32.3	33.5	31.5	29.7
Mp68:616				52.1	53.6	51.4
				34.7	35.2	33.6
Oh545					58.9	55.8
					34.7	33.2
Tx601						56.1
						33.0

[a] Upper and lower values represent floret number per row and kernels per row, respectively.

BLSD (0.05) Floret number = 4.59
Kernels per row = 5.13

Table 15. Cob length and filled ear length of 15 hybrids over 21 montrly plantings

(Unit : cm)

	B68	Hi27	Mp68:616	Oh545	Tx601	Array mean
B37	15.4[a]	14.4	15.2	16.5	15.6	15.4
	12.2	11.8	13.5	14.0	13.5	13.0
B68		15.4	17.0	18.0	16.7	16.5
		12.4	14.8	14.7	14.3	13.7
Hi27			15.9	16.9	15.4	15.6
			14.0	14.6	13.4	13.2
Mp68:616				17.5	15.7	16.3
				15.4	14.0	14.3
Oh545					17.5	17.3
					15.2	14.8
Tx601						16.2
						14.1

[a] Upper and lower values represent cob length and filled ear length, respectively.

BLSD (0.05) Cob length = 1.93
Filled ear length = 2.13

Few hybrids had significantly different row number. Hybrids Hi27 x Mp68:616 and Hi27 x Tx601 had a higher row number than other hybrids and significantly higher values than B37 x Oh545 and B37 x B68 hybrids. Kernels per ear showed the same trend as kernels per row. Mp68:616 x Tx601 and OH545 x Tx601 had more than 500 kernels per ear, while B37 x B68, B37 x Hi27 and B68 x Hi27 had less than 400 kernels per ear, average for 21 plantings.

Estimates of SCA effects were also computed for all the ear characters in combined analysis of combining ability over 21 plantings (Table 17). Hybrids B68 x Mp68:616, B37 x Tx601, B68 x Oh545, B68 x Tx601 and Hi27 x Mp68:616 had positive SCA effects for all characters with exceptions. This indicated possible gene interactions (non-additive effects) leading to improved expression above that expected on the basis of GCA alone. Hybrids B37 x B68, B68 x Hi27, Mp68:616 x Oh545, Mp68:616 x Tx601 and Oh545 x Tx601 had negative SCA effects for all ear characters with only occasional exceptions. In general, hybrids among inbreds with high mean values and among inbreds with lower mean values of certain character showed lower and negative SCA effects, while hybrids between inbreds with intermediate mean values and inbreds with high or low mean values for each character showed greater and positive SCA effects. For example, B68 with intermediate mean values for all ear characters showed high SCA effects with Oh545 and Tx601, which had high mean values for almost all ear characters.

Table 16. Kernel row number and kernels per ear of 15 hybrids over 21 monthly plantings

	B68	Hi27	Mp68:616	Oh545	Tx601	Array mean
B37	13.6[a] 364	14.3 373	13.8 448	13.3 417	14.0 458	13.8 412
B68		14.6 375	14.5 484	14.2 454	14.7 463	14.3 428
Hi27			15.2 496	14.2 476	15.0 474	14.7 439
Mp68:616				14.0 487	14.6 518	14.4 486
Oh545					14.4 503	14.0 467
Tx601						14.5 483

[a] Upper and lower values represent kernel row number and kernels per ear, respectively.

BLSD (0.05) Kernel row number = 1.44
Kernels per ear = 83.6

Table 17. Estimates of SCA effects for the ear characters over 21 monthly plantings

Hybrids	Floret number per row	Cob length	Filled ear length	Row number	Kernels per row	Kernels per ear
B37 x B68	-0.01	-0.19	-0.39	-0.08	-0.45	- 7.2
B37 x Hi27	0.02	-0.08	-0.22	0.19	-1.16	-11.5
B37 x Mp68:616	0.10	-0.09	0.13	-0.06	-0.50	3.8
B37 x Oh545	-0.55	-0.04	0.01	-0.04	-0.18	- 3.1
B37 x Tx601	0.45	0.41	0.47	-0.02	1.29	17.9
B68 x Hi27	-1.01	-0.39	-0.44	-0.21	-1.53	-29.2
B68 x Mp68:616	0.96	0.38	0.53	0.00	1.42	19.9
B68 x Oh545	1.63	0.03	-0.10	0.24	0.39	13.6
B68 x Tx601	-1.58	0.17	0.39	0.05	0.16	2.8
Hi27 x Mp68:616	-0.13	0.36	0.27	0.33	0.40	18.1
Hi27 x Oh545	-0.02	0.12	0.38	-0.23	2.05	22.0
Hi27 x Tx601	1.13	-0.02	-0.00	-0.09	0.24	0.5
Mp68:616 x Oh545	-0.99	-0.09	-0.19	-0.15	-1.45	-26.5
Mp68:616 x Tx601	0.06	-0.55	-0.75	-0.13	-0.88	-15.3
Oh545 x Tx601	-0.06	-0.02	-0.11	0.17	-0.82	- 6.0

4.2.3 Response of kernel number and ear length to seasonal environments

The effects of seasonal variation on kernel number, ear length, and related ear characters were studied. A general mean of all the hybrids for each planting and environmental index, defined as the deviation from the overall mean of 21 plantings, are given for all the characters studied (Appendix 7). The mean and environmental index indicated the degree of average performance of 15 hybrids for each planting. The negative sign of the environmental index indicates that a given planting was poor than average. The environmental indices clearly demonstrate that plantings made in winter months were poorer than average for all the characters studied. Cob length, filled ear length, row number, kernels per row and kernels per ear were lower than average in September, October, November and December plantings with a few exceptions. However, floret number did not show as clear a trend as other characters.

General means of each hybrid over 21 plantings and their phenotypic index, defined as a deviation from overall mean of 15 hybrids, are presented for all characters studied in Appendix 8. The phenotypic index shows whether hybrids performed better or worse in the average over 21 plantings. The hybrid with the highest floret number was B68 x Oh545, while Hi27 x Mp68:616 was the hybrid with the lowest floret number. Mp68:616 x Oh545 and Oh545 x Tx601 showed the longest ear length and Mp68:616 x Tx601 had the highest number of kernels per row. Hybrids B37 x B68, B37 x Hi27 and B68 x Hi27 had generally short ears with fewer kernels per row.

Number of florets per row, kernels per row, kernels per ear, row number, cob length and filled ear length of 15 hybrids for 21 plantings are presented in Appendices 9 - 14. Range of the ear characters is summarized to compare the approximate variation among plantings (months) and hybrids (Table 18). The highest values for the ear characters were recorded in March planting, 1979, while the lowest values were obtained in October planting, 1978. The difference in number of florets per row among plantings with the highest and the lowest averages was smaller than the difference among hybrids of the highest and the lowest averages in respective planting. The difference among hybrids within a planting was greater than the difference among plantings of a hybrid. For other characters studied, the difference between plantings with the highest and the lowest averages was greater than the difference between hybrids of the highest and the lowest averages. The range among plantings of a hybrid was greater than the range among hybrids within a planting. These results indicate that the effect of seasonal environments was greater than genetic variations for all the ear characters studied except number of florets per row.

Graphs showing average number of florets per row, kernels per row, kernels per ear, row number, cob length and filled ear length, averaged over 15 hybrids per planting are presented in Figure 7. Average temperature and total solar radiation accumulated over the period from planting to harvest are also graphed to show the coinciding changes between characters studied and climatic factors. All values are expressed as percentages of the overall mean for convenience. The seasonal change of solar radiation and temperature were described in

Table 18. Range of ear characters among plantings and hybrids in monthly plantings

Among	Floret number per row	Cob length	Filled ear length	Row number	Kernels per row	Kernels per ear
Plantings						
Highest average (A)	57.1	19.8	17.7	15.0	40.6	606
Highest hybrid (1)	63.0	22.9	19.5	17.0	44.8	706
Lowest hybrid (2)	48.3	18.2	15.2	13.0	32.6	478
1 - 2	14.7	4.7	4.3	4.0	12.2	228
Lowest average (B)	53.3	11.4	9.1	12.7	21.0	267
Highest hybrid (1)	60.4	13.9	11.4	13.4	28.8	355
Lowest hybrid (2)	46.7	9.7	7.5	11.8	15.6	184
1 - 2	13.7	4.2	3.9	1.6	13.2	171
A - B	3.8	8.4	8.6	2.3	19.6	339
Hybrids						
Highest average (A)	59.0	18.0	15.4	15.2	35.2	518
Highest planting (1)	63.9	22.9	19.9	16.6	44.1	715
Lowest planting (2)	54.0	13.7	9.6	12.4	26.8	355
1 - 2	9.9	9.2	10.3	4.2	17.3	360
Lowest average (B)	46.9	14.4	11.8	13.3	24.5	364
Highest planting (1)	50.0	18.5	15.8	14.2	35.3	526
Lowest planting (2)	41.9	10.2	7.7	12.0	15.0	193
1 - 2	8.1	8.3	8.1	2.2	20.3	333
A - B	12.1	3.6	3.6	1.9	10.7	154

an earlier part of this chapter.

The seasonal change of kernels per row, kernels per ear, cob length and filled ear length was strikingly similar to that of solar radiation except for three plantings in early 1978. Although solar radiation during this period was lower than average, the ear characters showed higher values than average. One possible explanation for this fact seems to be related to the growing period of these plantings and environmental conditions other than solar radiation. The growing period of these plantings was longer than that of previous months or later months due to lower temperature. Rainfall was lower than that of the same period in 1979. The seasonal change of floret number per row and row number did not show the same cyclic changes as for other characters and climatic factors.

Correlation coefficients were computed among the ear characters and climatic factors (Table 19). In general, highly significant correlations were present among the ear characters and solar radiation values except for average daily solar radiation during the first month. However, statistically significant correlations between the ear characters and the fourth month solar radiation values should not be considered as biologically significant considering the fact that the fourth month of the growth corresponds to late stage of grain filling and dry down period at Waimanalo. This holds true for correlation coefficients between row number and the third month solar radiation values. It is worthy to note that no significant correlations were present between floret number per row and solar radiation. As already pointed out, environmental change does not significantly affect floret

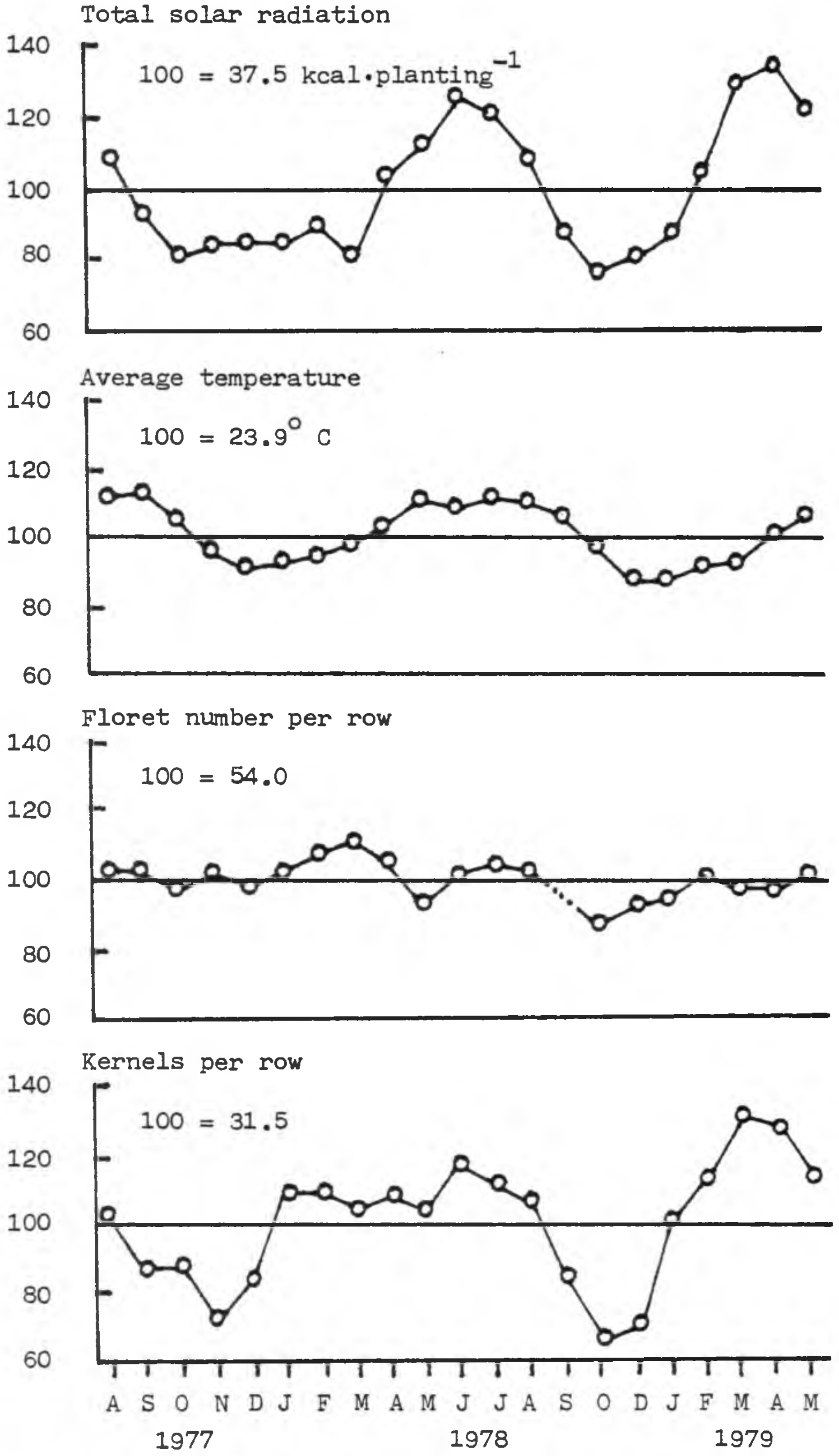

Figure 7. Seasonal changes of total solar radiation, average temperature and ear characters in percentage of overall mean

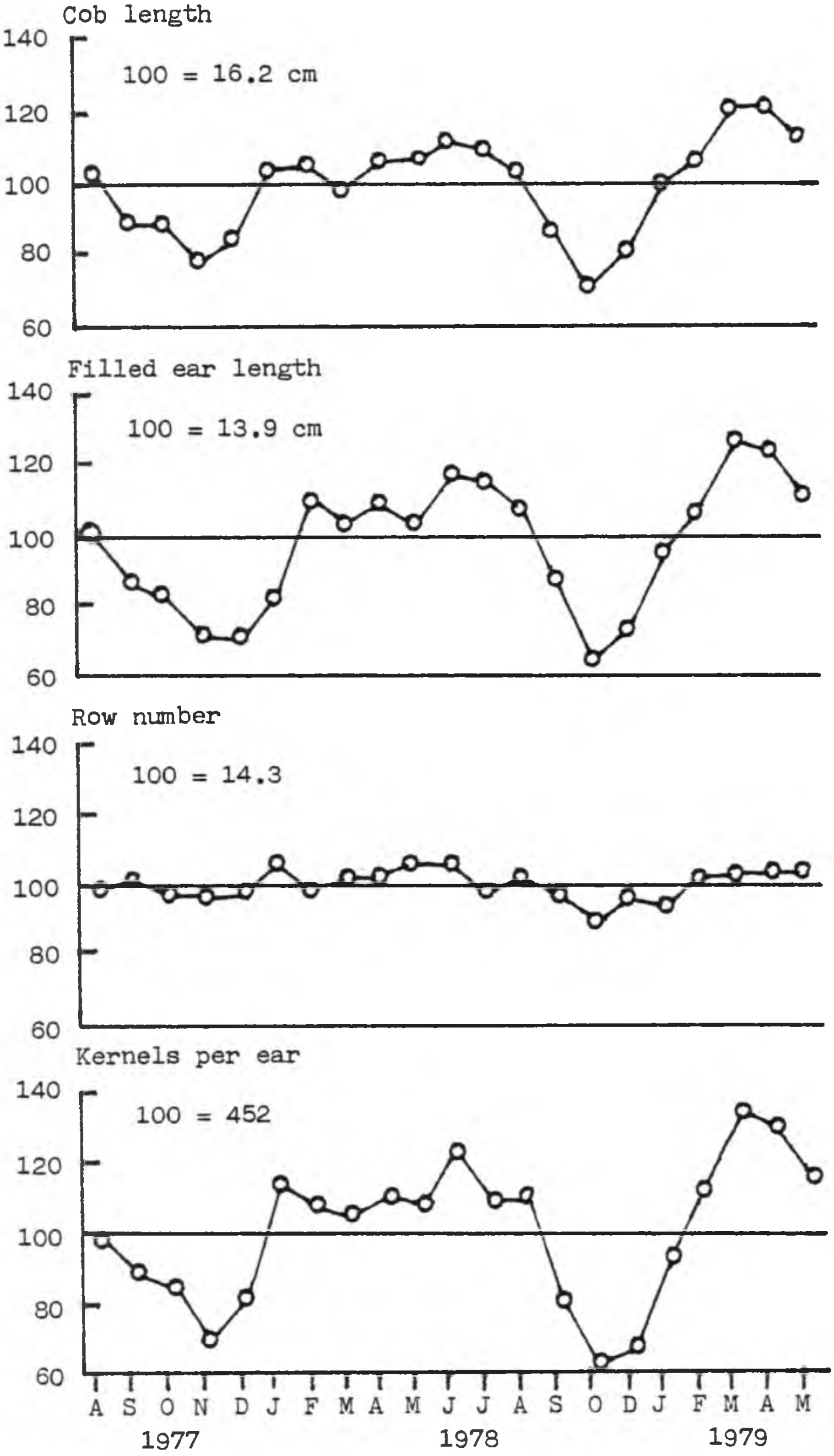

Figure 7. (Continued) Seasonal changes of total solar radiation, average temperature and ear characters in percentage of overall mean

Table 19. Correlation coefficients among ear characters and climatic factors

Climatic factors	Florets per row	Cob length	Filled ear length	Kernels per row	Row number	Kernels per ear
Solar radiation :						
Total (S_T)	0.13	0.85**	0.82**	0.80**	0.63**	0.80**
Average (S_A)	0.21	0.84**	0.81**	0.79**	0.65**	0.80**
1st month (S_1)	0.23	0.24	0.25	0.19	0.13	0.19
2nd month (S_2)	0.26	0.67**	0.67**	0.64**	0.60**	0.65**
3rd month (S_3)	0.04	0.82**	0.78**	0.77**	0.60**	0.78**
4th month (S_4)	0.09	0.64**	0.58**	0.61**	0.51**	0.62**
Temperature :						
Average (T_A)	0.33	0.42*	0.44*	0.37	0.46*	0.40
Avg. min. (T_{min})	0.30	0.42*	0.44*	0.36	0.45*	0.40
Avg. max. (T_{max})	0.37	0.41	0.42*	0.36	0.46*	0.41

* Significant at 5 % level.

** Significant at 1 % level.

number per row.

Multiple regression analyses were carried out using the ear characters and meteorological data (Table 20). The ear characters were used as dependent variables in the regression analysis and average daily solar radiation for four months was used as the independent variable. Number of florets per row and row number were not included in the regression analysis since number of florets per row did not show significant correlation with solar radiation and because row number is set early stage of growth. The sequential F-test of regression analysis shows the additional cotribution of the variable entered to the equation given that the other variable is already in the equation. only the average daily solar radiation of the third month was significant and the additional entry of other solar radiation data failed to contribute significantly to the equation. This was due partly to the fact that the independent variables are highly correlated to each other. However, the average daily solar radiation of the third month appeared to be the one independent variable that explains most of the variation in the dependent variables, i.e. kernel number and ear length. Regression lines between kernels per row and filled ear length and the average daily solar radiation of the third month are presented in Figure 8 and 9. Cob length and kernels per ear showed similar response to seasonal environments as filled ear length and kernels per row. Regression lines in Figure 8 and 9 show that the average daily solar radiation of the third month explains nearly 60 % of the variation in kernels per row and filled ear length. Considering the fact that the four month solar radiation data explain less than

Table 20. Sequential F-test of regression analysis between yield components and average monthly solar radiation

Source	df	Mean squares			
		Cob length	Filled ear length	Kernels per row	Kernels per ear
Regression/b_0	4	19.2**	19.6**	102.0**	29529**
Partition:					
b_3/b_0	1	68.2**	68.33**	357.1**	16668*
$b_2/b_3,b_0$	1	5.0	7.2	27.6	10867
$b_4/b_2,b_3,b_0$	1	3.8	3.0	22.4	5401
$b_1/b_4,b_2,b_3,b_0$	1	0.0	0.0	0.9	399
Residual	16	1.5	2.2	11.8	3080

b_0,b_1,b_2,b_3,b_4 = Regression due to mean, average solar radiation of the 1st, 2nd, 3rd and 4th months, respectively.

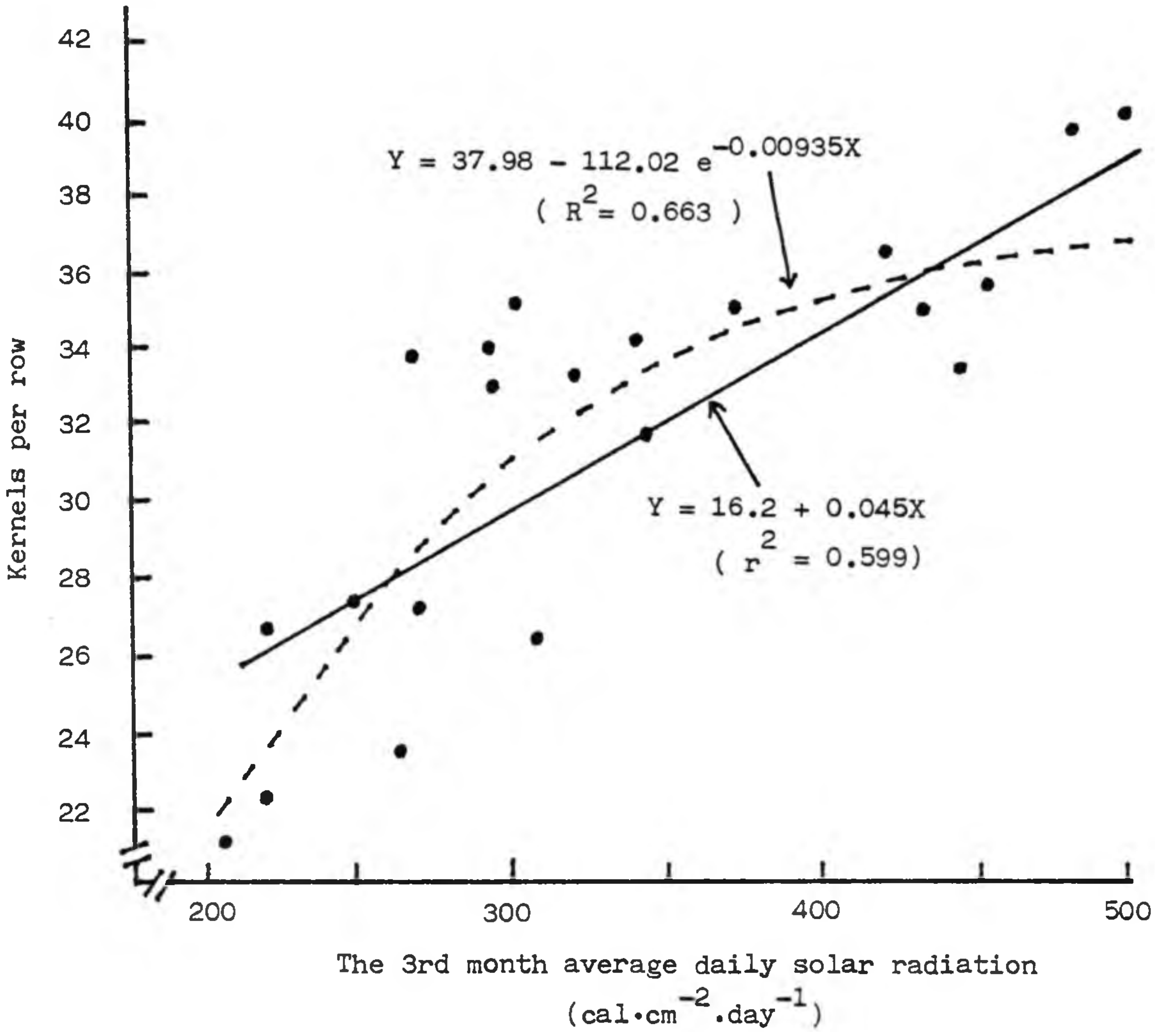

Figure 8. Relationship between kernels per row and the 3rd month average daily solar radiation

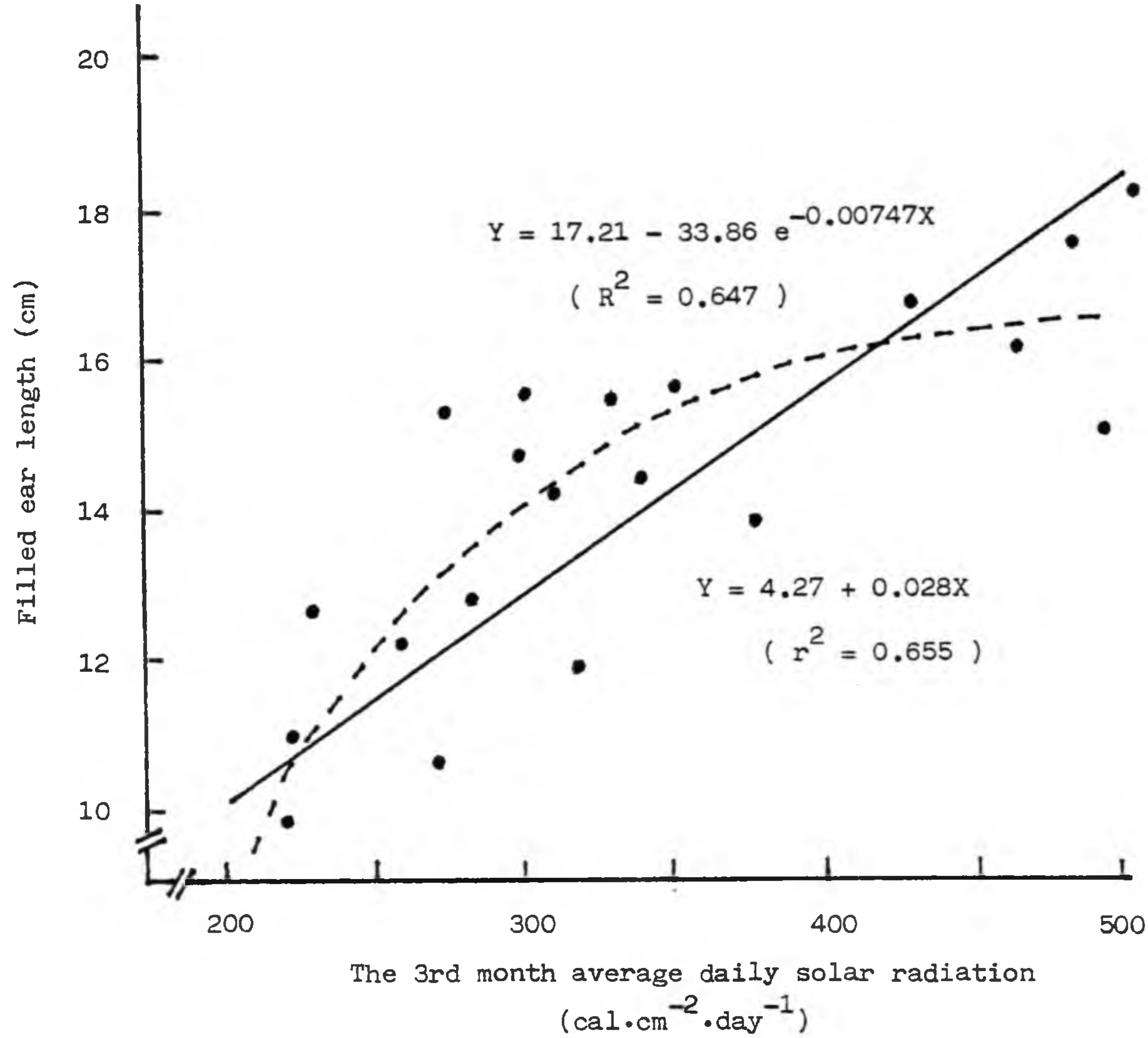

Figure 9. Relationship between filled ear length and the 3rd month average daily solar radiation

70 % variation in these characters and given the results of sequential F-test, the average daily solar radiation of the third month appears as the most single important climatic factor determining not only kernels per row and filled ear length but also cob length and kernels per ear. A similar single most important environmental factor controlling the floret number and row number could not be found. Since linear regression lines appeared to overestimate values under low solar radiation conditions, non-linear asymptotic regression lines were computed for kernels per row and filled ear length. Non-linear asymptotic regression improved the regression sum of squares slightly for kernels per row and filled ear length and provided a better fit for low radiation level. However, the increase of regression sum of squares was not significant, and linear regression was adequate to explain the variations of kernels per row and filled ear length in the range of solar radiation of this experiment.

Correlation coefficients between two ear characters (kernels per row and filled ear length) and climatic factors (average daily solar radiation for each planting and the third month average maximum temperature) were computed for the 15 hybrids (Table 21). All the correlation coefficients except for B68 x Tx601 and B68 x Oh545 were highly significant. Coefficients of determination (r^2) ranged from 0.34 for B68 x Tx601 to 0.69 for Hi27 x Tx601 for the contribution of climatic factors to kernels per row and filled ear length. The contribution of temperature to the explanation of variations in kernels per row was less than that of solar radiation for all the hybrids. The correlation coefficients of 15 hybrids were not significantly

Table 21. Correlation coefficients among two ear characters and solar radiation and temperature

Hybrids	Kernels per row			Filled ear length		
	S_A[a]	S_3	$T_{R.max}$	S_A	S_3	$T_{R.max}$
B37 x B68	0.77	0.71	0.58	0.74	0.62	0.58
B37 x Hi27	0.79	0.72	0.68	0.79	0.72	0.63
B37 x Mp68:616	0.76	0.75	0.66	0.75	0.75	0.64
B37 x Oh545	0.75	0.72	0.66	0.85	0.80	0.73
B37 x Tx601	0.70	0.69	0.58	0.73	0.71	0.65
B68 x Hi27	0.68	0.64	0.54	0.68	0.63	0.58
B68 x Mp68:616	0.66	0.73	0.60	0.71	0.74	0.67
B68 x Oh545	0.62	0.62	0.47	0.61	0.58	0.48
B68 x Tx601	0.58	0.58	0.47	0.68	0.65	0.54
Hi27 x Mp68:616	0.76	0.71	0.70	0.80	0.76	0.72
Hi27 x Oh545	0.84	0.81	0.77	0.87	0.57	0.77
Hi27 x Tx601	0.83	0.81	0.73	0.83	0.76	0.78
Mp68:616 x Oh545	0.75	0.76	0.65	0.78	0.74	0.74
Mp68:616 x Tx601	0.65	0.75	0.56	0.71	0.81	0.59
Oh545 x Tx601	0.78	0.77	0.65	0.81	0.80	0.71
Means	0.78	0.72	0.62	0.76	0.71	0.65

Significance level of r (correlation coefficient):

0.05 = 0.43
0.01 = 0.55 with df = 19

[a] S_A, S_3, $T_{R.max}$ = Average daily solar radiation during the whole growing period, the 3rd month average daily solar radiation and the average maximum temperature after silking, respectively.

different each other. This indicated that the 15 hybrids had the similar response to environmental conditions in this experiment. This relationship will be discussed further in a later section.

4.2.4 Relationships between kernel number, ear length and yield in seasonal environments

The response of grain yield to seasonal environments and the relationships between kernel number and ear length and yield in monthly plantings will be discussed in this section. Kernel size in terms of 100 kernel weight is also included to relate the basic yield components, i.e. number and size of kernel, to the final grain yield. Data of 100 kernel weight and grain yield of 15 hybrids in 21 plantings are presented in Appendix 15 and 16. The results of the individual analysis of variance for 100 kernel weight are summarized in Appendix 5. Monthly average variation was about 5 % of the overall average (29.2 g) except December, 1977 planting. No apparent cyclic change was observed for 100 kernel weight.

The results of the individual analyses of variance for grain yield, mean squares for hybrids and error, and coefficients of variation are given in Table 22. Average yield of the 15 hybrids in 21 plantings showed the same cyclic pattern as climatic factors and other ear characters discussed earlier. The highest yield was recorded in March, 1979 followed by April, 1979 and June, 1978 plantings, while October, and December plantings of 1977 and 1978 recorded the lowest grain yield. Hybrids were significantly different in their yields in most of the winter plantings and some high yielding plantings of summer months.

Table 22. Average grain yield of 15 hybrids, mean squares of hybrids and error and coefficients of variation for grain yield in 21 monthly plantings

Months		Average yield(T/ha)	Mean squares		C.V.(%)
			Hybrids	Error	
August	1977	8.21	1.05	0.86	11.3
September	1977	6.94	1.71	1.48	17.5
October	1977	7.20	1.38	0.76	12.2
November	1977	5.02	3.77**	0.77	17.5
December	1977	5.57	2.21*	0.77	15.7
January	1978	8.67	1.61	1.35	13.4
February	1978	9.40	3.12*	0.85	9.8
March	1978	8.20	2.30	1.33	14.0
April	1978	8.72	2.26	0.91	10.9
May	1978	8.11	3.38	1.81	16.6
June	1978	10.39	6.00*	1.70	12.5
July	1978	9.35	1.98	2.87	18.1
August	1978	7.96	2.61*	0.83	11.5
September	1978	6.56	1.15	1.34	17.6
October	1978	3.52	1.47*	0.57	21.4
December	1978	4.19	1.44**	0.20	10.6
January	1979	6.90	1.75*	0.60	11.3
February	1979	8.77	1.60*	0.60	8.8
March	1979	11.60	4.05**	0.92	8.3
April	1979	10.58	2.38	2.22	14.1
May	1979	8.85	1.26	0.90	10.7
Average		7.84			13.5

* Significant at 5 % level.

** Significant at 1 % level.

The error variances were relatively small, but the homogeneity test of variances was significant. The variances were significantly correlated with mean grain yields of 15 hybrids (r = 0.505*) in 21 plantings. However, when variances of July, 1978 and April, 1979 plantings, which were the highest among 21 variances, were removed from the homogeneity test, the result was not significant (P = 0.75 - 0.50). The correlation coefficient between mean and variance was also not significant (r = 0.440). This suggested that the variances of these two plantings mainly contributed to the significant results in homogeneity test and correlation coefficient. The removal of the two plantings from the combined analysis, however, did not change the result significantly and all 21 plantings were used in further analysis. The hybrid x month interaction was not significant in the combined analysis (Table 23). This indicated that the inclusion of the two plantings would not create significant bias in the interpretation of the results. The coefficients of variation were in acceptable range and generally were greater in winter plantings, when heavy rainfall often resulted in lodging and occurrence of disease.

The estimates of GCA effects for 100 kernel weight and grain yield of 6 parental lines over 21 plantings are presented in Appendix 23 and 24, respectively. Variances analyses of combining ability showed that GCA and SCA effects were highly significant for both 100 kernel weight and grain yield (Table 24). The GCA x month interaction was also highly significant for both characters but SCA x month interaction was significant only for 100 kernel weight. Although both GCA and SCA effects were highly significant, GCA effect was much

Table 23. Combined analysis of variance for 100 kernel weight and grain yield over 21 plantings

Source	df	Mean squares	
		100 kernel weight	Grain yield
Months (M)	20	140.32**	128.05**
Reps. in M	21	4.71	3.06
Hybrids (H)	14	135.13**	21.36**
H x M	280	8.36**	1.35
Error (b)	294	4.61	1.13

** Significant at 1 % level.

Table 24. Analysis of combining ability of 100 kernel weight and grain yield in a 6-entry diallel over 21 plantings

Source	df	Mean squares	
		100 kernel weight	Grain yield
GCA	5	178.66**	24.36**
SCA	9	7.40**	3.13**
Months (M)	20	70.83**	64.04**
GCA x M	100	4.90**	1.01**
SCA x M	180	3.69**	0.49
Error	194	2.31	0.56

** Significant at 1 % level.

more important than SCA effect for both characters when the two mean squares were compared. The mean square of GCA effect was 24 times larger than that of SCA effect for 100 kernel weight and 8 times greater than that of SCA effect for grain yield.

Average 100 kernel weight and grain yield of 15 hybrids over 21 plantings and estimates of GCA effects for 6 parental lines from combined analysis are given in Table 25. Hybrids of B68 showed higher 100 kernel weight as indicated by high GCA effect of B68 for this character. B37 and Tx601 also had relatively high GCA effect for 100 kernel weight. Hybrids among B68, Mp68:616 and Tx601 showed higher average grain yield than hybrids among B37, Hi27 and Tx601. Mp68:616, Oh545 and Tx601 had significantly greater GCA effect than B68, Hi27 and B37 for grain yield.

The hybrid with the highest SCA effect for 100 kernel weight was B37 x Hi27 followed by B68 x Tx601. The cross Hi27 x Tx601 showed the largest negative SCA effect for this character. SCA effects for grain yield showed that the hybrids with very high and positive SCA effects were Hi27 x Oh545 and B37 x Tx601, while hybrids B68 x Hi27 and Mp68:616 x Oh545 were negative.

GCA effects for 100 kernel weight of B68 were positive and the highest in all 21 plantings, while those of Mp68:616 were negative in all plantings. The other four parental lines showed both positive and negative GCA effects depending on the time of planting (Appendix 23). All GCA effects for grain yield of B37 and Hi27 were negative except three plantings of Hi27, while the majority of GCA effects of Oh545 and Tx601 were positive and higher than the other inbreds.

Table 25. Average 100 kernel weight and grain yield of 15 hybrids over 21 plantings and estimates of GCA effects

(100 kernel wt. = g
Grain yield = T/ha)

	B68	Hi27	Mp68:616	Oh545	Tx601	GCA effects
B37	32.2[a] 6.90	30.3 6.52	27.9 7.54	29.4 7.07	28.9 7.93	0.65 -0.82
B68		31.3 6.95	29.1 8.47	31.4 8.48	31.3 8.67	2.32 0.06
Hi27			26.7 7.90	29.0 8.26	26.6 7.67	-0.53 -0.48
Mp68:616				27.9 8.12	27.0 8.39	-1.86 0.30
Oh545					29.1 8.81	0.19 0.38
Tx601						-0.77 0.56
SE($g_i - g_j$)						0.23 0.12

[a] Upper and lower values are 100 kernel weight and grain yield, respectively.

BLSD (0.05) 100 kernel weight = 3.75
Grain yield = 1.88

There were indications that B37 and Tx601 showed higher GCA effects under favorable conditions. On the other hand Hi27 showed higher GCA effects under unfavorable plantings than favorable months. Since GCA effects of B37 and Hi27 were mostly negative, the higher GCA effects here meant smaller absolute values.

Monthly change in average daily solar radiation over four month period and grain yield for the 21 plantings are presented in Figure 10. This graph visualize the change of solar radiation during the period of corn growth for each planting and grain yield of respective planting. The plantings from July to October passed through a period of decreasing irradiance, while plantings from March to June received solar radiation in a successively increasing fashion. In general October, November and December plantings grew under very low irradiance and May, June and July plantings grew under high irradiance regardless of the monthly change of solar radiation.

When both the second and third month solar radiations were the lowest among 21 plantings, grain yields were also the lowest as in plantings of November, 1977 and October and December, 1978. When either one of the second or third month solar radiation was higher, however, the yield was significantly greater than the lowest ones as in plantings of October and December, 1977, September, 1978 and January, 1979. This indicated that better grain yield was a result of either better leaf development before silking or more solar energy available after silking, since corn plants silked around the end of the second month or at the beginning of the third month in those plantings.

Discrepancies in yields from solar radiation change in January and February, 1978 are explained in relation to growing period of these plantings. Number of days to mid-silking for these plantings were about one week longer than October of March plantings when more than over half of the growing period experienced similar solar radiation environments. This increase in growing period resulted in more solar radiation received during one of vegetative or grain filling period (before or after silking). Although the total solar radiation received during the growing period was similar, higher solar radiation at one stage affected the final grain yield significantly. This relationship will be discussed later in more detail. This same relationship, however, was not observed in 1979 when solar radiation was lower than the previous year. Referring to Figure 8 and 9, the effect of solar radiation on corn plants appeared to be more critical at lower solar radiation levels. The same relationship was apparantly true between yield and solar radiation. When grain yield was compared with total solar radiation during the period before and after silking (Figure 11),the discrepancies in January and February of 1978 became less significant. Solar radiation received during the whole growing period for January and February plantings in 1978 was greater than either November and December, 1977 or March, 1978.

Relationships between various solar radiation and grain yield data were examined to find out the most reliable solar radiation data in prediction of grain yield (Appendix 25). Solar radiation data were calculated based on daily solar radiation and number of days from planting to harvest for each planting. The coefficients of

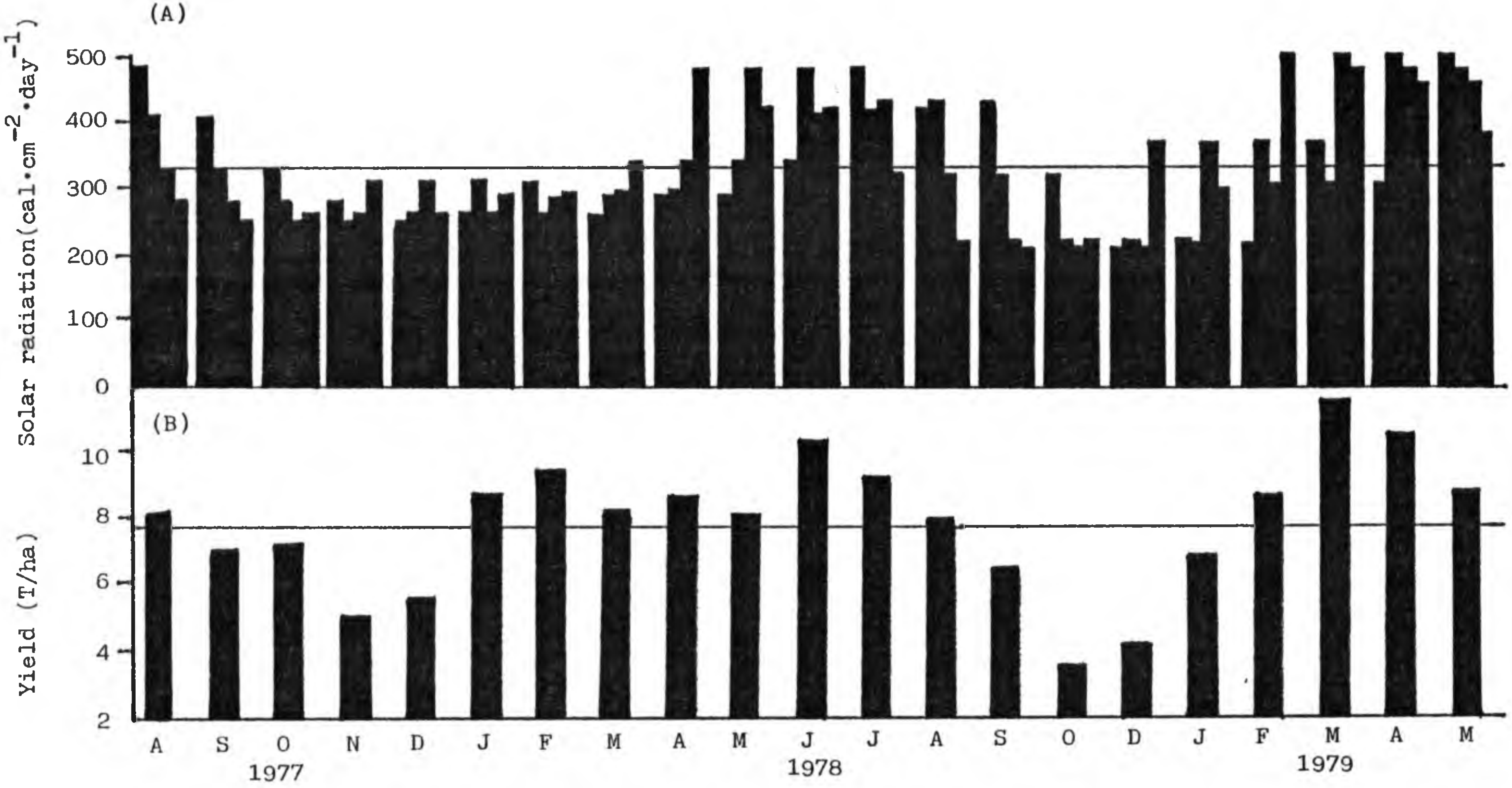

Figure 10. Monthly changes in average daily solar radiation over four month period begining with the first month (A) and grain yield for the 21 monthly plantings (Horizontal lines show overall mean values)

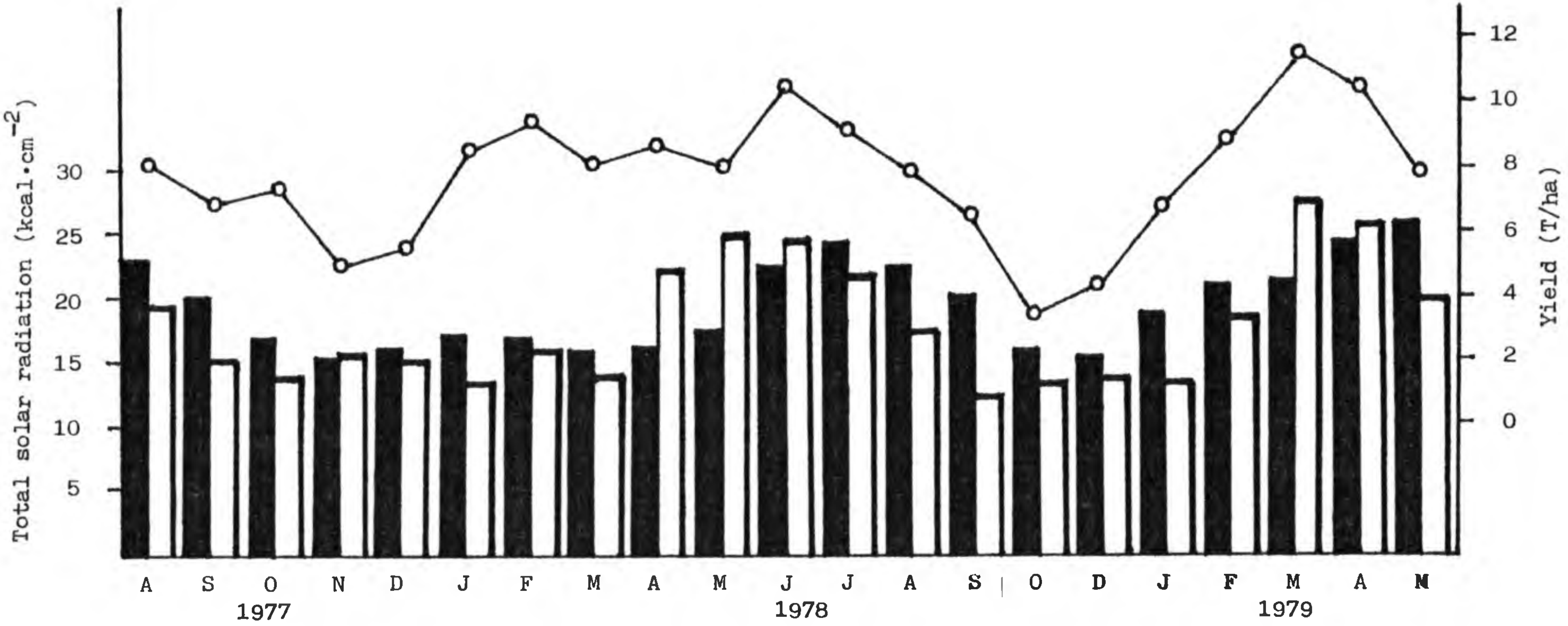

Figure 11. Total solar radiation received before (■) and after (□) silking for each planting and grain yield (o—o) for 21 monthly plantings

determination in regression analysis indicated that there was no significant differences among total solar radiation (S_T), average daily solar radiation (S_A) and average daily solar radiation of each month (S_1 to S_4) in explaining the variations of grain yield. Average daily solar radiation before silking, average solar radiation of the first and fourth months as well as average temperature were poor independent variables in regression analysis to explain the yield variation in 21 monthly plantings. Results suggested that collecting solar radiation data during the whole growing period would be better for estimation of corn grain yield, but also indicated that the third month average daily solar radiation is acceptable for the same purpose. The separation of solar radiation data according to the growth stage of corn plant appeared not to be advantageous.

