A COMPARATIVE STUDY OF MATURITY INDICES AND GRAIN FILLING PERIOD IN RELATION TO YIELD IN CORN SINGLE CROSSES AND THEIR CONSTITUENT INBREDS

BY

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1. INTRODUCTION

To meet an ever growing challenge of food requirements for a rapidly rising world population, crop scientists continue to search for methods that will not only raise the output of each cultivated acre but also the quality of the produce. For plant breeders, this has involved breeding for higher yielding, disease and insect resistant, cold and drought tolerant varieties. One other improvement that has received considerable attention is breeding for fast maturing varieties that will escape cold or drought. Furthermore, the need to produce more than one crop on the same field in a given year requires early harvesting so that yield losses will not occur. In temperate climates, a farmer needs to plan a harvesting schedule that will give ample time to harvest his crop before the onset of winter and to possibly prepare the land for the next growing season. In corn a single, satisfactory criterion for maturity has been lacking despite attempts to devise such.

Corn farmers and breeders have used different criteria as indicators of maturity. Among the earliest used was visual evaluation of the ears. Changing of color to brown and subsequent drying of the husks has often been used. Thumbnail punching has also been used. The relative ease to punch decreases as the kernels approach maturity. The moisture content of kernels has also been used as an estimate of corn maturity. Heat units for the growing season have also been considered as an indicator of relative maturity in corn. More recently, the formation of a black layer at the base of the embryo or germ has been used. It can be exposed by breaking off the tip of the kernel where it was attached to the cob.

Relative maturities of corn hybrids must be accurately determined in order to measure their relative yielding abilities. Furthermore, planting of varieties with a proper maturity rating can reduce damage due to frost, particularly in temperate climate zones. The widely used classification of relative maturity in days is inadequate by itself, as the day rating may not apply to many ecological areas. The heat unit system fails to establish a specific stage when a crop can be considered to be physiologically mature. There is a need to examine various methods and their relationships in search of a more satisfactory criterion of corn maturity.

The objectives of this study were:

(i) To study the relationships between duration from planting to mid-silking and from mid-silking to black layer formation (total grain filling period) and yield.

(ii) To study the relationships among moisture percentage in the grain, heat unit accumulation, and black layer formation as criteria for corn maturity in inbreds and some of their single crosses.

2. LITERATURE REVIEW

2.1 Visual evaluation

The most commonly used method of maturity estimation in the past was the visual evaluation of certain characteristics of the ear or plant, such as glazing, denting of kernels, or drying of husks or the entire plant. This method has not been very satisfactory because of possible variation in moisture content of kernels judged to have comparable denting or relative hardness. Aldrich (2) ranked ears on the basis of external appearance into five groups, namely: early milk (kernels pale yellow in color and not yet maximum in size), late milk (kernels much deeper yellow in color and having attained maximum size), soft dough (kernel denting but easily punctured with thumbnail, average dry matter 50%), hard dough (kernels more than 90% dented and difficult to puncture with thumbnail), and ripe kernels (fully dented and no milk in the base, dry matter about 70% or above). These were named appearance factors. The correlation coefficients between ear appearance factors and percentages of dry matter in the grain were +0.953, +0.971 and +0.966 in three plantings (2). These correlations suggest that it is possible to estimate rather accurately the dry matter in the grain of corn. Aldrich considered maturity reached when one-third to one-half of the ears in a plot were in the ripe stage and the remainder in the hard dough stage. He also noted plant appearance on each harvest date and counted number of dry husks per plot and found that the number of dead leaves at each given level of moisture in the grain differed greatly between the two years. The appearance of the plant therefore did not give a satisfactory basis on which to estimate the development of the grain.