Regression lines of two different equations are given in Figure 12. The simple linear regression equation explained about 60 % of yield variation based on average daily solar radiation. This is a quite satisfactory equation considering the fact that there are numerous environmental factors affecting growth of corn plants. However, this equation apparently overestimates grain yield under low solar radiation environments. An asymptotic equation improved the regression line and explained about 72 % of variations in grain yield and was better than any simple or multiple regression equation. The discrepancy of grain yield in January and February plantings in Figure 10 also could be explained by the asymptotic regression equation to a certain extent. When average daily solar radiation was lower than average, a small increase in solar radiation resulted in greater

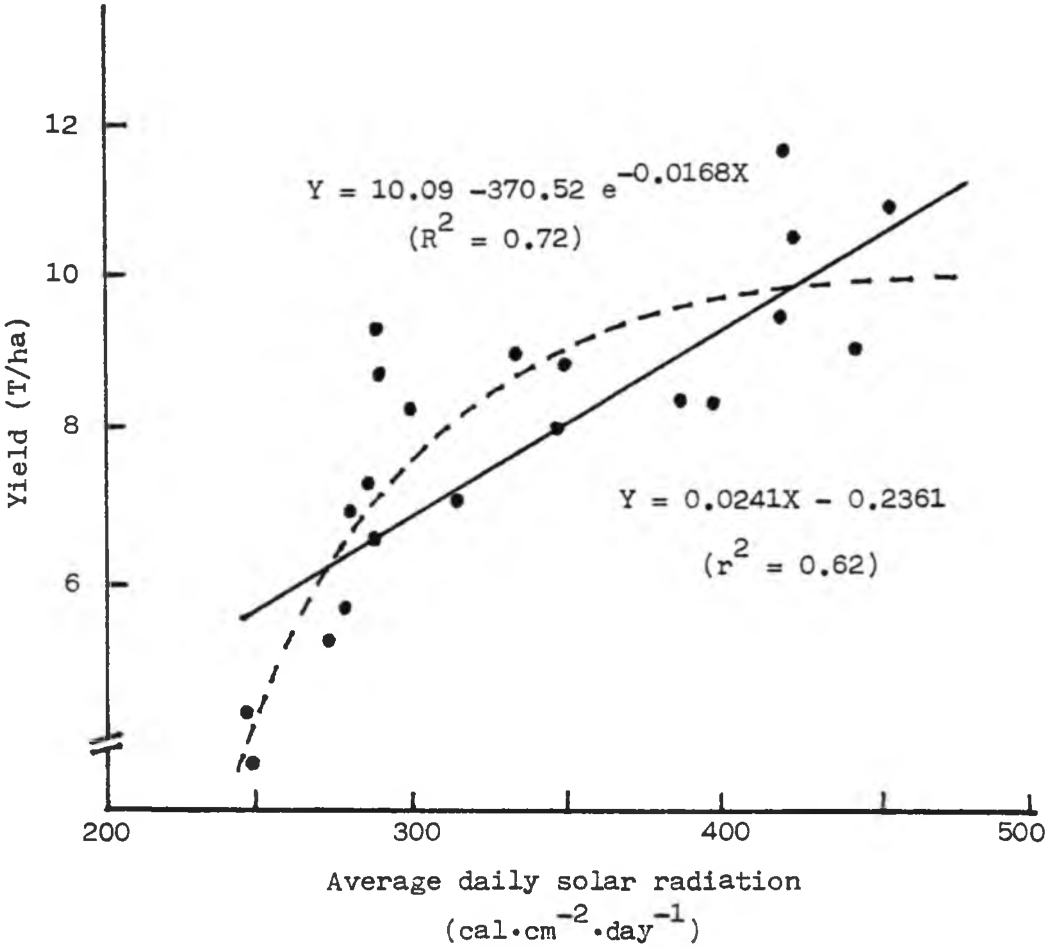

Figure 12. Relationship between grain yield and average daily solar radiation

increase of grain yield. The increase in solar radiation received by January and February plantings was brought by slower growth rate due to lower temperature in those plantings. A five day longer growing period at 280 $\text{cal}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$ would result in an increase of monthly average daily solar radiation of about 45 $\text{cal}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$. This increase in solar radiation could make yield difference as great as 1.78 T/ha at 280 $\text{cal.cm}^{-2}\cdot\text{day}^{-1}$ level. However, at 400 $\text{cal}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$ level, the difference in yield is less than 0.25 T/ha. This relationship also explained the lower grain yield in October and December, 1978 plantings than November and December plantings, 1977 with difference of 28 $\text{cal}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$ in average. This is equivalent to 2.26 T/ha of yield difference at 245 $\text{cal}\cdot\text{cm}^{-2}\cdot\text{day}^{-1}$ level. The actual mean difference was only 1.54 T/ha. Days to mid-silking in October and December plantings, 1978 was more delayed than that of November and December plantings, 1977. But weather conditions in 1978 were worse than the previous winter. The difference between actual and estimated yield was caused by other factors rather than solar radiation. In general, the cyclic change of yield was well explained by the asymptotic regression equation based on average solar radiation combined with the temperature effect on growing period.

Since grain yield in 21 monthly plantings showed the same cyclic changes as ear characters, there should be close relationship between grain yield and ear characters. Simple correlations among yield and yield components were calculated (Table 26). Kernels per row, kernels per ear and filled ear length showed highly significant correlation coefficients and their coefficients of determination were higher than

Table 26. Correlation coefficients (above diagonal) and coefficients of determination (below diagonal) among yield components and yield

	Kernels per row	Row number	Kernels per ear	100 kernel weight	Filled ear length	Grain yield
Kernels per row	-	0.77**	0.99**	0.42	0.99**	0.97**
Row number	0.60	-	0.84**	0.17	0.79**	0.78**
Kernels per ear	0.98	0.71	-	0.38	0.99**	0.97**
100 kernel weight	0.18	0.03	0.15	-	0.47*	0.55**
Filled ear length	0.98	0.63	0.97	0.22	-	0.97**
Grain yield	0.94	0.61	0.94	0.30	0.96	-

* Significant at 5 % probability level.

** Significant at 1 % probability level.

90 %. Although row number and 100 kernel weight showed highly significant correlation coefficients, they were able to explain less than 60 % of the variations in grain yield.

One interesting relationship between ear characters should be mentioned here. Although the correlation coefficient between 100 kernel weight and kernels per row or kernels per ear was not significant, the correlation between 100 kernel weight and filled ear length was significant at the 5 % level. This indicated that filled ear length could be considered as one character which can represent both kernel number and kernel size, when reflecting seasonal differences.

Regression lines showing the relationship between kernels per row and yield and filled ear length and yield are given in Figure 13 and 14, respectively. The estimation of grain yield based on kernels per row or filled ear length agreed well with the observed yield data. Although filled ear length represented both kernel number and size, the regression equation explained variation of yield only slightly better than that of kernels per row. This was an expected results since variation in kernel weight was small in seasonal environments.

Although the correlation coefficient between kernels per row and 100 kernel weight was not significant, response surface of grain yield versus kernels per row and 100 kernel weight revealed a certain relationship among the three characters. Response surface representing grain yield (within the range of current data, response surface appeared as straight lines rather than curve) showed a somewhat compensating relationship between the two yield components. The

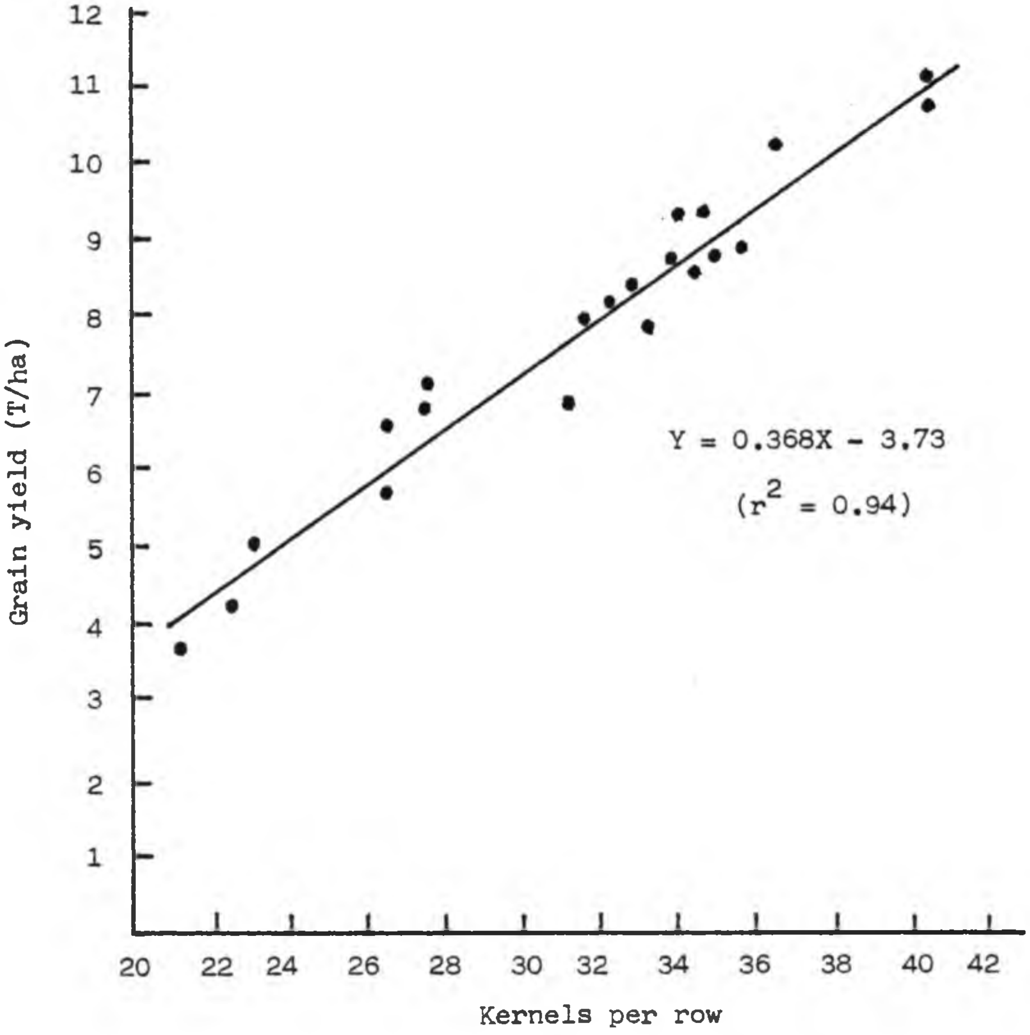

Figure 13. Relationship between kernels per row and grain yield in monthly plantings

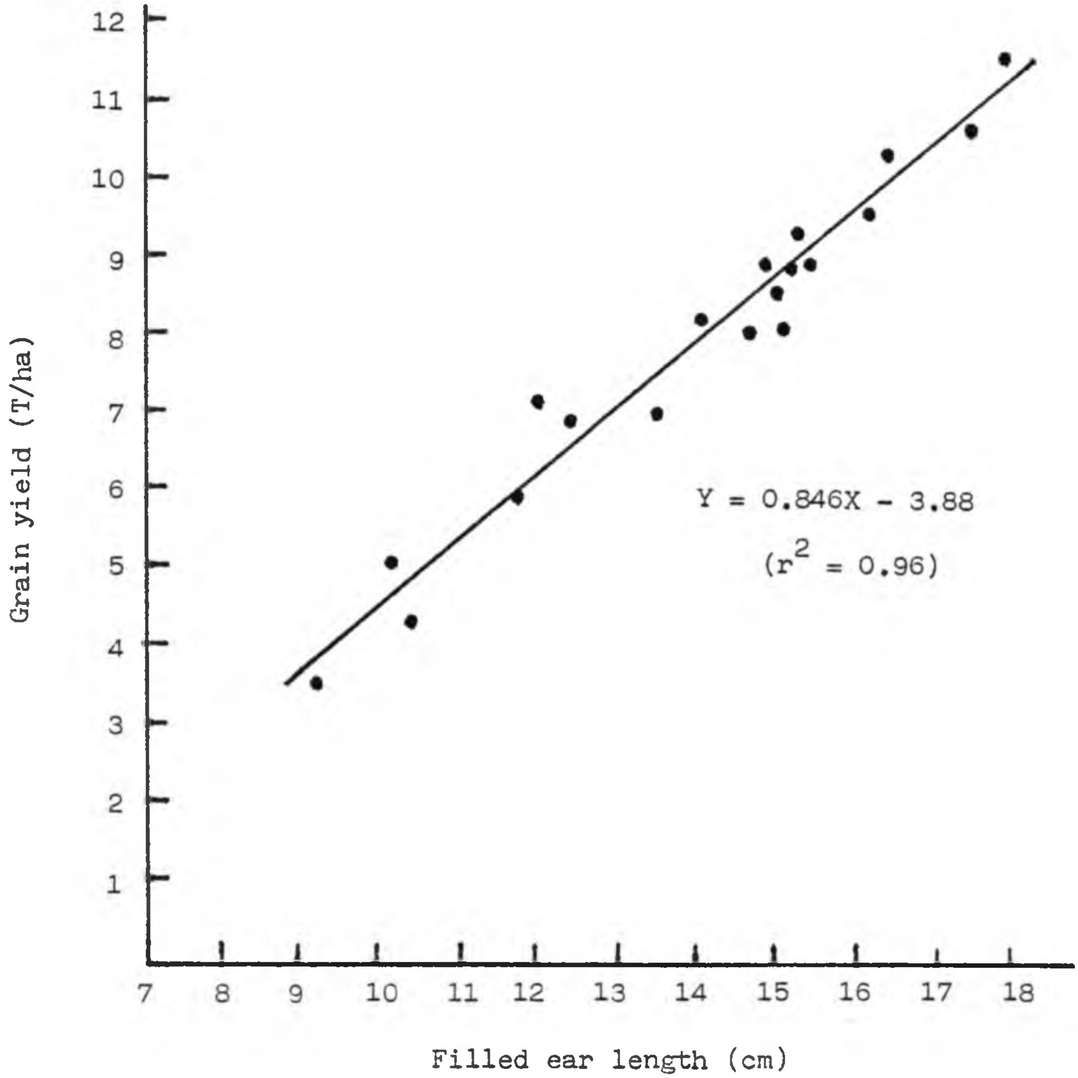

Figure 14. Relationship between filled ear length and grain yield in monthly plantings

downward trend of lines toward heavier 100 kernel weight would indicate negative correlation between kernel number and kernel size. However, the relationship between observed kernels per row and kernel weight was positive. This seemed to be a unique relationship between these two components under the seasonal environments where solar radiation is a major limiting factor for higher grain yield. When solar radiation is severely reduced as in winter, both kernel number and size may limit grain yield. The multiple regression equation (Figure 15) indicated that contribution of kernel size to grain yield was less than half of kernel number. This Figure also showed that more than 35 kernels per row and greater than 28 g per 100 kernels are necessary to insure higher than 8 T/ha of grain yield.

Although the relationships between floret number and other characters are not provided in detail, it is worthwhile to mention some of these. Floret number showed no significant correlation coefficients with any ear characters studied. Figure 16 shows how different hybrids can have similar floret number as potential kernel number but different numbers of kernels per row. Their cob length was also similar but filled ear length was quite different. B37 x B68 apparently had enough florets that could be developed to matured kernels. The gradual decrease in kernel size toward the tip end indicated that they were fertilized and assimilate accumulated for a while. B37 x B68 had poor yields in all 21 plantings, while B68 x Tx601 produced the highest grain yield in almost all plantings.

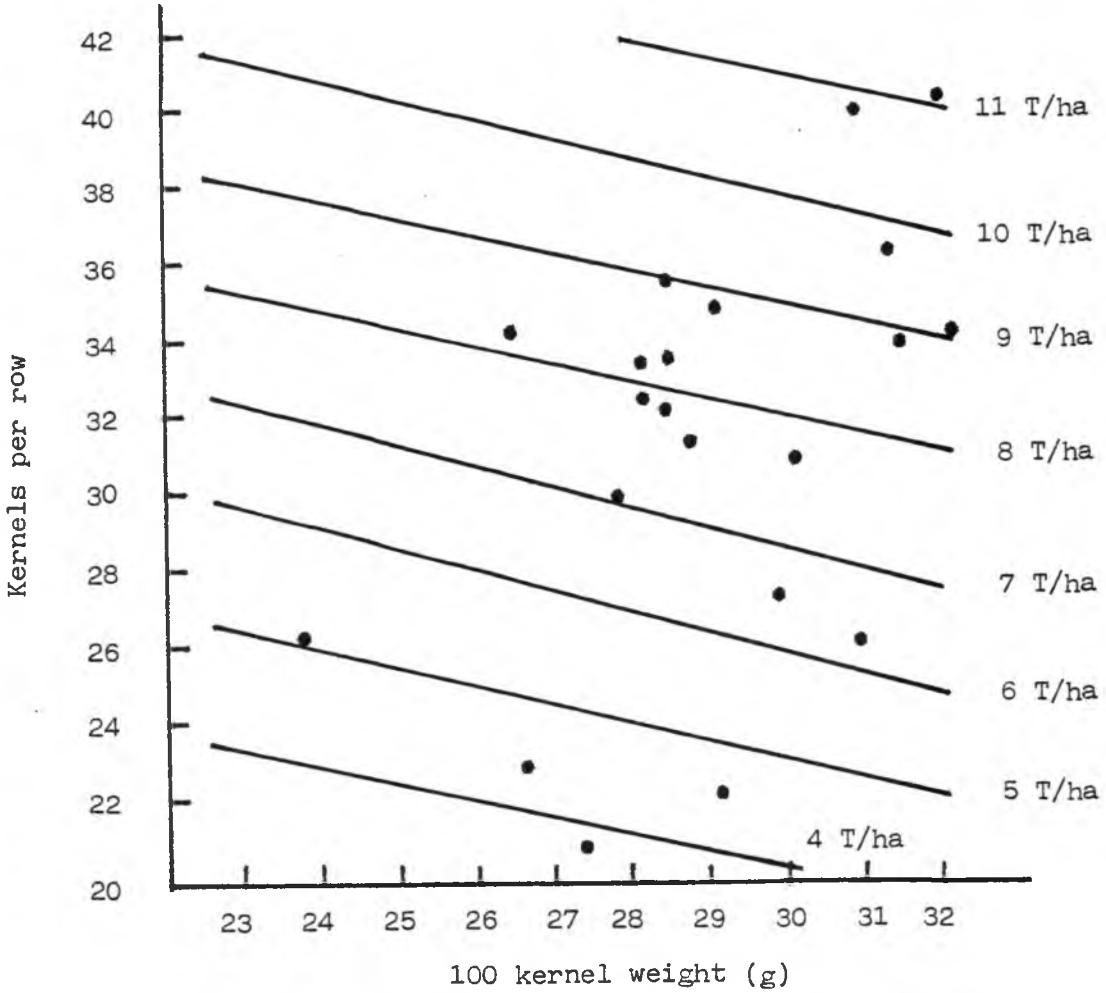

Figure 15. Response surface representing grain yield versus kernels per row and 100 kernel weight in monthly plantings (Dots are actual observed yields)

$Y = -7.72 + 0.34X_1 + 0.16X_2$

where, Y = grain yield, X_1 = kernels per row and X_2 = 100 kernel weight.

Figure 16. Ear samples of three hybrids representing different number of kernels per row and filled ear length

4.2.5 Stability estimates for kernel number, ear length and yield in seasonal environments

The effects of seasonal environments on kernel number and ear length and their relationships were discussed in preceding sections, focusing more on average response of 15 hybrids than on genotypes separately. The response of each genotype to the seasonal environments was then analyzed to determine genetic difference among inbreds. The identification of any genotype which is tolerant to light-limiting environment would be an important contribution to breeding work.

Floret number and row number did not show apparent response to seasonal environments, and kernels per ear and cob length had the same cyclic response as kernels per row and filled ear length. Therefore, only kernels per row, filled ear length and grain yield were included in the following analyses of stability parameters (Table 27). Two different indices were used in the analysis. The environmental index was calculated as a difference between the average of all hybrids of each planting and the overall mean of 21 plantings. The radiation index was based on the difference between solar radiation received during the growing periods of each planting and the overall average solar radiation.

Hybrid mean squares were highly significant when tested against pooled deviation. This confirmed previous analyses of variance. Mean squares of months for the two different indices also were extremely large reflecting the fact that variations of ear characters and grain yield were greater than those of solar radiation among 21 monthly plantings.

Table 27. Analysis of variance of stability parameters for kernels per row, filled ear length and grain yield in monthly plantings, based on data in Appendix Tables 7, 10, 14 and 16

Source	df	Mean squares		
		Kernels per row	Filled ear length	Grain yield
Hybrids (H)	14	204.43**	24.45**	10.71**
Environmental index				
Months(M) (linear)	1	9361.70**	1708.86**	1284.78**
H x M	14	11.68**	2.17**	0.76
Pooled deviation	285	3.19	0.86	0.61
Radiation index				
Months(M) (linear)	1	5683.43**	1157.22**	809.83**
H x M	14	10.40	2.19	1.09
Pooled deviation	285	16.16	2.79	2.26

** Significant at 1 % probability level.

Regression coefficients, phenotypic index which measures a deviation of each genotype mean from the overall mean, and deviation from the regressions of the 15 hybrids are summarized in Table 28. The regression coefficients ranged from 0.76 to 1.30 for kernels per row, from 0.73 to 1.33 for filled ear length and from 0.87 to 1.20 for grain yield. The temperate hybrid B37 x Oh545 had the greatest regression coefficients for both kernels per row and filled ear length. The tropical hybrid Mp68:616 x Tx601 showed the lowest regression coefficients. This indicated that B37 x Oh545 performed well under favorable conditions, while the opposite was true for Mp68:616 x Tx601. In general, temperate x temperate hybrids showed higher regression coefficients and tropical x tropical hybrids showed low regression coefficients for both kernels per row and filled ear length. Hybrids between tropical x temperate inbreds showed the intermediate values. However, regression coefficients for grain yield were almost uniformly similar.

Considering the regression coefficient and deviation from the regression, a stable genotype is a hybrid with regression coefficient of unity and small deviation. Any hybrid with a negative phenotypic index should be excluded in selecting a stable genotype since that genotype would perform poorly on the average. Since no deviations were significantly different from zero, any hybrid with larger phenotypic index and regression coefficient with near unity might be considered as to be stable one. B68 x Oh545, Mp68:616 x Oh545 and Oh545 x Tx601 were stable genotypes for kernels per row and filled ear length. B68 x Tx601 and Mp68:616 x Tx601 appeared to be stable

Table 28. Phenotypic index (PI), regression coefficient (b) and deviation from regression (s_d^2) of 15 hybrids on environmental index in monthly plantings

	Kernels per row			Filled ear length			Grain yield		
Hybrids	PI	b	s_d^2	PI	b	s_d^2	PI	b	s_d^2
B37 x B68	-4.94	1.13	2.77	-1.67	1.02	1.26	-0.94	1.06	0.61
B37 x Hi27	-5.55	0.96	1.80	-2.05	0.98	0.79	-1.33	0.91	0.43
B37 x Mp68:616	0.89	1.16	1.99	-0.34	1.02	0.47	-0.30	1.08	0.37
B37 x Oh545	-0.29	1.30	0.39	0.12	1.33	0.47	-0.78	1.03	0.47
B37 x Tx601	1.04	1.15	1.93	-0.32	0.97	0.59	0.08	1.14	0.44
B68 x Hi27	-5.98	0.99	3.20	-1.41	1.04	0.91	-0.90	0.96	0.55
B68 x Mp68:616	1.76	1.01	5.03	0.92	0.97	1.23	0.62	1.06	0.58
B68 x Oh545	0.22	1.06	4.40	5.06	1.05	1.39	0.63	0.89	0.50
B68 x Tx601	-0.16	0.86	4.03	2.29	0.89	1.00	0.82	0.95	0.64
Hi27 x Mp68:616	0.84	0.90	1.26	0.09	0.92	0.42	0.05	0.94	0.38
Hi27 x Oh545	1.98	1.17	2.01	0.78	1.17	0.39	0.42	0.94	0.21
Hi27 x Tx601	0.02	0.88	6.17	-0.48	0.85	0.72	-0.18	0b87	0.70
Mp68:616 x Oh545	3.26	1.07	2.46	1.58	1.07	1.17	0.28	0.96	1.36
Mp68:616 x Tx601	3.67	0.76	6.94	0.12	0.73	1.13	0.54	1.01	1.02
Oh545 x Tx601	3.24	1.10	3.46	1.34	1.01	0.99	0.96	1.20	0.92
Average		1.00	3.19		1.00	0.86		1.00	0.61
Pooled error M.S.			8.68			1.49			1.13

grain yield.

Figure 17, 18 and 19 illustrated the differences in stability of three hybrids and their performance in relation to the average of the test for kernels per row, filled ear length and grain yield. Figure 17 clearly showed that Hi27 x Oh545 had large number of kernels per row under favorable environments but had lower number under extremely unfavorable enviornments. B68 x Tx601 had a near unity regression coefficient and smaller number of kernels per row under favorable conditions than Hi27 x Oh545 but had larger number than the latter under unfavorable conditions. B37 x Hi27 showed uniformly poor performance for kernels per row in all environments although its regression coefficient was almost equal to unity. B68 x Tx601 would be a desirable hybrid to insure the stable performance within the range of environments tested. But if environmental conditions were optimum, Hi27 x Oh545 would be better choice.

Regression coefficients and deviations from the regression based on radiation index are presented in Table 29. Regression coefficients ranged from 0.44 to 0.76 for kernels per row, from 0.21 to 0.40 for filled ear length and from 0.18 to 0.31 for grain yield. All regression coefficients were smaller than unity, due to the different scale between environmental index and radiation index. Hybrids which had smaller deviation in regression analysis based on environmental index showed non-significant deviation in Table 29. This indicated that hybrids responded similarly to both overall environments and radiation. The regression coefficients of 15 hybrids were not significantly different from each other. Therefore, it could be concluded that 15

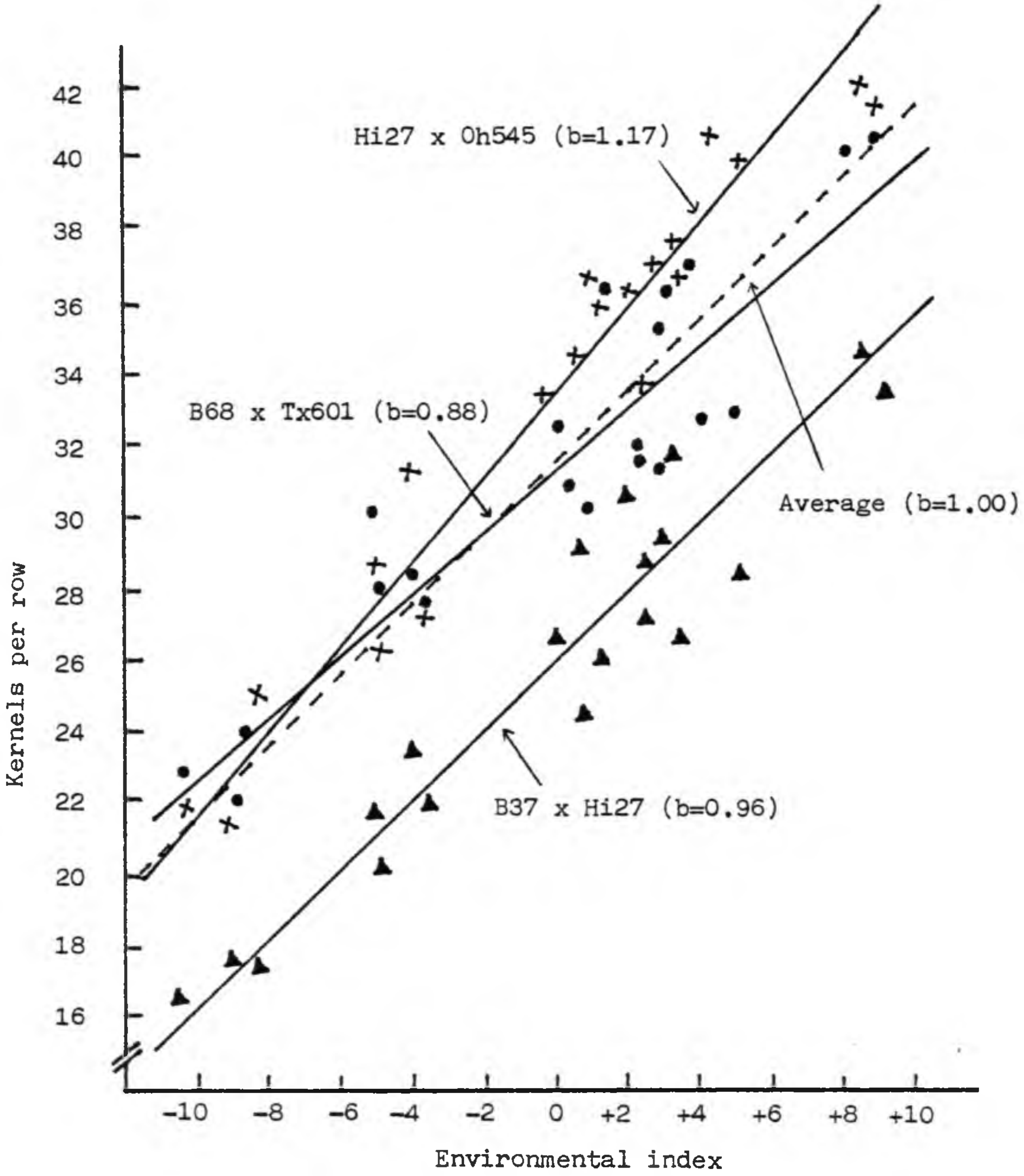

Figure 17. The response of kernels per row of three hybrids to varying environments

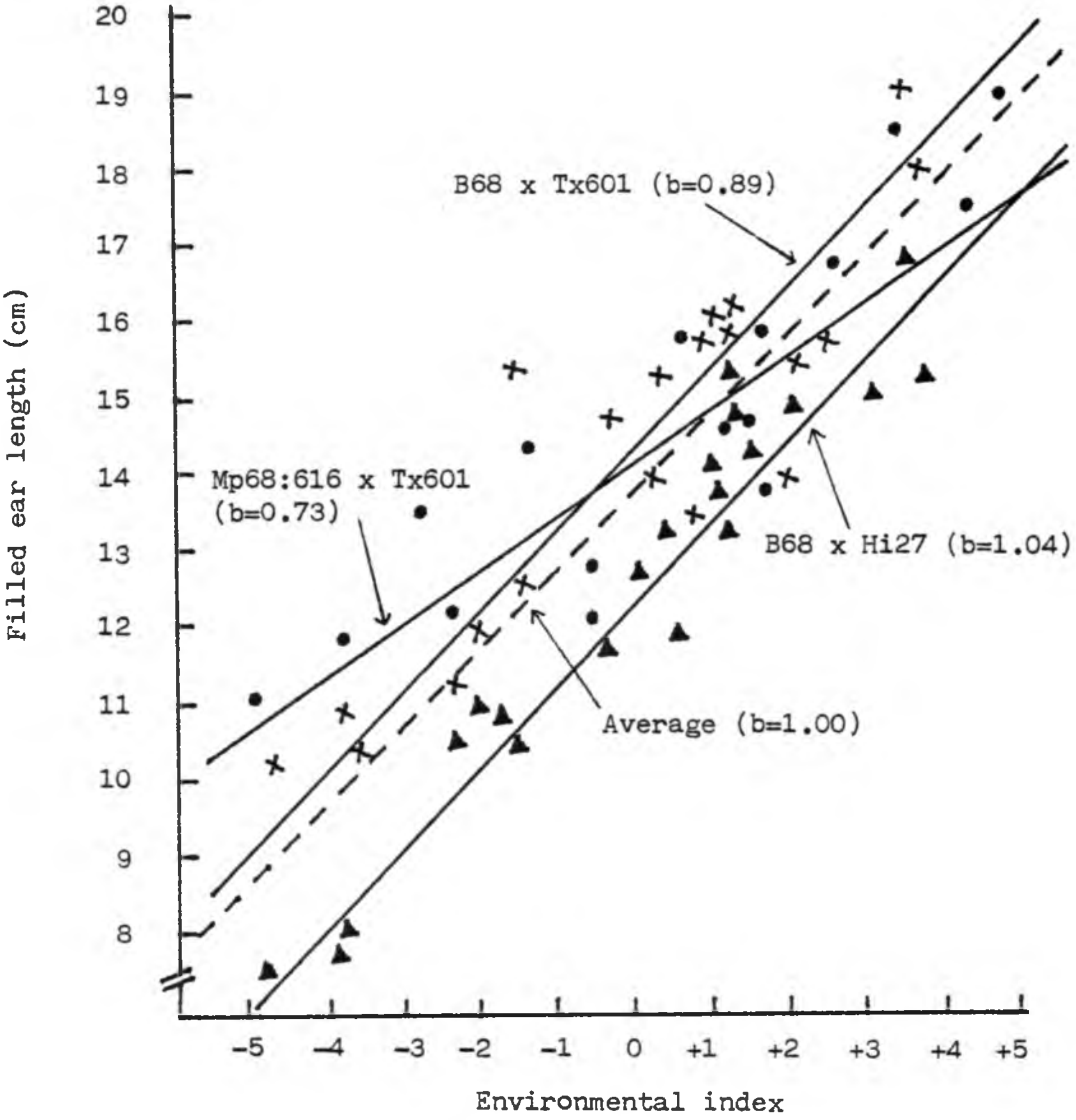

Figure 18. The response of filled ear length of three hybrids to varying environments

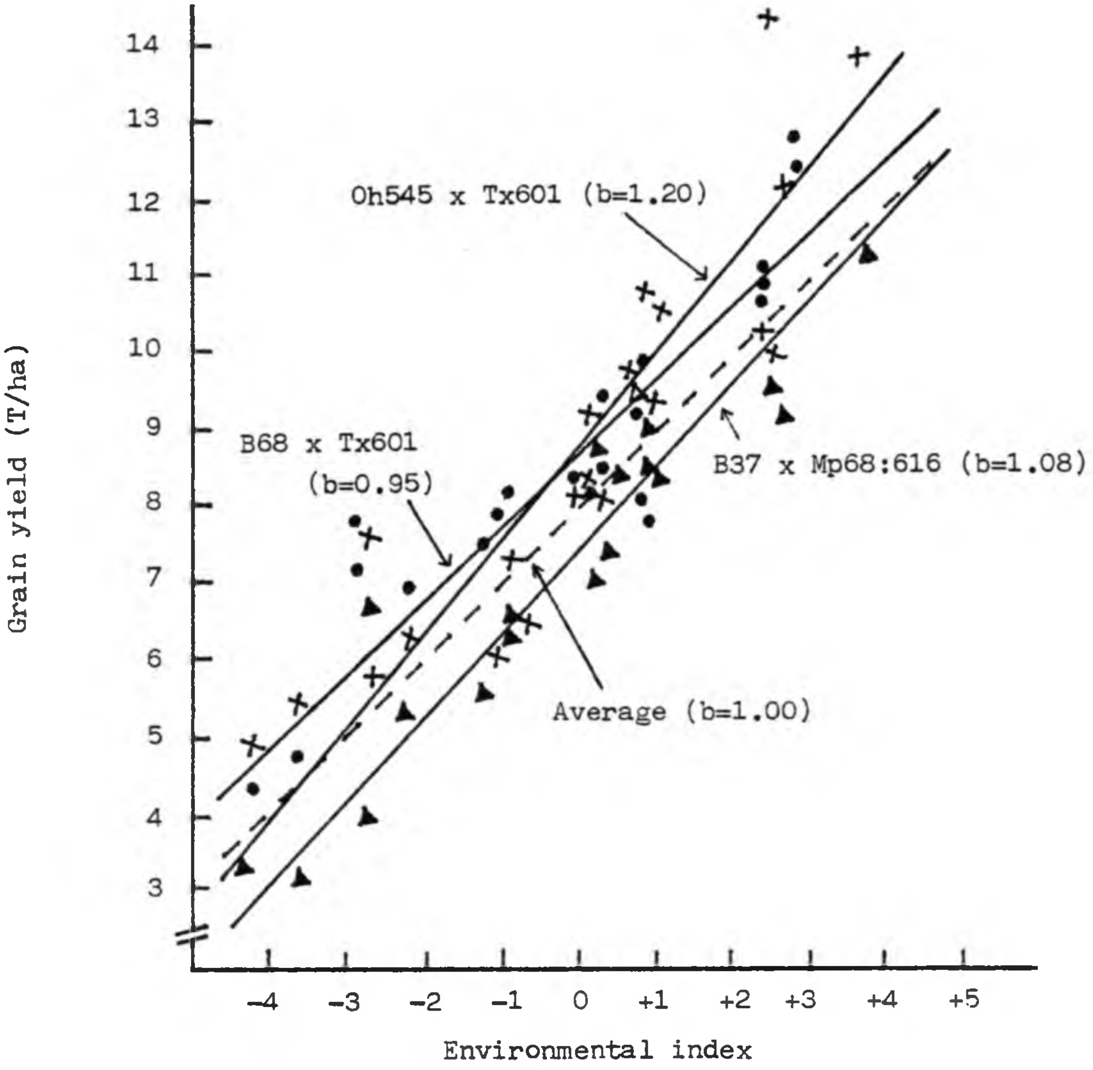

Figure 19. The response of grain yield of three hybrids to varying environments

Table 29. Regression coefficients and deviation from regression on radiation index in monthly plantings

	Kernels per row		Filled ear length		Grain yield	
Hybrids	b	s_d^2	b	s_d^2	b	s_d^2
B37 x B68	0.72	15.0*	0.29	3.03*	0.25	2.60*
B37 x Hi27	0.61	11.1	0.29	2.29	0.21	1.88
B37 x Mp68:616	0.71	17.5*	0.28	2.67*	0.25	2.46**
B37 x Oh545	0.76	22.6**	0.40	2.92*	0.25	1.94*
B37 x Tx601	0.66	20.1**	0.26	2.82*	0.26	2.84**
B68 x Hi27	0.56	17.3	0.26	3.85**	0.20	2.60**
B68 x Mp68:616	0.55	20.9**	0.25	3.52**	0.23	2.86**
B68 x Oh545	0.58	22.2**	0.25	4.80**	0.18	2.40**
B68 x Tx601	0.44	17.6*	0.24	2.78*	0.22	2.25*
Hi27 x Mp68:616	0.54	10.9	0.26	2.04	0.21	2.08*
Hi27 x Oh545	0.77	13.4	0.35	2.26	0.22	1.82
Hi27 x Tx601	0.62	10.1	0.26	1.70	0.21	1.86
Mp68:616 x Oh545	0.67	14.9*	0.32	2.99*	0.29	1.18
Mp68:616 x Tx601	0.46	14.3	0.21	2.07	0.25	2.58**
Oh545 x Tx601	0.72	13.9	0.31	2.10	0.31	2.57**
Average	0.64	16.16*	0.29	2.79*	0.24	2.26*
Pooled error M.S.		8.68		1.49		1.13

* Significant at 5 % probability level.

** Significant at 1 % probability level.

hybrids were the same in their genetic ability to respond to different radiation environments within this experiment.

Analysis of variance of stability parameters for GCA and SCA effects for kernels per row, filled ear length and grain yield are summarized in Table 30. GCA effects and SCA effects were significantly different among parental lines and 15 hybrids, respectively. The regression of GCA effects on both environmental index and radiation index was significant for kernels per row and filled ear length but not for grain yield. This suggested that GCA effects of different parental lines were not the same in their response to different environmental conditions. However, GCA effects involving grain yield were the same in their response to different environmental conditions or radiation change. The regression of SCA effects on both environmental index and radiation index was not significant for all three characters studied. This indicated that SCA effect involving kernels per row, filled ear length and grain yield were all the same in their response to both overall environments and radiation change in the 21 monthly plantings.

Estimates of GCA effects, regression coefficients and deviation from regression for 6 parental lines are presented in Table 31. B37 and Oh545 had positive regression coefficients. B68 and Hi27 had negative regression coefficients. The regression coefficients of Mp68:616 and Tx601 were negative for kernels per row and filled ear length but positive for grain yield. One interesting fact was that regression coefficients of GCA effects had both positive and negative signs, while regression coefficients of phenotypic values had positive sign only.

From the model in section 3.5.2,

Table 30. Analyses of variance of stability parameters for GCA and SCA effects for kernels per row, filled ear length and grain yield

Source	df	Mean squares		
		Kernels per row	Filled ear length	Grain yield
GCA effects				
Inbreds (I)	5	125.29**	15.07**	6.08**
Environmental index				
I x Months	5	5.81**	1.25**	0.24
Pooled deviation	114	1.63	0.28	0.21
Radiation index	5	5.01*	1.19*	0.46
I x Months	114	1.67	0.28	0.30
SCA effects				
Hybrids (H)	14	24.05**	2.85**	2.00**
Environmental index				
H x Months	14	2.84	0.35	0.41
Pooled deviation	285	2.22	0.44	0.29
Radiation index				
H x Months	14	3.23	0.49	0.44
Pooled deviation	285	2.20	0.44	0.29

* Significant at 5 % probability level.

** Significant at 1 % probability level.

Table 31. Estimates of GCA effects, regression coefficients and deviation from regression for 6 inbreds

	Kernels per row			Filled ear length			Grain yield		
Inbreds	GCA	b	s_d^2	GCA	b.	s_d^2	GCA	b	s_d^2
B37	-2.21	0.13	1.44	-1.07	0.07	0.29	-0.82	0.05	0.21
B68	-2.28	-0.03	1.75	-0.21	-0.01	0.37	0.06	-0.02	0.22
Hi27	-2.17	-0.07	1.23	-0.77	-0.01	0.18	-0.48	-0.09	0.27
Mp68:616	2.61	-0.07	2.21	0.59	-0.07	0.40	0.30	0.01	0.15
Oh545	2.10	0.13	1.04	1.78	0.16	0.14	0.38	0.00	0.17
Tx601	1.96	-0.10	1.98	0.29	-0.14	0.27	0.56	0.04	0.27
Pooled error M.S.			4.35			0.75			0.56

$$Y_{ijk} = m + g_i + g_j + s_{ij} + e_k + (b_{g_i} + b_{g_j} + b_{s_{ij}})I_k + d_{ijk} ,$$

$(b_{g_i} + b_{g_j} + b_{s_{ij}})$ represents the genetic response to particular environment and would contribute to the stability of a particular genotype. When environmental index I_k is negative, i.e. unfavorable, negative regression coefficients of GCA and SCA effects would result in enhanced effect on Y_{ijk} and vice versa. Therefore, inbred Hi27 which showed all negative regression coefficients for three characters would respond better under unfavorable conditions and increase stability for the portion controlled by additive genes. On the other had, additive genes of B37 and Oh545 would contribute more to these characters under favorable environments but less under unfavorable conditions.

When signs of regression coefficients for GCA and SCE effects and regression coefficients representing stability were compared for the three characters studied (Table 32), the contribution of GCA effects on stability became clear. Hybrids between two inbreds which had negative regression coefficients showed regression coefficients smaller than unity, while hybrids between two inbreds with positive regression coefficients showed regression coefficients greater than unity. This relationship clearly indicated that interaction of GCA effects expressed as regression coefficients was an important factor contributing to stability of a particurar genotype.

Analysis of variance for joint combining ability and regression analysis for kernels per row, filled ear length and grain yield are given in Tables 33 and 34. These two tables are identical in their

Table 32. Signs of regression coefficients of GCA and SCA effects and relative stability (regression coefficients) for kernels per row, filled ear length and grain yield

Hybrids	Kernels per row				Filled ear length				Grain yield			
	b_{g_i}	b_{g_j}	$b_{s_{ij}}$	b	b_{g_i}	b_{g_j}	$b_{s_{ij}}$	b	b_{g_i}	b_{g_j}	$b_{s_{ij}}$	b
B37 x B68	+	−	−	1.13	+	−	−	1.02	+	−	+	1.06
B37 x Hi27	+	−	−	0.96	+	−	−	0.98	+	−	−	0.91
B37 x Mp68:616	+	−	+	1.16	+	−	+	1.02	+	+	+	1.08
B37 x Oh545	+	+	+	1.30	+	+	+	1.33	+	+	−	1.03
B37 x Tx601	+	−	+	1.15	+	−	+	0.97	+	+	+	1.14
B68 x Hi27	−	−	+	0.99	−	−	+	1.04	−	−	+	0.96
B68 x Mp68:616	−	−	+	1.01	−	−	+	0.97	−	+	+	1.06
B68 x Oh545	−	+	−	1.06	−	+	−	1.05	−	+	−	0.89
B68 x Tx601	−	−	−	0.88	−	−	+	0.89	−	+	−	0.95
Hi27 x Mp68:616	−	−	+	0.90	−	−	+	0.92	−	+	+	0.94
Hi27 x Oh545	−	+	+	1.17	−	+	+	1.17	−	+	+	0.94
Hi27 x Tx601	−	−	+	0.88	−	−	−	0.85	−	+	−	0.87
Mp68:616 x Oh545	−	+	−	1.07	−	+	−	1.07	+	+	−	0.96
Mp68:616 x Tx601	−	−	−	0.76	−	−	−	0.73	+	+	−	1.01
Oh545 x Tx601	+	−	+	1.10	+	−	−	1.01	+	+	+	1.20

Table 33. Analyses of variance for joint combining ability and regression analysis of kernels per row, filled ear length and grain yield on environmental index

Source	df	Mean squares		
		Kernels per row	Filled ear length	Grain yield
Environments (E)	20	446.03	85.20	64.04
Genotypes (G)	14	204.50**	24.50**	10.72**
GCA	5	510.78**	60.85**	24.36**
SCA	9	34.34**	4.31**	3.13**
G x E	280	5.38*	1.00*	0.68
GCA x E	100	8.07**	1.47**	1.02**
Slope of g_i	5	25.43*	5.02*	0.97
Residual	95	7.15	1.29	1.02
SCA x E	180	3.89	0.74	0.49
Slope of s_{ij}	9	4.05	0.54	0.64
Residual	171	3.88	0.75	0.48
Pooled residual	266	2.98	0.97	0.67
Average error	294	4.34	0.75	0.56

* Significant at 5 % probability level.

** Significant at 1 % probability level.

Table 34. Analyses of variance for joint combining ability and regression analysis of kernels per row, filled ear length and grain yield on radiation index

Source	df	Mean squares Kernels per row	Filled ear length	Grain yield
Environments (E)	20	446.03	85.20	64.04
Genotypes (G)	14	204.50**	24.50**	10.72**
GCA	5	510.78**	60.85**	24.36**
SCA	9	34.34**	4.31**	3.13**
G x E	280	5.38*	1.00*	0.68
GCA x E	100	8.07**	1.47**	1.02**
Slope of g_i	5	20.05**	4.77**	1.83*
Residual	95	7.44	1.30	0.97
SCA x E	180	3.89	0.74	0.49
Slope of s_{ij}	9	5.02	0.76	0.68
Residual	171	3.83	0.94	0.48
Pooled error	266	5.12	0.94	0.65
Average error	294	4.34	0.75	0.56

* Significant at 5 % probability level.

** Significant at 1 % probability level.

basic format except that Table 33 was based on environmental index and Table 34 was based on radiation index. Therefore, only the mean squares of slope of g_i, slope of s_{ij} and their residuals were different. In Table 33, mean squares of slope of g_i were significant for kernels per row and filled ear length, but mean square of slope of g_i for grain yield was not significant. Mean squares of all three GCA effects were highly significant. Since mean squares of slope of g_i was a partition of GCA x month interaction mean squares, this indicated that hybrid x month interaction was basically due to the linear response of GCA effects on environments. Mean squares of slope of s_{ij} were not significant in both Tables. This indicated that non-additive effects were constant over the environments for the three characters studied, while additive genes responded significantly in their expression to different environments. The magnitude of mean squares for the slope of combining ability effects on radiation index was almost the same in two Tables. Therefore, it could be concluded that the response of GCA effects to environments was basically response of GCA effects on radiation change in 21 monthly plantings.

4.2.6 Discussion

Seasonal changes of climatic conditions in the tropics, especially rainfall and/or solar radiation, limit year-round production of corn. Yield levels of corn in the tropics are known to be disappointingly low due to those limitations (Milbourn, 1977). Genetic information on possible tolerance to these environmental stresses would allow corn breeders to develop better hybrids in the tropics. Monthly plantings of corn hybrids of a diallel set in Hawaii served to screen the best period of the year in which corn could be produced with high yields as well as to identify any genetic systems working on environmental stress, especially solar radiation, since irrigation was applied in the field experiments.

In this experiment, days to mid-silking were greater in the winter months than in the summer. The 15 hybrids tested were single crosses involving temperate x temperate, temperate x tropical and tropical x tropical inbreds. Even though the hybrids were made up of different adaptation groups, their trends are more or less the same in the seasonal environments. Similar conclusions were obtained by Lee (1978). The fact that flowering occurred early in the long days of summer and late in the short days of winter indicates that temperature is the major determinant of days to flowering for corn in the subtropics. However, daylength may have contributed to the slight modification of days to mid-silking in summer for daylength sensitive genotypes.

The longer days to mid-silking in winter has significant importance for grain yield of corn. As growth rate of corn plants is slow due to low temperature in winter, more total solar radiation is beign received by corn plants. The increase in total solar radiation promotes a higher yield than would be expected in many instances of low daily solar radiation during winter months. Corn in high altitude tropical locations associated with low temperature also results in high grain yield. This high yield is mainly due to long growing period in which long ears with more kernels per row were developed (Cuany et al., 1969; Grobman et al., 1962). Results of monthly plantings in the present study suggested that the high yield in high altitudes results from higher accumulated solar radiation due to a longer growing period. Lee (1978) concluded that temperature was the main factor determining days to mid-silking, considering the fact that solar radiation, day-length and temperature are closely correlated climatic factors.

Combining ability analyses indicated the relative signficance of GCA and SCA effects for floret number, cob length, filled ear length, row number, kernels per row, kernels per ear, 100 kernel weight and grain yield. The GCA/SCA ratios were greater than unity in all cases, suggesting that additive genes are predominant in the genetic variations for all characters.

The additive genes were not stable in their expression for all the characters studied except row number, while non-additive genes were quite stable in their expression for all the characters studied except floret number and 100 kernel weight as indicated by the highly significant GCA x month and non-significant SCA x month interactions. Eberhart and Russell (1966, 1969) reported that the additive genes were the primary cause of the genotype-environment interactions for their diallel crosses. Lin et al. (1977) also concluded that the additive genes are more important from the point of view of adaptation and non-additive genes remained constant over environments. Lee (1978) tested a diallel set in different seasons in Hawaii and concluded that the GCA was more important than SCA for grain yield and yield components.

Among inbreds tested in diallel crosses, Mp68:616, Oh545 and Tx6C1 have good combining ability for almost all characters studied, while B37 and Hi27 have poor combining ability for nearly all characters.

There are some indications that hybrids of temperate x tropical inbreds performed better on an average in all seasonal environments. The fact that B37 and B68 showed positive GCA effect for floret number and negative GCA effect for kernels per row, while Mp68:616 had negative GCA effect for floret number and positive GCA effect for kernels per row indicated that different systems may be involved in control of kernel number and floret number. B68 and Tx601 indicated the same aspect for ear length by their different sign for GCA effects of cob length and filled ear length.

Studies on effect of climatic factors on corn yield in temperate regions usually lead to the conclusions that rainfall and temperature, but not solar radiation, as being the most important limiting factors (Shaw, 1977). This is an expected conclusion since corn plants pass through long summer days with high irradiance. In the tropics where long rainy season limits solar radiation, grain yield is more affected by available solar radiation than other climatic factors (Lee, 1978; Evans and De Datta, 1979). In this study, kernel number, ear length and grain yield were found to follow the cyclic change of solar radiation. Asymptotic regression analysis as well as linear regression analysis revealed that kernel number, ear length and grain yield are more sensitive to available solar radiation in winter months when solar radiation level is low. Kernels per row, ear length and grain yield were influenced principally by the 3rd month solar radiation, followed by that of the 2nd month. Considering the fact that kernels per row and ear length are determined during early 3rd month and grain yield is highly correlated with kernels per ear and ear length, this was quite reasonable.

The increase of kernel number, ear length and grain yield for January and February plantings due to the prolonged growing period and thus more total solar radiation suggested possible ways of increasing grain yield in winter seasons. One way is to increase planting density in winter and the other way is to produce hybrids with longer growing period in winter. Percentage light interception for corn hybrids increased from 89.4 % to 96.7 % by increasing plant population from 40,000 plants/ha to 80,000 plants/ha at 40^{o} N latitude in the Corn Belt (Mock, 1977). On the assumption that these values will be similar at 20^{o} N latitude, this increase of solar radiation interception by 7 % at 250 $cal \cdot cm^{-2} \cdot day^{-1}$ level would result in grain yield increase by 2.29 T/ha according to the asymptotic equation in Figure 12. A longer growing and grain-filling period, by 5 days in winter months when solar radiation is around 250 $cal \cdot cm^{-2} \cdot day^{-1}$, would bring 2.72 T/ha increase of grain yield.

Evans and De Datta (1979) also reported that yields of rice in monthly plantings over 10 years were most significantly correlated with irradiance during both reproductive and ripening stages of the crop. But they obtained higher correlations for crops grown under high irradiance and lower correlations for crops grown during the wet season, probably because of pest and disease problems. Regardless of whether irradiance was rising or falling progressively, high irradiance at any stage after panicle initiation was associated with higher yields in all varieties tested. Despite the different photosynthetic systems in rice and corn, their response to solar radiation seems to be strikingly similar under seasonal environments.

Floret number was relatively unaffected by the environmental conditions in the present study. This indicated that a sink limitation for higher grain yield may not exist. Unless additional information is available to answer the reason for preventing complete development of florets, the conclusion that the sink is the main limiting factor for higher grain yield of corn needs more detailed examination. The effect of environmental conditions on kernel number suggested a major limiting role of assimilate supply under the environment with light stress. Bingham (1971) reported that at least half of the florets initiated failed during the period of rapid stem growth before the grain has set in winter wheat. The information is insufficient to decide if this failure is due simply to there being insufficient time for complete development, to competition from other organs for assimilates, or to hormonal effects within ear. However, Bingham (1971) suggested that the increase of ear size to increased sink strength of the developing ear was a potentially better way improving yield in winter wheat. Similar conclusions were obtained between corn grain yield and sink relationships. Grain sink size is adjusted to the source size of the plant during the flowering period by abortion of initiated ear during presilking and silking, and by ceasation of growth of fertilized florets during the first 20 days postsilking (Nishikawa and Kudo, 1973). Yamaguchi (1974) and Goldsworthy (1974) demonstrated that differences in grain yield were accounted for mainly by differences in kernel number. However, Tollenaar and Daynard (1977) found a high correlation between kernel number and grain yield even though a source limitation was present. Therefore, the relationship between grain yield and kernel number may not reflect limitation in storage as suggested by Yamaguchi (1974) and Goldsworthy (1974), but may be rather a sensitive adjustment of floret number and kernel number by the plant to environmental conditions during the early post-silking period (Tollenaar, 1977). Egharevba et al. (1976) reported that grain test weight was relatively unaffected when plants were defoliated at 10 days post-silking and later. It is possible that genotypes which adjusted kernel number at an early stage of kernel development to the potential capacity of the plants to fill the kernels were selected in search for higher test weight.

In the present study, the heterogeneity among regressions was significant but the pooled deviations were not significantly different from zero when stability was analyzed based on environmental index. Therefore, the regression coefficient was suggested to be an important parameter for the final selection of genotypes. When stability was analyzed based on radiation index, it appeared that both regression coefficients and deviations from regression should be considered in the final analysis of genotypes. Radiation index can be considered as an independent measure of environments not based on average performance of tested materials. Radiation index increased deviation mean squares in the stability analysis. However, radiation index represents only one of many environmental factors which affect corn growth. If any environmental index, which represent all environmental factors could be estimated, regression coefficients and deviations from regression would be identical for both indices (environmental index based on average performance of tested materials and environmental index based on physical measurement of various environmental factors). The beta response method proposed by Nor and Cady (1979) should be useful if several environmental factors can be measured independently from crop growth. But the effects of environmental factors may be confounded together and this will also create difficulty in interpretation of results. Solar radiation was here shown to be as the single most important environmental factor, explaining a major portion of the variation of the traits analyzed in different environments.

Both GCA and SCA effects were important in the inheritance of ear characters, and grain yield, and former was of much greater importance. Interaction (GCA x month and SCA x month) also contributed significant variation, indicating the importance of multi-environment testing. For regression estimates, mean squares due to GCA were much larger than those due to SCA; while mean squares due to GCA and SCA for deviation did not differ significantly. A predominance of additive effects in inheritance of linear response was obtained by Eberhart and Russell (1966, 1969) and Hallauer (1972). Both additive and non-additive effects were involved in inheritance of deviation from regression (Eberhart and Russell, 1969).

GCA effects of inbreds B68, Hi27, Mp68:616 and Tx601 produced negative regression coefficients for kernels per row and filled ear length in the stability analyses. The sign and the regression coefficient indicated the relative contribution of the additive genetic component in the inheritance of stability parameters. Combined diallel analyses and regression analyses showed the relative importance of GCA and SCA effects in stability analysis. Inbreds Hi27 and Mp68:616 appeared as two parental lines which enhanced stability in their hybrids while B37 and Oh545 were parental lines that contributed better response to favorable environments. It is interesting that tropical inbreds showed greater contribution to stability than temperate inbreds among the materials studied. This may be due to the greater variations in the tropics where corn needed greater stability in the way of evolution.

The presence of a substantial proportion of variability due to the additive genetic component in the inheritance of stability parameter suggested that it should be possible to exploit this fraction of variability in developing high-yielding, stable hybrids. Such an approach should be feasible through intra-population improvement programs involving multi-environment testing. The nonsignificant SCA interactions with environments for several ear characters and yield also indicated that a selection scheme such as mass selection should be effective in changing those traits studied.

4.3 Effects of geographic environments on kernel number and ear length

4.3.1 Response of corn plants to geographic environments

A 10-entry diallel set, involving 5 tropical inbreds and 5 temperate inbreds, was tested at 6 different locations in tropical and temperate regions, i.e. 3 locations in Hawaii (Waimanalo, Kamuela and Kapaa); Ames, Iowa; CIAT, Cali, Colombia; Suweon, Korea. Three plantings were made in different seasons at Waimanalo and one planting was made at each of the other locations. A randomized complete block design with 3 replications was used for all plantings.

Average daily solar radiation, mean temperature and average daylength during the period of corn growth at different locations are given in Appendix 26. Corn plants experienced higher solar radiation in plantings at Waimanalo-3 and Ames, while corn plants for Waimanalo-2 (winter planting) passed through the lowest solar radiation condition among 8 plantings. Average temperature during the growing period of corn plants at Waimanalo-2, Kamuela and Ames was lower than that of other locations. Daylength at Ames and Suweon was longer than 14 hours, while daylength for Waimanalo-2 planting was about 11 hours.

Mean, minimum and maximum numbers of days to mid-silking, plant height and ear height at different locations are summarized in Table 35. Number of days to mid-silking varied from 52 days at Waimanalo-1 to 88 days at Ames. The difference in number of days to mid-silking between the earliest and the latest hybrids ranged from less than 10 days at Waimanalo, Kapaa and CIAT to about 30 days at Ames. Corn plants at Kamuela flowered much later than those at other places in Hawaii, and

Table 35. Mean, minimum and maximum values of plant characters over 45 hybrids at different locations

Characters	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	CIAT	Suweon
Date of planting	7/26 '77	11/26 '77	5/15 '79	8/4 '77	8/25 '77	5/15 '78	3/31 '78	5/29 '78
Days to mid-silking								
Mean	51.7	60.2	53.0	81.8	61.5	88.0	61.0	80.9
Minimum	47.3	57.0	49.7	70.7	56.0	77.1	57.0	72.9
Maximum	55.7	64.5	58.3	92.7	65.3	105.3	66.0	87.9
Plant height (cm)								
Mean	276	201	260	237	204	316	268	172
Minimum	247	179	235	207	179	281	248	147
Maximum	310	228	293	272	222	359	305	207
Ear height (cm)								
Mean	121	77	112	119	132	147	101	84
Minimum	86	64	79	86	105	97	83	55
Maximum	159	95	148	161	156	212	124	107

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

this was due to the lower temperature during the growing period at the higher elevations. Corn plants at Kamuela, Ames and Suweon, which experienced lower temperatures and/or longer daylength at the early stages of growth, showed the longer growing period before silking. In general, hybrids involving temperate inbreds showed a smaller range in the number of days to mid-silking, while hybrids involving daylength sensitive tropical inbreds (i.e. Tx601) showed the greatest difference in number of days to mid-silking at different locations. However, only mean temperature showed a significant correlation with number of days to mid-silking ($r = -0.697^*$). As mean temperature decrease 1° C, number of days to mid-silking increased about 4 days, which was similar to the result in monthly plantings (Section 4.2.1).

Average plant height ranged from 172 cm at Suweon to taller than 300 cm at Ames. The shorter plant height at Suweon was due to drought stress at the early stage of growth. Plant heights at tropical locations ranged from about 200 cm at Waimanalo-2 (winter planting) and Kapaa to 276 cm at Waimanalo-1 (summer planting).

Combined analyses of variance for days to mid-silking, plant height and ear height are given in Table 36. Since the test of homogeneity of error variances was highly significant, unweighted and weighted tests for the interaction were conducted following Cochran (1954). The interaction mean squares of hybrids x locations for plant characters were highly significant in all three methods of analysis, except for plant height in the unweighted analysis. In general, the weighted analysis showed greater F-values than the conventional method of combined analysis. These results indicated that the number of

Table 36. Combined analyses of variances for days to mid-silking, plant height and ear height of a 10-entry diallel evaluated at different locations

	Days to mid-silking		Plant height		Ear height	
Source	df	m.s.	df	m.s.	df	m.s.
Locations (L)	5	31287.8	5	2674.2	4	1087.1
Reps. in L	12	23.0	12	22.8	10	21.3
Hybrids (H)	44	161.2**	44	27.8**	44	28.9**
H x L	220	17.9**	220	3.2**	176	2.8**
Error (b)	528	5.1	528	1.6	440	0.6
<u>Unweighted</u>						
Interaction	1.2	232.2**	2.3	0.3	1.7	8.1**
Error	109.9	5.1	210.5	1.9	156.5	0.6
<u>Weighted</u>						
Interaction	5	577.3**	5	14780.3**	4	14511.3**
Error	235.7	5.1	242.0	5.1	209.4	4.0

** Significant at 1 % probability level.

days to mid-silking, plant height and ear height of different hybrids responded differently at different locations. When considering the fact that 45 hybrids were produced among parental lines with differing daylength sensitivities and that the effects of temperature and daylength were confounded at different locations, the highly significant interaction was predictable.

4.3.2 Combining ability estimates of kernel number and ear length in geographic environments

Analysis of variance was conducted for all the ear characters that determine kernel number and ear length, except in the plantings at CIAT and Suweon where no data on ear characters were measured. The results of each individual analysis of variance are summarized in Appendix 30. Hybrids were highly significantly different at all locations for floret number per row, kernels per row, cob length, filled ear length and row number. Combined analyses of variance of the ear characters studied are given in Table 37. The differences among hybrids were highly significant for all characters. The hybrid x location interaction was also highly significant for all characters except cob length. Since the homogeneity tests of error variances appeared to be significant (Appendix 31), the interaction effects were separately tested following Cochran (1954). Unweighted analysis resulted in non-significant interactions for cob length and filled ear length. However, all characters except row number showed significant interactions in weighted analysis. Since unweighted analysis is usually insensitive in detecting the presence of interaction, the

Table 37. Combined analyses of variance for the ear characters of a 10-entry diallel evaluated at different locations

	Floret number		Kernels per row		Cob length	
Source	df	m.s.	df	m.s.	df	m.s.
Locations (L)	3	6328.0	5	2442.9	4	387.3
Reps. in L	8	45.5	12	33.5	10	3.4
Hybrids (H)	44	116.7**	44	135.1**	44	10.2**
H x L	132	22.8**	220	14.9**	176	0.9
Error (b)	352	9.3	528	7.2	440	0.8
<u>Unweighted</u>						
Interaction	1.6	22.3	0.6	17.9	3.8	2.8**
Error	147.1	9.3	305.3	7.1	345.8	0.8
<u>Weighted</u>						
Interaction	3	10.3*	5	13.1*	4	13.9**
Error	192.6	3.0	245.4	5.1	219.6	4.0

(Continued)

	Filled ear length		Row number		Kernels per ear	
Source	df	m.s.	df	m.s.	df	m.s.
Locations (L)	5	899.9	5	19.0	5	693366
Reps. in L	12	6.8	12	1.2	12	9676
Hybrids (H)	44	11.3**	44	9.1**	44	19760**
H x L	220	2.4**	220	0.7**	220	4235**
Error (b)	528	1.1	528	0.5	528	2078
<u>Unweighted</u>						
Interaction	4.4	6.6**	4.4	0.4	2.2	5175
Error	446.0	1.1	352.1	0.5	200.4	2078
<u>Weighted</u>						
Interaction	5	29.1**	5	3.0	5	207.4*
Error	245.6	5.1	272.5	6.1	244.9	5.1

* Significant at 5 % probability level.

** Significant at 1 % probability level.

results of the weighted analysis should be considered to be more reliable. These results indicated that most ear characters of the 45 hybrids showed differential response at the different locations, except in the case of row number. This result will be discussed in more detail in the next section.

Combining ability analyses (Griffing, 1956) were carried out for all the ear characters (Appendix 40). GCA and SCA effects for floret number, row number and kernels per ear were highly significant or significant at all locations, except for row number at Waimanalo-2 which was winter planting. The GCA effect was significant at all locations for all other characters. However, the SCA effect was significant only for kernels per row, cob length and filled ear length in those locations providing less favorable environments. These results indicated that the hybrids which made full use of the non-additive genes for expression of these characters were not same under different environmental conditions. GCA mean squares for all the ear characters were greater than SCA mean squares at all locations. The additive gene effects were more important for all the characters studied at all locations.

Combined analyses of combining abilities for the ear characters are summarized in Table 38. GCA, SCA and GCA x location interaction mean squares were highly significant for all the characters. The SCA x location interaction mean square was significant for floret number, row number and kernels per ear. However, considering the non-significant hybrid x location interaction effect in weighted analysis (Table 37), GCA x location and SCA x location interaction mean squares for

Table 38. Combined analyses of combining ability for the ear characters studied for a 10-entry diallel evaluated at different locations

	Floret number		Kernels per row		Cob length	
Source	df	m.s.	df	m.s.	df	m.s.
GCA	9	155.35**	9	179.81**	9	12.29**
SCA	35	9.23**	35	10.78**	35	1.10**
GCA x L	27	18.35**	45	13.01**	36	1.73**
SCA x L	105	4.72**	175	2.84	140	0.35
Error	352	3.10	528	2.40	440	0.28

(Continued)

	Filled ear length		Row number		Kernels per ear	
Source	df	m.s.	df	m.s.	df	m.s.
GCA	9	13.60**	9	11.69**	9	18853**
SCA	35	1.26**	35	0.81**	35	3511**
GCA x L	45	2.14**	45	0.32**	45	3324**
SCA x L	175	0.44	175	0.20*	175	909*
Error	528	0.37	528	0.15	528	693

*Significant at 5 % probability level.

**Significant at 1 % probability level.

row number should probably not be considered significant. The smaller GCA x location and SCA x location mean squares, in comparison to the SCA mean square, also supported this. For all characters except kernels per ear, the GCA x location mean square was greater than the SCA mean square. This indicated that the GCA effects were more important in the expression of these ear characters. The smaller GCA x location mean square for kernels per ear simply reflected the effect of row number on kernels per ear, since kernels per ear was computed by multiplying kernels per row by row number. The combined analysis also suggested the importance of additive gene effects on the expression of these characters.

GCA effects for floret number, kernels per row and filled ear length and their mean values, which are GCA estimates in combined analysis, are presented in Tables 39 and 40. CI21E, Mo17 and Tx601 showed generally positive and high GCA effects for floret number and kernels per row, indicating that they were good combiners for these characters at all locations. B37 and B68 were also good combiners for floret number at most of the locations. Inbreds Hi27, CM105 and Mp68: 616, which are all tropical material, were poor combiners for floret number at all locations, while inbreds B68, Hi27 and CM105 were poor combiners for kernels per row at all locations. Inbred B68, as noted in the monthly plantings, was a good combiner for floret number but a poor one for kernels per row. Tropical inbreds CM105 and CM111 seemed to show a higher GCA effect for kernels per row at locations which could be considered unfavorable environments, while temperate inbreds CI21E and Oh545 were better under favorable conditions. Although a

Table 39. Estimates of GCA effect for floret number of 10 inbreds at different locations

Inbreds	Waimanalo-3	Ames	CIAT	Suweon	Mean
B37	1.17	4.05	-0.82	-1.51	0.72
B68	-0.54	0.68	1.81	0.45	0.60
CI21E	0.42	1.68	2.48	1.99	1.64
Hi27	-4.25	-6.32	-2.69	-2.84	-4.03
CM105	-1.42	-2.03	-0.44	-0.93	-1.20
CM111	-1.37	-2.74	0.64	-0.34	-0.95
Mo17	2.63	2.34	-0.03	1.62	1.64
Mp68:616	-0.54	-3.07	-3.11	-2.43	-2.29
Oh545	1.75	2.05	-2.53	-0.05	0.31
Tx601	2.17	3.38	4.68	4.03	3.57
S.E. $(g_i - g_j)$	0.49	0.58	0.46	1.58	

Table 40. Estimates of GCA effect for kernels per row of 10 inbreds at different locations

Inbreds	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
B37	-1.58	-2.68	-1.44	0.63	-1.85	3.55	-0.56
B68	-2.99	-3.32	-2.76	-0.96	-3.41	-0.84	-2.38
CI21E	1.55	1.02	2.16	0.31	1.90	3.52	1.74
Hi27	-3.88	-2.92	-3.61	-2.84	-3.03	-4.43	-3.45
CM105	-0.54	0.74	-1.23	-0.02	-0.31	-3.66	-0.84
CM111	-0.57	0.92	-0.20	0.56	0.85	-1.21	0.06
Mo17	3.83	3.04	3.81	2.56	2.80	2.03	3.01
Mp68:616	1.38	1.41	0.50	0.45	1.29	-1.56	0.58
Oh545	0.54	-0.71	1.46	-0.73	1.14	2.32	0.67
Tx601	2.31	2.51	1.31	0.06	0.63	0.28	1.18
S.E. $(g_i - g_j)$	0.48	0.39	0.37	0.55	0.70	1.07	

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[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

significant GCA x location interaction indicated that care should be taken in interpreting the results in combined analysis, estimates of GCA effects in combined analysis (mean GCA effects in the Tables) showed certain inbreds to be superior over several locations tested. Although tropical inbred Tx601 appeared to be the best combiner for floret number at all locations, temperate inbreds were, in general, better combiners for both floret number and kernels per row. Temperate inbreds Mo17 and CI21E were the best combiners for kernels per row among the parental lines tested.

Estimates of GCA effect for cob length and filled ear length showed a trend similar to floret number and kernels per row, respectively (Tables 41 and 42). Temperate inbreds B68, Mo17 and Oh545 were the best combiners for cob length, while all tropical inbreds that tend to be highly prolific appeared to be poor combiners for this character. Mo17 and Oh545 were also good combiners for filled ear length at all locations. B68 was a good combiner for cob length, but had negative GCA effect for filled ear length. This result was expected since GCA effect of B68 for kernels per row was also negative at all locations. Tropical inbreds Hi27, CM105, CM111 and Tx601 appeared to be poor combiners for cob length and filled ear length in most of the environments tested.

Inbreds B37, Mo17 and Oh545 had negative GCA effects for row number, indicating that these inbreds are poor combiners for row number (Table 43). B68, Hi27 and CM105 appeared to be good combiners for this character at all locations. For the character of kernels per ear, CI21E and Tx601 were the best combiners among 10 inbreds, while

Table 41. Estimates of GCA effects for cob length of 10 inbreds at different locations

Inbreds	W-1[a]	W-2	W-3	Kamuela	Kapaa	Mean
B37	-0.78	-1.44	-0.28	0.54	-0.81	-0.55
B68	0.62	0.08	0.14	0.65	0.47	0.39
CI21E	0.14	-0.33	0.12	-0.50	-0.13	-0.14
Hi27	-1.52	-0.75	-1.06	-0.04	-0.42	-0.76
CM105	-0.18	-.30	-0.56	-0.17	-0.13	-0.15
CM111	-0.90	-0.05	-0.43	-0.29	-0.37	-0.41
Mo17	1.28	1.06	1.10	0.40	0.72	0.91
Mp68:616	0.01	0.21	-0.39	0.12	-0.01	-0.01
Oh545	1.36	0.63	1.48	-0.22	0.84	0.82
Tx601	-0.02	0.30	-0.13	-0.47	-0.17	-0.10
S.E.(g_i-g_j)	0.07	0.05	0.07	0.08	0.07	

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

Table 42. Estimates of GCA effects for filled ear length of 10 inbreds at different locations

Inbreds	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
B37	-0.81	-1.31	-0.91	0.79	-0.44	0.55	-0.36
B68	-0.31	-0.57	-0.27	0.43	-0.34	0.87	-0.03
CI21E	0.37	-0.38	0.61	-0.27	0.27	-0.05	0.09
Hi27	-1.61	-0.71	-1.15	-0.66	-0.68	-1.38	-1.03
CM105	0.00	0.53	-0.45	-0.17	-0.09	-0.66	-0.14
CM111	-0.65	0.15	-0.17	0.03	-0.08	-0.85	-0.26
Mo17	1.33	0.93	1.19	0.44	0.54	0.42	0.81
Mp68:616	0.41	0.62	-0.05	0.08	0.31	-0.25	0.18
Oh545	1.04	0.39	1.06	-0.34	0.80	1.47	0.74
Tx601	0.24	0.37	0.15	-0.33	-0.30	-0.12	0.00
S.E.(g_i-g_j)	0.08	0.05	0.09	0.10	0.12	0.11	

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

B37, B68 and Hi27 were poor combiners (Table 44). Although Mo17 and Oh545 were the good combiners for kernels per row, they were not very good combiners for kernels per ear, as were CI21E and Tx601, because of their lower row number. On the other hand, inbred CM105 was not a good combiner for kernels per row, but it appeared to be a good combiner for kernels per ear with more row number which contributed to a higher number of kernels per ear. This result indicated that not only kernels per row but also row number was significant in the determination of kernel number per ear.

Although number of ears per plant contributes to kernel number, number of ears per plant of 45 hybrids in most of the plantings at different locations was not significantly different. Second ears were seldom observed in Waimanalo plantings under current planting density. Number of ears per 100 plants of 45 hybrids at Ames and Kamuela is shown in Appendix 44. Corn plants at Ames showed great differences in number of ears per 100 plants ranging from 90 to 157. Planting density at Ames was much lower than that at other locations. However, there was no significant difference among hybrids at Kamuela. Therefore, number of ears per plant did not significantly contribute to kernel number in most of the plantings.

SCA effects of 45 crosses at all locations were also estimated. Since SCA x location interactions were non-significant or relatively small comparing to GCA effects and GCA x location interactions, only estimates of SCA effects in combined analysis are given in Appendix 41. Crosses B37 x CM111, B37 x Mp68:616, B68 x CM111, CI21E x Hi27, CI21E x CM105, Hi27 x Mp68:616 and Mo17 x Tx601 showed high SCA effects

Table 43. Estimates of GCA effects for row number of 10 inbreds at different locations

Inbreds	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Suweon	Mean
B37	-0.52	-0.61	-0.75	-0.48	-0.74	-0.49	-0.61	-0.60
B68	0.19	0.18	0.49	0.23	0.31	0.20	0.21	0.27
CI21E	-0.42	-0.21	-0.15	-.16	-0.04	0.11	0.04	-0.09
Hi27	0.64	0.66	0.77	0.16	0.78	0.93	0.60	0.65
CM105	0.92	0.74	0.73	0.96	0.86	0.28	0.59	0.75
CM111	-0.20	0.14	-0.24	0.30	-0.05	-0.14	-0.30	-0.03
Mo17	-0.92	-0.82	-0.88	-0.84	-0.74	-0.94	-0.74	-0.85
Mp68:616	0.28	-0.08	0.00	-0.19	-0.34	0.33	-0.50	0.00
Oh545	-0.12	-0.10	-0.12	-0.09	-0.21	-0.20	-0.57	-0.14
Tx601	0.16	0.10	0.15	-0.18	0.17	-0.09	1.28	0.05
S.E.(g_i-g_j)	0.03	0.03	0.02	0.04	0.05	0.04	0.08	

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

Table 44. Estimates of GCA effects for kernels per ear of 10 inbreds at different locations

Inbreds	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
B37	-40.2	-55.0	-47.4	-8.3	-46.3	30.6	-27.7
B68	-36.0	-42.2	-20.1	-4.2	-39.9	-3.8	-24.4
CI21E	8.2	8.3	25.5	10.1	25.7	57.5	22.6
Hi27	-34.8	-20.7	-22.5	-35.4	-20.9	-31.7	-27.6
CM105	23.9	32.5	9.6	34.5	22.8	-42.2	13.5
CM111	-16.2	16.7	-11.4	18.8	13.1	-23.5	-0.4
Mo17	21.3	16.5	18.5	4.3	13.9	-8.6	11.0
Mp68:616	29.4	17.4	7.3	-0.4	7.6	-9.8	8.6
Oh545	5.0	-11.5	16.1	-13.9	8.1	29.0	5.5
Tx601	39.6	38.1	24.6	-5.4	15.9	2.5	19.2
S.E.(g_i-g_j)	7.3	6.3	6.9	8.4	8.8	13.2	

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

for all ear characters studied. On the other hand, crosses B37 x Hi27, B68 x Hi27, CI21E x Mo17, CI21E x Tx601, CM105 x CM111, CM111 x Mo17, CM111 x Mp68:616 and Mp68:616 x Tx601 showed low SCA effects for all ear characters.

4.3.3 Response of kernel number and ear length to geographic environments

Mean, minimum and maximum values of all the ear characters at different locations are given in Table 45. Floret number per row varied from 42 at Waimanalo-2 (winter planting) to 58 at Ames. Waimanalo in winter could be considered as the worst environment, having low solar radiation, while the Ames planting had the best environment of a long growing period, high solar radiation and wide spacing. The difference between the hybrids with the smallest and highest floret number per row at any of the four locations was about the same as the difference in average floret number between the two plantings at Waimanalo-2 and Ames. This indicated that the difference between the highest and the smallest hybrids in floret number at any location was of the same magnitide regardless the environmental conditions. The average difference in floret number in the 3 locations, not including Ames, was less than four florets per row. Considering the longer growing period before silking at Ames and Suweon, during which time floret number was determined, the increase in floret number was very small. A small variation in floret number was also observed in monthly plantings.

The relative number of kernels per row in different locations was

Table 45. Mean, minimum and maximum values of the ear characters over 45 hybrids at different locations

Characters	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	CIAT	Suweon
Floret number								
Mean		42.0	48.6			58.2	47.8	51.6
Minimum		32.5	41.3			51.0	40.3	42.3
Maximum		53.5	55.0			67.0	56.3	59.7
Kernels per row								
Mean	34.7	30.0	38.7	35.7	30.9	40.8		
Minimum	23.9	20.3	30.4	28.8	22.4	29.9		
Maximum	41.9	36.8	44.9	41.3	36.7	47.8		
Cob length (cm)								
Mean	17.3	15.0	18.8	16.9	14.8			
Minimum	14.0	12.3	16.5	14.3	12.2			
Maximum	19.9	16.9	22.6	18.4	16.2			
Filled ear length (cm)								
Mean	15.2	13.1	17.0	15.1	12.8	19.7		
Minimum	11.7	9.9	14.4	12.9	10.5	17.5		
Maximum	17.4	15.0	20.3	17.2	15.5	22.3		
Row number								
Mean	14.4	13.9	14.2	14.2	14.3	15.0		13.0
Minimum	12.6	12.0	12.7	12.3	12.2	13.4		11.2
Maximum	15.9	15.2	16.0	15.7	15.7	16.7		16.5
Kernels per ear								
Mean	499	416	550	508	440	613		
Minimum	346	287	445	428	352	510		
Maximum	598	508	611	586	532	732		

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[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

the same as floret number in corresponding locations. It was also noted that all florets developed were not matured into kernels in the temperate area (Ames) as they did not in the tropics, although comparable data were obtained at only three locations. No cob length was measured in the Ames planting, and thus the ratio of filled ear length to cob length in the Ames planting was not available for comparison with that in the tropics. The ratio of filled ear length to cob length was about 88 %, an average of 5 plantings in Hawaii. Row number in the Ames planting (planting density was 39,000 plants/ha) was a little higher. This higher row number, as well as higher kernels per row, in the Ames planting contributed to a greater number of kernels per ear. However, the comparison between the Ames and Hawaii plantings was not straight-forward since the planting densities were different.

Average number of kernels per row and average filled ear length of the parental lines of a 10-entry diallel set at each location were graphed (Figures 20 and 21). Although these Figures show the same trends as GCA effects in Tables 40 and 42, they demonstrate the genetic effects of each parental line more clearly. Hybrids of inbred lines B68 and Hi27 had lower kernels per row than average at all locations, while hybrids of CI21E, Mo17 and Tx601 had higher kernel number per row at all locations. In general, hybrids of temperate inbreds had higher number of kernels per row under temperate conditions (Kamuela and Ames - although Kamuela is located in Hawaii, its longer gorwing period and lower average temperature during the early growth period provided the corn plants with an environment similar to that of a temperate area). Hybrids of CI21E at Kamuela showed an above average kernels per row,

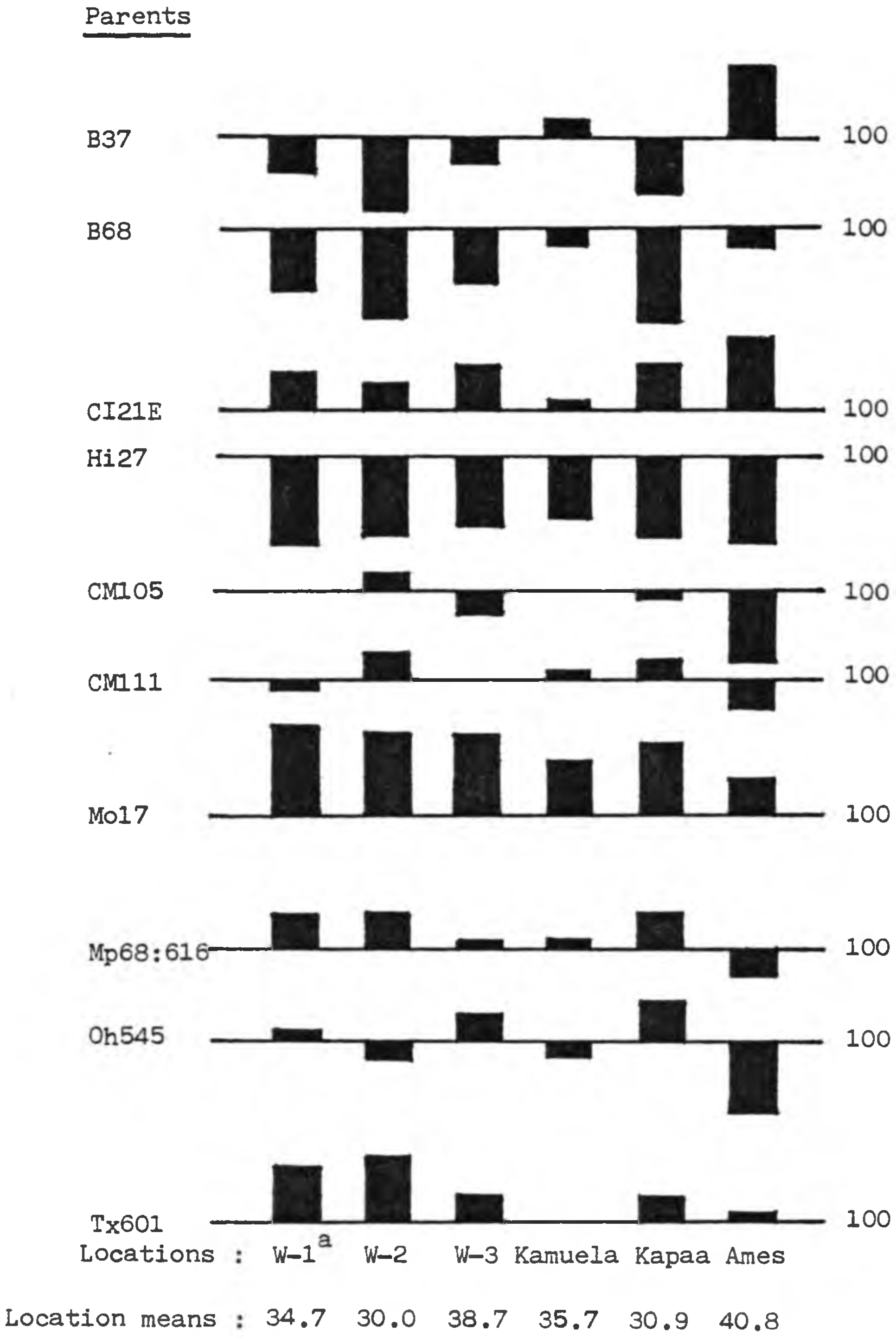

Figure 20. Average kernels per row of hybrids in a 10-entry diallel set evaluated at different locations, as percentage of location means (100 %)

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

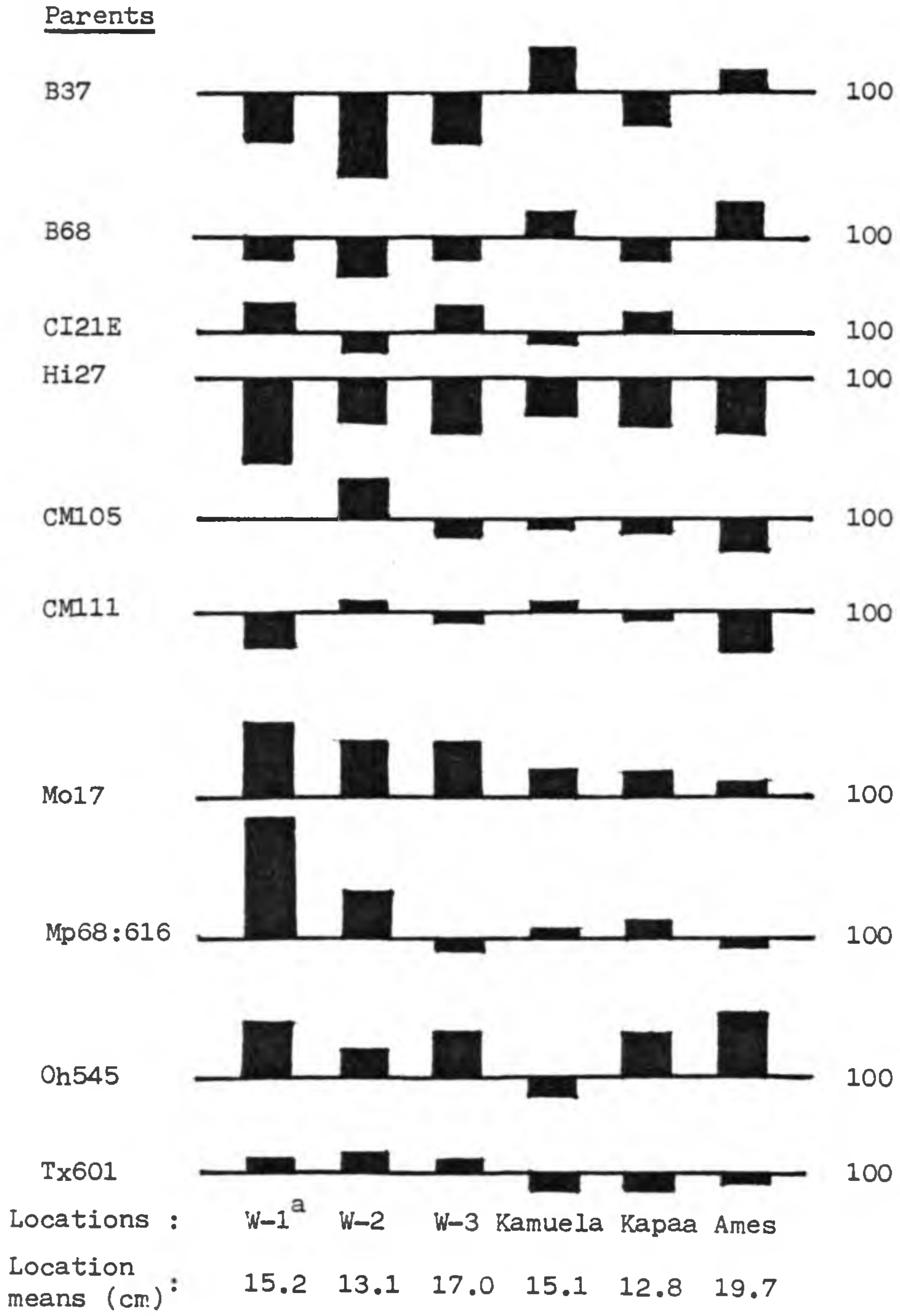

Figure 21. Average filled ear length of hybrids in a 10-entry diallel evaluated at different locations, as percentage of location means (100 %)

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

but it was lower than in other plantings. This appeared to be due to susceptibility to leaf blight (Appendix 44). Hybrids of tropical inbreds showed a higher average number of kernels per row under unfavorable conditions like Waimanalo-2 and Kapaa.