Alberts (1) found that all dent varieties which silked the same date reached the dent stage approximately the same date, regardless of whether they required a long or a short growing period prior to reaching the silk stage. The period required from the time of silking to the time of denting was approximately 40 days for early and late planting. Alberts (1) described a visual method of determining maturity. He noted that the beginning of maturity could be observed by noting the color of the husks at the lower side at the tip end of the drooping ear. At this place, the outer husks did not cover the inner husks, but left them exposed. When an area of about one-half inch in diameter of this exposed portion of the inner husks had turned yellowish in color, it indicated that the entire inner husk had begun to change color. Upon examining kernels, it was found that about 50% or more of the kernels had begun to dent. Beginning of change in color of husk on the lower tip end of the ear, when used as an index of denting during one season (summer), was not a reliable index in another season (fall). When the weather was cool, denting began before the inner husks turned yellow.

Morrow and Gardener (as quoted by Aldrich, 2) planted two different varieties of corn in two different years and found that the time from tasseling to glazing was 42 days. In his study, Aldrich (2) noted that the time at which the ear husks dried or turned straw-colored appeared to be more characteristic of the strain and less dependent upon weather conditions than the appearance of the leaves. High positive correlations were found between the percentage of dry ear husks and percentages of dry matter in the grain ($r = +0.833$). None of the strains he studied had reached maximum grain development until at least 90% of the ear husks were dead. However, despite the high correlation between the percentage of dry ear husks and dry matter in the grain, the number of dry ear husks was not a reliable index of relative maturity among the strains of corn, because some strains which did not exceed 60 or 70% in dry matter in the grain showed the highest number of dry husks throughout the period in which records were kept (2). Aldrich concluded that ear appearance was the best practical guide for farmers to cut and shock corn unless moisture testing equipment was readily available.

However, he noted that plant appearance was not a reliable index of relative or actual maturity. Appreciable development of the grain apparently cccurred after immature plants were cut and shocked.

Snelling and Hoerner (39) studied relationships among methods of measuring maturity in inbred lines and single crosses of corn and that the percentage of plants with bleached husks at the approach of maturity seemed to be an indicator of dry matter in the grain. At maturity, however, the percentage of plants with bleached husks had a lower correlation with percentage of dry matter, although significant correlations were obtained with inbred lines and single crosses but not with double crosses.

The ears were obtained in conditions free from Diplodia and pathogenic infection.

The general conclusion is that such methods cannot be used solely as a basis of maturity rating. Changes in appearance could be induced by other environmental factors and could be mistaken for maturity.

2.2 <u>Moisture</u>

Moisture content has also been used as a maturity estimate. Maturity can be defined as the point at which the maximum dry weight of the grain is first attained (2). This definition may be the most acceptable to most workers for corn maturity (Daynard and Duncan, 11; Shaw and Thom, 37; Rench and Shaw, 34; and Dessureaux et al., 13). This criterion has also been designated as physiological maturity by Shaw and Loomis (37) and morphological maturity by Anderson (3).

Corn hybrids and inbreds differ considerably in their moisture content at maturity. Miles (30) concluded that corn matures fully only if it reaches 26% moisture in the grain before cool weather retards development. Ranges from 28 to 48% have been reported (Rather and Martson, 33; Robinson, 35; Tsotsis, 41). Physiological maturity is defined as the time when maximum dry weight is reached (2, 3, 36). Percentage of dry matter or moisture in the grain has received considerable attention as a measurement of maturity (2). There has been considerable variation in moisture values at which corn grain development is considered complete. Lambert (1939) (cited by Aldrich, 2) put the value at 37.5%, Rather and Marston (33) at 40%, and Robinson (35) at 40%. Hopper (24) found 68.7%, 98.9% and 100.0% of maximum dry weight in the grain of corn in the dough, glazed and ripe stages, respectively. Aldrich (2) concluded that corn was not mature until it reached a minimum of about 65% dry matter, and percentage dry matter in the grain was the best single criterion of relative and actual maturation in corn. The number of days to mid silking was considered the second best criterion, although it was misleading in some cases. A combination of these two criteria, with greater emphasis on dry matter in the grain, was the most desirable for corn investigations. He noted, however, that there was difficulty in determining the end point in kernel development.