A similar trend was observed for filled ear length. Hybrids of Hi27 had a shorter filled ear length on the average, while hybrids of Mo17 showed a longer filled ear length over all locations. For both characters, hybrids of CM105 and CM111 showed less variation than other hybrids. The response of each hybrid at different locations will be discussed in more detail in a later section on stability.

Average kernels per row and average filled ear length of 45 hybrids over several locations are summarized in Table 46. Mo17 x Tx601 had the highest number of kernels per row. Hybrids B37 x CI21E, B37 x Tx601, CI21E x CM105, CM105 x Mo17, CM111 x Mo17, CM111 x Oh545, CM111 x Tx601, Mo17 x Oh545 and Mp68:616 x Oh545 had more than 37 kernels per row, while B68 x Hi27 had less than 30 kernels per row. Hybrid Mo17 x Oh545 had the longest filled ear length, followed by B37 x Mo17, B68 x Mp68:616, Mp68:616 x Oh545, Mo17 x Mp68:616, Mo17 x Tx601 and Oh545 x Tx601. Hybrids B37 x B68, B37 x CM105, Hi27 x CM105, Hi27 x CM111, Hi27 x Mp68:616 and Hi27 x Tx601 had the shortest filled ear length on the average. For both characters at all locations, one of the hybrids of inbred Mo17 and Oh545 showed the highest number of kernels per row or the longest filled ear length. On the other hand, B68 x Hi27 had the smallest number of kernels per row and the shortest filled ear length in almost all locations. Although significant hybrid x location interactions indicated the need for careful interpretation of results

Table 46. Average number of kernels per row and filled ear length in cm of a 10-entry diallel set evaluated over several locations

Inbreds	B68	CI21E	Hi27	CM105	CM111	Mo17	Mp68:616	Oh545	Tx601	Array mean
B37	31.6[a] 14.8	37.3 15.3	30.1 13.5	33.7 14.9	35.9 15.1	38.1 16.4	35.9 15.6	33.3 16.0	36.0 15.2	34.7 15.2
B68		35.6 15.8	27.0 13.5	32.3 15.7	33.6 15.7	34.0 16.5	35.7 16.5	33.1 15.8	34.4 15.6	33.0 15.6
CI21E			33.8 15.2	37.5 15.6	36.5 15.1	39.0 16.1	37.4 15.8	36.7 16.0	36.4 15.3	36.7 15.6
Hi27				30.4 14.4	31.6 14.2	35.5 15.8	32.4 14.9	35.5 15.7	32.4 14.0	32.1 14.6
CM105					33.3 15.0	37.5 15.7	35.2 15.3	33.0 15.5	36.8 16.1	34.4 15.4
CM111						37.9 15.9	33.7 14.7	37.0 16.0	37.3 15.5	35.2 15.2
Mo17							38.9 16.5	38.5 17.3	40.9 16.4	37.8 16.3
Mp68:616								37.3 16.6	34.3 15.0	35.6 15.7
Oh545									37.2 16.4	35.7 16.1
Tx601										36.2 15.5

[a] Upper and lower values are number of kernels per row and filled ear length, respectively.

BLSD (0.05) : Kernels per row = 1.58, Filled ear length = 0.63.

Table 47. Combined analyses of variance for 100 kernel weight and grain yield of a 10-entry diallel evaluated at different locations

	100 kernel weight		Grain yield	
Source	df	m.s.	df	m.s.
Locations (L)	5	776.8	6	522.3
Reps. in L	12	20.4	14	8.9
Hybrids (H)	44	51.3**	44	6.5**
H x L	220	16.8**	264	3.0**
Error (b)	528	6.4	616	1.2
<u>Unweighted</u>				
Interaction	3.6	5.7	4.7	3.9**
Error	37.4	6.4	463.1	1.2
<u>Weighted</u>				
Interaction	5	7.2	6	18.6**
Error	245.0	5.1	273.1	6.1

** Significant at 1 % probability level.

in different locations, the average values in Table 46 showed the general performance of each hybrid over several locations, with a few exceptions.

The hybrids between inbreds with higher number of kernels per row, and more rows per ear produced higher number of kernels per ear (Appendix 35). CI21E x CM105 had the highest number of kernels per ear, followed by Mo17 x Tx601 and Oh545 x Tx601. Inbreds CI21E and Tx601 had the highest number of kernels per ear on the average. Hybrids CI21E x CM105 and Mo17 x Tx601 had the highest number of kernels per ear among 45 hybrids in almost all locations, while hybrid B68 x Hi27 had the lowest number of kernels per ear in all locations, as expected from their GCA effects for kernels per row and row number.

4.3.4 Relationship between kernel number and ear length and yield in geographic environments

Analyses of variance were conducted for 100 kernel weight and grain yield for each planting at different locations (Appendix 30). Hybrids were significantly different for 100 kernel weight and grain yield for all plantings, except for 100 kernel weight at the Waimaoalo-2. Combined analyses of variance showed that hybrids were significantly different for 100 kernel weights and grain yield as they were for individual plantings (Table 47). Although hybrid x location interaction was highly significant for 100 kernel weight, the weighted analysis for interaction was not significant. This indicated that 100 kernel weight was relatively stable from location to location. On the other hand, hybrid x location interaction for grain yield was highly significant, and this indicated that hybrids responded differently from location to location for grain yield. This result agreed well with the significant interaction for kernel number and ear length in the earlier section of this chapter. The stable 100 kernel weight or kernel size suggested that grain yield variation was basically due to variation in kernel number under different environments.

Analysis of combining ability (Griffing, 1956) for 100 kernel weight and grain yield showed that GCA effects were highly significant at all locations. But SCA effects were significant at Waimanalo-2 and -3 and Kapaa plantings for 100 kernel weight and at Waimanalo-2, Kapaa, Ames and CIAT plantings for grain yield (Appendix 40). Combined analysis of combining ability (Table 48) showed that all GCA, SCA, GCA x location interaction and SCA x location interaction effects were highly significant for 100 kernel weight, and all but SCA x location were significant for grain yield. The relative magnitude of GCA and GCA x location interaction mean squares were greater than SCA and SCA x location interaction mean squares. This indicated that additive genes and their interaction with locations were more important in the expression of 100 kernel weight and grain yield. Although the non-additive gene effect contributed significantly to the expression of these characters, their relative importance was small. The significant interaction mean squares indicated that additive gene effect for both 100 kernel weight and grain yield and non-additive gene effect for 100 kernel weight were not stable in different environments.

Inbreds B37 and B68 were good combiners for 100 kernel weight while Mp68:616, Mo17 and CI21E were found to be poor combiners for

Table 48. Combined analyses of combining ability for 100 kernel weight and grain yield of a 10-diallel evaluated at different locations

	100 kernel weight		Grain yield	
Source	df	m.s.	df	m.s.
GCA	9	64.49**	9	3.96**
SCA	35	4.98**	35	1.72**
GCA x L	45	15.14**	54	2.98**
SCA x L	175	3.07**	210	0.48
Error	528	2.12	616	0.40

** Significant at 1 % probability level.

this character (Table 49). Tropical inbreds Tx601, CM105 and CM111 were, on the average, good combiners for grain yield (Table 50). Although Oh545 and Mo17 were good combiners for kernels per row and filled ear length, they were poor combiners for grain yield. This was mainly due to the low row number of hybrids of these inbreds. Among temperate inbreds, CI21E was a good combiner for better yield. Crosses B68 x Tx601, Hi27 x CM105 and B37 x CM105 showed high SCA effects for 100 kernel weight, while B68 x CM111, CI21E x Hi27 and Oh545 x Tx601 had high SCA effects for grain yield.

Average grain yields of parental lines are graphed in Figure 22. Hybrids of tropical inbreds CM105 and Tx601 showed higher than average grain yield in all locations except Ames. On the other hand, hybrids of temperate inbreds CI21E, B37, B68, Mo17 and Oh545 showed higher grain yield than that of tropical x tropical hybrids (Appendix 39). Hybrids of temperate inbreds generally performed poorly under tropical conditions. Hybrids of Hi27 showed higher grain yield in the CIAT planting. Hybrids of Hi27 were more resistant to *Puccinia polysora* rust than other hybrids (Appendix 43). Since Hi27 is originally from Colombia, its hybrids might be better adapted to CIAT environment. Hybrids of Hi27 were poor at all locations except CIAT. Hybrids B68 x CM111 and CM111 x Tx601 gave the highest average grain yield among the 45 hybrids tested in 7 plantings, followed by B37 x CM105, B68 x Mp68:616, B68 x Tx601 and Oh545 x Tx601, while hybrids B37 x B68 and B37 x Hi27 performed poorly on the average (Table 51). Grain yield of 45 hybrids in different locations are presented in Appendix 39.

Correlation coefficients between grain yield and plant and ear

Table 49. Estimates of GCA effects for 100 kernel weight of 10 inbreds at different locations

Inbreds	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
B37	-0.60	-0.34	2.32	3.16	2.64	2.34	1.59
B68	1.33	3.83	1.72	2.15	2.85	2.33	2.37
CI21E	0.73	-2.46	1.78	-2.18	-1.91	0.61	-0.57
Hi27	0.61	0.79	-2.04	0.37	1.44	-1.95	-0.13
CM105	-0.50	1.88	-0.73	-1b80	0.65	1.20	0.12
CM111	-0.39	-0.59	-0.48	0.34	0.21	-1.43	-0.39
Mo17	-1.10	-2.22	0.34	-0.61	-0.58	-0.48	-0.78
Mp68:616	0.10	-1.23	-1.45	-1.37	-3.72	-1.14	-1.47
Oh545	-0.49	-0.20	-0.33	-0.64	-2.07	1.96	-0.29
Tx601	0.32	0.56	-1.13	0.59	0.50	-3.45	-0.43
S.E.(g_i-g_j)	0.45	0.30	0.31	0.79	0.61	0.71	

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

Table 50. Estimates of GCA effects for grain yield of 10 inbreds at different locations

Inbreds	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	CIAT	Mean
B37	-9.98	-0.96	-0.47	1.33	0.01	0.58	-0.64	-0.16
B68	-0.09	0.10	-0.18	0.47	0.01	0.38	-0.39	0.04
CI21E	0.43	-0.49	1.18	-0.61	0.05	1.00	-0.47	0.16
Hi27	-0.61	-0.25	-1.08	-0.55	-0.11	-1.03	1.36	-0.32
CM105	0.73	1.18	0.05	-0.01	0.59	-0.67	0.47	0.33
CM111	-0.14	0.05	-0.05	0.51	0.47	-0.28	1.13	0.24
Mo17	0.27	-0.29	0.43	-0.09	0.14	0.i3	-0.19	0.06
Mp68:616	-0.04	0.05	-0.29	-0.68	-0.96	-0.35	-0.01	-0.33
Oh545	-0.01	-0.37	0.00	-0.63	-0.53	0.57	-1.27	-0.32
Tx601	0.45	0.97	0.42	0.25	0.33	-0.32	0.01	0.30
S.E.(g_i-g_j)	0.08	0.06	0.12	0.15	0.09	0.08	0.12	

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

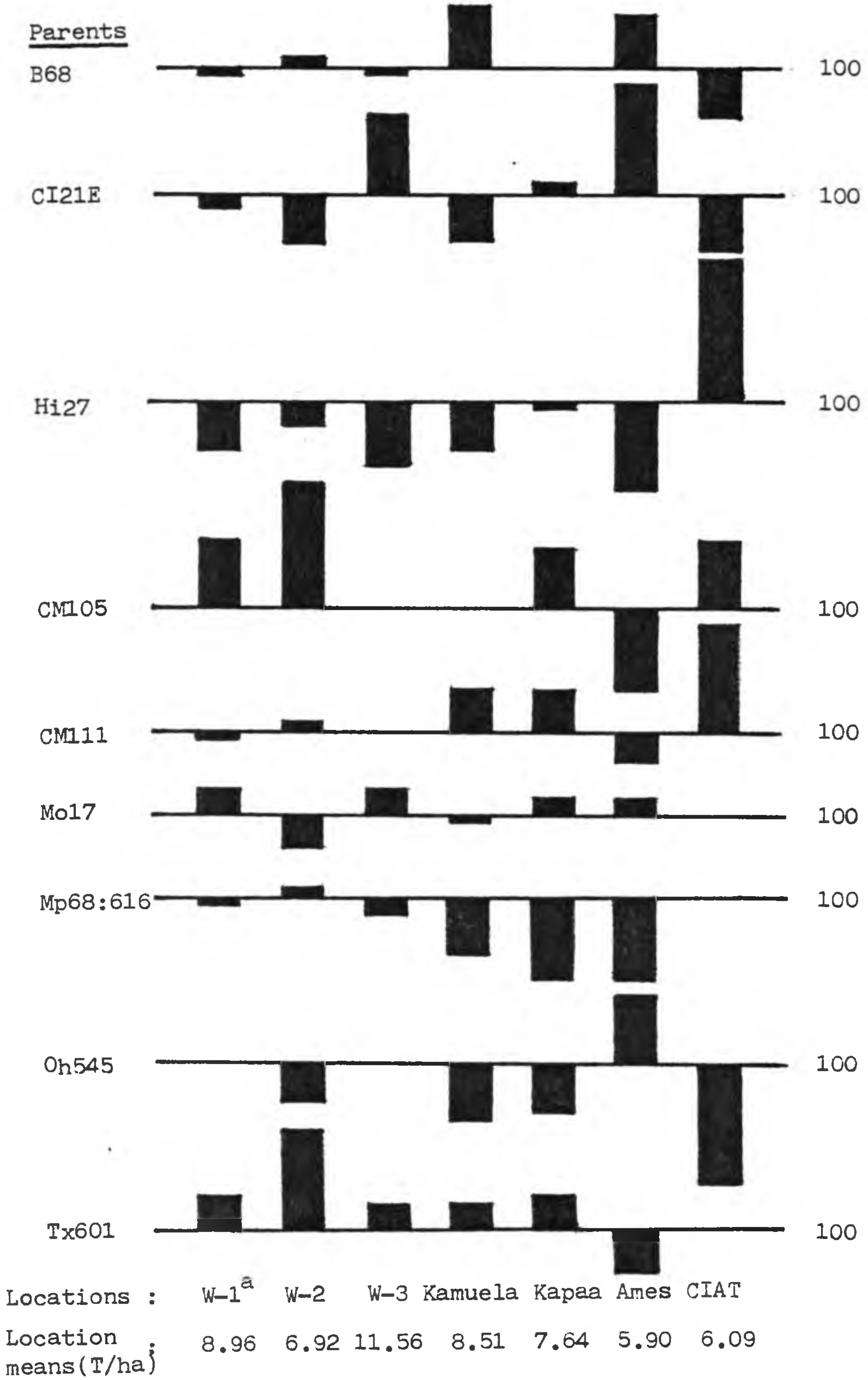

Figure 22. Average grain yield of hybrids in a 10-entry diallel evaluated at different locations, as percentage of location means (100 %)

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

Table 51. Average grain yield of a 10-entry diallel set evaluated at 7 different locations

(unit : T/ha)

Inbreds	B68	CI21E	Hi27	CM105	CM111	Mo17	Mp68:616	Oh545	Tx601	Array mean
B37	7.12	8.31	7.17	8.63	8.23	7.57	7.94	6.86	8.33	7.80
B68		8.08	6.64	8.38	8.99	8.08	8.60	7.32	8.58	7.97
CI21E			8.44	8.41	8.04	8.07	7.37	7.76	8.22	8.08
Hi27				8.02	7.94	8.07	7.36	7.94	7.31	7.65
CM105					8.16	8.46	8.17	7.62	8.28	8.24
CM111						8.16	6.91	8.22	8.74	8.15
Mo17							7.78	7.28	8.44	7.99
Mp68:616								7.31	7.39	7.65
Oh545									8.58	7.65
Tx601										8.21

BLSD (0.05) = 0.64

characters over 45 hybrids were computed separately for each location (Table 52). Days to mid-silking showed a significant positive correlation with grain yield at Waimanalo-2, while it had significant negative correlations at Waimanalo-3, Kamuela and Ames. This different relationship between days to mid-silking and grain yield in different locations could be explained by the solar radiation difference. Since solar radiation was lower for the Waimanalo-2 (winter) planting, the longer growing period with delayed flowering helped the corn plants to receive more irradiance during the growing season. On the other hand, plantings at Kamuela and Ames passed through a higher solar radiation environment from planting to flowering but lower solar radiation during later stage of grain filling period. Therefore, the delayed growth indicated less irradiance during the late grain filling period, and this resulted in a negative correlation coefficient between days to mid-silking and grain yield. Although the Kapaa planting passed through a similar radiation condition as the Kamuela planting, the growing period was shorter than the latter and showed a non-significant negative correlation coefficient. Waimanalo-1 and -3 plantings had the similar radiation condition, and the differences in days to mid-silking among the 45 hybrids was very small. The significant negative correlation coefficient for the Waimanalo-3 planting (Table 52) was basically due to the lower grain yield of hybrids with longer days to mid-silking rather than the effect of solar radiation.

Filled ear length, kernels per row, 100 kernel weight and kernels per ear showed highly significant correlations with grain yield at all locations. The correlation coefficient between row number and grain

Table 52. Correlation coefficients between grain yield and ear characters over 45 hybrids at different locations

Characters	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames
Days to mid-silking	0.123	0.277**	-0.226*	-0.428**	-0.119	-0.516**
Plant height	0.443**	0.452**	0.550**	0.610**	0.086	-0.105
Filled ear length	0.616**	0.577**	0.800**	0.713**	0.445**	0.548**
Kernels per row	0.589**	0.500**	0.693**	0.536**	0.436**	0.742**
Row number	0.157	0.367**	0.078	0.051	0.129	0.029
100 kernel weight	0.207*	0.491**	0.517**	0.687**	0.457**	0.280**
Kernels per ear	0.670**	0.673**	0.761**	0.540**	0.513**	0.686**

* Significant at 5 % probability level.

** Significant at 1 % probability level.

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

Table 53. Partial correlation coefficients between grain yield and kernels per row, kernels per ear and 100 kernels weight over 45 hybrids at different locations

	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames
$r_{y1.2}$[b]	0.627**	0.751**	0.734**	0.621**	0.704**	0.736**
$r_{y2.1}$	0.333**	0.747**	0.592**	0.738**	0.712**	0.243**
$r_{y3.2}$	0.692**	0.646**	0.920**	0.690**	0.778**	0.688**
$r_{y2.3}$	0.307**	0.794**	0.857**	0.781**	0.759**	0.398**

** Significant at 1 % probability level.

[a] W-1, -2 and -3 are Waimanalo-1, -2 and -3, respectively.

[b] y, 1, 2, and 3 refer to grain yield, kernels per row, 100 kernel weight and kernels per ear, respectively.

yield was highly significant at only Waimanalo-2, a winter planting, where low solar radiation and low temperature provided an unfavorable environment for corn plants. This indicated that row number in the range of materials and environments of this experiment was not a limiting trait for higher grain yield when the environmental condition was not extremely poor.

Partial correlation coefficients between grain yield and kernels per row, kernels per ear and 100 kernel weight were calculated (Table 53). Partial correlation coefficients were highly significant at all locations, which indicated that both kernel number and kernel size were important in the determination of grain yield. When environmental conditions were more or less favorable, kernel number appeared to be more important, while kernel weight showed a closer relationship with grain yield when environmental conditions were less favorable, as in the case of Waimanalo-2 and Kamuela plantings. Although kernels per row had a significant partial correlation, the coefficients of kernels per ear were greater than the former. This was natural since kernels per ear represented both kernels per row and row number.

4.3.5 Stability estimate for kernels per row, ear length and grain yield under geographic environments

Analyses of variance of stability parameters for kernels per row, filled ear length and grain yield of a 10-entry diallel set, evaluated at different locations in temperate and tropics, were carried out following Eberhart and Russell (1966). The environmental index was computed as a difference between the average of the 45 hybrids of each planting at different locations and the mean of the plantings over all locations. The significant hybrid mean squares tested against the pooled deviation indicated that hybrids were significantly different for the three characters tested. Since these analyses were based on the mean of 3 replications for each hybrid in each planting, three times these mean squares should be equal to the mean squares in Table 37, within a range of rounding error. None of the hybrid x location (linear) interactions were significant (Table 54). This indicated that the slope of the 45 hybrids for kernel number per row, filled ear length and grain yield were not different from each other.

Data on 15 hybrids, representing the same 6-entry diallel set which was tested in monthly plantings, were extracted from the 10-entry diallel set. Analyses of variance of stability parameters for kernels per row, filled ear length and grain yield were conducted (Table 55) to compare with the results of the monthly plantings. Hybrid x location (linear) interactions for the three characters of this extracted 6-entry diallel set were not significant. Considering the significant hybrid x month (linear) interactions in the monthly plantings, this was a somewhat unexpected result. However, since regression analysis of this extracted 6-entry diallel set was based on only six or seven observations for each genotype and the greater variation in plantings of the 10-entry diallel set existed in different locations, it was a plausible result.

Regression coefficients of the 45 hybrids on environmental index for kernels per row and filled ear length are summarized in Table 56. Regression coefficients of kernels per row ranged from 0.22 for CM105 x Tx601 to 1.79 for B37 x B68, while those of filled ear length varied

Table 54. Analyses of variance of stability parameters for kernels per row, filled ear length and grain yield of a 10-entry diallel evaluated at different locations

	Kernels per row		Filled ear length		Grain yield	
Source	df	Mean squares	df	Mean squares	df	Mean squares
Hybrids (H)	44	45.24**	44	3.81**	44	2.20**
H x Location (linear)	44	10.36	44	1.07	44	0.77
Pooled deviation	180	8.15	180	1.45	225	1.02

** Significant at 1 % probability level.

Table 55. Analyses of variance of stability parameters for kernels per row, filled ear length and grain yield of a 6-entry diallel evaluated at different locations

	Kernels per row		Filled ear length		Grain yield	
Source	df	Mean squares	df	Mean squares	df	Mean squares
Hybrids (H)	14	47.30**	44	6.23**	14	2.96**
H x Location (linear)	14	11.79	14	1.52	14	0.83
Polled deviation	60	7.48	60	1.95	75	0.69

** Significant at 1 % probability level.

from 0.66 for CM105 x CM111 to 1.38 for B37 x B68. The array mean of regression coefficients shows the pooled regression coefficient of each parental line. For both kernels per row and filled ear length, all temperate inbreds had greater regression coefficients than tropical inbreds. This indicated that, in general, hybrids of temperate inbreds were more susceptible to environmental changes than those of tropical inbreds. The data may also be interpreted to indicate that hybrids of temperate inbreds responded better under favorable environmental conditions than did those of tropical inbreds.

This relationship is shown graphically in Figure 23 and 24. For both characters, hybrids among tropical inbreds appeared to have high stability (regression coefficient smaller than unity) with a wide range in number of kernels per row and filled ear length. On the other hand, hybrids among temperate inbreds had regression coefficients greater than unity. This indicated that they had more kernels per row under favorable environments but fewer kernels per row under unfavorable environments. Hybrids between tropical and temperate inbreds showed a wide range of stability in terms of regression coefficients, with more kernels per row than hybrids among tropical inbreds. These results indicated the possibility of improving yield components, i.e. kernels per row and filled ear length, and the stability of corn hybrids at the same time by selection of appropriate genotypes of inbreds and their hybrids. Temperate x tropical hybrids such as CI21E x CM105, CI21E x CM111 and CM111 x Mo17 had greater number of kernels per row with high stability. Also, several hybrids between temperate and tropical inbreds showed greater filled ear length with high stability.

Table 56. Regression coefficients of 45 hybrids on environmental index for kernels per row and filled ear length

Inbreds	B68	CI21E	Hi27	CM105	CM111	Mo17	Mp68:616	Oh545	Tx601	Average
B37	1.79[a]	1.67	1.41	1.21	1.50	1.49	1.23	1.56	1.21	1.45
	1.38	1.10	1.08	0.99	1.04	1.03	1.08	1.22	0.85	1.09
B68		1.08	1.10	1.06	1.41	1.30	0.91	1.26	1.34	1.25
		1.11	0.88	0.94	1.17	1.23	0.94	1.17	1.08	1.10
CI21E			1.45	1.06	0.86	0.98	1.25	1.42	1.25	1.22
			1.14	0.88	0.78	0.79	0.88	1.12	0.97	0.97
Hi27				0.66	0.84	0.87	0.70	1.07	0.67	0.97
				0.78	0.79	0.84	0.63	0.91	0.79	0.87
CM105					0.58	0.73	0.67	1.08	0.22	0.81
					0.66	0.77	0.78	1.02	0.71	0.84
CM111						0.68	0.60	0.93	0.96	0.93
						0.70	0.82	0.93	0.80	0.85
Mo17							0.97	1.38	1.18	1.06
							0.87	1.04	1.16	0.94
Mp68:616								1.08	0.56	0.89
								0.97	0.75	0.86
Oh545									1.46	1.25
									1.29	1.07
Tx601										0.98
										0.94

[a] Upper and lower values are regression for kernels per row and filled ear length, respectively.

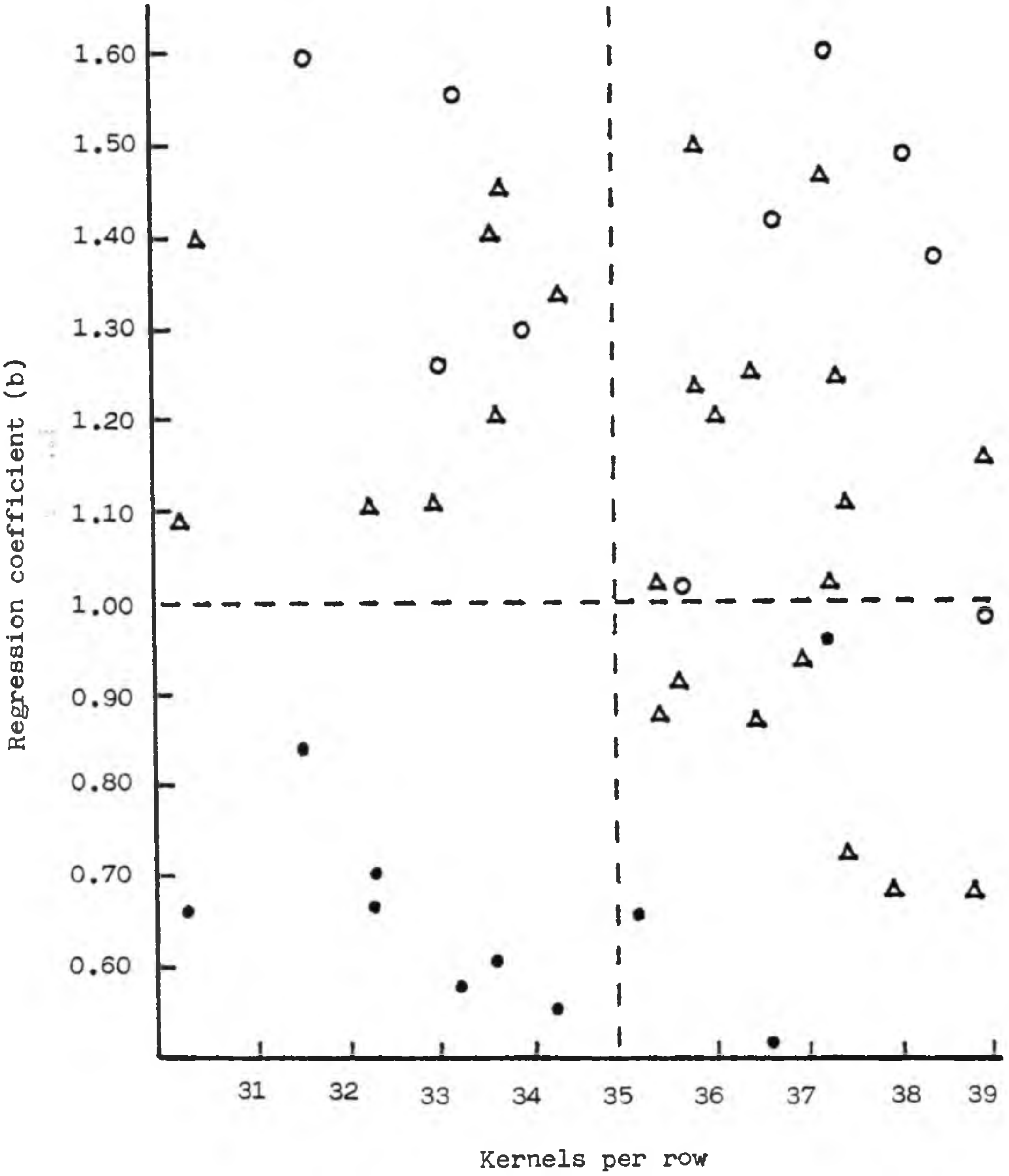

Figure 23. The relationship between average kernels per row and regression coefficient of 45 hybrids

○ Temperate x temperate hybrids
△ Temperate x tropical hybrids
● Tropical x tropical hybrids

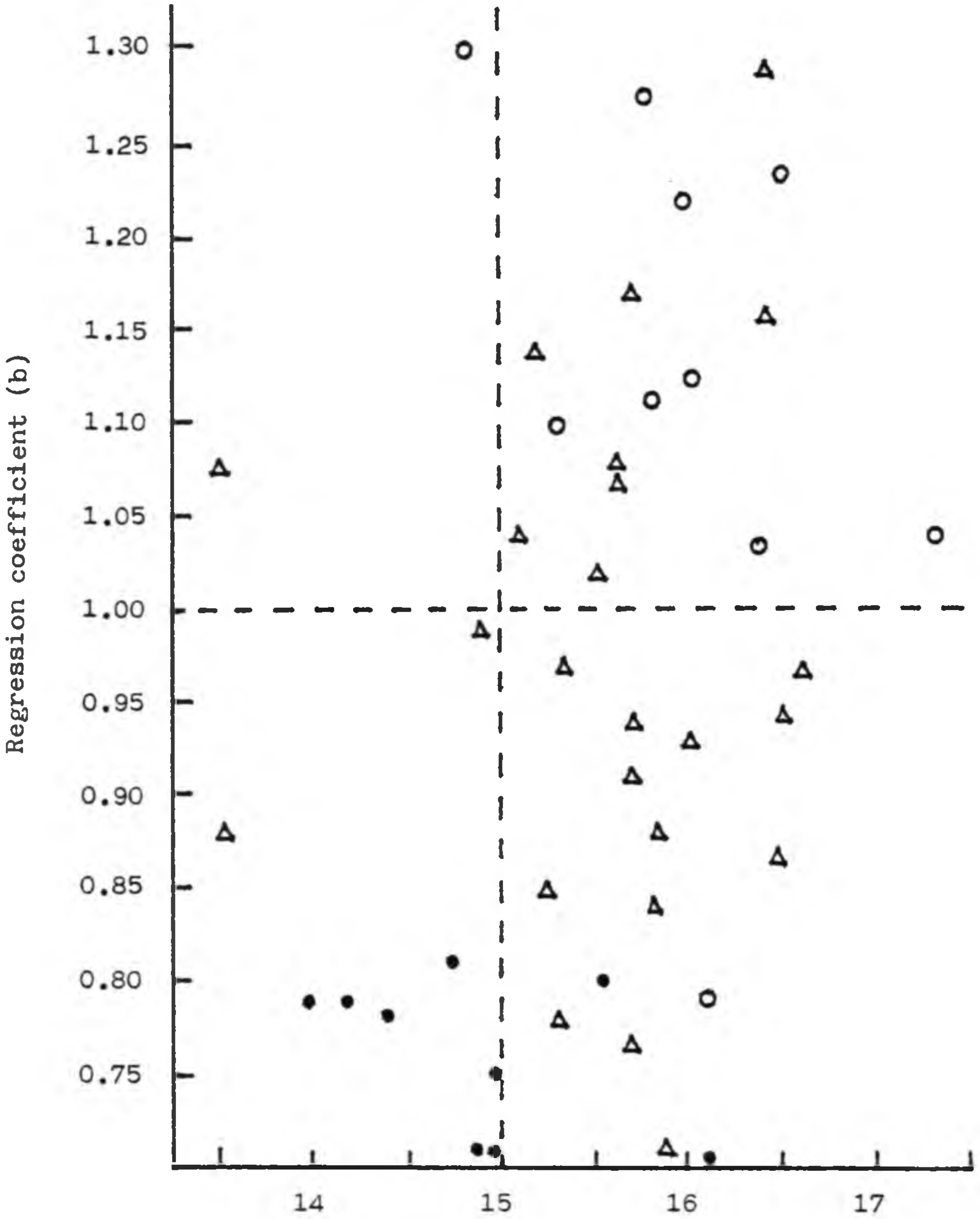

Figure 24. The relationship between average filled ear length and regression coefficient of 45 hybrids

○ Temperate x temperate hybrids
△ Temperate x tropical hybrids
● Tropical x tropical hybrids

Regression coefficients of 45 hybrids on environmental index and deviation from regression for grain yield are given in Table 57. Hybrids among tropical inbreds, Hi27 x CM105, Hi27 x CM111, Hi27 x Mp68:616, CM105 x CM111 and CM105 x Tx601 and hybrids between temperate and tropical inbreds, B37 x Tx601, CI21E x CM105, CI21E x CM111, Hi27 x Mo17 and CM111 x Mo17 were found to be stable hybrids with small deviations from the regression for grain yield. The graphic relationship between regression coefficients and grain yields of 45 hybrids (Figure 25) showed trends similar to kernels per row and filled ear length, except that hybrids among tropical inbreds had a wide range of variation in average grain yield and stability. Considering the facts that tropical inbreds had high GCA effects for row number and that kernels per row or kernels per ear was closely related with grain yield, this was not an unexpected result. This graph also showed that about a half of the hybrids between temperate and tropical inbreds had higher average grain yield and high stability. This result, as well as those of the relationship between kernels per row and filled ear length and their respective regression coefficients, suggested that many of the hybrids between temperate and tropical inbreds performed better under a wide range of environmental conditions.

Analyses of variance of stability parameters for GCA and SCA effects for kernels per row, filled ear length and grain yield are given in Table 58. GCA and SCA effects were significantly different among parental lines and crosses, respectively. The mean squares for regression of GCA effects on environmental index were significant for kernels per row and filled ear length but not for grain yield. None of the mean

Table 57. Regression coefficients of 45 hybrids on environmental index and deviation from the regression for grain yield

Inbreds	B68	CI21E	Hi27	CM105	CM111	Mo17	Mp68:616	Oh545	Tx601	Average
B37	1.38[a] 2.49	1.10 2.85	1.08 1.65	0.99 1.98	1.04 1.76	1.03 1.22	1.08 1.66	1.22 1.88	0.85 0.95	1.09 1.83
B68		1.11 1.31	0.88 1.61	0.94 1.31	1.17 2.22	1.23 1.23	0.94 1.32	1.17 1.18	1.08 1.19	1.10 1.54
CI21E			1.14 1.09	0.88 0.98	0.78 0.78	0.79 1.17	0.88 1.52	1.12 2.25	0.97 1.97	0.97 1.55
Hi27				0.78 0.87	0.79 1.47	0.84 0.83	0.63 0.66	0.91 1.22	0.79 0.90	0.87 1.14
CM105					0.66 0.88	0.77 1.29	0.78 1.04	1.02 1.64	0.71 0.68	0.84 1.19
CM111						0.70 0.87	0.82 1.15	0.93 1.66	0.80 1.01	0.85 1.31
Mo17							0.87 1.42	1.04 2.18	1.16 3.97	0.94 1.58
Mp68:616								0.97 1.48	0.75 1.03	0.86 1.25
Oh545									1.29 1.56	1.07 1.67
Tx601										0.94 1.47

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[a] Upper and lower values are regression coefficient and deviation from the regression, respectively.

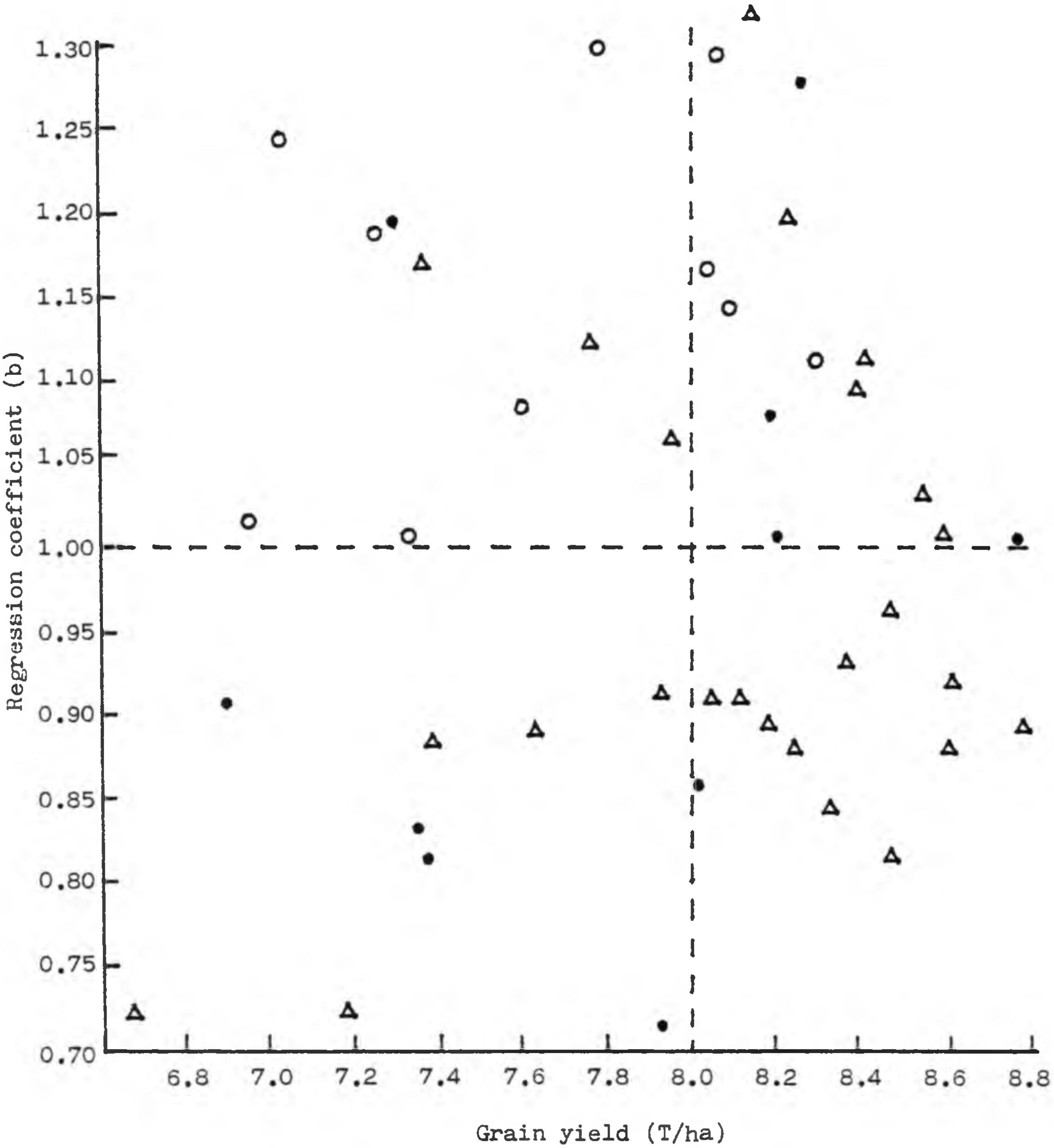

Figure 25. The relationship between grain yield and regression coefficient of 45 hybrids

○ Temperate x temperate hybrids
△ Temperate x tropical hybrids
● Tropical x tropical hybrids

squares for regression of SCA effects on environmental index was significant. This indicated that GCA effects of different parental lines were not the same in their response to different environments. But GCA effects for grain yield and SCA effects for all the three characters were similar in their response to different environmental conditions.

Regression coefficinets and deviations from regression for GCA effects of 10 inbreds are given in Table 59. It was noticed that all tropical inbreds showed negative regression coefficients with small deviations from the regression for both kernels per row and filled ear length. These results agree well with the trend in Figure 23 and 24. Although temperate inbred Mo17 showed negative regression coefficients for both characters, their magnitude relative to other tropical inbreds was very small. Regression coefficients of the tropical inbreds, except Tx601, tended to be negative for grain yield. Two temperate inbreds B37 and B68 also showed negative regression coefficients for grain yield. This indicated that all tropical inbreds contributed to the stability of their hybrids for kernels per row, filled ear length and grain yield. On the other hand, temperate inbreds contributed to better performance of their hybrids under favorable environments. These results explain the better performance with high stability of tropical x temperate hybrids in Figure 23, 24 and 25.

Analysis of variance for joint combining ability and regression analysis for kernels per row, filled ear length and grain yield are given in Table 60. Mean squares of regression of GCA effects over the 6 locations were significant for all three characters, but mean squares

Table 58. Analyses of variance of stability parameters for GCA and SCA effects for kernels per row, filled ear length and grain yield of a 10-entry diallel evaluated at different locations

	Kernels per row		Filled ear length		Grain yield	
Source	df	Mean squares	df	Mean squares	df	Mean squares
GCA effects						
Inbreds (I)	9	21.91**	9	1.68**	9	1.49**
I x Locations (linear)	9	4.70**	9	0.45**	9	0.25
Pooled deviation	40	0.90	40	0.20	50	0.36
SCA effects						
Crosses (C)	44	9.08**	44	1.00**	44	1.37**
C x Locations (linear)	44	2.65	44	0.32	44	0.34
Pooled deviation	180	2.02	180	0.35	225	0.38

** Significant at 1 % probability level.

Table 59. Regression coefficients and deviations from the regression of GCA effects on environmental index in a 10-entry diallel evaluated at different locations

Inbreds	Kernels per row		Filled ear length		Grain yield	
	b	s_d^2	b	s_d^2	b	s_d^2
B37	0.42	2.65	0.16	0.69	−0.04	0.88
B68	0.19	0.89	0.16	0.16	−0.03	0.11
CI21E	0.16	0.93	0.03	0.18	0.16	0.53
Hi27	−0.12	0.18	−0.10	0.13	−0.21	0.60
CM105	−0.31	0.79	−0.13	0.06	0.00	0.43
CM111	−0.17	0.27	−0.11	0.09	−0.08	0.26
Mo17	−0.02	0.62	−0.02	0.19	0.09	0.04
Mp68:616	−0.22	0.50	−0.11	0.03	−0.02	0.17
Oh545	0.19	1.09	0.14	0.35	0.06	0.39
Tx601	−0.11	1.08	−0.01	0.11	0.07	0.17

of the regression of SCA effects were not significant. This again indicated that the additive gene effects of these three characters differed significantly in response to different environmental conditions, while non-additive gene effects were rather constant over the different environments. Since the mean square of the slope of GCA effects was a partition of the hybrid x location interaction, the hybrid x location interaction was basically due to the linear response of GCA effects to different environments.

4.3.6 Discussion

The possibilities for the further improvement of corn through a more complete exploitation of the many different germplasm complexes existing in the tropics have been stressed by corn breeders (Wellhausen, 1965). The use of exotic germplasm to broaden genetic variability attracted the corn breeder's attention, especially after the 1970 Southern Corn leaf blight epiphytotics in the Corn Belt. In Hawaii, heterosis between tropical x temperate crosses has been used extensively for hybrid production (Brewbaker, 1974). Knowledge of the genotype-environment interaction and of the relationship between yield components and yield in different environments is of great importance in breeding programs which utilize both tropical and temperate materials.

Growth of corn at different locations in this study was influenced by temperature, daylength and daylength sensitivity of the hybrids. Average temperature during the period of the experiments at Kamuela, being at a high altitude in Hawaii, and at Ames and Suweon in temperate areas were lower than at other locations. Daylength was longer in

Table 60. Analyses of variance for joint combining ability and regression analysis for kernels per row, filled ear length and grain yield on environmental index for a 10-entry diallel evaluated at different locations

	Kernels per row		Filled ear length		Grain yield	
Source	df	M.S.	df	M.S.	df	M.S.
Locations (L)	5	817.29	5	299.99	6	174.12
Hybrids (H)	44	45.35**	44	3.78**	44	2.18**
GCA	9	179.81**	9	13.60**	9	3.96**
SCA	35	10.78**	35	1.26**	35	1.72**
H x L (linear)	220	4.92**	220	0.79**	264	0.99**
GCA x L	45	13.02**	45	2.14**	54	2.98**
Slope of g_i	9	37.63**	9	3.63**	9	1.99*
Residual	36	6.86	36	1.77	45	3.18
SCA x L	175	2.84	175	2.84	210	0.48
Slope of s_{ij}	35	3.33	35	0.40	35	0.42
Residual	140	2.27	140	0.45	175	0.49
Pooled error	176	3.57	176	0.72	220	1.04
Average error	528	2.40	528	0.37	616	0.40

* Significant at 5 % probability level.