Dessureaux et al. (13), studying four inbred lines and two of their hybrids of contrasting relative maturity, found that they varied in rate of moisture depletion and in the rate of deposition of dry matter in the grain. The strain that flowered early matured more rapidly than those flowering late; but rate of herbal maturation may be relatively slow in some early strains and relatively rapid in some late ones. Moisture depletion was hastened by cross pollination. The use of pollen from early maturing inbreds (13) tended to hasten the rate of moisture depletion. Heterosis appeared responsible for the more rapid rate of moisture depletion in kernels after cross pollination. They concluded that the rate of corn maturation appeared to result from the complex interaction of genetic and pathologic factors, and an adequate measure of maturity should consider not only the time of flowering and kernel moisture content, and the time at which dry matter increase is completed, but also the degree of susceptibility to stalk rot infection.

Ralph, quoted by Snelling and Hoerner (39), found a negative correlation between silking date and percentage dry matter in the grain at the approach of maturity. This was highly significant among the inbreds, single crosses and double crosses which he examined. The correlation between silking date and dry matter at harvest was negative and not significant in the double crosses, even at the 5% level. This was considered important because both criteria have been used extensively in the maturity rating of commercial hybrid corn.

Carter and Poneleit (6) reported that the moisture content of kernels at the time of black layer development varied among the inbreds from 15.4 to 35%. Differences among inbreds were significant. According to Rench and Shaw (34), who referred to Brown, Newman and Blair, and Neal in their heat unit calculation, corn was classified as mature when it contained approximately 30% moisture. To be a satisfactory maturity criterion, this would require that all varieties attain maximum dry weight at 30% moisture. As noted earlier, various workers have reported considerable variation in moisture content at maximum dry weight. Thus, Shaw and Thom (37) found physiological maturity to occur at 30%, 37% or 42% moisture in varieties with diverse maturity ratings. Daynard (9) reported levels of 28 to 42% moisture at black layer formation.

2.3 Heat Units and Maturity

Tsotsis (41) investigated the possibility of devising a system for designating the maturity rating of recommended hybrids on the basis of measurements of thermal and photo-thermal units from planting to flowering and ripening. He concluded that such a system could constitute an improvement on the customary use of calendar days.

For a long time corn producers have sought methods that would provide a consistent and reliable guide in estimating maturity, and a method that would provide a measure of plant growth. One such method studied in corn improvement programs is the use of heat units accumulated during a growing season and hence often called Growing Degree Day System (GDDS). This system has been adapted to corn. Temperature is a major factor that influences growth of corn considerably (along with other environmental factors). According to Hanna (1925) (quoted by Gilmore and Rogers, 17), temperature is particularly highly correlated with growth, and it is largely responsible for variation in number of days to silking. Nevertheless, by itself it cannot be used as a measure of maturity in corn but can be an improvement on other methods (4, 17). The optimum temperature for growth of corn seedlings, according to Lehenbauer (quoted by Gilmore and Rogers, 17), is 86°F, and temperatures above this level retard growth. The effective growing temperature for corn begins at 50°F. Based on this growth response, the temperature range of 50 to 86°F was selected for measuring effective heat units using the formula by Gilmore and Rogers (17). They suggested that breeding material may be effectively classified according to maturity on the basis of effective degree days to silking, and that such classification should vary little from one area to another or from year to year. This should make it possible to compare maturity of genetic material grown in different years or areas accurately. They also suggested the use of GDD to predict the silking date without extensive testing, a technique useful in areas where drought is a problem during silking.