** Significant at 1 % probability level.

temperate locations. Among inbreds used, all tropical inbreds, i.e., Hi27, CM105, CM111, Mp68:616 and Tx601, were sensitive or highly sensitive to daylength (Lee, 1978). The days to mid-silking at Kamuela, Ames and Suweon were more than 80 days while it was about 50 days at Waimanalo-1 and -2 which were summer plantings. The difference between the earliest and the latest hybrids was smaller at Waimanalo. The number of days to mid-silking of 45 hybrids at different locations at different altitudes, temperatures and daylengths in this study confirmed other reported results. The rate of development of corn from planting to anthesis is a function of temperature rather than of photosynthesis (Duncan, 1975) and longer daylength delays anthesis and silking in sensitive genotypes to daylength (Lee, 1978). Average days to tasseling was delayed about 27 days per km of increased altitude in Kenya (Eberhart et al., 1973; Darrah and Penny, 1974).

Both GCA and SCA effects were significant in contributing to the genetic variation of ear characters and grain yield at all locations. The GCA/SCA ratio was greater than unity in all cases, and this indicated that additive genes were predominant in the genetic variations. Additive genes were not stable over locations in their expression for all ear characters and grain yield, while non-additive genes were stable in their expression for ear characters and grain yield. Combining ability analysis revealed that temperate inbreds CI21E, Mo17 and Oh545 were good combiners for kernels per row and filled ear length, while tropical inbreds CM105 and Tx601, as well as CI21E and Mo17, were good combiners for kernels per ear. Tropical inbreds CM105 and Tx601 had a high GCA effect for row number, which was responsible for a high GCA effect for kernels per ear for these inbreds.

Eberhart and Russell (1966, 1969) reported that additive genes were the primary cause of the genotype-environment interactions in their diallel crosses. Their evaluations were based on different environments of the same season, i.e. summer in the temperate regions. The present study was based on different environmental conditions of both season and location, i.e. greater variation in environments; however, the same conclusion was derived. On the other hand, Lee (1978) obtained a highly significant SCA x season interaction in Hawaii and concluded that non-additive genes were also not stable in seasonal environments. His materials were selected on the basis of daylength sensitivity, and most of daylength insensitive temperate inbreds showed very poor yield in winter plantings. When these inbreds were crosses with tropical inbreds the high SCA effect significantly contributed to the grain yield. Although the GCA/SCA ratio was greater than unity, the relative ratio was much smaller than that obtained in this experiment. Dhillon and Singh (1979) also reported that SCA was stable in their evaluation of a large number of hybrids among tropical populations.

When tropical materials are planted in a temperate area, they are unnecessarily tall and late in maturity. On the other hand, the excellent Corn Belt germplasm mature too early in the tropics for maximal yields (Brewbaker, 1974). However, when hybrids are produced between tropical and temperate inbreds, they are only weakly daylength responsive and their maturity and yield potential are significantly improved. Although it was at only one location where yield data was obtained in a temperate area, the Ames planting showed high yield potential among temperate x tropical hybrids which also performed well at the tropical locations in Hawaii and CIAT. The GCA effect indicated that hybrids of temperate inbreds were better in temperate areas and hybrids among tropical inbreds were better at tropical locations. However, hybrids between temperate and tropical inbreds performed as well as their counterparts at different geographic locations. The yielding ability of the hybrids was closely related to their kernel number and ear length. CI21E x CM105, Mo17 x Tx601 and Oh545 x Tx601, which are all tropical x temperate hybrids, showed high kernel number as well as long filled ear length, resulting in high kernel number per ear. This insured stable high yield for these hybrids at both tropical and temperate locations. At all locations, grain yield was highly significantly correlated with kernel number and filled ear length. However, this does not necessarily mean that sink limitation is the main reason restricting higher yield as Tollenaar (1977) pointed out.

Wellhausen (1965) listed several varieties from Central and Latin America such as Antigua 2D, Tuxpeño and ETO which combined well with Corn Belt genotypes. Lonnquist (1974) reported that more than 12,000 of Latin America collections and 6,000 European-Mediterranian collections are preserved for future use in breeding and genetics. Considering the small number of inbreds used in this experiment, the results were very significant. If continuous and careful testing of available germplasm were carried out, it should provide promising materials with high yield potential for both tropical and temperate regions.

A multidisciplinary approach could lead to the identification of physical and physiological factors primarily responsible for the genotype-environment interactions in a particular breeding program. This information could then be translated into selection criteria which would be used to evaluate the genetic worth of promising new genotypes (Hill, 1975). Although the effects of solar radiation and temperature were apparently confounded in monthly plantings, solar radiation was pointed out as the single most important environmental factor responsible for variation in kernel number, ear length and grain yield. However, it was not possible to isolate such a factor in this study where great variations in environmental and management factors were encountered. But joint combining ability and regression analysis proved to be useful for the identification of genotypes which can be utilized as parents in a breeding program. Temperate inbreds were found to be capable of high performance for kernels per row and filled ear length under favorable environments, while tropical inbreds appeared to be very stable under a wide range of environments.

In this study, the hybrids between temperate and tropical inbreds showed high stability for a high number of kernels per row, filled ear length and grain yield. This suggested that temperate inbreds provided the genetic ability to exploit favorable environments and tropical inbreds provided the stability for better performance under unfavorable conditions. Temperate x tropical hybrids B37 x Tx601, CI21E x CM105, CI21E x CM111, Hi27 x Mo17 and CM111 x Mo17 were found to be stable hybrids with small deviations from the regression. One of the parents of these hybrids was a good combiner for kernels per row or row number. This might have insured a high kernel number for stable high grain yield at different locations. Among 10 inbreds entered in a diallel cross, tropical inbreds CM105, CM111 and Tx601 were good parents for hybridization programs as they had a high GCA effect for grain yield and a low GCA effect for linear response to environments, thus transmitting both high grain yield and above average stability. Dhillon and Singh (1979) also reported that tropical materials had high stability with a high GCA effect for grain yield. The more vigorous heterozygous groups were capable of high performance under favorable conditions and were disproportionately reduced by unfavorable environments (Rowe and Andrew, 1964). The hybrids between temperate and tropical inbreds probably carried increased heterozygosity as they were of quite different genetic backgrounds.

Comparison of a 6-entry diallel set in seasonal environments and in geographic environments did not provide enough information about the comparative genetic and genotype-environment interaction involvement in character expression. However, the results indicated that hybrids responded similarly to environmental factors which apparently influence the development of corn plants. Therefore, it might be possible to identify any genotypes which have good performance as well as high stability in seasonal environments where one or two factors contribute to the variation of genotypes and to use this information in other environments with greater variation. The information on seasonal environment will be useful in understanding genetic variation in a wide range of environmental variations, since it would be possible to determine one or two important factors which are mainly responsible for the genotype-environment interactions.

4.4 Genetics of kernel number and ear length

4.4.1 Generation mean analysis

Crosses among four inbred lines, B37, Hi27, Mo17 and Tx601, and their advanced populations were evaluated for the genetic studies of kernel number and ear length. The average floret number per row, kernels per row, cob length and filled ear length for the six population means - P_1, P_2, F_1, F_2, B_1 and B_2 of these crosses - are presented in Table 61 and 62. Inbreds B37 and Hi27 had lower floret numbers, kernels per row and shorter cob and filled ear lengths than Mo17 and Tx601. Mo17 had the highest floret number per row and kernels per row as well as the longest cob and filled ear lengths. Tx601 showed intermediate values for all characters evaluated.

For floret number, the F_1 means were greater than both parental means for all crosses except Hi27 x Mo17, which showed an intermediate F_1 value for the two parents. The crosses B37 x Tx601 and Hi27 x Tx601 showed greater heterosis effects than other crosses, while all crosses involving Mo17 showed very low heterosis. F_2 generation means were smaller than F_1 and better parent means for all crosses except B37 x Tx601. This cross showed the greatest heterosis effect among the six crosses and had more floret numbers than the better parent. The mean values of backcross populations were intermediate to F_1 means and respective recurrent parental means for all crosses. These results suggested that high floret number was dominant to low floret number for these crosses.

A similar relationship among generation means was obtained for kernels per row, cob length and filled ear length. The F_1 means were

Table 61. Average floret number and kernels per row and results of scaling tests

Crosses	Generation means							Heterosis[b]	Scaling tests		
	P_1	P_2	MP[a]	F_1	F_2	B_1	B_2		A	B	C
<u>Floret number</u>											
B37 x Hi27	43.3	38.5	40.9	43.9	42.0	46.1	41.3	7.0	5.0	0.2	-2.0
B37 x Mo17	43.3	53.2	48.3	55.9	45.2	46.2	52.0	15.7	-6.8**	-5.1	-27.5**
B37 x Tx601	43.3	47.8	45.6	56.2	48.4	46.2	51.9	23.2	-7.1**	-0.2	-9.9*
Hi27 x Mo17	38.5	53.2	45.9	46.4	44.4	45.9	51.7	10.9	6.9**	3.8	6.9
Hi27 x Tx601	38.5	47.8	43.2	52.8	43.3	44.6	51.6	22.2	2.9	2.6	-18.7**
Mo17 x Tx601	53.2	47.8	50.5	55.9	49.2	52.5	52.8	10.7	4.0	1.9	-16.0*
<u>Kernels per row</u>											
B37 x Hi27	28.5	27.9	28.2	35.4	31.5	34.1	29.7	25.5	4.3	-3.9	-1.2
B37 x Mo17	28.5	45.0	36.8	46.5	35.8	39.3	44.2	12.6	3.6	-3.1	-23.3**
B37 x Tx601	28.5	31.9	30.2	42.2	35.3	35.5	37.8	39.7	0.3	1.5	-3.6
Hi27 x Mo17	27.9	45.0	36.5	39.9	36.4	35.5	42.9	9.3	3.2	0.9	-7.1*
Hi27 x Tx601	27.9	31.9	29.9	41.8	31.4	32.2	38.5	39.8	4.6	-2.7	-17.8**
Mo17 x Tx601	45.0	31.9	38.5	48.9	38.5	44.0	41.5	27.0	-5.9**	2.2	-20.7**

* Significant at 5 % probability level.

** Significant at 1 % probability level.

[a] $MP = (P_1 + P_2)/2$

[b] $\text{Heterosis (\%)} = (F_1 - MP) \times MP^{-1} \times 100$

Table 62. Average cob length and filled ear length and the results of scaling tests

(unit : cm)

Crosses	Generation means							Heterosis[b]	Scaling tests		
	P_1	P_2	MP[a]	F_1	F_2	B_1	B_2		A	B	C
Cob length											
B37 x Hi27	15.9	15.4	15.7	19.1	16.5	18.3	16.8	21.7	1.6	–0.9	–3.5**
B37 x Mo17	15.9	21.8	18.9	22.1	19.4	19.3	19.7	16.9	0.6	–4.5**	–4.3
B37 x Tx601	15.9	16.5	16.2	20.0	17.0	18.1	19.7	23.4	0.3	–0.1	4.4
Hi27 x Mo17	15.4	21.8	18.6	20.3	17.7	18.8	18.2	9.1	1.9*	0.5	–7.0**
Hi27 x Tx601	15.4	16.5	16.0	20.3	16.8	17.0	18.6	26.7	–1.7	0.4	–5.3**
Mo17 x Tx601	21.8	16.5	19.2	22.0	18.2	20.3	19.4	14.6	–3.2	0.3	–9.5**
Filled ear length											
B37 x Hi27	13.6	13.3	13.5	17.0	14.5	16.2	14.7	25.9	1.8	–0.9	–2.9
B37 x Mo17	13.6	20.0	16.8	20.5	17.6	17.9	18.5	22.0	1.7	–3.5**	–4.2
B37 x Tx601	13.6	13.9	13.8	17.7	14.8	16.0	15.8	28.3	0.7	0.0	–3.7
Hi27 x Mo17	13.3	20.0	16.7	18.5	16.3	16.9	19.7	10.8	2.0	0.9	–5.1**
Hi27 x Tx601	13.3	13.9	13.6	17.8	14.7	14.9	17.0	30.9	–1.3	2.3	–4.0*
Mo17 x Tx601	20.0	13.9	17.0	20.7	16.3	19.0	17.9	21.8	–2.7*	0.4	–10.1**

* Significant at 5 % probability level.

** Significant at 1 % probability level.

[a] $MP = (P_1 + P_2)/2$

[b] $\text{Heterosis (\%)} = (F_1 - MP) \times MP^{-1} \times 100$

greater than both parental means for all three characters in all crosses except the cross Hi27 x Mo17. The F_1 means of the cross Hi27 x Mo17 for the three characters were closer to that of the better parent, i.e. Mo17. The F_2 means of the crosses B37 x Hi27 and Hi27 x Tx601 were greater than the means of the better parents for cob length and filled ear length. These two crosses showed greater heterosis than other crosses. F_2 generation means for these crosses were closer to midparental mean values for the three ear characters. The mean values of backcross populations were between F_1 and recurrent parental means for all crosses and characters. In general, kernels per row and filled ear length which are determined at later stages of growth showed greater heterosis effects.

Frequency distributions for floret number per row for these crosses are presented in Figure 26. Frequency distributions of the parental populations for the crosses B37 x Hi27 and Mo17 x Tx601 were not separated widely, while frequency distributions of the parental populations for the crosses B37 x Mo17, Hi27 x Mo17 and Hi27 x Tx601 were well separated from each other. The F_1 distributions of all the crosses were situated within the range of better parents for all characters, however, the modes of F_1 populations were greater than those of the better parent except the cross Hi27 x Mo17.

The F_2 distribution of all the crosses was widely distributed within the range of distribution of both parental populations. This indicated no transgressive segregation in the segregating generations. The distribution of backcrosses showed distinct skewness towards the recurrent parents except the cross Mo17 x Tx601 which showed the

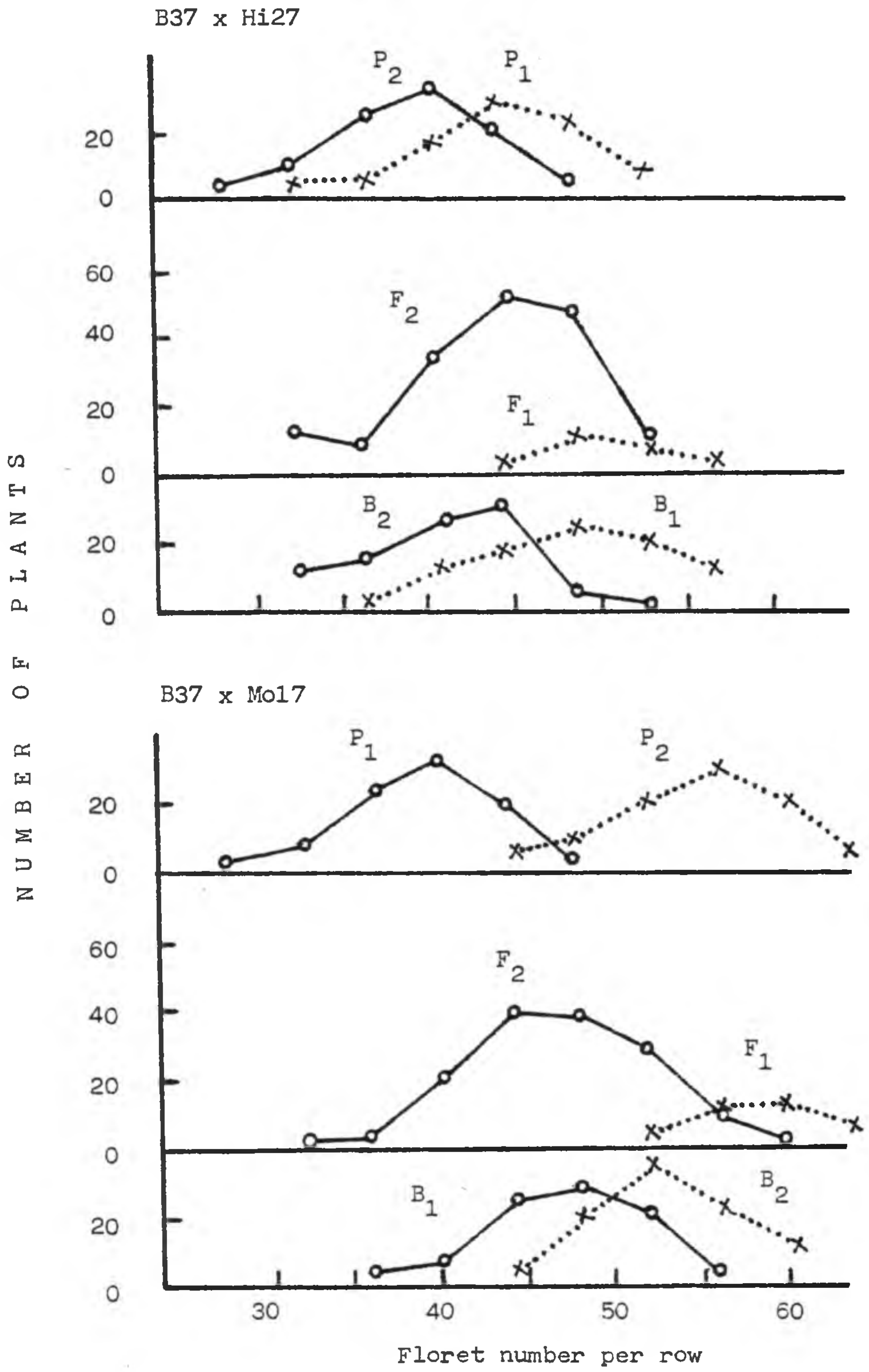

Figure 26. Frequency distribution of floret number per row in different genetic populations

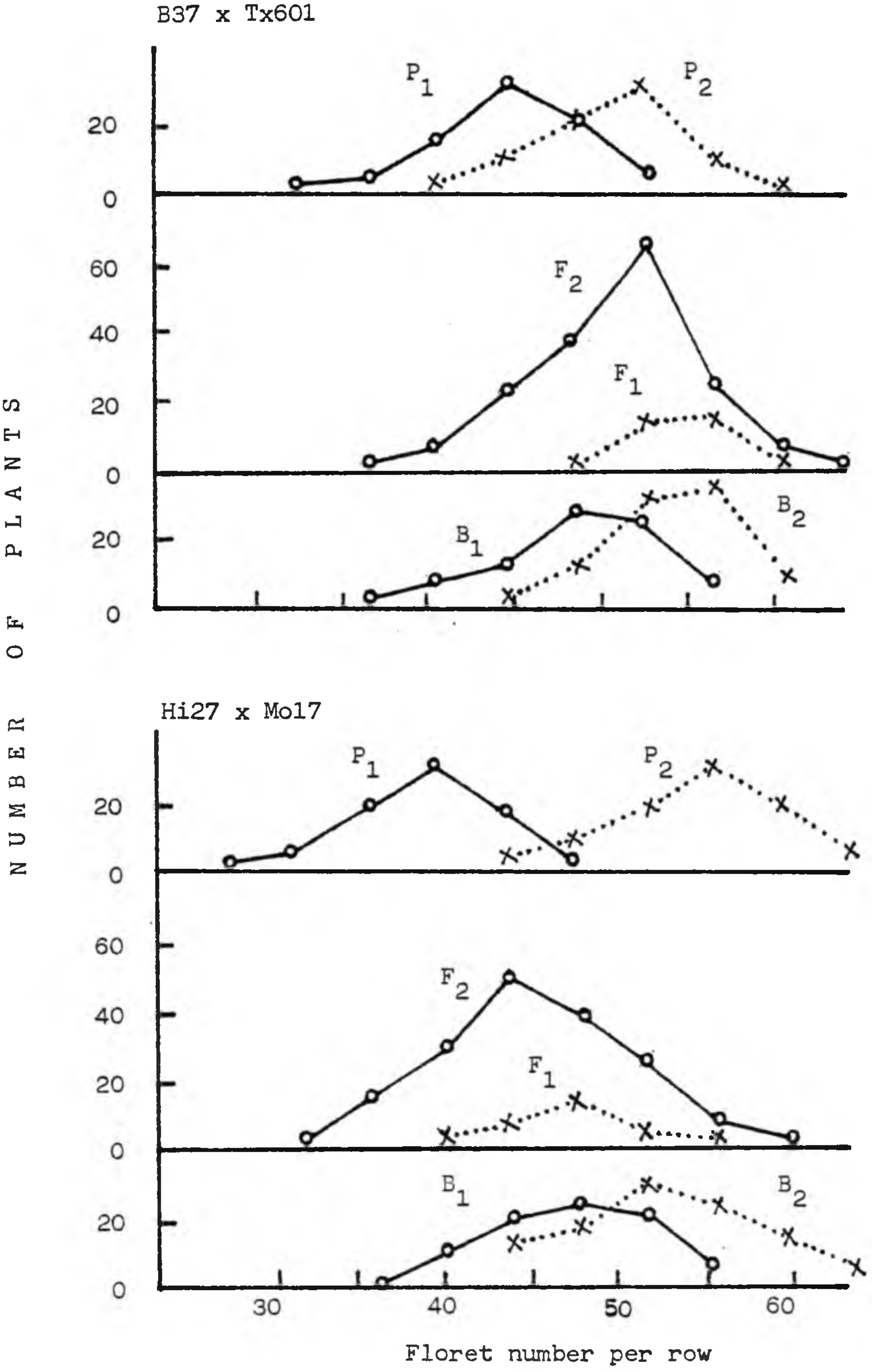

Figure 26. (Continued) Frequency distribution of floret number per row in different genetic populations

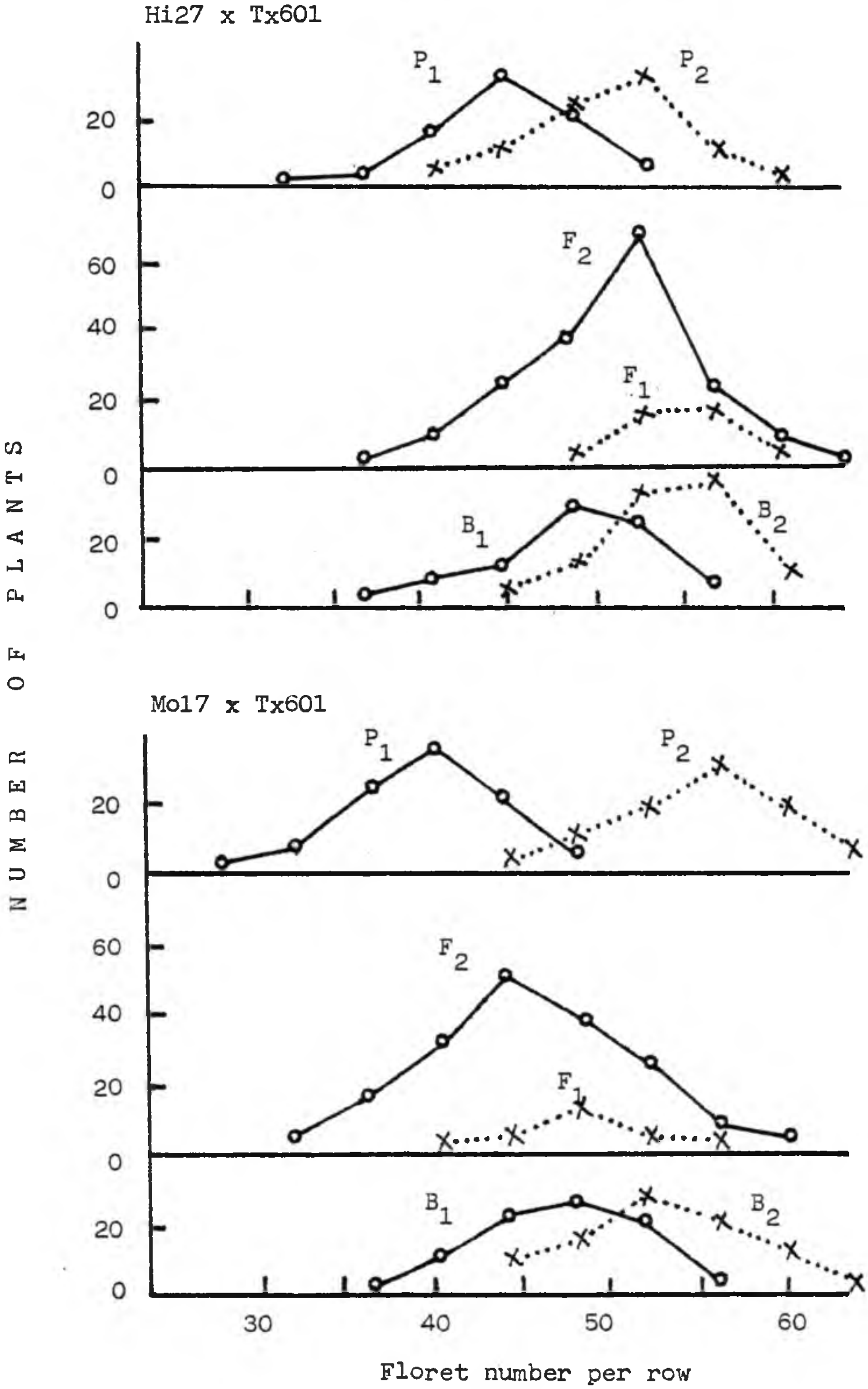

Figure 26. (Continued) Frequency distribution of floret number per row in different genetic populations

identical distribution for both backcross populations.

The individual scaling tests outlined by Mather and Jinks (1971, 1977) were used to assess the adequacy of the additive-dominance model for all the crosses (Table 61 and 62). The cross B37 x Hi27 showed no significant values of A, B and C for floret number, kernels per row and filled ear length but significant C value for cob length. The cross B37 x Tx601 had the values of A, B and C which are not significantly different from zero for all characters except floret number. These results indicated that epistasis or non-allelic interaction was absent in expression of these characters in the crosses B37 x Hi27 and B37 x Tx601.

The three parameter model was fitted by unweighted least squares method following Hayman (1958, 1960) and Gamble (1962). This model includes a mean (m), an additive genetic component (a) and a dominance genetic component (d) (Table 63). Only kernels per row of the cross B37 x Tx601 showed significant additive and dominant effects. The Chi-square values were lower than the critical value for $P = 0.05$, i.e. non-significant. The additive and dominant effects of other characters of the two crosses were not different from zero.

Although the three parameter model was found not to be adequate for other crosses by the scaling tests, the three genetic components were estimated to assess the adequacy of the model with different testing methods. The Chi-square goodness of fit and F-test of residual mean squares after fitted by additive and dominant effects were used for all the crosses and characters. Significant Chi-square values and residual mean squares indicate the presence of epistasis or

Table 63. Estimates of the components of generation means fitting a three-parameter model and Chi-square goodness of fit tests

Crosses & Characters	m	a	d	Chi-square	P
B37 x Hi27					
Floret number	42.8**	2.9	3.2	5.89	0.25 - 0.10
Kernels per row	31.8**	1.1	7.2	6.82	0.10 - 0.05
Filled ear length	15.2**	0.4	3.5	7.27	0.10 - 0.05
B37 x Tx601					
Kernels per row	36.2**	-1.8**	12.0**	1.36	0.75 - 0.50
Cob length	17.9**	-0.3	3.7	1.35	0.75 - 0.50
Filled ear length	15.6**	-0.1	3.9	2.01	0.75 - 0.50

** Significant at 1 % probability level.

non-allelic interaction in controlling the expression of characters. Although scaling tests indicated the presence of epistasis effect for other crosses and characters, Chi-square goodness of fit and F-test revealed that the possibility of fitting the three parameter model for kernels per row for the cross Hi27 x Mo17, cob length for the cross Hi27 x Tx601 and filled ear length for the crosses B37 x Mo17, Hi27 x Tx601 and Mo17 x Tx601 (Appendix 45 and 46).

Since these three methods did not agree in testing the presence of epistasis effect except a few cases, the six parameter model as outlined by Hayman (1958) and using Gamble's (1962) notations were applied to all the crosses and characters. The six parameter model includes the mean (m) which is referenced by the F_2 population mean, the additive gene effect (a), the dominance gene effect (d), the additive x additive epistasis effect (aa), the additive x dominance epistasis effect (ad) and the dominance x dominance epistasis effect (dd).

The estimates of the six parameter gene effects using generation means are shown in Table 64. The absence of epistatic effects were confirmed by the cross B37 x Hi27 for floret number and filled ear length, the cross B37 x Tx601 for kernels per row and the cross Hi27 x Tx601 for filled ear length. Epistatic gene effects were found to be significant for kernels per row of the cross B37 x Hi27, cob length and filled ear lenxth of the cross B37 x Tx601 even though epistasis was found to be absent in the previous tests. These results suggest that if a particular cross fitted a three parameter model, estimation of gene effect on a six parameter model would cause unreliable estimate of gene effects.

Table 64. Mean estimates of the six genetic parameters for floret number, kernels per row, cob length and filled ear length

Crosses	m	a	d	aa	ad	dd
Floret number						
B37 x Hi27	42.0**	4.8**	9.8**	6.8**	2.4	-12.0**
B37 x Mo17	45.2**	-5.8**	23.3**	15.6**	-0.8	-3.7
B37 x Tx601	48.4**	-5.7**	13.3**	2.6	-3.5	4.7
Hi27 x Mo17	44.4**	-5.8**	18.2**	17.6**	1.6	-28.3**
Hi27 x Tx601	43.3**	-7.0**	28.9**	19.2**	-2.4	-19.7*
Mo17 x Tx601	49.2**	-0.3	19.2**	13.8*	-3.0	-11.6
Kernels per row						
B37 x Hi27	31.5**	4.4**	8.8**	1.6	4.1*	-2.0
B37 x Mo17	35.8**	-4.9**	33.6**	23.8**	3.4**	-24.3**
B37 x Tx601	35.3**	-2.3**	17.4**	5.4*	-0.6	-7.2
Hi27 x Mo17	36.4**	-7.4**	14.7**	11.2**	1.2	-15.3**
Hi27 x Tx601	31.4**	-6.3**	27.7**	15.8**	-4.3**	-13.8**
Mo17 x Tx601	38.5**	2.5**	27.5**	17.0**	-4.1**	13.3**
Cob length						
B37 x Hi27	16.5**	1.5	7.7**	4.2**	1.3**	-4.9**
B37 x Mo17	19.4**	-0.4	3.7**	0.4	2.6**	3.5**
B37 x Tx601	17.0**	-0.1	8.4**	4.6**	0.2	-4.8**
Hi27 x Mo17	17.7**	-2.5**	11.1**	9.4**	0.7	-11.8**
Hi27 x Tx601	16.8**	-1.6	8.4**	4.0**	-1.1	-2.7
Mo17 x Tx601	18.2**	0.9**	9.5**	6.6**	-1.8**	-3.7*
Filled ear length						
B37 x Hi27	14.5**	1.5	7.4**	3.8	1.4	-4.7
B37 x Mo17	17.6**	-0.6	6.1*	2.4	2.6**	-0.6
B37 x Tx601	14.8**	0.2	8.4**	4.4**	0.4	-5.1
Hi27 x Mo17	16.3**	-2.8**	9.9**	8.0**	0.6	-10.9**
Hi27 x Tx601	14.7**	-2.1	9.2*	5.0	-1.8	-6.0
Mo17 x Tx601	16.3**	1.5*	11.6**	7.8*	-6.0**	-5.5

* Significant at 5 % probability level.

** Significant at 1 % probability level.

Significant epistatic gene effects were obtained for all the crosses and characters except those mentioned above. The cross B37 x Mo17 showed all highly significant epistatic gene effects for kernels per row. All other crosses including the crosses which were fitted to the three parameter model showed one or two significant epistasis effects. It should be noted that the sign of parameters a and ad depends upon the parents being considered as P_1 or P_2. If the better performing inbred had been used as P_1 in each cross, most of the estimates for a and ad would have been positive. The estimates of parameter a, additive gene effect, are relatively small in magnitude relative to parameter m in the six crosses for all characters evaluated. However, all the additive gene effects were highly significant except floret number of the cross B37 x Mo17 and Mo17 x Tx601 and kernels per row of the cross Mo17 x Tx601. These suggest that additive gene effects made only a minor contribution to the inheritance of floret number, kernels per row, cob length and filled ear length. The estimates do indicate, however, that additive gene effects contributed relatively more to the attributes floret number and kernels per row than cob length and filled ear length. All estimates of additive gene effects were negative for the attributes except the estimate for the crosses B37 x Hi27 and Mo17 x Tx601.

In the inheritance of all characters the dominance gene effects made the major contribution. All the dominance effects were significant except floret number and kernels per row of the cross B37 x Hi27. But this cross was tested to the three parameter model already. All estimates of dominance gene effects were positive. The magnitude of dominance gene effects relative to the magnitude of the mean effects were almost the same for all characters except the cross B37 x Mo17, which showed relatively smaller attribute for cob length and filled ear length. The relative magnitude of the dominance estimates was associated with the relative performance of the F_1 and the better parent.

Considering the aa, ad and dd estimates, epistatic gene effects, although of minor importance in certain crosses for any one attribute, are important in general in the inheritance of the characters. The relative magnitude of the epistatic gene effects suggested that their contribution to inheritance of the attributes is greater than that of the additive gene effects. Of the individual type of epistatic effects the dominance x dominance estimates and additive x additive estimates were almost similar in magnitude in all the crosses. The cross Hi27 x Mo17 showed significant larger dominance x dominance estimates than the dominance estimates for all the attributes although the differences are small. All the crosses which were not fitted by the three parameter model showed the significant aa gene effects. The aa gene effects were all positive , suggesting an enhancing effect in the inheritance of the characters studied. In most cases, the ad gene effects and dd gene effects were negative suggesting a diminishing effect due to this type of gene effect. However, the ad gene effects were the smallest in magnitude among the crosses even though several of them were significant.

Components of genetic variation for four traits were estimated and presented in Table 65. It should be noted that these estimates of variances are not to be related to the genetic parameters described earlier. The method described by Mather and Jinks (1971, 1977) assumed no epistasis and linkage in estimating components of genetic variation. The mean variances of P_1, P_2 and F_1 provided an estimate of environmental variance (V_E) for the respective characters, whereas the values for additive variance (V_A) and dominance variance (V_D) were estimated from the variances of F_2, B_1 and B_2 populations.

In general, the environmental variance was much larger than the genetic variances (V_A and V_D). This resulted from the big variance of the non-segregating populations, i.e. P_1, P_2 and F_1. The variance of the F_1 population was especially large having the smallest sampling number. Also the parental lines were inbreds which are of low vigor and succumb to environmental fluctuations. As a result of this as well as the small variance associated with the F_2 populations in some cases, a half of the dominance variances was negative, which suggested estimates of zero variance or small positive values. The genetic variances for floret number and kernels per row were relatively larger than those of cob length and filled ear length with a few exceptions. The additive variances of cob length were relatively large except the crosses B37 x Hi27 and Mo17 x Tx601, while the additive variances of kernels per row were much smaller than environmental variances. This suggested that kernel number is subject to more environmental variation than cob length. For the traits of cob length and filled ear length, the genetic variances were much smaller than environmental variances except the crosses B37 x Hi27 and B37 x Mo17. In some crosses the environmental variances were larger than genetic variances by more than

Table 65. Genetic variances and heritability estimates for floret number, kernels per row, cob length and filled ear length

Crosses	V_A	V_D	V_E	h_n^2	h_b^2
Floret number					
B37 x Hi27	-8.74	12.42	29.59	-26.3	11.1
B37 x Mo17	16.20	-12.03	23.61	58.3	15.0
B37 x Tx601	12.93	5.24	12.93	41.6	58.4
Hi27 x Mo17	17.78	-3.56	21.51	49.7	40.0
Hi27 x Tx601	29.18	-5.32	14.14	76.8	62.8
Mo17 x Tx601	2.84	1.48	22.37	10.6	16.2
Average[a]	13.16	3.19	20.69	39.5	33.9
Kernels per row					
B37 x Hi27	14.27	-8.47	22.99	49.6	20.1
B37 x Mo17	14.51	-8.84	21.46	53.5	20.9
B37 x Tx601	9.51	-1.89	30.03	25.3	20.2
Hi27 x Mo17	-15.89	14.39	15.54	-113.2	48.1
Hi27 x Tx601	2.39	6.03	29.46	6.3	22.2
Mo17 x Tx601	-5.39	12.53	24.76	-18.9	26.7
Average	6.78	5.49	24.04	22.5	26.4
Cob length					
B37 x Hi27	4.67	-2.65	4.30	73.9	32.0
B37 x Mo17	4.88	-0.41	2.25	72.6	66.5
B37 x Tx601	0.22	-0.12	3.95	5.5	2.5
Hi27 x Mo17	0.39	0.67	3.41	8.7	23.7
Hi27 x Tx601	-9.34	10.86	3.60	-39.2	29.5
Mo17 x Tx601	0.15	0.28	3.37	3.9	11.3
Average	1.72	1.97	3.48	27.4	27.6
Filled ear length					
B37 x Hi27	2.40	-0.69	4.91	66.2	25.8
B37 x Mo17	5.50	-2.64	3.17	91.1	47.4
B37 x Tx601	0.33	0.38	4.25	6.7	14.3
Hi27 x Mo17	-0.49	1.25	3.19	-12.4	19.2
Hi27 x Tx601	-0.84	2.07	4.29	-14.0	20.4
Mo17 x Tx601	-0.77	1.86	3.39	-17.1	41.5
Average	1.37	0.33	3.95	27.3	28.1

[a] Only positive values were used to compute averages.

ten folds.

Narrow sense heritability estimates were obtained for all crosses (Table 65). Narrow sense heritability estimates of the crosses B37 x Hi27 and B37 x Mo17 were high for all characters except one case. In general, high narrow sense heritability estimates were obtained for floret number, while low heritability estimates were common for other characters. On average the heritability estimates was 39.5 % for floret number and lower than 30 % for other characters. Broad sense heritability estimates were also computed using the three non-segregating populations to estimate environmental variance. The broad sense heritability estimates were lower than those of narrow sense heritability in many cases because of negative dominaece variance. Average estimates of broad sense heritability were about 34 % for floret number and 26 to 28 % for kernels per row, cob length and filled ear length.

The minimum number of genetic factors affecting floret number, kernels per row, cob length and filled ear length was estimated by Castle-Wright's (Frey, 1949) and Sewall Wright's (Burton, 1951) formulae (Table 66). On the average, it was found that relatively few genetic factors were involved in control of floret number, while a rather complex inheritance pattern for other traits was indicated by relatively large number of genetic factors. Although two formulae were used to estimate the minimum number of genetic factors, Sewall Wright's formula (Burton, 1951) is more appropriate for this study because dominance exists in all the crosses. Estimates of minimum 3 genetic factors for floret number and minimum 5 to 8 genetic factors for kernels per row, cob length and filled ear length were obtained. Although only 3 genetic

Table 66. Estimates of minimum number of genetic factors controlling floret number, kernels per row, cob length and filled ear length

Characters	Crosses	Castle-Wright	Sewall Wright
Floret number	B37 x Hi27	0.15	0.19
	B37 x Mo17	1.88	2.08
	B37 x Tx601	1.80	8.51
	Hi27 x Mo17	1.31	3.74
	Hi27 x Tx601	0.40	0.40
	Mo17 x Tx601	0.77	2.31
	Average	1.05	2.87
Kernels per row	B37 x Hi27	0.14	3.31
	B37 x Mo17	8.28	11.05
	B37 x Tx601	0.19	2.66
	Hi27 x Mo17	9.09	20.66
	Hi27 x Tx601	0.43	3.75
	Mo17 x Tx601	1.63	1.77
	Average	3.29	7.20
Cob length	B37 x Hi27	0.08	5.52
	B37 x Mo17	1.26	1.26
	B37 x Tx601	0.02	1.42
	Hi27 x Mo17	4.61	9.58
	Hi27 x Tx601	0.31	5.68
	Mo17 x Tx601	9.75	10.05
	Average	2.67	5.59
Filled ear length	B37 x Hi27	0.01	1.70
	B37 x Mo17	1.96	2.67
	B37 x Tx601	0.03	8.57
	Hi27 x Mo17	4.07	8.33
	Hi27 x Tx601	0.06	4.32
	Mo17 x Tx601	3.35	4.34
	Average	1.58	4.99

factors controlled floret number, the F_2 distribution of all the crosses were rather smooth and continuous. This was due to the larger non-genetic variances than the genetic variances for all the crosses (Table 65).

4.4.2 Discussion

The analysis used for the generation mean analysis was based on unweighted least squares, whereas Mather and Jinks (1971, 1977) and Hayman (1958) used weighted least squares. The different generations included are expected to contain different amounts of genetic variability. To compensate partly for this, larger number of rows were included of the more genetically variable generations. Since it is unlikely the differences in number of rows would exactly compensate for differences in variability, the justfication for using unweighted least squares might be improper. However, the weights in the weighted analysis must be estimated from the data and they would add extraneous variability which might be sufficient to offset any advantage the weighted analysis might have (Moll et al., 1963). Moll et al. (1963) compared weighted and unweighted least squares for the analysis of generation means of corn for resistance to brown spot and observed no difference in terms of fraction of variance accounted for by fitting genetic effects.

The genetic models used in the study of quantitative inheritance have involved certain assumptions in order to simplify statistical procedures. Some of the assumptions are more important than others in causing bias in the estimates of gene effects. The assumptions listed by Anderson and Kempthorne (1954) are (1) multiple alleles absent, (2) linkages absent, (3) lethal genes absent, (4) constant viability for all genotypes, and (5) environmental effects are additive with the genotypic value. Since the segregating populations used in the generation mean analysis are the F_2 and first backcross generations of a cross between two presumably homozygous lines, multiple allels would not be present. Also lethal genes are not likely to be present in the crosses since parental inbred lines have been maintained by selfing for many generations. Viability may not be constant for all genotypes but was satisfactory in the test and no bias would be expected. The presence of linkage among genes may cause important bias in the estimates of the additive x additive and dominance x dominance effects. However, apparant linkage bias might be due to trigenic or higher epistasis which are not considered in these models (Gamble, 1962; Kempthorne, 1957). The bias caused by the genotype-environment interactions which were assumed to be additive is of unknown magnitude and direction since the material was tested in only one environment.

In all of the attributes, the F_1 population mean was greater than the better parental population means for all the crosses except the cross Hi27 x Mo17. This advantage in performance of the F_1 was greater for kernels per row and filled ear length than floret number and cob length. There seems to be an association between the advantage of the F_1 performance over the better parent performance and the relative importance of the dominance gene effects in the inheritance of characters studied for the generation mean analysis. The importance of dominance gene effects for an attribute will be indicated by the relative performance of the F_1 mean to the better parent mean. If the F_1 performs better than the better parent, dominance effects will generally be the most important in inheritance and the relative importance becomes greater as the advantage of the F_1 mean over the better parent mean becomes greater.

Although the majority of the crosses exhibited significant estimates of additive gene effects which indicated the presence of additive variation in the inheritance of floret number and kernels per row, the magnitude of the estimates suggest that additive gene effects are less important than the other types of gene effects. This is more apparent for cob length and filled ear length for which fewer crosses showed significant additive gene effect. Gamble (1962) also showed that dominance gene effects are more important than additive gene effects in the inheritance of ear length as well as other characters such as grain yield, plant and ear heights and seed weight. However, when random mating populations were used to estimate gene actions, the additive gene effect is, generally, the most important in inheritance of agronomic traits (Stuber and Moll, 1969 and 1971).

For the material used in this study, epistatic gene effects are present in sufficient magnitude to be considered important in the inheritance of four characters studied. They are relatively more important than additive gene effects, but generally less important than the dominance gene effects. All aa gene effects are positive indicating an enhancing effect on performance while dd gene effects are negative giving a diminishing effect. The dd gene effects always have a positive coefficient in the expectation equation for any generation mean (Hayman, 1958). Thus, a negative estimates of these gene effects will have a diminishing effect (Gamble, 1962). Since all significant estimates of dd gene effects for the characters were negative, these gene effects are undesirable form of epistasis. It is quite significant in certain crosses such as B37 x Tx601 for floret number and kernels per row and Hi27 x Mo17 for cob length and filled ear length.

Comstock and Robinson (1948) presented theoretical derivations on the estimates of additive genetic and non-additive variance portions. Several basic assumptions in the derivation of variances and the genetic interpretation should be considered. The assumptions of diploid organism, no multiple alleles, an absence of linkage, and no epistasis are undoubtedly applicable in these kinds of studies. The negative dominance variance estimates were obtained in the study. One possible explanation was that of sampling error. The actual existence of negative dominance variance is not in question, since as Robinson et al. (1955) pointed out, variances, by definition, are never negative. If sampling error were the only contribution, repeated sampling of a tested material in which the dominance variance is zero should give estimates fluctuating about zero. For the floret number and kernels per row the dominance variances were large indicating some factors other than sampling error may have been operating. Also positive and negative genetic factors which tend to cancel in the expression of means will contribute to variances, and it is not unreasonable that a variance analysis will detect variation that is not manifested among the means. The mean analysis also indicated that the presence of epistatic effects in these crosses which could not be separated from estimates of genetic and environmental variances in the analysis of generation means unless include more generations derived from these crosses. Moll et al. (1963) also noticed the discrepancies between variance estimates and the analysis of means. The discrepancies were varied depending on the cross estimated. According to Lawrence and Jinks (1973), the additive variance component would be underestimated if the model used was inadequate.

If additive effects have only minor importance in the total variation of performance of characters, more rapid advance will be made in a breeding program which emphasize recurrent selection and epistasis. The reciprocal recurrent selection may be the one which meets the requirement (Comstock et at., 1949). This procedure designed to be equally effective for both additive and non-additive gene effects. Theoretical considerations indicate that the procedure would be superior to recurrent selection for general combining ability if non-additive gene effects or overdominance effects were important. It would be more effective than recurrent selection for specific combining ability if additive gene effects are important.