One problem associated with GDD as a maturity estimate is the termination point. Brickbauer (5) noted that since GDD is the sum of heat units from planting to a termination point, there is a need to define such a point which corresponds to maximum dry weight accumulation in the grain. Prior to the 1970 black layer report by Daynard and Duncan (11), a cutoff point for heat accumulation in dent corn was usually some moisture percentage at which physiological maturity was thought to occur. Neal (32), quoting such a study, noted that it provided a basis for developing a system of maturity designation that would be preferable to that based on number of days from planting or from emergence.

Daynard and Duncan (11) and Rench and Shaw (34) have shown that black layer stage of development in corn occurs at or near maximum kernel dry weight accumulation. Sutton and Stucker (40), evaluating 28 commercial corn hybrids at two dates of planting, found hybrids, locations, years, and dates of planting to be significant sources of variation for GDD from planting to black layer. Variance for GDD from planting to black layer among hybrids with the (Minnesota) relative maturity groups of check hybrids was highly significant, but was considerably less than the variance among maturity groups. They found a strong association between growing degree days to black layer and relative maturity ratings for both commercial and check hybrids, but in a number of instances hybrids that differed by ten or more relative maturity units had similar growing degree days.

Sutton and Stucker (40) also reported moisture percentage values ranging from 22.6 to 32.9% at black layer and noted that the use of growing degree days from planting to 30% moisture content would tend to increase the range in GDD for the hybrids studied.

Carter and Poneleit (6) reported that the growing degree days required to reach black layer varied from 1337 to 1808, and that the growing degree days required for kernel filling varied from 512 to 821. Year differences were significant, but interaction of inbreds with years was minor. Variability among inbreds was always much greater than among years. They noted that the growing degree days required for the filling period had positive phenotypic and genotypic correlations with the growing degree days required from planting to pollination, but that the correlations were small, suggesting possible selection of types with a long filling period and a short time to pollination.

Cross and Zuber (8) evaluated 22 methods of computing thermal units and reported that the best equation for predicting flowering date on the basis of thermal units utilized a base temperature of 10^{o}C (50^{o}F) and an optimum of 30^{o}C (86^{o}F). The excess temperature above 30^{o}C was subtracted to account for high temperature stress. Gamble (15) discussed the Ontario corn hear unit system (CCHU), a non linear formula accumulating heat units from planting to 35% kernel moisture, and concluded that OCHU was preferable to other systems. Comparing the OCHU and GDD heat unit accumulation system, Daynard (9) noted that the two systems were of comparable precision and that they were superior to number of days *per se* in characterizing the length of the interval from planting to mid-silking. However, they are not superior to number of days from mid-silking to maturity on the basis of their variance.

2.4 Black Layer Formation as a Criterion for Maturity

In their study, Daynard and Duncan (11) noted that at maturity a black closing layer develops in the placental region of corn (*Zea mays* L.). The black layer formation was described and studied by Kiesselbach and Walker (28). The black closing layer develops in a region of cells several layers thick which are formed between the basal endosperm of the kernel and the vascular area of the pedicel early in seed development. As physiological maturity is approached, these cells shrink and become compressed into a dense layer which appears black to the naked eye. At approximately the same time, the basal conducting cells of the endosperm become disorganized and are crushed tangentially so that their translocation function probably ceases. At maturity the black closing layer connects with the testa and the pericarp to form a suberized barrier around the seed (11).

The suitability of this black layer as an indicator of physiological maturity was studied in four hybrids with a range in maturity (11). As viewed by the naked eye, the layer developed in three days or less and its appearance coincided with the achievement of maximum kernel dry weight. An examination of a wide range of genotypes indicated that black layer formation is a common feature of commercial hybrids at maturity (11, 45). The fact that the formation of a black layer occurs in all commercial hybrids studied, and that it coincides with maximum grain weight, renders it a useful criterion of maturity. Furthermore, it is easily observed by the naked eye, and this makes it a better choice over other more relatively laborious methods of maturity estimate. Daynard and Duncan (11) reported that since the initial visual occurrence of black layer development was highly correlated with predicted dates of maturity (maximum kernel dry weight), then definite end points for the filling period could be determined. This indicated that more precise physiological maturity dates could be obtained by using this method than by using either kernel dry matter or moisture content. Attempts to use dry matter as an indicator of the date of physiological maturity, as was done by Shaw and Thom (37), showed that determination of maximum dry matter accumulation can be difficult. This is because (34) dry matter accumulation curves tend to approach a maximum value asymptotically, making the determination of a precise end point a difficult problem. Shaw and Thon (37) circumvented this difficulty by using 95% of the maximum dry weight determined by harvests taken after physiological maturity as their end point.