In summary, all the gene effects were found to contribute to inheritance of the attributes in the crosses studied. However, not all gene effects are present in all crosses. The dominance gene effects were the most important contributors to the inheritance of the characters studied. Additive gene effects were of minor importance in controlling variation in the materials used. Additive x additive epistasis and dominance x dominance epistasis effects appeared to contribute more or less equally to the inheritance of floret number, kernels per row, cob length and filled ear length, but additive x additive epistasis was more important among the crosses. Environmental variances were greater than genetic variances and heritability estimates were generally low except a few cases. The minimum number of genetic factor was 3 for floret number and 5 to 8 for kernels per row, cob length and filled ear length.

5. CONCLUSION

Testing a diallel set in seasonal environments has provided very useful information for corn breeding programs. Genetic information, the nature of the genotype-environment interaction and identification of climatic factors responsible for this interaction were obtained. Corn growth in seasonal environments, where solar radiation is the single most important factor, followed the cyclic change of solar radiation. The response of kernel number, ear length and grain yield to these environments was the same. Small change of solar radiation under low solar radiation level has greater effect on kernel number, ear length and grain yield. Therefore, the effect of extended growing period due to low temperature in winter season was important for the compensation of this low irradiance condition.

Although kernel number was mainly responsible for variation in grain yield, quite stable floret number indicated that sink strength or limitations at the source rather than a limited sink size for higher grain yield. Further studies on physiological components such as leaf area index, leaf area duration, grain filling period and grain growth rate should provide more profound understanding of yield determination through kernel number.

Temperate inbreds were capable of high performance under favorable environments for kernel number and ear length, while tropical inbreds appeared to perform better under unfavorable conditions. The hybrids between temperate and tropical inbreds, thus, performed better in a wide range of environments. The genotype-environment interaction was primarily due to response of additive genes to environments. The stability of hybrids was obtained from parental lines with negative linear response of GCA effects to environments.

Since stability in seasonal environments was basically response to solar radiation change, regression analysis of stability parameter was found to be useful method to identify any genotypes tolerant to light stress. For the same reason, this regression analysis could be used to identify genotypes tolerant to environmental stress coused by one or two predominant environmental factors.

The dominance gene effects were the most important contributor to the inheritance of floret number, kernels per row, cob length and filled ear length. Inheritance of floret number was found to be relatively simple with the minimum number of genetic factors of 3, while inheritance of kernels per row, cob length and filled ear length was rather complex with the minimum number of genetic factors of 5 to 8.

APPENDIX

Appendix 1. Analyses of variances of plant characters and means of 15 hybrids for each planting in monthly plantings

	F-tests for hybrids			Means		
Months	Days to mid-silking	Plant height	Ear height	Days to mid-silking	Plant height	Ear height
Aug. '77	**	n.s.	n.s.	50.9	250	108
Sep. '77	**	n.s.	n.s.	53.6	228	98
Oct. '77	**	n.s.	*	57.2	224	87
Nov. '77	**	n.s.	**	59.6	207	71
Dec. '77	**	n.s.	**	62.4	202	70
Jan. '78	**	**	**	62.9	228	93
Feb. '78	**	**	**	59.8	229	91
Mar. '78	*	n.s.	*	56.6	226	86
Apr. '78	**	n.s.	*	56.1	249	99
May '78	**	n.s.	**	52.8	218	92
Jun. '78	**	**	**	53.0	255	107
Jul. '78	**	n.s.	n.s.	54.3	243	103
Aug. '78	**	n.s.	*	52.9	228	91
Sep. '78	**	n.s.	**	57.4	222	94
Oct. '78	**	*	**	59.3	182	64
Dec. '78	**	*	n.s.	70.5	137	45
Jan. '79	**	**	**	74.8	174	50
Feb. '79	**	**	**	71.1	193	61
Mar. '79	**	**	**	62.1	243	89
Apr. '79	*	**	**	57.3	259	105
May '79	**	*	**	53.7	235	84

[*] Significant at 5 % probability level.

[**] Significant at 1 % probability level.

[n.s.] Non-significant.

Appendix 2. Number of days to mid-silking of 15 hybrids in monthly plantings

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	52.0	50.0	50.8	47.6	50.8	52.3	52.0	49.3	51.9	50.0	50.4	54.7	48.5	52.7	50.8	50.9
Sep. '77	53.2	50.8	53.4	48.3	53.5	56.6	55.0	52.8	55.2	51.4	51.7	58.6	54.1	55.7	54.1	53.6
Oct. '77	56.7	55.8	56.6	54.6	57.9	59.9	57.9	56.0	58.3	57.3	54.8	62.1	54.0	59.3	56.5	57.2
Nov. '77	60.7	57.7	59.7	55.0	60.3	62.4	61.2	57.5	61.4	58.7	56.7	64.2	56.8	62.4	61.0	59.6
Dec. '77	61.5	60.0	61.1	59.1	64.1	65.4	63.3	60.5	65.8	61.3	59.8	66.4	58.9	66.9	62.8	62.4
Jan. '78	63.8	62.5	60.9	58.3	63.9	64.7	63.9	61.0	67.0	62.8	60.0	67.1	59.7	65.9	63.3	62.9
Feb. '78	59.5	58.5	58.3	56.9	60.8	61.2	58.6	57.8	63.2	60.3	58.0	64.4	56.3	62.6	61.4	59.8
Mar. '78	56.2	56.2	55.5	55.6	57.4	57.2	55.9	54.3	58.8	56.4	54.4	60.6	55.6	57.6	58.2	56.6
Apr. '78	55.2	56.9	54.0	52.7	57.7	57.1	55.3	54.1	58.1	56.3	53.4	62.5	53.5	58.1	56.4	56.1
May '78	53.5	54.0	50.0	50.8	53.5	54.1	51.1	52.5	56.5	52.7	50.4	56.4	50.0	53.0	54.0	52.8
Jun. '78	52.3	53.9	50.0	53.3	53.1	55.4	51.8	52.0	56.4	52.0	53.4	56.8	49.4	52.5	53.2	53.0
Jul. '78	54.2	53.4	51.2	51.3	55.1	53.6	55.0	55.7	57.5	54.3	52.4	57.7	50.0	57.6	56.2	54.3
Aug. '78	53.2	54.5	49.9	51.5	53.2	55.9	53.4	49.0	57.9	52.6	51.1	56.7	49.0	54.1	52.4	52.9
Sep. '78	55.2	59.8	53.6	51.5	56.7	57.7	55.4	56.8	62.9	54.6	57.8	62.5	53.8	62.5	60.7	57.4
Oct. '78	59.0	60.1	54.4	54.7	59.9	62.4	59.0	57.0	61.8	60.2	59.2	63.6	55.8	62.5	60.0	59.3
Dec. '78	70.2	71.9	67.8	67.1	70.0	73.7	72.7	67.6	73.5	70.4	67.9	73.9	69.5	72.1	70.1	70.5
Jan. '79	75.1	81.2	70.7	69.4	75.5	79.7	76.9	71.2	78.3	73.1	71.7	77.6	70.8	76.2	74.9	74.8
Feb. '79	70.5	74.5	67.6	67.6	67.2	72.1	70.8	72.4	68.7	75.3	69.4	74.9	67.8	73.0	73.5	71.1
Mar. '79	59.9	64.8	58.1	58.9	62.5	63.7	62.4	59.4	65.1	65.6	61.1	64.3	58.1	65.3	63.9	62.1
Apr. '79	56.9	58.1	54.5	53.8	57.7	58.3	58.0	55.7	60.7	56.4	56.3	60.6	53.6	58.7	60.4	57.3
May '79	53.4	51.5	50.5	51.7	53.9	56.2	53.6	53.7	58.6	52.8	53.4	57.5	50.1	55.0	53.5	53.7
Mean	58.6	59.3	56.5	55.7	59.5	60.8	59.2	57.2	62.1	58.4	57.3	63.0	55.9	61.1	59.8	59.0

1 = B37, 2 = B68(Hi31), 3 = Hi27 (CM104), 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 3. Plant height of 15 hybrids in monthly plantings

(unit :cm)

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	244	240	246	239	272	246	265	260	259	246	263	236	245	244	243	250
Sep. '77	236	212	217	227	246	218	241	243	238	226	231	223	220	215	220	228
Oct. '77	222	214	212	210	239	226	240	235	234	227	221	225	219	212	219	224
Nov. '77	201	190	207	187	220	206	218	197	214	194	205	224	202	220	223	207
Dec. '77	200	184	198	201	207	197	212	203	220	186	196	196	202	207	219	202
Jan. '78	235	220	232	216	238	228	232	235	230	204	212	235	225	237	245	228
Feb. '78	228	213	231	222	241	228	229	227	249	210	206	236	222	235	251	229
Mar. '78	213	215	210	228	241	213	231	229	235	222	214	243	210	242	243	226
Apr. '78	235	245	243	243	260	239	236	254	288	247	228	257	259	234	264	249
May '78	215	215	209	212	232	219	221	215	234	214	222	206	216	214	225	218
Jun. '78	222	250	259	248	259	265	253	266	272	242	253	236	263	251	285	255
Jul. '78	222	243	235	251	249	246	256	219	264	227	247	252	259	216	255	243
Aug. '78	201	212	227	215	240	225	230	229	239	230	213	232	235	241	253	228
Sep. '78	234	209	227	222	217	213	231	220	226	214	215	224	232	210	234	222
Oct. '78	174	179	177	169	180	170	181	188	196	168	169	188	183	190	210	182
Dec. '78	136	128	127	141	143	132	137	138	157	116	133	144	130	131	154	137
Jan. '79	169	159	164	177	187	151	168	181	201	154	172	161	180	187	197	174
Feb. '79	180	174	190	190	206	180	186	201	216	178	181	211	188	192	225	193
Mar. '79	237	231	237	239	244	216	235	239	274	239	232	234	246	261	278	243
Apr. '79	243	254	226	243	271	235	257	258	285	241	252	268	271	273	305	259
May '79	207	231	222	218	245	234	221	239	254	230	230	252	235	259	252	235
Mean	212	210	214	214	231	214	223	223	228	210	214	223	221	223	238	221

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 4. Ear height of 15 hybrids in monthly plantings

(unit : cm)

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	106	107	102	88	103	118	119	101	112	121	114	122	90	114	96	108
Sep. '77	94	94	94	80	102	98	106	92	113	109	102	105	86	109	88	98
Oct. '77	86	83	77	69	92	95	90	79	95	99	86	107	74	96	74	87
Nov. '77	72	68	68	58	77	75	71	54	77	74	70	95	56	79	71	71
Dec. '77	63	63	62	60	73	75	74	62	89	70	67	85	57	77	87	70
Jan. '78	89	85	91	81	96	102	98	85	101	91	88	106	81	103	96	93
Feb. '78	86	85	92	74	99	96	91	76	109	86	84	113	73	102	97	91
Mar. '78	75	82	75	79	93	91	93	83	94	90	82	111	65	96	82	86
Apr. '78	94	103	93	79	103	101	94	85	120	103	86	136	88	95	95	99
May '78	86	94	80	72	105	97	99	79	102	94	92	113	68	94	103	92
Jun. '78	96	114	104	83	113	119	104	92	113	105	113	122	92	116	114	107
Jul. '78	90	110	101	87	111	115	106	71	117	101	103	129	100	88	107	103
Aug. '78	73	79	90	70	105	83	94	89	98	100	90	107	89	100	93	91
Sep. '78	94	99	76	77	91	97	95	83	109	93	94	114	88	97	103	94
Oct. '78	56	63	64	52	64	60	63	61	76	54	58	79	62	66	73	64
Dec. '78	42	43	40	38	51	44	40	41	59	40	39	60	35	44	54	45
Jan. '79	40	48	36	41	56	49	39	50	70	45	57	55	49	57	58	50
Feb. '79	53	63	49	47	56	68	57	60	86	55	54	86	47	55	78	61
Mar. '79	83	95	80	66	84	88	84	73	116	99	82	102	72	104	106	89
Apr. '79	91	112	81	78	102	111	105	85	127	100	97	134	93	120	131	105
May '79	68	91	73	63	81	92	78	73	95	83	76	105	80	105	94	84
Mean	78	85	78	69	89	89	86	75	99	87	83	104	74	91	90	85

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 5. Analysis of variance for each planting: Significance of hybrid mean squares for the ear characters

Months	Cob length	Floret number	Filled ear length	Row number	Kernels per row	Kernels per ear	100 kernel weight	Grain yield
Aug. '77	n.s.	*	n.s.	*	n.s.	n.s.	n.s.	n.s.
Sep. '77	n.s.	**	n.s.	n.s.	n.s.	n.s.	**	n.s.
Oct. '77	**	**	*	**	n.s.	*	**	n.s.
Nov. '77	**	*	**	n.s.	**	**	**	**
Dec. '77	**	**	**	n.s.	**	**	n.s.	*
Jan. '78	*	**	n.s.	**	**	*	n.s.	n.s.
Feb. '78	**	**	**	**	**	*	**	**
Mar. '78	n.s.	**	*	*	**	*	*	n.s.
Apr. '78	*	**	**	*	**	**	*	n.s.
May '78	*	n.s.	*	n.s.	**	**	n.s.	n.s.
Jun. '78	**	**	**	n.s.	**	**	n.s.	*
Jul. '78	n.s.	*	n.s.	n.s.	n.s.	n.s.	**	n.s.
Aug. '78	*	**	n.s.	n.s.	*	**	**	*
Sep. '78	n.s.	-	n.s.	n.s.	n.s.	n.s.	**	n.s.
Oct. '78	**	**	**	n.s.	**	**	**	*
Dec. '78	*	**	*	n.s.	**	**	n.s.	**
Jan. '79	**	**	*	n.s.	**	*	**	*
Feb. '79	**	**	*	n.s.	*	**	**	*
Mar. '79	*	**	*	*	**	**	n.s.	**
Apr. '79	*	**	n.s.	*	n.s.	n.s.	**	n.s.
May '79	**	**	*	*	n.s.	*	n.s.	n.s.

* Significant at 5 % probability level.

** Significant at 1 % probability level.

n.s. Non-significant.

Appendix 6. Homogeneity tests of variances for several agronomic characters in monthly plantings

Characters	Mean variances over 21 plantings	Range of variances	Chi-squares	Probability
Cob length	1.20	0.59 - 2.34	28.71	0.10-0.05
Floret number	7.52	1.96 - 8.10	23.99	0.10-0.05
Filled ear length	1.48	0.58 - 3.03	16.87	0.75-0.50
Kernels per row	8.39	3.78 -13.94	23.95	0.25-0.10
Row number	6.48	2.45 -14.70	10.77	0.98-0.95
Kernels per ear	22.98	10.04 -52.02	29.79	0.10-0.05
100 kernel weight	4.58	2.35 - 8.06	16.51	0.75-0.50
Grain yield	11.25	0.20 - 2.87	42.24	0.005
Grain yield (excluding July, '78 and April, '79)			27.17	0.50-0.25

Appendix 7. Mean values and environmental index of several agronomic characters over 15 hybrids

	Cob length		Floret number		Filled ear length		Kernels per row	
Months	Mean	Index	Mean	Index	Mean	Index	Mean	Index
Aug. '77	16.8	0.57	54.5	0.57	13.9	0.08	31.8	0.37
Sep. '77	14.5	-1.72	54.3	0.31	12.3	-1.55	27.4	-4.12
Oct. '77	14.8	-1.44	54.8	-0.31	11.8	-2.02	27.6	-3.91
Nov. '77	12.8	-3.43	54.8	0.80	10.0	-3.90	23.0	-8.43
Dec. '77	13.8	-2.37	52.7	-1.27	11.4	-2.44	26.4	-5.04
Jan. '78	16.9	0.72	54.4	0.41	14.9	1.00	34.4	2.89
Feb. '78	17.1	0.86	56.2	2.24	15.2	1.30	34.2	2.72
Mar. '78	16.1	-0.12	57.1	3.11	14.3	0.43	32.8	1.27
Apr. '78	17.3	1.04	55.8	1.79	15.1	1.24	34.0	2.53
May '78	17.3	1.06	52.1	-1.89	14.5	0.63	32.4	0.91
Jun. '78	18.2	1.95	54.4	0.40	16.3	2.46	36.5	5.07
Jul. '78	17.9	1.70	55.3	1.30	16.0	2.13	34.7	3.17
Aug. '78	16.9	0.72	54.4	0.48	15.0	1.10	33.4	1.94
Sep. '78	14.1	-2.09	-	-	12.3	-1.61	26.4	-5.06
Oct. '78	11.4	-4.81	50.2	-3.78	9.1	-4.75	21.0	-10.46
Dec. '78	13.2	-3.02	51.7	-2.24	10.3	-3.59	22.4	-9.04
Jan. '79	16.2	-0.01	52.5	-1.47	13.4	-0.47	31.5	0.00
Feb. '79	17.4	1.21	54.2	0.28	14.8	0.95	35.0	3.48
Mar. '79	19.8	3.61	53.3	-0.62	17.7	3.82	40.6	9.08
Apr. '79	19.7	3.50	53.1	-0.85	17.4	3.52	39.9	8.42
May '79	18.3	2.09	54.7	0.74	15.5	1.65	35.7	4.19

Appendix 7. (Continued) Mean values and environmental index of several agronomic characters over 15 hybrids

	Row number		Kernels per ear		100 kernel weight(g)		Grain yield (T/ha)	
Months	Mean	Index	Mean	Index	Mean	Index	Mean	Index
Aug. '77	14.0	-0.28	446	-7	30.2	0.96	8.22	0.37
Sep. '77	14.5	0.19	396	-57	29.9	0.67	6.94	-0.90
Oct. '77	13.9	-0.36	385	-68	31.9	2.72	7.20	-2.82
Nov. '77	13.7	-0.58	317	-136	26.6	-2.62	5.02	-2.82
Dec. '77	14.0	-0.32	370	-83	23.7	-5.53	5.57	-2.27
Jan. '78	15.0	0.72	515	62	26.3	-2.88	8.67	0.82
Feb. '78	14.2	-0.11	484	31	31.5	2.27	9.40	2.55
Mar. '78	14.6	0.28	479	26	28.1	-1.10	8.20	0.36
Apr. '78	14.6	0.26	496	43	28.9	-0.30	8.72	0.87
May '78	15.1	0.83	492	39	28.3	-0.91	8.11	0.26
Jun. '78	15.1	0.76	550	97	31.3	2.07	10.39	2.54
Jul. '78	14.2	-0.06	494	41	32.1	2.93	9.35	2.50
Aug. '78	14.8	0.48	495	42	28.4	-0.80	7.96	0.11
Sep. '78	13.9	-0.39	368	-85	30.8	1.61	6.56	-1.28
Oct. '78	12.7	-1.64	267	-186	27.3	-1.87	3.52	-4.32
Dec. '78	13.7	-0.60	307	-146	29.1	-0.07	4.19	-3.65
Jan. '79	13.6	-0.71	427	-26	28.7	-0.49	6.90	-0.94
Feb. '79	14.1	0.05	501	48	29.0	-0.22	8.77	0.92
Mar. '79	14.9	0.64	606	153	32.0	2.76	11.60	3.75
Apr. '79	14.7	0.38	586	133	30.9	1.73	10.58	2.73
May '79	14.7	0.44	525	72	28.3	-0.91	8.85	1.00

Appendix 8. Mean values and phenotypic index of several agronomic characters of 15 hybrids over 21 monthly plantings

	Cob length		Floret number		Filled ear length		Row number	
Hybrids	Mean	Index	Mean	Index	Mean	Index	Mean	Index
B37 x B68	15.4	-0.77	55.8	1.85	12.2	-1.67	13.6	-0.65
B37 x Hi27	14.4	-1.81	51.0	-3.00	11.8	-2.05	14.3	0.01
B37 x Mp68:616	15.2	-1.02	51.6	-2.33	13.5	-0.34	13.8	-0.53
B37 x Oh545	16.5	0.33	56.4	2.47	14.0	0.12	13.3	-1.01
B37 x Tx601	15.6	-0.60	57.9	3.90	13.5	-0.32	14.0	-0.32
B68 x Hi27	15.4	-0.77	50.3	-3.62	12.4	-1.41	14.6	0.29
B68 x Mp68:616	17.0	0.81	52.9	-1.05	14.8	0.92	14.5	0.22
B68 x Oh545	18.0	1.76	59.0	5.06	14.7	0.90	14.2	-0.05
B68 x Tx601	16.7	0.52	56.3	2.29	14.3	0.40	14.7	0.43
Hi27 x Mp68:616	15.9	-0.36	46.9	-7.02	14.0	0.09	15.2	0.92
Hi27 x Oh545	16.9	0.70	52.5	-1.46	14.6	0.78	14.2	-0.13
Hi27 x Tx601	15.4	-0.83	54.1	0.13	13.4	-0.48	15.0	0.67
Mp68:616 x Oh545	17.5	1.30	52.1	-1.84	15.4	1.58	14.0	-0.34
Mp68:616 x Tx601	15.7	-0.55	53.6	-0.35	14.0	0.12	14.6	0.34
Oh545 x Tx601	17.5	1.29	58.9	4.97	15.2	1.34	14.4	0.15
BLSD (0.05)	1.38		3.25		1.53		1.05	

Appendix 8. (Continued) Mean values and phenotypic index of several agronomic characters of 15 hybrids over 21 monthly plantings

	Kernels per row		Kernels per ear		100 kernel weight		Grain yield	
Hybrids	Mean	Index	Mean	Index	Mean	Index	Mean	Index
B37 x B68	26.5	-4.94	364	-88.7	32.2	2.97	6.90	-0.94
B37 x Hi27	25.9	-5.55	373	-79.9	30.3	1.05	6.52	-1.33
B37 x Mp68:616	32.4	0.89	448	-5.0	27.9	-1.34	7.54	-0.30
B37 x Oh545	31.2	-0.29	417	-35.6	29.4	0.22	7.07	-0.78
B37 x Tx601	32.5	1.04	458	5.4	28.9	-0.27	7.93	0.08
B68 x Hi27	25.5	-5.98	375	-77.3	31.3	2.11	6.95	-0.90
B68 x Mp68:616	33.2	1.76	484	31.3	29.1	-0.07	8.47	0.62
B68 x Oh545	31.7	0.22	454	1.4	31.4	2.18	8.48	0.63
B68 x Tx601	31.3	-0.16	463	10.6	31.3	2.09	8.67	0.82
Hi27 x Mp68:616	32.3	0.84	496	42.9	26.7	-2.48	7.90	0.05
Hi27 x Oh545	33.5	1.98	476	22.9	29.0	-0.23	8.26	0.42
Hi27 x Tx601	31.5	0.02	474	21.4	26.6	-2.58	7.67	-0.18
Mp68:616 x Oh545	34.7	3.26	487	34.2	27.9	-1.31	8.12	0.28
Mp68:616 x Tx601	35.2	3.67	518	65.3	27.0	-2.23	8.39	0.54
Oh545 x Tx601	34.7	3.24	503	50.8	29.1	-0.10	8.81	0.96
BLSD (0.05)	3.69		59.8		2.71		1.71	

Appendix 8-A. Average floret number, kernels per row and filled ear length (cm) of 15 hybrids over 21 monthly plantings

Inbreds	B68	Hi27	Mp68:616	Oh545	Tx601	Array mean
B37	55.8[a]	51.0	51.6	56.4	57.9	55.5
	26.5	25.9	32.4	31.5	32.5	29.7
	12.2	11.8	13.5	14.0	13.5	13.0
B68		50.3	52.9	59.0	55.2	54.8
		25.5	33.2	31.7	31.3	29.6
		12.4	14.8	14.7	14.3	13.7
Hi27			46.9	52.5	54.0	51.9
			32.3	33.5	31.5	29.7
			14.0	14.6	13.4	13.2
Mp68:616				52.1	53.6	51.4
				34.7	35.2	33.6
				15.4	14.0	14.3
Oh545					58.9	55.8
					34.7	33.2
					15.2	14.8
Tx601						56.2
						33.0
						14.1

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[a] Upper, middle and lower values are floret number, kernels per row and filled ear length, respectively.

BLSD (0.05) Floret number = 4.59
Kernels per row = 5.13
Filled ear length = 2.13

Appendix 9. Number of florets per row of 15 hybrids in monthly plantings

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	53.2	55.7	52.7	59.5	57.8	55.5	46.0	56.7	55.0	50.0	50.9	58.6	52.0	57.2	57.5	54.5
Sep. '77	55.8	52.7	51.1	57.3	59.5	51.4	51.5	59.5	58.3	46.4	54.1	50.3	53.4	55.6	57.2	54.3
Oct. '77	57.8	47.9	48.0	53.5	60.7	55.6	48.2	57.5	57.1	46.0	56.0	54.2	49.6	51.1	61.4	54.8
Nov. '77	56.2	52.8	50.8	57.3	58.4	50.8	55.2	56.8	58.5	49.3	52.4	56.4	54.2	51.5	61.1	54.8
Dec. '77	53.4	52.5	48.3	54.0	58.7	48.4	51.6	57.5	56.1	44.9	48.3	54.7	51.6	53.4	56.9	52.7
Jan. '78	57.3	52.7	56.0	56.6	58.5	49.1	53.9	61.1	58.2	47.7	51.7	46.3	54.2	52.6	59.7	54.4
Feb. '78	60.0	54.5	54.4	57.5	58.8	51.7	56.9	62.9	56.6	48.4	56.3	55.4	53.1	55.6	60.9	56.2
Mar. '78	57.5	53.8	55.9	60.3	59.7	55.0	55.7	63.0	62.5	48.3	56.0	56.8	53.1	56.5	62.0	57.1
Apr. '78	58.1	51.8	54.1	59.9	60.7	50.1	52.7	62.7	58.8	47.6	55.2	57.5	52.8	56.4	57.9	55.8
May '78	54.0	49.0	54.8	59.7	52.6	49.6	57.5	54.0	44.7	48.8	53.1	47.0	49.5	50.1	56.6	52.1
Jun. '78	58.2	52.6	54.2	54.2	58.8	50.6	53.7	58.8	57.2	45.8	53.2	55.7	51.8	52.3	58.3	54.4
Jul. '78	59.6	51.0	52.3	58.5	60.0	48.8	52.4	59.9	58.1	49.4	53.9	56.6	50.9	55.3	62.2	55.3
Aug. '78	58.4	52.9	51.1	57.1	57.0	48.6	45.5	60.4	55.7	49.3	52.2	56.6	51.7	58.9	61.3	54.4
Sep. '78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oct. '78	52.1	45.0	46.2	51.6	57.6	46.0	49.6	56.0	53.4	43.9	46.2	49.4	50.4	49.3	55.3	50.2
Dec. '78	51.3	47.6	45.7	52.0	55.9	48.4	52.9	55.9	55.5	41.9	51.1	53.6	52.8	52.3	58.8	51.7
Jan. '79	54.2	45.4	49.2	54.7	57.7	48.8	51.6	58.5	53.3	44.9	49.7	55.5	51.5	51.5	60.9	52.5
Feb. '79	53.1	49.7	52.5	56.2	55.5	52.2	57.7	63.9	54.6	47.0	50.9	55.8	52.1	53.4	59.3	54.2
Mar. '79	53.3	51.6	49.5	56.6	56.6	46.7	55.9	60.4	59.2	47.3	50.1	54.4	49.8	53.3	55.6	53.3
Apr. '79	53.2	50.1	52.3	56.4	55.9	51.3	55.4	55.8	55.4	46.6	50.8	51.8	51.9	52.7	57.0	53.1
May '79	59.4	49.9	53.5	55.9	57.1	47.7	54.5	59.2	56.9	45.4	57.9	55.1	55.9	53.2	58.9	54.7
Mean	55.8	51.0	51.6	56.4	57.9	50.3	52.9	59.0	56.3	46.9	52.5	54.1	52.1	53.6	58.9	54.0

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 10. Number of kernels per row of 15 hybrids in monthly plantings

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	29.2	28.9	34.2	33.1	34.8	28.5	30.3	26.4	30.9	33.1	34.5	30.9	32.5	35.0	35.2	31.8
Sep. '77	24.1	23.4	27.6	27.3	29.7	20.3	27.7	28.5	28.3	29.7	31.1	25.2	30.1	27.6	29.8	27.4
Oct. '77	24.2	21.8	29.4	23.7	27.4	25.3	29.7	28.1	27.7	29.1	27.2	30.4	26.8	31.4	31.3	27.6
Nov. '77	16.0	17.3	22.6	17.9	21.9	15.0	24.6	23.5	24.0	26.6	25.1	26.0	25.7	33.1	26.1	23.0
Dec. '77	17.4	20.0	28.5	23.2	28.2	20.5	33.6	23.7	27.7	28.3	26.5	26.9	30.9	34.1	27.0	26.4
Jan. '78	30.8	29.3	37.4	35.4	39.2	28.2	38.5	35.4	31.2	36.7	37.6	27.9	36.6	37.1	34.3	34.4
Feb. '78	28.6	28.6	37.9	36.9	34.5	31.0	38.7	35.1	35.1	35.8	31.1	28.2	37.3	38.1	35.9	34.2
Mar. '78	24.3	25.9	30.9	34.1	32.9	25.8	34.9	33.8	36.1	31.3	36.1	37.4	36.6	36.0	35.2	32.8
Apr. '78	28.0	27.0	36.8	34.6	34.9	24.0	37.2	35.1	36.3	37.0	33.5	32.2	39.0	37.8	36.8	34.0
May '78	25.7	24.3	33.8	34.1	34.4	22.0	38.0	26.9	30.0	35.1	36.8	34.7	35.0	37.4	37.7	32.4
Jun. '78	32.0	28.1	37.3	35.9	36.9	29.9	38.2	36.1	32.9	35.6	40.9	36.4	40.8	44.1	43.1	36.5
Jul. '78	28.7	31.6	40.0	36.3	35.2	28.9	36.8	33.4	31.0	36.1	37.3	35.6	40.3	33.3	35.3	34.7
Aug. '78	26.2	30.6	33.8	34.0	34.2	28.2	33.2	32.5	32.0	35.1	36.3	35.6	41.0	31.3	37.5	33.4
Sep. '78	24.3	21.5	23.9	25.4	25.8	21.1	31.2	28.4	30.3	28.5	28.5	27.0	29.1	26.8	24.4	26.4
Oct. '78	15.8	16.4	22.6	17.4	23.3	15.6	20.6	20.1	22.1	20.5	21.7	21.1	22.3	28.8	26.9	21.0
Dec. '78	17.8	17.4	19.5	21.3	19.9	16.8	21.6	25.3	21.9	23.3	21.2	25.5	29.0	29.1	26.9	22.4
Jan. '79	26.1	26.3	30.3	31.3	31.2	28.1	32.5	34.8	32.5	29.7	33.8	29.3	35.6	36.4	34.4	31.5
Feb. '79	30.5	26.4	34.7	36.1	40.1	29.1	32.7	36.9	37.0	34.9	36.9	34.1	35.0	37.1	43.1	35.0
Mar. '79	38.4	33.2	42.3	40.7	44.2	32.6	42.1	41.4	40.4	38.6	42.2	39.9	44.1	43.5	44.8	40.6
Apr. '79	38.6	34.4	40.4	40.0	40.5	35.3	38.3	42.9	40.1	37.8	43.3	39.6	43.4	39.9	44.0	39.9
May '79	30.5	32.1	35.7	36.2	33.6	29.3	37.8	37.2	30.3	35.9	40.9	37.6	38.2	40.5	39.3	35.7
Mean	26.5	25.9	32.4	31.2	32.5	24.5	33.2	31.7	31.3	32.3	33.5	31.5	34.7	35.2	34.7	31.5

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 11. Number of kernel rows of 15 hybrids in monthly plantings

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	13.4	13.8	13.4	12.8	13.4	15.8	14.4	13.4	13.7	15.8	13.6	14.3	13.6	14.6	14.3	14.0
Sep. '77	14.3	14.6	13.1	14.2	14.3	14.8	15.5	14.4	15.2	15.5	14.0	15.7	13.5	14.8	13.7	14.5
Oct. '77	13.0	13.6	13.8	12.2	12.5	16.2	14.3	14.4	14.2	14.4	13.6	14.1	13.1	15.4	14.4	13.9
Nov. '77	12.9	13.9	12.9	12.7	13.0	13.9	14.8	13.8	14.8	14.2	14.0	13.4	13.8	13.2	14.4	13.7
Dec. '77	13.6	13.4	13.8	13.5	12.6	14.3	14.8	13.8	14.4	15.6	14.4	14.4	13.6	13.4	14.0	14.0
Jan. '78	14.8	15.2	15.4	13.6	14.0	15.8	13.8	14.8	14.0	16.2	15.8	17.0	14.8	14.5	15.6	15.0
Feb. '78	14.4	13.4	13.2	13.4	13.2	15.6	13.6	14.6	14.6	15.2	15.0	14.8	13.6	13.8	14.4	14.2
Mar. '78	14.2	14.6	14.6	13.2	14.0	15.4	13.8	13.6	15.0	15.2	15.0	15.4	15.0	16.0	13.8	14.6
Apr. '78	13.6	15.6	13.4	13.0	14.0	14.4	14.8	14.2	16.2	14.8	14.5	15.2	13.6	15.8	15.4	14.6
May '78	14.2	15.4	14.6	13.8	15.2	14.8	16.0	15.2	15.0	16.6	15.8	15.4	14.2	15.0	15.8	15.1
Jun. '78	15.0	15.2	14.8	13.4	14.6	15.4	15.2	14.4	15.8	16.4	13.8	15.4	14.6	16.2	15.8	15.1
Jul. '78	12.8	15.0	13.4	13.4	14.7	13.8	13.6	13.2	16.0	15.2	14.0	15.4	14.0	14.6	14.4	14.2
Aug. '78	13.8	14.4	14.8	13.4	14.8	14.4	14.5	14.2	15.6	15.8	14.4	15.8	15.4	15.4	15.2	14.8
Sep. '78	13.2	14.2	13.0	13.4	13.4	13.8	14.4	13.6	14.4	15.6	13.2	14.6	14.2	14.0	13.6	13.9
Oct. '78	12.2	11.4	12.8	12.0	13.4	11.8	13.2	13.2	12.8	12.4	12.4	13.4	13.4	12.3	13.2	12.7
Dec. '78	12.8	13.6	13.6	12.8	13.4	13.0	14.2	13.8	14.0	14.6	14.6	14.8	13.0	13.0	14.2	13.7
Jan. '79	12.8	15.2	13.4	12.6	13.0	14.1	14.3	13.8	13.4	14.0	13.2	13.6	13.4	13.2	13.8	13.6
Feb. '79	13.6	14.7	13.8	14.2	14.2	15.2	13.8	14.2	14.8	14.4	14.3	15.2	13.8	15.0	14.4	14.1
Mar. '79	13.5	14.4	13.6	14.2	15.6	15.4	16.4	15.4	14.6	16.2	14.3	16.0	14.2	16.2	14.2	14.9
Apr. '79	13.5	15.0	13.8	13.8	15.0	13.6	15.2	15.8	15.2	16.0	14.0	15.2	14.4	15.8	14.0	14.7
May '79	15.0	14.0	14.0	13.6	15.2	15.0	14.4	15.4	15.8	15.6	13.6	15.4	14.0	15.4	14.8	14.7
Mean	13.6	14.3	13.8	13.3	14.0	14.6	14.5	14.2	14.7	15.2	14.2	15.0	14.0	14.6	14.4	14.3

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 12. Number of kernels per ear of 15 hybrids in monthly plantings

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	391	399	458	426	466	450	437	358	424	523	469	441	445	509	502	446
Sep. '77	346	337	362	385	425	301	426	411	430	461	436	396	409	409	409	396
Oct. '77	315	296	406	388	345	410	424	405	391	419	368	429	351	484	451	385
Nov. '77	206	239	299	228	284	209	366	325	356	376	351	348	354	434	377	317
Dec. '77	237	269	392	312	355	294	497	327	400	442	382	388	419	455	378	370
Jan. '78	456	445	576	481	549	446	531	523	438	570	594	475	542	537	534	515
Feb. '78	413	383	500	495	456	484	526	513	512	544	470	418	508	526	517	484
Mar. '78	344	378	452	451	461	403	481	460	544	480	542	576	549	576	486	479
Apr. '78	379	421	494	450	489	345	551	496	588	548	490	490	529	600	567	496
May '78	365	374	495	475	519	325	611	409	449	583	582	535	497	561	597	492
Jun. '78	481	425	552	481	541	461	582	520	521	581	563	562	595	715	681	550
Jul. '78	368	474	536	486	517	399	501	441	494	554	524	551	565	486	511	494
Aug. '78	362	439	499	455	509	406	479	461	497	555	524	563	631	484	570	495
Sep. '78	318	306	311	340	346	293	450	392	437	444	380	393	414	374	332	368
Oct. '78	193	187	290	209	312	184	272	266	283	254	270	283	300	355	355	267
Dec. '78	228	236	265	273	267	219	308	347	307	341	310	378	377	376	383	307
Jan. '79	334	398	408	395	406	396	461	480	436	416	446	397	476	481	475	427
Feb. '79	415	382	479	510	568	440	450	517	547	502	526	519	483	559	620	501
Mar. '79	518	478	576	578	690	502	691	636	590	627	603	639	626	706	635	606
Apr. '79	526	516	558	552	609	480	583	678	610	605	607	602	625	631	616	586
May '79	458	450	501	493	511	440	545	573	478	560	556	578	534	624	582	525
Mean	364	373	448	417	458	375	484	454	463	496	476	474	487	518	503	453

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 13. Cob length of 15 hybrids in monthly plantings

(unit : cm)

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	17.1	14.8	16.0	17.0	17.3	16.6	17.7	17.2	16.2	16.7	18.3	16.0	18.4	15.5	17.6	16.8
Sep. '77	14.3	11.8	12.9	15.8	15.7	13.7	15.6	15.4	14.2	13.7	16.6	14.3	16.2	12.7	15.8	14.5
Oct. '77	14.0	11.4	12.9	14.4	14.7	15.5	17.6	17.3	14.9	14.9	14.7	14.0	15.1	14.4	16.1	14.8
Nov. '77	10.2	10.2	11.3	11.6	11.1	11.2	14.2	15.2	13.8	13.9	13.9	12.8	14.3	14.1	14.2	12.8
Dec. '77	11.7	10.6	13.3	12.7	13.7	12.8	17.0	15.2	14.7	13.6	13.8	12.1	16.1	15.1	15.6	13.8
Jan. '78	16.0	14.6	17.8	16.7	17.2	16.5	18.5	18.6	17.2	17.0	17.5	16.1	17.8	16.3	16.9	16.9
Feb. '78	16.5	14.3	16.3	17.6	17.4	17.4	18.6	19.0	17.6	17.2	17.1	15.2	18.0	16.0	18.6	17.1
Mar. '78	13.9	13.7	14.6	16.2	15.8	15.4	17.3	17.7	16.7	15.2	17.0	16.9	17.7	16.6	16.8	16.1
Apr. '78	16.0	15.8	16.9	18.2	16.3	14.9	18.1	19.9	17.3	17.8	18.2	15.7	19.8	16.0	18.2	17.3
May '78	16.3	14.8	15.8	18.6	17.7	15.6	18.7	17.5	17.6	17.4	19.4	16.8	17.7	16.5	19.0	17.3
Jun. '78	18.2	15.1	17.4	18.0	16.7	17.5	18.7	19.8	18.1	17.2	19.1	17.1	20.7	18.4	20.9	18.2
Jul. '78	17.1	17.5	18.4	19.8	16.4	17.7	19.1	18.7	17.6	17.5	18.2	16.6	21.1	15.3	18.0	17.9
Aug. '78	15.4	16.5	15.3	16.9	17.0	16.9	16.8	18.3	17.5	16.4	17.5	17.2	19.8	15.2	17.7	16.9
Sep. '78	14.2	13.8	11.6	13.1	13.4	13.4	15.1	16.2	16.4	14.6	13.9	14.8	14.4	13.4	13.9	14.1
Oct. '78	9.7	10.4	11.1	10.5	10.8	10.2	11.7	13.7	12.6	10.8	10.8	10.6	12.2	12.4	13.9	11.4
Dec. '78	13.4	12.1	12.1	13.6	11.9	11.9	12.9	14.6	13.4	12.6	13.1	12.3	15.9	12.9	15.3	13.2
Jan. '79	15.2	15.2	15.2	16.1	15.8	15.9	16.2	18.7	17.5	14.9	16.3	14.0	17.0	16.8	18.4	16.2
Feb. '79	17.0	16.1	16.5	18.2	17.1	17.0	16.3	19.5	18.9	16.8	17.9	16.8	17.2	17.0	19.7	17.4
Mar. '79	20.1	18.2	19.4	21.7	18.6	18.2	20.2	22.9	20.7	18.3	20.5	18.4	19.7	19.2	21.7	19.8
Apr. '79	20.0	18.5	18.4	20.9	18.1	19.1	19.5	21.9	22.2	18.6	22.0	18.5	20.1	17.9	20.3	19.7
May '79	18.1	17.2	16.6	20.1	16.7	17.5	18.5	20.8	16.7	18.3	20.2	17.4	19.3	18.1	19.5	18.3
Mean	15.4	14.4	15.2	16.5	15.6	15.4	17.0	18.0	16.7	15.9	16.9	15.4	17.5	15.7	17.5	16.2

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 14. Filled ear length of 15 hybrids in monthly plantings

(unit : cm)

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	13.3	12.2	13.9	14.9	14.7	12.8	14.6	12.6	13.9	14.4	15.5	13.0	15.2	13.8	14.9	13.9
Sep. '77	12.1	10.4	11.9	12.5	12.9	10.5	12.9	12.6	12.5	12.1	13.7	13.1	13.5	10.8	13.5	12.3
Oct. '77	10.7	9.1	11.7	10.5	11.5	11.1	13.7	13.7	12.0	12.6	11.8	11.6	12.0	12.4	13.6	11.8
Nov. '77	7.2	7.7	9.0	8.1	8.9	7.8	11.3	10.9	10.9	11.1	11.0	10.9	11.1	12.5	11.3	10.0
Dec. '77	7.4	8.2	11.8	10.3	11.5	10.5	15.1	10.9	11.4	11.9	11.4	11.0	13.7	13.4	12.3	11.4
Jan. '78	13.5	13.0	15.8	14.5	15.5	14.1	16.6	16.4	13.6	15.8	15.6	13.4	16.0	14.9	14.8	14.9
Feb. '78	14.1	12.1	15.1	15.6	15.3	15.4	17.0	16.9	15.8	15.6	15.4	12.8	15.8	14.5	16.3	15.2
Mar. '78	11.4	11.6	12.9	13.9	14.2	13.3	15.5	16.0	15.3	13.3	15.5	15.9	16.2	14.7	15.1	14.3
Apr. '78	13.2	13.0	15.5	15.8	13.8	11.8	16.2	17.4	16.2	16.2	15.0	13.5	18.3	14.5	16.6	15.1
May '78	11.7	11.7	14.0	16.1	15.9	10.9	16.8	12.3	14.6	15.6	16.4	14.4	15.9	14.9	16.6	14.5
Jun. '78	15.1	12.1	15.7	16.2	15.2	14.9	17.3	17.3	15.8	15.8	17.4	15.8	19.0	17.5	20.0	16.3
Jul. '78	13.9	15.2	16.6	18.1	14.6	14.8	17.7	15.8	15.4	16.1	16.7	15.3	19.9	14.1	16.2	16.0
Aug. '78	11.4	14.5	14.2	15.7	15.1	14.8	14.7	15.3	16.2	15.0	15.6	14.9	18.2	12.8	16.0	15.0
Sep. '78	12.7	11.1	10.6	11.7	11.4	10.8	13.5	14.1	15.2	12.4	13.0	11.5	13.1	11.7	11.4	12.3
Oct. '78	7.5	7.9	9.6	8.1	8.9	7.5	9.3	9.3	10.1	8.9	9.0	9.0	9.6	10.8	11.4	9.1
Dec. '78	9.7	8.6	9.4	9.8	9.6	8.1	9.6	11.9	10.6	10.2	9.6	10.3	13.4	11.2	12.3	10.3
Jan. '79	11.4	11.8	13.2	13.0	12.8	12.8	13.6	15.2	14.4	12.8	13.6	11.8	14.9	14.8	14.9	13.4
Feb. '79	13.3	12.7	14.4	15.7	15.2	13.5	13.7	16.1	15.9	14.3	16.0	14.6	14.8	14.8	17.8	14.8
Mar. '79	16.7	15.5	18.0	19.0	17.2	15.2	18.7	19.5	18.0	16.7	18.9	16.7	18.5	18.0	19.0	17.7
Apr. '79	16.3	15.8	16.4	18.0	16.4	16.9	17.1	18.6	19.0	16.8	19.5	16.4	18.7	16.4	18.7	17.4
May '79	13.4	14.3	14.6	16.8	14.4	14.2	15.8	17.0	13.7	16.1	17.3	15.4	16.8	15.8	17.4	15.5
Mean	12.2	11.8	13.5	14.0	13.5	12.4	14.8	14.7	14.3	14.0	14.6	13.4	15.4	14.0	15.2	13.9

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 15. 100 kernel weight of 15 hybrids in monthly plantings

(unit : g)