Rench and Shaw (34) reported that maximum dry matter accumulation coincided with initial occurrence of a visual black layer. Kernel moisture declined significantly during black layer development. They also noted that black layer mature kernels had moisture levels that differed statistically among varieties and within a variety planted at different dates. Analysis of dry weights of black layer samples revealed a significant quadratic relationship between kernel dry weight and phase of black layer development for all varieties tested. Daynard (9) reported that percent grain moisture at black layer varied from 30 to 37, and in some hybrids, black layer developed "prematurely" at a grain moisture of 39 to 42%. The premature black layer formation was suggested to be a consequence of cool weather during the week prior to black layer. He also noted considerable plant-to-plant variation in date of black layer formation for plants of common genetic background. From mid-silking, the mean standard deviation for date of black layer formation for an individual plant varied from 5.8 days in his 1969/70 study, to a mean value of 2.4 days in earlier work (11).

Carter and Poneliet (6) studied 20 inbred lines and observed that the color of the black layer and the rate at which it developed varied among the inbreds. For each inbred, the black layer was observed at a time that was coincident with the maximum dry weight accumulation. Carter and Poneliet (6) noted that some inbreds developed a black layer in 3 or 4 days, while others took about 15 to 20 days for complete black layer development. The actual color of the layer at black layer maturity ranged from almost coal black for most inbreds to a brownish tan for a few inbreds. Early or late maturity had little or no influence on color of the layer. Rench and Shaw (34) reported that black layer started to form as a brown area opposite the embryo when the milk line was near the tip of the kernel. Daynard et al. (11) noted that black layer was formed approximately at the same time for all kernels in the central position of the ear.

The coincidence of physiological maturity with black layer formation (9, 11, 37) provides a basis of equating physiological maturity to black layer formation. Therefore, use of black layer maturity is suggested as an alternative to maximum dry weight as a maturity criterion, which is difficult to determine.

2.5 Grain Filling Period

Shaw and Loomis (36) studied the bases for the prediction of corn yields. They concluded that the interval from silking to maturity appears very little affected by weather, and in Iowa this interval was 51 days and very constant. Because of the constancy, it can be used to predict maturity. Further studies by Dessureaux et al. (13) indicated that this interval may be longer than 51 days and may not be as constant as reported by Shaw et al. Hallauer and Russell (19) suggested that the interval from silking to maximum dry weight of grain may not be constant. They found that this duration to be longer than reported by Shaw et al. with a range of 57 to 70 days and a mean of 63 days. Hillison and Penny (23) and Gunn and Christensen (18) found a sizeable difference of 8 or more days among corn hybrids for length of the grain filling period. Thus, there is considerable variation in results obtained regarding the length of time from silk emergence to grain maturity in corn.

The interval between pollination and physiological maturity establishes the length of the grain filling period (2, 3, 36). Yield in corn is a function of rate and duration of dry matter accumulation (25). While both components are important in determining the yield potential, the latter has received inadequate attention by many research workers. This may be partly due to considerable variation among corn genotypes in the length of the period from silk emergence to grain maturity (13, 19, 37). More recent results of Duncan and Kannenberg, cited by Daynard (10), indicated that the length of the grain filling period varied from less than 50 days to well over 70 days among a wide range of genotypes. Gunn and Christensen (18) found that late maturing hybrids were characterized by longer filling periods and larger kernels than their earlier equivalents. However, significant exceptions were noted. Hanway and Russell (20) reported that a large proportion of yield differences among several corn belt hybrids could be explained by grain filling period differences. Because of the simplicity, accuracy, and precision of this procedure, the black layer method appears ideally suited to measure filling period duration in corn. Daynard (10) equated physiological maturity to the date of black layer formation and the filling period duration as the number of days from silk emergence to black layer formation on an individual ear basis. He postulated that filling period duration is determined during a relatively short period following silk emergence since most kernel cell division is completed within two to three weeks after silk emergence, during which grain storage capacity is set, and the remainder of the filling period involves only a filling of the storage capacity determined earlier.

Daynard et al. (12) found a significant linear relationship among several corn hybrids between grain yield and effective filling period duration (EFPD). EFPD was defined as the final grain yield divided by average rate of grain dry weight accumulation during the linear period of grain formation, and hence was regarded as a relative measure of the length of the grain filling period. In two years of this work, they found that yield differences were more closely related to EFPD differences than to differences in the rate of dry weight accumulation. EFPD was unaffected by plant density. Results from this work suggested a significant potential in corn for higher yields through a general extension of grain filling period. The relationship betweeen yield and duration of grain filling period has been studied more in other crops; Hanway and Weber in soybeans, Gardener in barley, Tsunoda in rice, and Stoy in spring wheat, as cited by Daynard et al. (12).

The actual length of the grain filling period can be measured as the length of time interval from silk emergence, i.e., pollination, to black layer formation. A major objective of this study was to measure this duration and to relate it to yield. This procedure, however, measures actual rather than effective grain filling period. Very limited information is available on the relationship between the two, and consequently on the relationship between actual filling duration and grain yield in corn (Daynard et al., 12).

Johnson and Tanner (25) reported a lag period of about two weeks after silking before the actual filling period started. The total grain filling period, i.e., from silking to maximum dry matter in the grain, was suggested to consist of two components: (i) a lag phase which ranged from 15 to 18 days in length in inbreds and hybrids, and (ii) a grain filling phase which ranged from 21 to 27 days for inbreds and 27 to 32 for hybrids. In another study (26), they found that an inbred and its single cross progeny differed in the length of their total filling period by only 3 days, but differed by 8 days in the length of the grain filling period due to a 5-day difference in the lag period. Carter and Poneleit (6) reported that the rate of kernel dry weight accumulation during the filling period was significantly different among inbreds and years, but there was a significant inbred x year interaction. They noted that rate of kernel dry weight accumulation was not correlated with any character other than dry weight at black layer maturity. In their study, Daynard and Duncan (11) noted a significant quadratic correlation between kernel dry weight and elapsed number of days after sampling began.

2.6 Genes for Maturity

Among the early workers to study maturity inheritance in corn were Hayes and East (21) and the latter with Emerson (reported by Duncan and Hartfield, 14). They reported that the F_1 was intermediate in maturity between the two parents. Warner (quoted by Giesbrecht, 16) in 1954 noted heterosis for earliness, while Agbe (quoted by Giesbrecht, 16), Jones (27), Yang (44) and Zoebisch (as quoted by Giesbrecht, 16) found earliness to be either partially or completely dominant. Emerson (14) and Agbe (16) found transgressive segregation for earliness in crosses they studied. Lindstrom (29) and Warner (cited by Giesbrecht, 16) obtained evidence for dominance and epistasis.

The number of genes differentiating lines which differ in quantitative traits, such as time of maturity, has lacked a general agreement among corn workers for a long time (Mohammed, 31). Data quoted by Giesbrecht (16) suggested a view that 100 to 200 genes condition quantitative inheritance (Svalof geneticists), although later studies failed to substantiate this. Zoebisch (Giesbrecht, 16) suggested that at least six factors governed the expression of silking time in a study of the progeny of corn crosses. Yang (44) reported two factors as differentiating the inbred lines of corn he studied. Giesbrecht (16), quoting Agbe, noted that in the progeny of two early by late crosses in corn, four gene pairs were responsible for differences in silking data and three gene pairs for percent ear moisture at harvest.