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	34.3	31.5	29.8	28.8	32.8	29.3	30.7	31.9	32.0	28.0	32.8	26.2	30.1	28.2	26.6	30.2
Sep. '77	33.7	27.8	29.3	34.1	29.7	32.3	28.1	32.0	31.2	23.6	30.1	29.2	30.4	29.1	27.8	29.9
Oct. '77	36.5	33.9	29.4	34.4	30.5	31.2	33.5	34.6	34.2	29.3	33.3	28.9	31.7	27.7	30.1	31.9
Nov. '77	25.9	28.3	23.0	25.1	22.6	32.2	25.2	30.8	33.7	23.5	25.9	28.4	24.5	24.9	25.0	26.6
Dec. '77	24.5	23.6	20.8	22.7	22.4	28.1	22.6	23.6	28.3	21.9	26.0	21.9	21.2	22.3	25.5	23.7
Jan. '78	26.4	27.5	25.7	26.8	27.5	27.5	26.7	28.4	28.1	25.7	26.7	25.1	22.2	23.7	27.0	26.3
Feb. '78	36.4	35.5	31.8	25.3	32.6	32.5	33.1	34.7	34.3	29.3	31.6	32.7	20.9	28.1	33.7	31.5
Mar. '78	30.5	29.2	26.5	25.6	30.1	31.6	30.8	30.6	27.8	28.6	25.6	27.1	24.0	26.4	27.5	28.1
Apr. '78	32.2	29.6	28.8	28.7	29.3	33.6	29.3	31.9	27.5	26.9	32.0	22.7	28.1	24.8	28.8	28.9
May '78	28.5	30.0	29.3	28.5	30.3	30.5	27.8	31.0	30.9	26.4	27.4	23.0	25.9	28.2	27.2	28.3
Jun '78	31.0	30.0	30.9	30.4	33.1	33.7	28.9	34.4	34.9	27.4	29.2	28.1	32.7	30.2	34.6	31.3
Jul. '78	34.7	31.0	30.0	32.1	30.1	33.0	32.6	32.8	35.2	29.5	33.3	28.0	35.0	33.0	32.3	32.1
Aug. '78	31.0	30.8	24.0	28.9	25.8	33.5	27.6	34.0	29.5	27.3	26.0	27.0	28.9	28.2	24.0	28.4
Sep. '78	35.8	33.7	29.4	31.8	30.7	33.8	30.2	33.5	30.3	27.1	28.1	28.2	30.2	27.2	32.6	30.8
Oct. '78	31.2	30.0	24.3	29.9	23.1	31.7	27.1	31.7	30.8	24.1	26.5	25.2	26.6	22.7	25.4	27.3
Dec. '78	35.2	33.3	24.5	29.7	32.9	29.9	29.3	31.3	30.1	28.5	28.6	24.1	26.5	23.8	27.7	28.7
Jan. '79	33.4	28.9	28.4	28.1	30.8	28.0	26.7	30.2	31.4	27.1	28.6	25.6	27.1	27.7	29.0	28.7
Feb. '79	33.5	29.5	31.8	31.6	25.8	29.9	30.6	31.5	28.4	26.3	28.2	25.2	29.0	26.6	27.2	29.0
Mar. '79	35.1	30.7	33.2	35.0	31.3	31.1	32.7	33.4	34.8	27.6	31.4	27.2	32.8	28.1	35.4	32.0
Apr. '79	35.3	30.2	27.4	31.8	27.6	35.1	31.8	29.6	37.0	27.1	30.9	30.1	30.2	28.9	31.5	30.9
May '79	31.3	30.9	27.1	29.1	29.1	29.7	26.9	27.7	27.1	26.7	26.7	26.0	28.5	27.4	30.8	28.3
Mean	32.2	30.3	27.9	29.4	28.9	31.3	29.1	31.4	31.3	26.7	29.0	26.6	27.9	27.0	29.1	29.2

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 16. Grain yield of 15 hybrids in monthly plantings

(unit : T/ha)

Months	1x2	1x3	1x4	1x5	1x6	2x3	2x4	2x5	2x6	3x4	3x5	3x6	4x5	4x6	5x6	Mean
Aug. '77	8.15	7.40	8.75	7.00	9.25	8.15	7.95	7.20	8.55	9.10	9.45	7.80	8.05	8.50	7.95	8.22
Sep. '77	6.75	5.70	6.50	7.55	7.75	4.95	6.95	8.10	8.15	6.70	8.05	6.45	7.55	6.55	6.35	6.94
Oct. '77	6.75	5.80	6.85	6.05	6.55	7.50	8.45	8.40	7.90	7.40	7.35	7.10	6.15	7.95	7.75	7.20
Nov. '77	2.85	3.65	4.00	3.20	3.90	3.60	5.55	6.25	7.20	5.25	5.55	6.30	5.55	6.65	5.85	5.02
Dec. '77	3.35	3.90	5.25	4.90	5.10	5.30	7.30	5.70	7.00	6.05	6.00	5.40	5.60	6.60	6.15	5.57
Jan. '78	7.20	8.05	9.35	8.25	9.55	7.75	9.40	9.75	8.10	9.65	9.75	7.75	7.75	8.40	9.40	8.67
Feb. '78	9.50	8.20	9.45	7.70	9.25	9.70	10.65	10.85	10.95	9.60	9.95	8.75	6.40	8.30	10.70	9.40
Mar. '78	6.45	6.80	7.35	6.75	8.90	7.70	8.90	8.55	9.45	8.05	8.65	9.85	7.85	9.70	8.10	8.20
Apr. '78	7.85	7.70	8.60	7.95	8.60	6.90	9.85	9.95	9.90	9.10	9.25	6.80	9.55	9.20	9.65	8.72
May '78	6.30	6.40	8.60	7.75	8.95	6 25	10.35	7.40	8.25	9.25	9.00	6.70	7.70	9.55	9.15	8.11
Jun. '78	9.00	7.60	10.15	8.65	11.10	9.15	10.45	10.30	10.80	9.90	9.90	9.85	11.10	13.55	14.35	10.39
Jul. '78	7.65	8.95	9.95	8.60	9.00	8.40	10.05	8.65	10.60	9.30	10.05	9.30	11.40	8.30	10.05	9.35
Aug. '78	5.96	7.27	6.97	6.99	6.94	8.11	7.57	8.88	8.52	8.53	8.48	8.90	10.67	7.21	8.29	7.96
Sep. '78	6.68	6.02	5.66	5.85	6.19	5.05	7.81	7.71	7.48	7.26	6.62	6.55	7.08	5.48	6.06	6.56
Oct. '78	2.54	2.15	3.37	2.57	3.33	2.60	3.65	4.39	4.44	3.01	3.43	3.46	4.41	4.53	4.90	3.52
Dec. '78	3.75	2.89	3.03	3.95	3.97	2.91	3.88	5.37	4.66	3.79	4.98	4.91	4.96	4.46	5.39	4.19
Jan. '79	6.04	5.51	6.40	5.64	7.34	6.14	7.34	8.30	8.04	6.61	7.27	5.84	7.48	8.13	7.43	6.90
Feb. '79	8.47	6.76	9.24	9.07	8.75	8.08	8.44	9.44	9.29	8.01	9.08	8.38	8.49	9.17	10.87	8.77
Mar. '79	10.88	8.67	11.31	12.03	13.17	9.37	13.36	11.89	12.34	10.46	11.04	10.92	12.42	12.38	13.71	11.60
Apr. '79	10.60	9.03	9.06	9.63	9.91	9.72	11.03	11.42	12.75	9.69	10.72	10.40	11.34	11.34	12.07	10.58
May '79	8.22	8.40	8.52	8.34	8.96	7.68	8.84	9.53	7.60	9.08	8.92	9.63	9.08	9.19	10.75	8.85
Mean	6.90	6.52	7.54	7.07	7.93	6.95	8.47	8.48	8.66	7.90	8.26	7.67	8.12	8.39	8.81	7.84

1 = B37, 2 = B68, 3 = Hi27, 4 = Mp68:616, 5 = Oh545, 6 = Tx601.

Appendix 17. Estimates of GCA effects of parental lines for cob length in 21 monthly plantings

Months	B37	B68	Hi27	Mp68:616	Oh545	Tx601	SE(g_i-g_j)
Aug. '77	-0.46	0.17	-0.45	0.04	1.09	-0.40	0.52
Sep. '77	-0.77	0.17	-0.60	-0.38	1.81	-0.23	0.55
Oct. '77	-1.64	1.33	-0.85	0.24	0.91	0.01	0.32
Nov. '77	-2.42	0.16	-0.50	0.96	1.30	0.51	0.19
Dec. '77	-1.83	0.52	-1.62	1.46	1.01	0.46	0.19
Jan. '78	-0.68	0.50	-0.78	0.60	0.66	0.29	0.18
Feb. '78	0.87	0.89	-1.11	0.13	1.16	-0.19	0.14
Mar. '78	-1.56	0.13	-0.57	0.23	1.21	0.58	0.39
Apr. '78	-0.79	-0.04	-0.99	0.57	1.97	-0.72	0.36
May '78	-0.83	-0.18	-0.62	-0.10	1.45	0.28	0.34
Jun. '78	-1.39	0.35	-1.24	0.35	1.90	0.05	0.30
Jul. '78	-0.12	0.12	-0.53	0.43	1.54	-1.43	0.59
Aug. '78	-0.91	0.03	-0.07	-0.33	1.34	-0.06	0.27
Sep. '78	-1.13	1.12	-0.05	-0.41	0.18	0.29	0.44
Oct. '78	-1.16	0.20	-1.08	0.28	0.99	0.77	0.15
Dec. '78	-0.70	0.07	-1.02	0.08	1.62	-0.05	0.22
Jan. '79	-0.90	0.59	-1.17	-0.25	1.37	0.35	0.45
Feb. '79	-0.62	0.35	-0.68	-0.89	1.29	0.55	0.15
Mar. '79	-0.28	0.70	-1.42	-0.63	1.80	-0.17	0.36
Apr. '79	-0.67	1.00	-0.50	-1.04	1.64	-0.42	0.62
May '79	-0.74	-0.02	-0.25	-0.24	2.06	-0.80	0.47
Combined	-0.97	0.39	-0.77	0.05	1.35	-0.04	0.12

Appendix 18. Estimates of GCA effects of parental lines for filled ear length in 21 monthly plantings

Months	B37	B68	Hi27	Mp68:616	Oh545	Tx601	SE(g_i-g_j)
Aug. '77	-0.19	-0.68	-0.50	0.50	0.78	0.10	0.35
Sep. '77	-0.47	-0.26	-0.45	-0.13	1.03	0.28	0.76
Oct. '77	-1.45	0.49	-0.79	-0.75	0.56	0.44	0.23
Nov. '77	-2.25	-0.46	-0.36	1.28	0.62	1.17	0.29
Dec. '77	-2.01	-0.25	-1.08	2.18	0.31	0.85	0.26
Jan. '78	-0.55	-0.06	-0.66	1.15	0.68	-0.56	0.31
Feb. '78	-0.93	0.81	-1.12	0.52	1.01	-0.29	0.16
Mar. '78	-1.90	-0.02	-0.50	0.25	1.27	0.89	0.43
Apr. '78	-1.11	-0.23	-1.53	1.28	1.88	-0.28	0.42
May '78	-0.79	-1.58	-0.90	1.15	1.18	0.95	0.66
Jun. '78	-1.85	-0.32	-1.43	0.90	2.05	0.64	0.42
Jul. '78	-0.45	-0.63	-0.50	1.06	1.67	-1.15	0.66
Aug. '78	-0.90	-0.53	-0.04	0.02	1.45	0.01	0.46
Sep. '78	-0.98	1.24	-0.66	0.03	0.50	-0.06	0.44
Oct. '78	-0.90	-0.47	-0.83	0.63	0.46	1.01	0.15
Dec. '78	-1.08	-0.38	-1.15	0.58	1.40	0.63	0.27
Jan. '79	-1.21	0.09	-1.03	0.57	1.17	0.42	0.26
Feb. '79	-0.75	-0.43	-0.80	-0.57	1.54	1.00	0.27
Mar. '79	-0.54	-0.09	-1.38	0.33	1.57	0.11	0.27
Apr. '79	-1.03	0.20	-0.40	-0.40	1.64	-0.02	0.39
May '79	-1.05	-0.90	-0.09	0.38	1.91	-0.24	0.63
Combined	-1.07	-0.21	-0.77	0.59	1.18	0.29	0.13

Appendix 19. Estimates of GCA effects of parental lines for floret number per row in 21 monthly plantings

Months	B37	B68	Hi27	Mp68:616	Oh545	Tx601	SE(g_i-g_j)
Aug. '77	1.53	-1.59	-0.52	-3.72	0.97	3.32	1.33
Sep. '77	1.25	1.29	-4.11	-3.34	2.53	2.39	0.80
Oct. '77	-0.07	2.00	-2.12	-6.32	2.45	4.08	1.44
Nov. '77	0.39	0.89	-3.06	-3.22	1.99	3.00	2.02
Dec. '77	0.87	0.89	-3.66	-3.41	1.22	4.09	0.85
Jan. '78	2.31	1.93	-6.09	-1.87	2.86	0.86	0.68
Feb. '78	1.05	1.78	-3.67	-3.15	2.43	1.58	0.83
Mar. '78	0.46	2.08	-3.87	-3.97	3.26	3.03	0.88
Apr. '78	1.46	0.91	-4.14	-3.79	2.43	3.13	0.75
May '78	2.45	-0.14	-3.20	0.10	3.15	-2.34	1.80
Jun. '78	1.55	1.68	-3.47	-3.50	1.13	2.63	1.39
Jul. '78	1.28	0.63	-4.15	-4.00	2.76	3.98	3.75
Aug. '78	1.07	-0.92	-3.15	-3.94	2.62	4.32	0.94
Sep. '78	-	-	-	-	-	-	-
Oct. '78	0.41	1.71	-4.94	-2.87	2.15	3.53	1.13
Dec. '78	-1.52	1.36	-3.99	-3.24	3.01	4.36	1.97
Jan. '79	-0.32	0.97	-4.55	-3.44	3.22	4.12	1.72
Feb. '79	-1.07	2.55	-3.95	-2.14	2.78	1.85	2.08
Mar. '79	0.21	2.20	-4.17	-2.74	1.42	3.08	2.16
Apr. '79	0.60	1.39	-3.72	-1.67	1.60	1.81	0.73
May '79	0.58	1.05	-4.37	-2.75	3.58	1.93	0.49
Combined	0.72	1.13	-3.75	-3.15	2.30	2.74	0.29

Appendix 20. Estimates of GCA effects of parental lines for kernels per row in 21 monthly plantings

Months	B37	B68	Hi27	Mp68:616	Oh545	Tx601	SE$(g_i - g_j)$
Aug. '77	0.24	-3.48	-0.83	1.52	0.67	1.89	1.79
Sep. '77	-1.19	-1.97	-1.76	1.49	2.50	0.95	4.34
Oct. '77	-2.82	-0.71	-1.01	2.15	-0.17	2.58	2.20
Nov. '77	-4.82	-3.02	-1.30	4.40	0.78	3.98	2.60
Dec. '77	-3.72	-2.32	-2.49	5.81	-0.22	2.93	1.40
Jan. '78	0.06	-1.94	-3.04	3.61	1.86	-0.54	1.61
Feb. '78	-1.11	-0.61	-4.06	4.22	1.34	0.22	0.99
Mar. '78	-3.92	-2.22	-1.82	1.48	3.01	3.46	2.09
Apr. '78	-2.19	-2.37	-4.09	4.43	2.23	1.98	1.82
May '78	-2.42	-4.84	-2.27	4.33	2.13	3.06	3.35
Jun. '78	-3.13	-3.41	-2.96	3.32	3.52	2.67	2.55
Jul. '78	-0.37	-3.62	-0.94	3.31	2.33	-0.72	3.49
Aug. '78	-2.09	-3.78	-0.33	1.80	3.55	0.86	2.16
Sep. '78	-2.79	0.81	-1.37	1.86	0.93	0.56	3.12
Oct. '78	-2.39	-2.72	-2.44	2.43	0.83	4.28	0.95
Dec. '78	-4.07	-2.20	-1.99	2.58	2.88	2.78	1.62
Jan. '79	-3.05	-0.87	-2.56	1.76	3.13	1.60	1.35
Feb. '79	-1.76	-2.17	-3.37	-0.13	3.29	4.14	2.62
Mar. '79	-1.00	-1.97	-4.07	1.95	2.60	2.50	1.22
Apr. '79	=1.40	-1.07	-2.27	0.08	3.52	1.15	2.06
May '79	-2.57	-3.31	-v.64	2.43	3.36	0.73	1.54
Combined	-2.21	-2.28	-2.17	2.61	2.10	1.96	0.32

Appendix 21. Estimates of GCA effects of parental lines for row number in 21 monthly plantings

Months	B37	B68	Hi27	Mp68:616	Oh545	Tx601	SE(g_i-g_j)
Aug. '77	-0.82	0.15	0.80	0.43	-0.61	0.04	0.12
Sep. '77	-0.51	0.42	0.53	-0.03	-0.70	0.29	0.17
Oct. '77	-1.16	0.59	0.54	0.33	-0.51	0.20	0.13
Nov. '77	-0.79	0.41	0.21	0.08	0.03	0.06	0.37
Dec. '77	-0.74	0.26	0.56	0.33	-0.15	0.26	0.11
Jan. '78	-0.53	-0.48	1.23	-0.10	-0.13	0.00	0.08
Feb. '78	-0.83	0.47	0.77	-0.38	0.02	-0.03	0.06
Mar. '78	-0.58	-0.23	0.67	0.42	-0.58	0.32	0.12
Apr. '78	-0.81	0.09	0.42	-0.11	-0.53	0.94	0.16
May '78	-0.62	-0.12	0.56	0.18	-0.22	0.18	0.16
Jun. '78	-0.58	0.12	0.22	0.47	-0.83	0.62	0.18
Jul. '78	-0.47	-0.44	0.56	-0.09	-0.54	0.98	0.26
Aug. '78	-0.69	-0.38	0.22	0.47	-0.33	0.71	0.12
Sep. '78	-0.58	-0.03	0.47	0.42	-0.38	0.12	0.27
Oct. '78	-0.38	-0.02	-0.47	0.20	0.22	0.45	0.15
Dec. '78	-0.56	-0.16	0.53	-0.01	-0.01	0.24	0.11
Jan. '79	-0.24	0.12	0.53	0.10	-0.28	-0.23	0.21
Feb. '79	-0.35	-0.07	0.47	-0.26	-0.25	0.45	0.27
Mar. '79	-0.85	0.13	0.40	0.47	-0.62	0.47	0.14
Apr. '79	-0.58	-0.03	-0.09	0.44	-0.36	0.44	0.10
May '79	-0.48	0.47	-0.03	-0.08	-0.58	0.72	0.36
Combined	-0.36	0.06	0.44	0.16	-0.35	0.32	0.09

Appendix 22. Estimates of GCA effects of parental lines for kernels per ear in 21 monthly plantings

Months	B37	B68	Hi27	Mp68:616	Oh545	Tx601	SE(g_i-g_j)
Aug. '77	-23.2	-43.1	12.3	34.8	8.2	27.4	48.4
Sep. '77	-31.3	-12.5	-12.5	21.5	17.1	22.0	92.8
Oct. '77	-69.1	4.4	-1.2	39.0	-16.2	43.3	55.0
Nov. '77	-82.1	-30.6	-15.2	61.4	12.6	54.0	51.2
Dec. '77	-71.0	-23.7	-18.7	89.2	-7.7	31.8	25.5
Jan. '78	-16.8	-45.2	-4.4	52.0	25.0	-10.5	45.3
Feb. '78	-43.7	6.6	-30.9	45.8	20.5	1.8	32.6
Mar. '78	-77.1	-40.5	-4.1	36.0	23.6	62.1	79.0
Apr. '78	-61.6	-29.4	-46.4	60.4	13.6	63.4	61.9
May '78	-57.8	-74.7	-15.1	71.9	25.2	50.5	95.5
Jun. '78	-68.6	-47.2	-40.2	67.9	21.5	66.5	62.1
Jul. '78	-22.2	-66.3	8.2	43.3	14.5	22.5	130.0
Aug. '78	-53.5	-68.3	2.3	42.7	40.5	36.3	44.9
Sep. '78	-55.6	11.7	-6.8	37.4	3.7	9.7	89.3
Oct. '78	-36.6	-34.9	-40.0	33.3	15.5	62.8	27.7
Dec. '78	-67.1	-32.2	-13.7	32.3	37.9	43.0	26.7
Jan. '79	-48.5	-7.0	-20.5	26.7	34.4	14.8	25.1
Feb. '79	-38.0	-34.0	-34.2	-8.2	37.8	76.8	46.1
Mar. '78	-47.8	-23.7	-45.5	48.6	11.6	56.8	55.6
Apr. '79	-44.0	-14.6	-30.4	17.9	36.8	34.4	64.2
May '79	-53.7	-33.3	11.0	34.1	27.6	36.4	23.9
Combined	-50.9	-30.6	-17.5	42.3	18.4	38.4	52.0

Appendix 23. Estimates of GCA effects of parental lines for 100 kernel weight in 21 monthly plantings

Months	B37	B68	Hi27	Mp68:616	Oh545	Tx601	SE(g_i-g_j)
Aug. '77	1.54	1.80	-0.81	-1.06	-0.18	-1.30	1.25
Sep. '77	1.28	1.98	-1.62	-2.22	1.24	-0.64	0.94
Oct. '77	1.25	2.55	-0b78	-2.03	1.10	-2.10	0.87
Nov. '77	-2.01	3.69	1.30	-2.96	-0.42	0.41	0.78
Dec. '77	-1.12	2.17	0.77	-2.42	0.13	0.48	1.61
Jan. '78	0.55	1.36	0.21	-1.92	-0.14	-0.06	2.02
Feb. '78	1.03	3.38	1.03	-3.57	-2.28	0.98	1.72
Mar. '78	0.32	2.65	0.38	-1.11	-1.81	-0.43	1.04
Apr. '78	0.96	2.46	0.01	-1.70	1.19	-2.92	1.28
May '78	1.25	1.77	-1.10	-1.01	-0.41	-0.51	1.88
Jun. '78	-0.31	1.61	2.20	-1.59	1.20	1.11	1.01
Jul. '78	-0.74	1.86	-1.51	-0.20	1.15	-0.56	1.51
Aug. '78	-0.40	3.37	0.62	-1.57	-0.10	-1.92	0.99
Sep. '78	1.81	2.36	-0.82	-2.52	0.49	-1.32	0.70
Oct. '78	0.42	3.94	0.17	-2.97	0.83	-2.38	1.23
Dec. '78	2.44	2.51	-0.35	-3.31	- .01	-1.27	1.08
Jan. '79	1.48	1.52	d1.38	-1.64	-0.18	0.20	0.92
Feb. '79	1.79	2.21	-1.49	-0.19	0.63	-2.95	0.59
Mar. '79	1.33	1.78	-2.97	-1.38	2.01	-0.78	0.61
Apr. '79	-0.63	3.49	-0.36	-2.35	0.22	0.07	1.05
May '79	1.45	0.27	-0.42	-1.28	0.30	-0.32	1.08
Combined	0.65	2.32	-0.53	-1.86	0.19	-0.77	0.23

Appendix 24. Estimates of GCA effects of parental lines for grain yield in 21 monthly plantings

Months	B37	B68	Hi27	Mp68:616	Oh545	Tx601	SE(g_i-g_j)
Aug. '77	-0.13	-0.27	0.20	0.32	-0.36	0.24	0.21
Sep. '77	-0.11	0.05	-0.71	-0.11	0.73	0.14	0.37
Oct. '77	-1.00	0.75	-0.21	0.20	-0.07	0.32	0.19
Nov. '77	-1.88	0.08	-0.19	0.47	0.32	1.20	0.19
Dec. '77	-1.34	0.20	-0.30	0.73	0.12	0.60	0.19
Jan. '78	-0.24	-0.29	-0.10	-0.30	0.38	-0.04	0.34
Feb. '78	-0.72	1.17	-0.20	-0.40	-0.35	0.49	0.21
Mar. '78	-1.19	0.01	0.01	0.21	-0.27	1.25	0.33
Apr. '78	-0.73	0.21	-0.97	0.67	0.68	0.13	0.23
May '78	-0.63	-0.50	-0.73	1.23	0.12	0.52	0.45
Jun. '78	-1.36	-0.56	-1.39	0.80	0.59	1.93	0.42
Jul. '78	-0.65	-0.35	-0.19	0.56	0.50	0.13	0.72
Aug. '78	-1.41	-0.18	0.38	0.30	0.89	0.03	0.21
Sep. '78	-0.60	0.71	-0.10	0.12	0.13	-0.26	0.33
Oct. '78	-0.91	0.01	-0.74	0.34	0.53	0.77	0.14
Dec. '78	-0.84	-0.10	-0.37	-0.21	0.92	0.61	0.05
Jan. '79	-0.89	0.34	-0.78	-0.36	0.40	0.57	0.15
Feb. '79	-0.39	-0.03	-0.86	-0.12	0.78	0.65	0.15
Mar. '79	-0.48	-0.04	-1.88	0.49	0.78	1.14	0.23
Apr. '79	-1.17	0.65	-0.84	-0.11	0.57	0.89	0.55
May. '79	-0.45	-0.59	-0.14	0.12	0.59	0.47	0.52
Combined	-0.82	0.06	-0.48	0.30	0.38	0.56	0.12

Appendix 25. Regression equations between grain yield (Y) and solar radiation (X) and their coefficient of determination (r^2).

Equations	r^2	Definition of X subscripts
$Y = 0.2357\ X_{S_T} - 0.9943$	0.63	S_T = Total solar radiation (TSR)
$Y = 0.4589\ X_{S_{TV}} - 0.3785$	0.37	S_{TV}= TSR before silking
$Y = 1.8826\ X_{S_{TR}} - 0.3313$	0.56	S_{TR}= TSR after silking
$Y = 0.0241\ X_{S_A} - 0.2361$	0.62	S_A = Average solar radiation (ASR)
$Y = 0.0141\ X_{S_V} + 2.8910$	0.31	S_V = ASR before silking
$Y = 0.0180\ X_{S_R} + 1.4704$	0.57	S_R = ASR after silking
$Y = 0.0168\ X_{S_{+3}} + 2.2065$	0.56	S_{+3}= ASR 3 weeks after silking
$Y = 0.0168\ X_{S_{+7}} + 3.0115$	0.40	S_{+7}= ASR 4 to 7 weeks after silking
$Y = 0.0136\ X_{S_{-3}} + 3.2871$	0.36	S_{-3}= ASR 3 weeks before silking
$Y = 0.0061\ X_{S_1} + 5.8055$	0.07	S_1 = ASR of the 1st month
$Y = 0.0146\ X_{S_2} + 2.9704$	0.40	S_2 = ASR of the 2nd month
$Y = 0.0164\ X_{S_3} + 2.3367$	0.54	S_3 = ASR of the 3rd month
$Y = 0.0128\ X_{S_4} + 3.5074$	0.33	S_4 = ASR of the 4th month
$Y = 0.3873\ X_{T_A} -21.1860$	0.20	T_A = Average temperature
$Y = 1.3798 + 0.0069\ X_{S_2} + 0.0124\ X_{S_3}$	0.54	
$Y = 0.6110 + 0.0075\ X_{S_2} + 0.0089\ X_{S_3} + 0.0052\ X_{S_4}$	0.60	
$Y = 0.0024 + 0.0024\ X_{S_1} + 0.0060\ X_{S_2} + 0.0081\ X_{S_3} + 0.0068\ X_{S_4}$	0.63	

Appendix 26. Average daily solar radiation, mean temperature and daylength at different locations where a 10-entry diallel was evaluated

	Average daily solar radiation (cal·cm^{-2}·d^{-1})				
Locations	Before silking	After silking	Whole period	Mean temp. (^{o}C)	Average daylength before silking[b]
					hr. min.
Waimanalo-1	458	336	386	25.7	13:03
Waimanalo-2	267	287	276	22.5	11:04
Waimanalo-3	478	405	442	25.2	13:12
Kamuela[a]	421	289	355	19.2	12:18
Kapaa[a]	499	324	395	25.6	12:34
Ames, Iowa	465	394	430	20.6	14:54
CIAT, Colombia[a]	376	400	388	23.8	12:17
Suweon, Korea	327	-	-	24.9	14:25

[a] Solar radiation values are average of several years.

[b] From Smithonian Meteorological Table. 1951. (Smithonian Miscellaneous Collections Vol. 114. 6th ed.).

Appendix 27. Days to mid-silking of 45 hybrids at different locations

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
B37 x B68	51.9	60.6	51.0	78.0	61.0	81.0	63.9
B37 x CI21E	52.6	61.1	52.3	78.0	61.0	83.5	64.8
B37 x Hi27	51.0	58.2	53.0	78.7	59.3	83.9	64.0
B37 x CM105	50.4	58.5	52.0	78.0	61.0	86.8	64.4
B37 x CM111	50.0	58.7	51.3	80.3	60.3	85.0	64.3
B37 x Mo17	48.8	57.9	50.3	71.7	56.0	79.5	60.7
B37 x Mp68[b]	49.1	57.9	49.7	72.3	58.3	83.0	61.7
B37 x Oh545	47.3	58.2	50.7	73.0	56.0	77.1	60.4
B37 x Tx601	52.0	59.5	55.7	79.3	62.0	87.3	66.0
B68 x CI21E	51.3	61.5	53.0	81.7	60.0	84.6	65.3
B68 x Hi27	54.1	63.4	53.7	85.0	64.3	87.0	67.9
B68 x CM105	53.9	59.8	53.7	83.0	65.0	87.3	67.1
B68 x CM111	51.9	60.9	53.0	80.3	64.3	87.4	66.3
B68 x Mo17	49.9	58.5	50.0	75.3	56.0	81.6	61.9
B68 x Mp68	52.3	58.6	51.7	79.3	62.0	92.6	66.1
B68 x Oh545	50.4	57.8	51.0	80.3	57.7	79.6	62.8
B68 x Tx601	52.8	64.1	56.3	83.3	63.0	89.1	68.1
CI21E x Hi27	54.0	62.0	54.3	86.3	64.0	86.5	67.9
CI21E x CM105	53.9	62.8	55.0	90.0	64.0	92.4	69.7
CI21E x CM111	53.3	62.5	56.3	89.0	62.0	90.8	69.0
CI21E x Mo17	51.5	59.2	52.7	84.3	62.0	85.0	65.8
CI21E x Mp68	51.4	59.1	53.3	87.3	61.0	88.2	66.7
CI21E x Oh545	52.1	60.4	53.7	85.0	60.3	82.1	65.6
CI21E x Tx601	54.7	63.7	55.7	92.0	64.3	93.4	70.6
Hi27 x CM105	52.4	61.1	53.7	86.3	65.3	95.9	69.1
Hi27 x CM111	52.3	60.0	53.3	82.3	61.0	90.3	66.5
Hi27 x Mo17	50.1	58.2	50.7	79.7	61.0	85.9	64.2
Hi27 x Mp68	51.4	58.6	52.3	84.7	63.0	93.1	67.2
Hi27 x Oh545	50.4	57.0	51.7	78.7	59.3	81.2	63.0
Hi27 x Tx601	55.1	63.6	57.3	92.7	65.3	97.0	71.8
CM105 x CM111	51.1	61.1	53.7	84.0	61.0	90.6	66.9
CM105 x Mo17	50.2	60.2	51.0	81.7	61.0	94.2	66.4
CM105 x Mp68	51.0	60.5	51.0	80.7	62.0	94.8	66.7
CM105 x Oh545	50.0	58.2	52.3	77.7	61.0	90.9	65.0
CM105 x Tx601	55.7	64.5	58.3	89.0	65.3	105.6	73b1
CM111 x Mo17	49.3	60.4	51.7	76.3	59.3	86.6	63.9
CM111 x Mp68	52.9	59.6	53.3	85.0	65.3	92.5	68.1
CM111 x Oh545	52.2	60.7	50.3	85.0	62.0	84.0	65.7
CM111 x Tx601	54.7	64.5	57.7	87.3	63.0	96.9	70.7
Mo17 x Mp68	49.1	57.7	50.0	76.0	59.3	89.5	63.6
Mo17 x Oh545	49.5	56.5	50.3	70.7	57.7	79.0	60.6
Mo17 x Tx601	54.4	62.9	54.7	88.0	65.3	91.2	69.4

Appendix 27. (Continued) Days to mid-silking of 45 hybrids at different locations

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
Mp68 x Oh545	49.7	57.7	50.7	74.0	58.7	82.2	62.2
Mp68 x Tx601	54.3	60.9	56.0	85.7	63.7	96.3	69.5
Oh545 x Tx601	52.1	59.2	53.7	82.0	62.0	86.2	65.8
Mean	51.7	60.2	53.0	81.8	61.5	88.0	66.0
BLSD (0.05)	0.24	1.08	1.63	4.84	2.77		
C.V.(%)	1.23	1.74	2.85	5.28	3.85		

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[a] W-1, W-2 and W-3 are Waimanalo-1, -2 and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 28. Plant height of 45 hybrids at different locations

(unit : cm)

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Suweon	Mean
B37 x B68	263	200	238	249	197	288	155	227
B37 x CI21E	276	216	276	262	199	317	166	244
B37 x Hi27	255	187	237	235	184	287	150	219
B37 x CM105	262	199	251	238	204	325	174	236
B37 x CM111	261	203	264	252	198	317	151	235
B37 x Mo17	243	192	240	255	186	275	173	223
B37 x Mp68[b]	247	188	253	232	202	286	180	227
B37 x Oh545	256	190	246	223	179	281	147	218
B37 x Tx601	277	206	279	251	201	336	165	245
B68 x CI21E	271	204	260	243	203	321	168	239
B68 x Hi27	266	198	236	229	198	284	165	225
B68 x CM105	287	216	273	249	217	322	168	247
B68 x CM111	280	217	267	263	212	323	182	249
B68 x Mo17	264	194	249	232	212	294	172	231
B68 x Mp68	278	201	235	246	201	309	173	234
B68 x Oh545	254	193	243	230	202	293	169	226
B68 x Tx601	300	221	274	272	219	338	186	258
CI21E x Hi27	285	192	269	252	197	312	171	240
CI21E x CM105	300	209	270	244	214	335	171	249
CI21E x CM111	292	213	285	236	214	347	202	256
CI21E x Mo17	293	206	277	247	206	315	170	245
CI21E x Mp68	289	197	265	222	208	325	178	241
CI21E x Oh545	289	197	272	231	202	320	165	240
CI21E x Tx601	310	218	283	252	213	355	207	263
Hi27 x CM105	272	190	254	213	201	306	156	227
Hi27 x CM111	282	198	257	219	207	312	183	237
Hi27 x Mo17	254	185	240	218	190	283	151	217
Hi27 x Mp68	270	180	243	207	204	305	170	226
Hi27 x Oh545	274	185	245	224	191	293	164	225
Hi27 x Tx601	282	208	263	224	196	346	160	240
CM105 x CM111	283	202	255	230	194	327	186	240
CM105 x Mo17	252	214	264	218	196	315	165	232
CM105 x Mp68	265	200	266	231	193	327	169	236
CM105 x Oh545	281	189	249	219	203	324	157	232
CM105 x Tx601	305	228	289	257	197	359	180	259
CM111 x Mo17	267	202	258	226	215	320	159	235
CM111 x Mp68	291	202	260	227	210	323	181	242
CM111 x Oh545	285	188	263	241	215	320	168	240
CM111 x Tx601	300	222	293	265	222	351	180	262
Mo17 x Mp68	264	184	245	212	199	312	184	229
Mo17 x Oh545	252	188	255	223	213	289	185	229
Mo17 x Tx601	291	220	288	233	208	337	200	254

Appendix 28. (Continued) Plant height of 45 hybrids at different locations

(unit:cm)

Hybrids	W-1	W-2	W-3	Kamuela	Kapaa	Ames	Suweon	Mean
Mp68 x Oh545	277	179	245	228	209	299	178	231
Mp68 x Tx601	258	204	264	243	207	339	179	242
Oh545 x Tx601	291	208	276	241	219	340	191	252
Mean	276	201	260	237	204	316	172	238
C.V. (%)	4.70	3.18	3.79	8.75		2.51	10.29	

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[a] W-1, -2, and -3 are Waimanalo-2, -2 and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 29. Ear height of 45 hybrids at different locations

(unit : cm)

Hybrids	W-1[a]	W-1	W-3	Ames	Suweon	Mean
B37 x B68	104	69	92	113	79	91
B37 x CI21E	123	85	117	134	82	108
B37 x Hi27	109	73	103	121	70	95
B37 x CM105	114	85	110	152	92	111
B37 x CM111	116	83	120	152	78	110
B37 x Mo17	99	70	88	112	86	91
B37 x Mp68[b]	98	70	98	127	85	96
B37 x Oh545	86	64	79	97	55	76
B37 x Tx601	123	78	104	152	76	107
B68 x CI21E	116	77	119	142	84	107
B68 x Hi27	118	75	112	129	79	103
B68 x CM105	131	80	122	139	85	111
B68 x CM111	117	81	116	150	93	111
B68 x Mo17	105	72	99	124	76	95
B68 x Mp68	119	74	98	141	83	103
B68 x Oh545	90	63	86	108	70	83
B68 x Tx601	129	82	118	165	90	117
CI21E x Hi27	147	80	130	151	81	118
CI21E x CM105	146	85	129	175	92	125
CI21E x CM111	145	89	135	177	99	129
CI21E x Mo17	127	77	117	145	85	110
CI21E x Mp68	128	73	116	157	86	112
CI21E x Oh545	113	72	108	128	73	99
CI21E x Tx601	140	82	128	177	106	127
Hi27 x CM105	136	80	134	153	80	117
Hi27 x CM111	136	82	126	165	99	122
Hi27 x Mo17	110	75	116	127	79	101
Hi27 x Mp68	125	74	108	148	84	108
Hi27 x Oh545	112	68	102	112	77	94
Hi27 x Tx601	148	91	124	190	86	128
CM105 x CM111	138	89	121	163	102	123
CM105 x Mo17	124	89	119	163	80	115
CM105 x Mp68	121	83	122	173	86	117
CM105 x Oh545	119	74	104	143	68	102
CM105 x Tx601	159	95	148	212	107	144
CM111 x Mo17	117	79	114	149	78	107
CM111 x Mp68	141	71	111	160	82	113
CM111 x Oh545	128	70	108	135	83	105
CM111 x Tx601	146	87	139	194	91	132
Mo17 x Mp68	108	77	98	147	78	102
Mo17 x Oh545	89	65	89	98	76	83
Mo17 x Tx601	131	77	121	164	98	118

Appendix 29. (Continued) Ear height of 45 hybrids at different locations

Hybrids	W-1	W-2	W-3	Ames	Suweon	Mean
Mp68 x Oh545	99	59	92	113	78	88
Mp68 x Tx601	113	78	109	183	84	113
Oh545 x Tx601	110	77	103	141	84	103
Mean	121	77	112	147	84	108
C.V. (%)	4.93	4.18	7.60	3.66	14.14	

[a] W-1, W-2, and W-3 are Waimanalo-1, -2 and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 30. Analyses of variance for the plant and ear characters studied for a 10-entry diallel evaluated at different locations

Locations	df	Mean squares					
		Floret number	Kernels per row	Cob length	Filled ear length	Row number	Kernels per ear
Waimanalo-1							
Hybrids	44		34.5**	5.2**	5.2**	2.3**	6654**
Error	88		5.8	0.8	0.9	0.4	1418
Waimanalo-2							
Hybrids	44		35.1**	3.5**	3.4**	1.5**	6819**
Error	88		4.7	0.6	0.6	0.4	1051
Waimanalo-3							
Hybrids	44	29.0**	31.7**	3.8**	3.9**	2.1**	4649**
Error	88	5.9	4.5	0.9	1.1	0.2	1274
Kamuela							
Hybrids	44		22.8**	2.9**	2.8**	1.9**	4677**
Error	88		6.6	1.0	1.2	0.5	1876
Kapaa							
Hybrids	44		33.1**	2.3**	3.2**	2.4**	6164**
Error	88		8.4	0.8	1.4	0.6	2077
Ames, Iowa							
Hybrids	44	71.0**	53.4**		4.8**	2.4**	12087**
Error	88	7.0	12.9		1.4	0.5	4706
CIAT, Colombia							
Hybrids	44	47.2**					
Error	88	5.5					
Suweon, Korea							
Hybrids	44	37.8**				3.4**	
Error	88	18.9				1.0	

** Significant at 1 % probability level.

Appemdix 30. (Continued) Analyses of variance for the plant and ear characters studied for a 10-entry diallel evaluated at different locations

		Mean squares				
Locations	df	100 kernel weight	Grain yield	Days to mid-silk	Plant height	Ear height
Waimanalo-1						
Hybrids	44	6.4	2.3**	11.5**	8.4**	8.6**
Error	88	5.4	0.9	0.4	1.7	0.4
Waimanalo-2						
Hybrids	44	26.7	2.9**	13.8**	4.5**	1.9**
Error	88	3.6	0.7	1.1	0.4	0.1
Waimanalo-3						
Hybrids	44	15.8**	3.3**	15.0**	7.4**	6.8**
Error	88	3.7	1.4	2.3	1.0	0.7
Kamuela						
Hybrids	44	24.1**	4.3**	87.1**	7.2**	
Error	88	9.5	1.8	18.7	4.3	
Kapaa						
Hybrids	44	33.4**	2.6**	20.4**		
Error	88	7.3	1.1	5.6		
Ames, Iowa						
Hybrids	44	29.0**	3.3**	103.8**	14.0**	19.7**
Error	88	8.5	0.9	2.1	0.6	0.3
CIAT, Colombia						
Hybrids	44		5.7**			
Error	88		1.5			
Suweon, Korea						
Hybrids	44				5.5**	3.0**
Error	88				3.1	1.4

** Significant at 1 % probability level.

Appendix 31. Homgeneity tests of variances for the ear characters studied for a 10-entry diallel evaluated at different locations

Characters	Largest/ smallest error variance	Ratio of interaction variance to error variance	Relative precision of unweighted means	Chi-square values	Probability
			Lager than		Smaller than
Floret number	3.21	2.44	97	50.33	0.005
Kernels per row	2.88	2.07	97	37.36	0.005
Cob length	1.62	1.06	97	5.75	0.25 - 0.10
Filled ear length	2.17	2.14	97	17.81	0.005
Row number	4.08	1.52	90	21.79	0.005
Kernels per ear	4.48	2.04	95	13.60	0.025- 0.01
100 kernel weight	2.63	2.63	97	36.84	0.005
Grain yield	2.57	2.47	97	28.06	0.005

Appendix 32. Floret number per row of 45 hybrids at different locations

Hybrids	W-2[a]	W-3	Ames	CIAT	Suweon	Mean
B37 x B68	42.5	48.0	65.7	46.3	48.3	49.6
B37 x CI21E	48.0	50.0	66.3	54.3	52.7	53.3
B37 x Hi27	42.0	42.3	58.0	44.7	44.3	44.8
B37 x CM105	42.5	51.0	58.0	46.0	50.7	48.9
B37 x CM111	43.0	50.0	60.7	51.0	50.0	50.4
B37 x Mo17	52.0	51.7	65.7	44.0	53.3	51.2
B37 x Mp68[b]	43.5	50.3	58.0	44.3	49.3	48.0
B37 x Oh545	44.5	51.7	59.3	40.3	49.3	47.7
B37 x Tx601	45.5	51.3	54.3	52.7	54.3	53.2
B68 x CI21E	44.0	49.3	62.7	56.0	55.7	53.4
B68 x Hi27	35.5	40.7	51.3	46.7	51.0	44.9
B68 x CM105	40.5	47.0	56.0	49.0	50.0	48.0
B68 x CM111	41.0	47.0	55.0	51.7	54.0	49.4
B68 x Mo17	45.5	50.7	61.3	47.3	50.7	50.0
B68 x Mp68	41.5	50.3	55.7	49.0	46.3	47.8
B68 x Oh545	44.0	50.0	61.7	44.3	52.3	49.6
B68 x Tx601	39.0	49.7	59.7	54.3	59.7	53.3
CI21E x Hi27	39.5	45.0	54.7	48.0	52.0	47.4
CI21E x CM105	39.5	49.7	62.0	49.0	51.0	50.4
CI21E x CM111	40.0	46.7	59.7	51.0	50.3	49.4
CI21E x Mo17	47.0	51.0	57.0	49.0	55.7	50.7
CI21E x Mp68	44.8	48.3	54.0	43.7	49.7	46.4
CI21E x Oh545	44.0	51.0	59.7	49.0	55.3	51.3
CI21E x Tx601	37.5	49.3	61.0	50.0	58.0	52.1
Hi27 x CM105	38.5	41.3	47.0	41.7	42.3	40.6
Hi27 x CM111	43.0	44.3	46.7	46.0	50.0	44.3
Hi27 x Mo17	40.5	48.7	51.0	45.7	49.7	46.3
Hi27 x Mp68	43.0	44.3	50.3	42.3	49.0	44.0
Hi27 x Oh545	39.0	47.7	55.7	43.0	52.3	47.2
Hi27 x Tx601	38.5	48.7	58.3	50.7	51.0	49.7
CM105 x CM111	34.0	42.7	54.3	44.7	50.7	45.6
CM105 x Mo17	43.0	50.0	60.0	51.7	53.3	51.3
CM105 x Mp68	42.0	45.0	50.3	46.0	48.0	44.8
CM105 x Oh545	43.0	49.7	59.0	47.3	53.7	49.9
CM105 x Tx601	32.5	49.3	60.7	51.3	57.3	52.2
CM111 x Mo17	41.5	48.0	56.3	47.0	52.3	48.4
CM111 x Mp68	38.0	47.0	54.0	44.3	46.7	45.5
CM111 x Oh545	37.5	49.3	57.0	48.0	49.7	48.5
Mo17 x Mp68	48.5	52.7	60.7	46.3	55.6	51.3
Mo17 x Oh545	53.5	50.3	63.3	42.7	50.3	49.2
Mo17 x Tx601	41.5	55.0	67.0	56.3	56.3	56.2

Appendix 32. (Continued) Floret number per row of 45 hybrids at different locations

Hybrids	W-2	W-3	Ames	CIAT	Suweon	Mean
Mp68 x Oh545	47.0	48.0	59.3	42.0	49.7	47.3
Mp68 x Tx601	39.0	46.7	56.7	47.3	50.7	47.8
Oh545 x Tx601	45.0	53.3	65.0	53.3	51.3	53.3
Mean	42.0	48.6	58.2	47.8	51.6	49.0
BLSD (0.05)		2.71	2.76	2.47	6.13	3.16
C.V. (%)		5.01	4.53	4.90	10.47	6.23

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[a] W-2 and -3 are Waimanalo-2 and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 33. Kernels per row of 45 hybrids at different locations

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
B37 x B68	33.0	20.3	34.9	31.8	26.6	42.9	31.6
B37 x CI21E	33.8	27.8	40.3	41.3	32.6	47.8	37.3
B37 x Hi27	28.1	23.9	32.3	31.6	24.7	40.0	30.1
B37 x CM105	33.0	28.5	37.0	36.8	27.1	39.5	33.7
B37 x CM111	33.3	28.6	38.1	38.0	31.1	46.4	35.9
B37 x Mo17	37.1	31.9	41.9	38.8	31.4	47.2	38.1
B37 x Mp68[b]	34.6	30.0	38.2	37.5	31.5	43.8	35.9
B37 x Oh545	32.5	26.2	36.6	34.5	26.7	43.1	33.3
B37 x Tx601	34.6	31.1	37.8	36b4	31.3	44.6	36.0
B68 x CI21E	34.5	30.1	38.5	36.7	31.9	41.7	35.6
B68 x Hi27	23.9	22.7	30.4	28.8	22.4	33.6	27.0
B68 x CM105	31.4	26.7	34.6	36.2	27.4	37.3	32.3
B68 x CM111	31.0	29.2	37.9	36.8	25.5	41.4	33.6
B68 x Mo17	33.9	29.4	38.5	35.7	26.1	40.3	34.0
B68 x Mp68	35.5	29.9	38.5	39.1	32.2	38.8	35.7
B68 x Oh545	31.3	28.4	37.1	34.1	27.1	40.4	33.1
B68 x Tx601	34.1	26.6	36.2	34.6	31.2	43.8	34.4
CI21E x Hi27	34.2	25.3	38.3	34.4	29.2	41.6	33.8
CI21E x CM105	36.0	34.5	40.6	37.2	32.3	44.3	37.5
CI21E x CM111	34.4	34.5	39.1	35.7	32.7	42.4	36.5
CI21E x Mo17	39.7	33.9	43.2	38.0	35.8	43.6	39.0
CI21E x Mp68	38.8	30.0	40.4	37.7	33.3	44.2	37.4
CI21E x Oh545	36.0	30.2	42.5	31.3	33.8	46.6	36.7
CI21E x Tx601	37.6	31.6	43.1	31.8	31.3	43.0	36.4
Hi27 x CM105	31.2	27.2	32.8	31.7	26.9	32.6	30.4
Hi27 x CM111	28.5	27.7	34.3	32.6	29.7	36.8	31.6
Hi27 x Mo17	34.7	31.0	39.2	36.9	32.1	38.9	35.5
Hi27 x Mp68	32.1	29.0	36.7	33.1	29.4	34.2	32.4
Hi27 x Oh545	34.3	30.1	38.0	37.3	31.7	41.6	35.5
Hi27 x Tx601	34.6	29.6	37.8	32.5	27.4	32.4	32.4
CM105 x CM111	33.2	28.6	35.2	36.1	31.9	34.5	33.3
CM105 x Mo17	38.6	34.9	41.3	37.2	33.0	39.8	37.5
CM105 x Mp68	33.9	32.8	38.9	34.7	32.6	38./	35.2
CM105 x Oh545	33.2	26.4	39.9	33.6	29.1	35.7	33.0
CM105 x Tx601	37.8	36.1	38.4	38.0	34.9	35.8	36.8
CM111 x Mo17	39.8	32.6	40.6	40.0	35.5	39.0	37.9
CM111 x Mp68	34.3	31.6	37.4	34.1	29.8	34.9	33.7
CM111 x Oh545	36.8	30.4	41.5	34.8	36.7	41.6	37.0
CM111 x Tx601	36.9	33.9	43.0	37.9	31.7	40.2	37.3
Mo17 x Mp68	40.3	33.0	45.3	38.9	35.2	40.8	38.9
Mo17 x Oh545	37.2	30.4	44.4	35.8	36.7	46.7	38.5
Mo17 x Tx601	41.9	36.8	44.9	40.7	34.1	46.9	40.9

Appendix 33. (Continued) Kernels per row of 45 hybrids at different locations

Hybrids	W-1	W-2	W-3	Kamuela	Kapaa	Ames	Mean
Mp68 x Oh545	38.1	31.2	39.8	37.1	34.1	43.6	37.3
Mp68 x Tx601	36.0	33.4	37.5	32.9	29.9	36.1	34.3
Oh545 x Tx601	37.6	30.7	40.5	37.2	30.9	46.4	37.2
Mean	34.7	30.0	38.7	35.7	30.9	46.4	35.1
BLSD (0.05)	2.63	2.30	2.27	3.03	3.33	4.09	2.74
C.V. (%)	6.94	7.20	5.46	7.20	9.39	8.80	7.64

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[a] W-1, -2, and -3 are Waimanalo-1, -2 and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 34. Row number of 45 hybrids at different locations

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Suweon	Mean
B37 x B68	14.2	14.2	13.5	14.0	13.8	14.7	12.9	13.9
B37 x CI21E	12.6	13.1	12.8	13.6	13.3	13.9	12.4	13.1
B37 x Hi27	14.5	13.6	13.8	14.1	13.7	15.5	13.6	14.1
B37 x CM105	15.1	14.2	14.7	14.4	14.3	15.5	12.5	14.4
B37 x CM111	14.1	13.3	12.9	14.8	14.0	14.2	12.4	13.7
B37 x Mo17	12.6	12.0	12.7	12.3	12.5	13.4	12.4	12.6
B37 x Mp68[b]	13.9	13.7	13.4	14.1	14.0	15.2	11.5	13.7
B37 x Oh545	13.9	13.0	13.7	13.6	13.7	14.0	11.3	13.3
B37 x Tx601	14.7	13.3	14.5	13.5	13.3	14.9	13.2	13.9
B68 x CI21E	14.0	13.7	14.4	14.4	14.8	14.9	12.7	14.1
B68 x Hi27	14.5	14.9	14.6	14.4	15.7	15.5	13.1	14.7
B68 x CM105	15.6	14.9	15.8	15.1	14.7	15.2	14.0	15.0
B68 x CM111	14.8	13.9	14.4	14.9	14.0	15.7	12.9	14.4
B68 x Mo17	14.6	13.3	14.7	15.5	14.9	14.7	13.1	14.4
B68 x Mp68	14.6	13.5	14.9	13.7	14.1	15.6	13.2	14.2
B68 x Oh545	13.9	13.7	14.9	13.7	14.8	15.1	11.3	13.9
B68 x Tx601	15.0	14.5	14.6	14.4	14.4	15.4	15.6	14.8
CI21E x Hi27	14.9	14.1	15.1	15.2	15.0	17.0	13.3	14.9
CI21E x CM105	15.9	14.4	15.4	15.7	16.8	15.5	13.6	15.3
CI21E x CM111	13.4	13.7	13.8	14.4	13.9	15.1	12.5	13.8
CI21E x Mo17	12.8	12.7	13.1	13.3	12.7	13.8	11.3	12.8
CI21E x Mp68	14.5	13.7	14.1	14.1	13.6	15.9	13.2	14.2
CI21E x Oh545	14.5	14.6	14.1	15.2	13.9	15.6	13.1	15.2
CI21E x Tx601	13.7	13.5	14.0	13.5	14.5	14.5	15.3	14.1
Hi27 x CM105	15.7	14.9	16.0	15.5	16.1	15.6	14.7	15.5
Hi27 x CM111	15.5	15.2	15.3	14.8	15.3	16.7	13.6	15.2
Hi27 x Mo17	14.1	14.0	14.0	12.5	14.3	15.1	12.4	13.8
Hi27 x Mp68	15.8	14.9	15.1	14.3	14.7	16.1	12.9	14.8
Hi27 x Oh545	14.3	14.4	14.6	14.0	14.8	15.4	13.9	14.5
Hi27 x Tx601	15.5	14.5	15.7	14.7	15.2	15.8	14.3	15.1
CM105 x CM111	14.3	14.9	14.7	15.2	14.3	15.7	13.5	14.7
CM105 x Mo17	14.3	14.4	14.0	14.7	14.3	14.5	13.6	14.3
CM105 x Mp68	15.9	14.5	15.1	15.5	14.9	17.1	12.7	14.6
CM105 x Oh545	15.7	14.6	13.9	14.9	15.3	14.6	12.9	14.6
CM105 x Tx601	14.5	14.3	14.2	14.9	14.9	13.8	14.3	14.4
CM111 x Mo17	12.9	12.9	13.2	13.5	14.5	13.3	11.2	13.1
CM111 x Mp68	14.7	14.2	13.9	14.3	13.5	14.7	12.9	14.0
CM111 x Oh545	14.7	13.9	13.7	14.9	14.5	14.6	11.2	13.9
CM111 x Tx601	13.7	14.3	14.2	13.9	14.1	14.1	14.4	14.1
Mo17 x Mp68	14.1	12.9	12.8	13.1	12.8	13.6	12.1	13.1
Mo17 x Oh545	12.7	12.5	13.3	13.2	12.2	13.7	12.1	12.8
Mo17 x Tx601	14.3	13.8	13.1	13.5	14.5	15.6	12.9	14.0

Appendix 34. (Continued) Row number of 45 hybrids at different locations

Hybrids	W-1	W-2	W-3	Kamuela	Kapaa	Ames	Suweon	Mean
Mp68 x Oh545	13.9	13.5	14.3	13.5	13.5	15.0	12.0	13.7
Mp68 x Tx601	14.5	13.7	14.3	14.1	14.8	14.8	12.5	14.1
Oh545 x Tx601	15.0	14.2	14.5	14.4	14.3	15.7	14.7	14.7
Mean	14.4	13.9	14.2	14.2	14.3	15.0	13.0	14.2
BLSD (0.05)	0.66	0.74	0.52	0.84	0.87	0.81	1.17	
C.V. (%)	4.20	4.60	3.44	5.08	5.35	4.81	7.61	

[a] W-1, -2, and -3 are Waimanalo-1, -2, and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 35. Kernels per ear of 45 hybrids at different locations

Hybrids	W-1[a]	W-1	W-3	Kamuela	Kapaa	Ames	Mean
B37 x B68	469	267	473	445	366	633	446
B37 x CI21E	426	363	516	560	436	666	495
B37 x Hi27	407	325	446	446	341	618	430
B37 x CM105	496	405	543	530	389	613	496
B37 x CM111	468	379	492	562	445	659	501
B37 x Mo17	467	385	539	476	392	632	482
B37 x Mp68[b]	479	412	513	531	441	668	507
B37 x Oh545	451	339	501	468	365	604	455
B37 x Tx601	509	413	546	490	417	666	507
B68 x CI21E	483	412	555	529	472	622	512
B68 x Hi27	346	337	445	415	352	520	402
B68 x CM105	490	396	547	546	403	569	492
B68 x CM111	458	405	546	548	358	649	494
B68 x Mo17	495	392	568	553	389	595	499
B68 x Mp68	518	403	575	537	455	605	516
B68 x Oh545	436	391	550	467	399	615	476
B68 x Tx601	512	386	528	499	448	675	508
CI21E x Hi27	508	359	578	524	437	706	519
CI21E x CM105	571	497	627	586	543	685	585
CI21E x CM111	461	474	540	512	456	641	514
CI21E x Mo17	508	431	564	506	452	602	510
CI21E x Mp68	565	411	568	533	453	701	538
CI21E x Oh545	523	439	600	476	465	727	538
CI21E x Tx601	514	427	603	428	454	624	508
Hi27 x CM105	489	405	525	491	434	510	476
Hi27 x CM111	440	420	524	484	454	615	490
Hi27 x Mo17	488	433	549	462	460	589	497
Hi27 x Mp68	508	434	553	473	431	549	491
Hi27 x Oh545	491	441	555	523	469	641	520
Hi27 x Tx601	537	427	594	474	417	513	494
CM105 x CM111	476	426	517	549	455	548	495
CM105 x Mo17	551	503	578	546	470	579	538
CM105 x Mp68	540	475	589	536	487	651	546
CM105 x Oh545	521	386	554	501	446	527	489
CM105 x Tx601	551	514	546	565	517	494	531
CM111 x Mo17	515	422	537	538	515	521	508
CM111 x Mp68	502	449	522	486	403	515	479
CM111 x Oh545	543	421	567	519	532	610	532
CM111 x Tx601	502	484	611	527	449	566	523
Mo17 x Mp68	566	425	580	510	451	555	514
Mo17 x Oh545	475	381	592	472	448	639	501
Mo17 x Tx601	598	508	590	548	496	732	578

Appendix 35. (Continued) Kernels per row of 45 hybrids at different locations

Hybrids	W-1	W-2	W-3	Kamuela	Kapaa	Ames	Mean
Mp68 x Oh545	529	421	569	500	457	656	522
Mp68 x Tx601	524	456	538	465	444	536	494
Oh545 x Tx601	565	436	588	535	444	728	549
Mean	499	416	550	508	440	613	504
BLSD (0.05)	42	35	42	56	56	87	
C.V. (%)	7.54	7.78	6.49	8.52	10.35	11.20	

[a] W-1, -2, and -3 are Waimanalo-1, -2 and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 36. Cob length of 45 hybrids at different locations

(unit : cm)

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Mean
B37 x B68	17.5	12.5	18.8	16.4	14.7	16.0
B37 x CI21E	16.2	13.3	18.7	17.7	14.4	16.1
B37 x Hi27	14.0	12.3	16.5	16.2	12.2	14.2
B37 x CM105	16.6	14.1	18.5	18.1	13.2	16.1
B37 x CM111	16.1	13.9	17.7	17.5	13.8	15.8
B37 x Mo17	18.3	15.4	19.6	17.9	15.0	17.2
B37 x Mp68[b]	16.1	13.6	18.6	18.4	14.1	16.2
B37 x Oh545	18.5	14.1	20.7	17.6	14.7	17.1
B37 x Tx601	16.5	14.7	18.2	16.8	14.2	16.1
B68 x CI21E	18.1	14.7	19.3	17.5	15.4	17.0
B68 x Hi27	15.3	14.2	16.9	16.2	14.7	15.5
B68 x CM105	17.7	16.5	18.6	17.7	15.4	17.2
B68 x CM111	17.5	16.3	19.2	18.3	14.4	17.2
B68 x Mo17	18.9	15.6	20.2	18.2	14.6	17.5
B68 x Mp68	18.7	15.9	19.1	18.8	16.0	17.7
B68 x Oh545	19.6	15.8	19.5	17.6	16.0	17.7
B68 x Tx601	17.6	14.4	19.0	16.7	15.3	16.6
CI21E x Hi27	16.9	14.5	18.4	18.3	14.0	16.4
CI21E x CM105	17.4	15.8	18.5	16.8	14.4	16.6
CI21E x CM111	16.2	14.9	18.1	15.8	14.3	15.8
CI21E x Mo17	18.4	15.9	19.4	16.5	15.3	17.1
CI21E x Mp68	18.2	14.2	18.6	16.7	14.5	16.4
CI21E x Oh545	18.4	15.2	20.3	14.9	15.0	17.8
CI21E x Tx601	17.4	14.2	19.3	14.3	14.5	15.9
Hi27 x CM105	16.7	13.9	17.3	16.6	13.9	15.7
Hi27 x CM111	14.7	14.2	17.3	16.5	14.7	15.5
Hi27 x Mo17	17.8	15.7	19.2	17.6	16.2	17.3
Hi27 x Mp68	15.8	15.2	18.2	17.1	14.9	16.3
Hi27 x Oh545	17.1	15.2	19.3	16.8	15.7	16.8
Hi27 x Tx601	15.7	14.2	17.9	16.8	13.2	15.6
CM105 x CM111	16.2	13.9	17.7	16.7	14.8	15.9
CM105 x Mo17	18.3	15.5	18.4	15.9	14.9	16.6
CM105 x Mp68	15.9	15.1	18.1	16.3	14.4	16.0
CM105 x Oh545	18.2	16.5	19.5	15.8	15.2	17.0
CM105 x Tx601	17.6	16.4	18.3	17.1	15.4	17.0
CM111 x Mo17	17.9	15.8	19.0	17.3	15.0	17.0
CM111 x Mp68	15.8	15.0	17.7	15.7	13.1	15.5
CM111 x Oh545	17.9	15.3	20.6	15.6	15.1	16.9
CM111 x Tx601	16.4	15.6	18.9	16.6	14.7	16.5
Mo17 x Mp68	19.0	16.5	20.0	17.6	15.3	17.7
Mo17 x Oh545	18.5	16.5	22.6	17.2	17.2	18.4
Mo17 x Tx601	18.3	16.9	20.0	17.4	15.1	17.7

Appendix 36. (Continued) Cob length of 45 hybrids at different locations

Hybrids	W-1	W-2	W-3	Kamuela	Kapaa	Mean
Mp68 x Oh545	19.9	16.0	19.1	17.5	16.0	17.7
Mp68 x Tx601	16.7	15.5	17.0	15.2	14.4	15.8
Oh545 x Tx601	18.7	15.7	19.8	17.6	14.6	17.3
Mean	17.3	15.0	18.8	16.9	14.8	16.6
BLSD (0.05)	1.00	0.85	1.08	1.23	1.12	
C.V. (%)	5.29	5.18	5.02	5.90	6.14	

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[a] W-1, -2, and -3 are Waimanalo-1, -2 and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 37. Filled ear length of 45 hybrids at different locations

(unit : cm)

Hybrids	w-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
B37 x B68	14.8	9.9	15.8	14.5	12.3	21.3	14.8
B37 x CI21E	13.6	11.4	16.7	16.9	12.9	20.1	15.3
B37 x Hi27	11.9	10.8	14.4	14.1	10.8	18.7	13.5
B37 x CM105	14.2	12.3	16.1	16.4	11.2	18.9	14.9
B37 x CM111	14.1	12.0	15.8	16.1	12.5	20.0	15.1
B37 x Mo17	16.7	13.2	17.5	16.6	13.4	20.8	16.4
B37 x Mp68[b]	14.5	12.6	16.5	16.5	12.7	20.6	15.6
B37 x Oh545	16.6	12.3	16.6	16.0	12.8	21.7	16.0
B37 x Tx601	14.1	13.0	16.1	15.4	12.8	19.7	15.2
B68 x CI21E	15.5	12.1	17.3	15.8	13.4	20.7	15.8
B68 x Hi27	11.7	11.6	14.4	14.2	11.1	17.8	13.5
B68 x CM105	15.0	14.1	16.2	15.6	12.7	20.4	15.7
B68 x CM111	14.5	13.8	17.5	16.6	11.2	20.7	15.7
B68 x Mo17	15.8	12.7	17.8	15.6	11.6	20.7	16.5
B68 x Mp68	16.2	13.7	17.2	17.2	13.9	20.9	16.5
B68 x Oh545	15.7	13.3	17.1	14.9	12.6	21.4	15.8
B68 x Tx601	15.4	12.1	17.0	15.2	13.3	20.5	15.6
CI21E x Hi27	15.0	11.8	16.9	15.4	12.1	20.0	15.2
CI21E x CM105	15.4	14.1	17.3	14.9	12.5	19.4	15.6
CI21E x CM111	14.8	13.2	16.7	14.1	13.2	18.6	15.1
CI21E x Mo17	16.6	14.0	18.2	15.1	13.6	19.1	16.1
CI21E x Mp68	17.0	12.9	17.4	15.3	12.9	19.1	15.8
CI21E x Oh545	16.2	12.8	18.8	13.8	13.7	20.7	16.0
CI21E x Tx601	15.9	12.7	18.2	12.9	12.7	19.3	15.3
Hi27 x CM105	15.0	12.4	15.5	14.5	11.7	17.5	14.4
Hi27 x CM111	12.3	12.5	15.5	14.6	12.3	18.0	14.2
Hi27 x Mo17	15.2	14.0	17.0	15.1	13.7	19.9	15.8
Hi27 x Mp68	14.3	13.6	16.4	14.6	12.7	17.5	14.9
Hi27 x Oh545	14.9	13.4	17.5	14.4	13.9	20.0	15.7
Hi27 x Tx601	13.8	12.1	15.9	14.0	11.1	16.9	14.0
CM105 x CM111	15.1	12.5	16.2	15.5	13.3	17.7	15.0
CM105 x Mo17	16.4	14.3	16.8	14.2	13.4	19.4	15.7
CM105 x Mp68	14.6	14.1	17.1	14.3	12.9	18.8	15.3
CM105 x Oh545	15.5	14.0	17.1	13.7	12.3	20.3	15.5
CM105 x Tx601	15.7	14.4	16.8	15.7	14.2	19.6	16.1
CM111 x Mo17	16.0	13.7	17.4	16.3	13.6	18.5	15.9
CM111 x Mp68	14.2	13.8	16.0	14.1	11.6	18.5	14.7
CM111 x Oh545	15.9	13.6	18.6	14.2	13.8	19.8	16.0
CM111 x Tx601	14.9	14.0	17.6	15.1	12.7	18.7	15.5
Mo17 x Mp68	17.2	14.4	18.6	15.1	13.8	20.0	16.5
Mo17 x Oh545	16.3	14.2	20.3	15.8	15.5	21.7	17.3
Mo17 x Tx601	17.4	15.0	18.6	16.1	10.5	20.6	16.4

Appendix 37. (Continued) Filled ear length of 45 hybrids at different locations

Hybrids	W-1	W-2	W-3	Kamuela	Kapaa	Ames	Mean
Mp68 x Oh545	17.4	13.9	17.3	15.6	14.2	21.3	16.6
Mp68 x Tx601	14.9	14.0	15.7	14.0	12.6	18.8	15.0
Oh545 x Tx601	16.8	13.6	17.8	15.1	12.5	22.3	16.4
Mean	15.2	13.1	17.0	15.1	12.8	19.7	15.5
BLSD (0.05)	1.04	0.88	1.20	1.47	2.06	1.37	1.10
C.V. (%)	6.23	6.10	6.06	7.33	9.25	5.90	6.78

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[a] W-1, -2, and -3 are Waimanalo-1, -2, and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 38. 100 kernel weight of 45 hybrids at different locations

(unit : g)

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	Mean
B37 x B68	30.3	28.5	38.2	30.1	30.7	30.7	31.4
B37 x CI21E	31.3	23.7	37.2	29.5	32.1	35.2	31.5
B37 x Hi27	30.6	27.4	33.1	33.0	33.7	30.8	31.4
B37 x CM105	30.0	27.5	35.4	31.8	34.9	33.1	32.1
B37 x CM111	30.5	26.7	35.0	31.2	32.7	32.3	31.4
B37 x Mo17	30.3	24.4	34.8	30.0	30.9	31.8	30.4
B37 x Mp68[b]	29.2	25.0	36.3	32.4	27.4	28.7	29.8
B37 x Oh545	29.3	28.2	37.2	29.5	28.9	33.1	31.0
B37 x Tx601	31.0	26.3	33.9	29.6	33.7	28.6	30.5
B68 x CI21E	34.8	26.5	37.4	28.5	31.3	33.1	32.0
B68 x Hi27	30.7	32.3	33.1	28.9	32.2	30.1	31.2
B68 x CM105	30.3	30.2	34.2	27.4	34.5	34.4	31.8
B68 x CM111	32.2	32.5	36.5	33.7	34.4	32.5	33.6
B68 x Mo17	30.5	24.8	35.7	27.5	31.7	33.2	30.6
B68 x Mp68	34.4	33.9	32.7	29.8	29.4	27.7	31.3
B68 x Oh545	31.6	31.4	32.9	29.3	30.2	32.4	31.3
B68 x Tx601	33.3	30.9	35.6	33.9	32.4	30.3	32.7
CI21E x Hi27	31.9	24.4	33.0	26.9	32.2	29.7	29.7
CI21E x CM105	30.7	25.3	34.0	22.2	23.2	29.6	27.5
CI21E x CM111	29.4	25.6	32.5	23.1	27.9	27.7	27.7
CI21E x Mo17	30.9	24.7	37.9	28.0	27.8	27.8	29.5
CI21E x Mp68	30.8	23.6	33.9	24.7	28.7	30.3	27.0
CI21E x Oh545	31.3	22.8	35.6	25.4	25.2	30.6	28.5
CI21E x Tx601	32.2	24.0	35.2	26.0	30.2	26.5	29.0
Hi27 x CM105	34.1	31.0	31.8	28.9	30.1	32.1	31.3
Hi27 x CM111	31.3	25.9	31.3	29.3	30.5	25.2	28.9
Hi27 x Mo17	29.8	25.2	32.7	29.0	31.3	26.8	29.1
Hi27 x Mp68	33.0	25.0	30.4	23.1	27.9	23.6	27.2
Hi27 x Oh545	30.6	26.7	33.1	28.8	28.2	28.4	29.3
Hi27 x Tx601	30.5	28.7	27.7	27.0	29.2	23.5	27.8
CM105 x CM111	29.8	25.2	34.4	26.3	30.6	27.7	29.0
CM105 x Mo17	30.7	27.7	31.9	23.5	28.1	26.8	28.1
CM105 x Mp68	28.7	26.5	33.5	24.1	28.0	33.6	29.1
CM105 x Oh545	29.8	32.4	29.9	24.3	28.8	33.0	29.7
CM105 x Tx601	29.3	29.6	31.6	29.0	30.9	24.9	29.2
CM111 x Mo17	28.4	24.6	32.8	29.0	29.7	27.7	28.7
CM111 x Mp68	30.9	21.6	30.3	28.1	25.0	26.8	27.1
CM111 x Oh545	30.7	24.6	34.0	26.7	23.2	29.6	28.1
CM111 x Tx601	31.3	28.9	31.8	27.2	31.6	24.8	29.3
Mo17 x Mp68	30.4	25.0	31.8	26.8	24.8	28.1	27.8
Mo17 x Oh545	28.7	22.0	33.4	27.6	29.3	34.4	29.2
Mo17 x Tx601	28.8	24.1	34.3	25.5	25.6	25.3	27.3

Appendix 38. (Continued) 100 kernel weight of 45 hybrids at different locations

Hybrids	W-1	W-2	W-3	Kamuela	Kapaa	Ames	Mean
Mp68 x Oh545	29.3	24.1	31.2	24.4	26.0	31.6	27.8
Mp68 x Tx601	31.5	25.8	30.8	27.6	26.9	26.1	28.1
Oh545 x Tx601	32.1	26.6	32.5	30.7	27.5	28.1	29.6
Mean	30.8	26.7	33.6	28.0	29.3	29.5	29.7
BLSD (0.05)	5.78	2.02	2.18	3.92	3.04	3.44	3.18
C.V. (%)	7.54	7.09	5.72	10.98	9.22	9.87	8.51

[a] W-1, -2, and -3 are Waimanalo-1, -2, and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 39. Grain yield of 45 hybrids at different locations

(unit : T/ha)

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	CIAT	Mean
B37 x B68	8.60	5.07	11.10	8.31	7.03	5.80	3.94	7.12
B37 x CI21E	8.27	5.36	12.12	11.14	8.63	7.87	4.75	8.31
B37 x Hi27	7.16	5.37	9.31	8.93	6.67	5.93	6.84	7.17
B37 x CM105	8.78	7.22	11.57	10.90	8.13	6.27	7.57	8.63
B37 x CM111	8.27	6.30	10.98	10.53	8.70	5.43	7.39	8.23
B37 x Mo17	8.58	6.25	11.05	9.35	7.47	6.63	3.64	7.57
B37 x Mp68[b]	7.92	6.44	11.71	10.39	7.37	6.47	5.30	7.94
B37 x Oh545	7.42	5.72	10.65	8.35	6.20	6.40	3.32	6.86
B37 x Tx601	7.82	6.87	11.82	9.29	8.60	6.97	6.95	8.33
B68 x CI21E	8.93	6.27	12.17	9.18	8.70	6.80	4.50	8.08
B68 x Hi27	6.83	6.66	8.65	6.91	6.37	4.40	6.64	6.64
B68 x CM105	9.46	7.91	11.69	8.47	8.43	5.87	6.81	8.38
B68 x CM111	9.30	7.56	12.40	10.82	7.42	7.23	8.15	8.99
B68 x Mo17	9.24	6.61	12.44	8.76	7.27	6.70	5.56	8.08
B68 x Mp68	9.79	8.26	11.56	9.54	8.10	6.27	6.70	8.60
B68 x Oh545	8.69	7.18	10.66	8.14	6.77	6.47	3.31	7.32
B68 x Tx601	9.05	7.56	11.94	10.19	8.67	6.60	6.07	8.58
CI21E x Hi27	8.92	6.36	11.95	8.62	8.17	6.87	8.17	8.44
CI21E x CM105	9.54	7.68	13.17	7.59	7.53	7.07	6.28	8.41
CI21E x CM111	8.24	7.62	11.42	8.18	9.07	6.33	5.39	8.04
CI21E x Mo17	9.78	5.86	13.37	7.47	7.60	6.87	5.52	8.07
CI21E x Mp68	9.95	6.55	12.16	6.32	5.20	5.67	5.76	7.37
CI21E x Oh545	9.74	6.16	13.24	6.46	7.10	6.93	4.68	7.76
CI21E x Tx601	10.68	6.52	13.86	6.73	7.13	6.67	5.94	8.22
Hi27 x CM105	9.67	7.85	10.48	8.67	7.57	4.10	7.80	8.02
Hi27 x CM111	7.80	6.51	10.69	8.46	8.33	5.17	8.64	7.94
Hi27 x Mo17	9.06	6.52	11.41	8.17	8.43	4.47	8.42	8.07
Hi27 x Mp68	8.79	6.57	10.52	6.76	7.07	4.40	7.38	7.36
Hi27 x Oh545	8.73	7.02	11.56	7.84	7.80	6.23	6.36	7.94
Hi27 x Tx601	8.79	7.44	10.87	7.84	7.50	3.27	5.45	7.31
CM105 x CM111	9.46	7.01	11.53	8.73	8.23	4.67	7.46	8.16
CM105 x Mo17	10.61	8.63	11.49	8.19	8.07	5.27	6.92	8.46
CM105 x Mp68	8.85	8.01	12.70	7.66	7.87	5.93	6.20	8.17
CM105 x Oh545	9.19	7.60	10.59	7.27	7.90	5.30	5.49	7.62
CM105 x Tx601	10.89	9.81	11.22	9.03	9.73	3.27	4.04	8.28
CM111 x Mo17	8.99	6.37	11.08	9.09	8.73	5.90	6.93	8.16
CM111 x Mp68	8.60	6.17	10.17	7.05	5.83	4.40	6.13	6.91
CM111 x Oh545	10.08	6.15	12.89	8.03	7.57	6.27	6.57	8.22
CM111 x Tx601	8.79	8.98	12.46	9.79	8.60	5.43	7.16	8.74
Mo17 x Mp68	9.08	6.75	11.98	8.35	6.93	5.37	6.02	7.78
Mo17 x Oh545	7.90	5.38	11.80	7.96	7.97	6.40	8.58	7.28
Mo17 x Tx601	9.54	7.59	12.85	8.54	7.40	6.50	6.65	8.44

Appendix 39. (Continued) Grain yield of 45 hybrids at different locations

Hybrids	W-1[a]	W-2	W-3	Kamuela	Kapaa	Ames	CIAT	Mean
Mp68 x Oh545	8.70	6.37	10.59	7.69	6.10	6.80	4.94	7.31
Mp68 x Tx601	8.63	7.51	10.32	7.37	6.63	4.97	6.26	7.39
Oh545 x Tx601	10.09	7.71	12.11	9.76	7.13	6.87	6.36	8.58
Mean	8.96	6.92	11.56	8.51	7.64	5.90	6.09	7.94
BLSD (0.05)	1.22	0.95	1.58	1.74	1.40	1.14	1.40	1.34
C.V. (%)	10.7	12.1	10.4	15.8	13.8	16.4	20.0	13.8

[a] W-1, -2, and -3 are Waimanalo-1, -2 and -3, respectively.

[b] Mp68 = Mp68:616

Appendix 40. Analyses of combining ability for the ear characters of a 10-entry diallel evaluated at different locations

		Mean squares							
Locations	df	Floret number	Kernels per row	Cob length	Filled ear length	Row number	Kernels per ear	100 kernel weight	Grain yield
Waimanalo-1									
GCA	9		45.97**	6.83**	6.26**	2.46**	7064**	4.49**	2.10**
SCA	35		2.62	0.44	0.58*	0.32**	974**	1.54	0.44
Error	88		1.94	0.28	0.30	0.12	473	1.80	0.31
Waimanalo-2									
GCA	9		42.00**	4.04**	4.06**	1.93**	7824**	28.62**	3.37**
SCA	35		3.93**	0.43**	0.36*	0.15	847**	3.86**	0.36*
Error	88		1.55	0.20	0.21	0.14	351	1.20	0.23
Waimanalo-3									
GCA	9	34.51**	42.33**	4.76**	4.82**	2.53**	4710**	17.85**	2.91**
SCA	35	3.30*	2.36	0.37	0.38	0.21**	739*	2.00*	0.63
Error	88	1.97	1.49	0.30	0.35	0.08	425	1.23	0.48
Kamuela									
GCA	9		15.25**	1.39**	1.61**	1.91**	2872**	23.05**	3.44**
SCA	35		5.60**	0.85**	0.77*	0.31*	1223**	4.18	0.93
Error	88		2.21	0.33	0.41	0.17	625	3.15	0.60
Kapaa									
GCA	9		35.48**	2.23**	1.78**	2.48**	5418**	35.61**	1.70**
SCA	35		4.74*	0.41	0.87*	0.37*	1191*	4.86**	0.63*
Error	88		2.80	0.27	0.46	0.19	692	2.44	0.37
Ames, Iowa									
GCA	9	90.88**	64.17**		5.86**	2.05**	7662**	31.92**	3.25**
SCA	35	6.42**	5.83		0.49	0.47**	3097**	3.96	0.55*
Error	88	2.32	4.30		0.45	0.17	1568	2.83	0.31
CIAT, Colombia									
GCA	9	49.75**							5.16**
SCA	35	7.01**							1.06**
Error	88	1.83							0.49

*Significant at 5 % probability level. **Significant at 1 % probability level.

Appendix 41. Estimates of SCA effects for the ear characters of a 10-entry diallel over several locations

Hybrids	Floret number	Kernels per row	Cob length	Filled ear length	Row number	Kernels per ear
B37 x B68	-0.77	-0.60	-0.42	-0.34	0.06	-6.75
B37 x CI21E	1.94	0.95	0.17	0.03	-0.44	-4.67
B37 x Hi27	-0.90	-1.03	-1.02	-0.64	-0.21	-18.64
B37 x CM105	0.36	-0.09	0.22	-0.12	0.21	5.71
B37 x CM111	1.61	1.27	0.18	0.20	0.16	24.54
B37 x Mo17	-0.23	0.47	0.30	0.44	-0.31	-5.77
B37 x Mp68[a]	0.53	0.79	0.14	0.25	0.30	22.10
B37 x Oh545	-2.40	-1.98	0.29	0.12	0.01	-27.46
B37 x Tx601	-0.16	0.21	0.15	0.05	0.23	10.83
B68 x CI21E	2.15	1.08	0.17	0.27	-0.15	9.73
B68 x Hi27	-0.69	-2.35	-0.75	-0.93	-0.35	-49.85
B68 x CM105	-0.43	0.35	0.37	0.36	-0.16	-1.73
B68 x CM111	0.74	0.83	0.59	0.54	0.01	14.33
B68 x Mo17	-1.27	-1.76	-0.38	-0.56	0.86	7.51
B68 x Mp68	0.49	2.33	0.75	0.87	-0.21	26.94
B68 x Oh545	-0.35	-0.36	-0.07	-0.36	-0.11	-9.06
B68 x Tx601	0.13	0.47	-0.26	0.15	0.05	8.78
CI21E x Hi27	0.77	0.39	0.72	0.63	0.29	19.40
CI21E x CM105	0.95	1.45	0.29	0.18	0.61	44.47
CI21E x CM111	-0.30	-0.46	-0.20	-0.22	-0.17	-12.59
CI21E x Mo17	-1.65	-0.86	-0.25	-0.29	-0.34	-27.51
CI21E x Mp68	-1.97	-0.05	-0.00	0.01	0.05	2.80
CI21E x Oh545	0.27	-0.85	-0.49	-0.32	0.52	6.08
CI21E x Tx601	-2.16	-1.66	-0.40	-0.30	-0.38	-37.80
Hi27 x CM105	-3.22	-0.46	0.01	0.13	-0.11	-14.67
Hi27 x CM111	0.20	-0.16	0.05	0.01	0.49	13.27
Hi27 x Mo17	-0.40	0.78	0.54	0.55	-0.14	9.18
Hi27 x Mp68	1.28	0.18	0.44	0.22	0.13	5.77
Hi27 x Oh545	1.85	3.14	0.18	0.51	-0.28	37.72
Hi27 x Tx601	1.09	-0.51	-0.16	-0.47	0.18	-2.27
CM105 x CM111	-1.29	-1.10	-0.17	-0.04	-0.21	-22.27
CM105 x Mo17	1.78	0.17	-0.73	-0.42	0.11	8.86
CM105 x Mp68	-0.71	0.29	-0.44	-0.23	0.41	19.78
CM105 x Oh545	1.78	-1.98	-0.20	-0.60	-0.13	-34.22
CM105 x Tx601	0.77	1.36	0.66	0.74	-0.72	-6.03
CM111 x Mo17	-1.30	-0.29	-0.09	-0.09	-0.06	-7.19
CM111 x Mp68	-0.29	-2.10	-0.68	-0.73	-0.10	-33.10
CM111 x Oh545	0.11	1.11	-0.07	0.04	0.22	22.78
CM111 x Tx601	0.52	0.89	0.38	0.28	-0.34	0.13

Appendix 41. (Continued) Estimates of SCA effects for the ear characters of a 10-entry diallel over several locations

Hybrids	Floret number	Kernels per row	Cob length	Filled ear length	Row number	Kernels per ear
Mo17 x Mp68	2.95	0.20	0.18	0.04	-0.30	-9.53
Mo17 x Oh545	-1.81	-0.29	0.10	0.26	-0.41	-19.81
Mo17 x Tx601	1.93	1.57	0.35	0.07	0.58	44.15
Mp68 x Oh545	0.20	0.94	0.31	0.22	-0.24	3.45
Mp68 x Tx601	-2.48	-2.58	-0.69	-0.65	-0.02	-38.31
Oh545 x Tx601	0.34	0.25	-0.03	0.13	0.43	20.41

[a] Mp68 = Mp68:616

Appendix 42. Estimates of SCA effects for 100 kernel weight and grain yield over several locations

Inbreds	B68	CI21E	Hi27	CM105	CM111	Mo17	Mp68:616	Oh545	Tx601
B37	-2.21[a]	0.82	0.32	0.77	0.53	-0.09	0.06	0.09	-0.29
	-0.70	0.37	-0.28	0.52	0.21	-0.27	0.49	-0.59	0.25
B68		0.49	-0.70	-0.33	2.00	-0.69	0.75	-0.44	1.12
		-0.06	-1.02	0.06	0.77	0.05	0.95	-0.34	0.30
CI21E			0.72	-1.71	-1.01	1.21	-0.61	-0.29	0.37
			0.67	-0.02	0.30	0.08	-0.39	-0.01	0.18
Hi27				1.68	-0.23	0.37	-0.90	0.07	-1.35
				0.07	0.08	0.40	0.07	0.64	-0.61
CM105					-0.40	-0.88	0.74	0.24	-0.12
					-0.36	0.13	0.23	-0.33	-0.29
CM111						0.19	-0.69	-0.85	0.44
						-0.08	-0.95	0.36	0.26
Mo17							0.42	0.65	-1.18
							0.11	-0.39	0.14
Mp68:616								-0.13	0.35
								0.02	-0.53
Oh545									0.65
									0.66

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[a] Upper and lower values represent estimates of SCA effects for 100 kernel weight and grain yield, respectively.

Appendix 43. Average scores for *Puccinia polysora* damage at CIAT, Cali, Colombia and *Helminthosporium turcicum* damage at Kamuela, Hawaii for 45 hybrids

Inbreds	B68	CI21E	Hi27	CM105	CM111	Mo17	Mp68:616	Oh545	Tx601	Array mean
B37	2.0[a] 2.7	1.7 3.3	1.3 4.0	1.3 3.7	1.3 4.0	2.0 5.0	1.7 4.3	1.3 4.7	1.7 3.3	1.58 3.88
B68		2.0 4.7	2.3 4.0	2.7 4.0	3.0 4.0	4.0 4.7	3.0 3.7	4.0 3.2	2.7 3.0	2.86 3.83
CI21E			1.7 4.3	1.3 4.3	1.0 5.0	2.0 5.0	1.3 5.0	1.6 4.3	1.7 3.3	1.48 4.36
Hi27				2.0 3.3	1.7 3.7	1.7 4.0	1.7 4.0	2.3 4.7	1.3 3.0	1.78 3.88
CM105					2.3 4.0	1.7 4.0	2.7 4.3	2.0 3.3	1.0 3.3	1.89 3.80
CM111						2.0 4.3	2.7 4.3	2.0 3.0	1.3 3.0	1.92 3.92
Mo17							2.7 5.0	4.0 5.0	1.3 3.3	2.38 4.48
Mp68:616								4.0 5.0	2.0 3.7	2.42 4.37
Oh545									2.7 3.1	2.59 4.00
Tx601										1.78 3.13

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[a] Upper and lower values are average scores for *P. polysora* damage and *H. turcicum* damage, respectively.

Appendix 44. Number of ears per 100 plants of 45 hybrids at Kamuela, Hawaii and Ames, Iowa

Inbreds	B68	CI21E	Hi27	CM105	CM111	Mo17	Mp68:616	Oh545	Tx601	Array mean
B37	106[a]	112	100	103	108	100	105	100	99	104
	103	120	100	103	81	130	113	100	110	107
B68		113	101	107	110	104	106	101	119	107
		110	100	94	107	133	137	123	91	111
CI21E			105	101	101	108	95	92	101	103
			113	130	103	137	117	107	123	118
Hi27				102	101	104	101	101	120	104
				97	106	116	107	117	94	106
CM105					107	103	98	104	108	104
					100	123	127	120	80	108
CM111						100	100	107	109	105
						157	70	110	90	103
Mo17							101	101	114	104
							100	107	117	124
Mp68:616								105	99	101
								100	97	106
Oh545									103	102
									113	111
Tx601										108
										102

[a] Upper and lower values are number of ears per 100 plants at Kamuela and Ames, respectively.

Appendix 45. Mean estimates of the three genetic parameters for floret number and kernels per row and analyses of variance

	Genetic parameters			Chi-squares		Analysis of varaince		
	m	a	d			a,d	Residual	Error
Floret number					df	2	3	10
B37 x Hi27	42.8**	2.9	3.2	5.89		14.34*	1.52	3.25
B37 x Mo17	49.9**	-5.1**	6.1	36.46**		45.88**	12.24**	1.42
B37 x Tx601	49.8**	-2.9**	9.9**	10.90**		45.11**	4.05**	0.51
Hi27 x Mo17	46.7**	-4.4**	1.0	33.37**		38.47**	21.19**	1.04
Hi27 x Tx601	47.2**	-5.1**	9.1	20.62**		61.71**	7.27**	1.09
Mo17 x Tx601	52.3**	2.1	4.8	15.20**		23.36**	9.12**	1.19
Kernels per row								
B37 x Hi27	31.8**	1.1	7.2	6.82		11.94**	2.41	1.57
B37 x Mo17	40.6**	-7.6**	9.1**	30.94**		100.99**	11.06**	1.65
B37 x Tx601	36.2**	-1.8**	12.0**	1.36		55.14**	0.45	2.29
Hi27 x Mo17	38.2**	-8.3**	3.5	5.82		90.44**	2.18	0.90
Hi27 x Tx601	34.9**	-2.9	11.3	22.46**		54.79**	7.70	2.60
Mo17 x Tx601	42.4**	5.7**	9.6	22.61**		74.60**	8.37**	1.47

* Significant at 5 % probability level.

** Significant at 1 % probability level.

Appendix 46. Mean estimates of the three genetic parameters for cob length and filled ear length and analyses of variance

	Genetic parameters			Chi-squares	Analysis of variance		
	m	a	d		a,d	Residual	Error
Cob length				df	2	3	10
B37 x Hi27	17.3**	0.5	3.4**	1.40	4.25**	0.55	0.15
B37 x Mo17	19.9**	-2.4**	2.9	4.03	10.36**	1.38**	0.21
B37 x Tx601	17.8**	-0.3	3.7	1.35	3.65**	1.18	0.77
Hi27 x Mo17	19.4**	-3.1**	1.6	3.92	12.50**	1.41**	0.15
Hi27 x Tx601	17.8**	-0.8	4.1*	1.72	6.90**	0.45	0.25
Mo17 x Tx601	19.9**	2.3**	2.4	5.34	8.65**	1.78**	0.04
Filled ear length							
B37 x Hi27	15.2**	0.4	3.5	7.27	4.74**	0.35	0.27
B37 x Mo17	18.1**	-2.7**	3.5**	6.95	13.47**	1.03	0.35
B37 x Tx601	15.6**	-0.1	3.9	2.01	3.60**	1.47	0.46
Hi27 x Mo17	17.6**	-3.2**	1.9	1.10	14.60**	1.13**	0.17
Hi27 x Tx601	15.6**	-0.7	4.1	2.38	6.54**	0.84	0.88
Mo17 x Tx601	18.2**	3.4**	3.3	6.80	15.83**	0.17	0.19

* Significant at 5 % probability level.

** Significant at 1 % probability level.

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