Jones (27), studying six early x late crosses, estimated that the maximum gene number ranged from five to 19 for silking date, two to 11 for moisture content of ears harvested at a uniform period after planting, and up to 54 for moisture content 50 days after silking, with heritability estimates of 11-48% for silking date, 36-58% for moisture content of ears harvested at a uniform period after planting, and 22-83% for moisture content 50 days after silking, with variability within individual crosses. Giesbrecht (16) reported the existence of partial phenotypic dominance for earliness in his study of two inbred lines and their F_1 and F_2 generations. He estimated maturity as days from seeding to silking and days from seeding to pollen shedding. Heritability estimates were very low. Four effective factors were suggested as differentiating the two characters: days to silking and days to pollen shedding. Van Eynatten (43) reported that the regression coefficient between tasseling time, silking time and maturation date (at Ibadan) could assist in estimating expected maturation date.

Hallauer and Russell (19) in their study of inheritance of maturity, using a model suggested by Hayman (22), obtained estimates of additive, dominance and epistatic effects in the genetic variance of generation means for days from silking to maturity and grain moisture and kernel weight at maturity. Significant effects of dominance were detected in each ear for kernel weight. Their data for days from silking to maturity indicated the presence of dominance and additive effects, with estimates of remaining effects being small. There was little heterosis for days from silking to maturity, with an average of 2.1% obtained for the three years. They suggested that due to the relative importance of the dominance and certain epistatic effects relative to additive effects, selection would appear not to be effective for isolation of lines with a shortened interval from silking to maturity for the material arising from the crosses they made. Genes controlling endosperm type have been observed by Andrew, Brink and Neal (32) to influence rate of maturation in corn, as measured by moisture content. Diseases may also influence maturation in corn. Smith and Trost (38) reported resistance to Diplodia infection was associated with lateness.

From the foregoing account, it appears that the duration from planting to silking and the effective filling period are related to yield in some way. Furthermore, there is great variation in the inheritance of these traits and perhaps selection will be worthwhile. However, there is a need for further investigations into these relationships to establish them more firmly. Compton et al. (7), in a selection program for adaptation and prolificacy, found increases in yield, plant height, and ear height, slight increases in days to flower and ears per plant, and no change in grain moisture at harvest. Troyer and Brown (42), while selecting for early flowering in three synthetic corn varieties, found a 1.00 q/ha yield increase, a 1.2 percent moisture decrease, a 5.2 cm ear height decrease, 1.8 days less to flower, and 0.3 days less silk delay per cycle, compared with the original synthetics, after 7 cycles of selection.

3. MATERIALS AND METHODS

3.1 Introduction

The field work in this study was conducted at the University of Wisconsin Arlington Experimental Farm, approximately located at 43^{o} 18' latitude and 89^{o} 21' longitude and at an elevation of 329 meters. The period of the experiment was from May through October, 1980. The laboratory work was carried out at the Seeds Building and in the basement laboratories at the Department of Agronomy, University of Wisconsin-Madison.

Land preparation was done in April, prior to planting on May 21, 1980. The soils at the site of the experiment were rich and well drained with an organic matter content of 85 metric tons per hectare, 107.6 kg of phosphorus/ha and 252 kg of potassium/ha. The average soil pH varied from 6.7 to 6.8.

The climatic conditions were quite favorable. The average temperature were 8.3, 15.6, 18.6, 22.9, 21.4, 16.2, and 7^{o} Celsius in the months of April, May, June, July, August, September and October, respectively, and were considered normal, on the basis of the averages of the period from 1941 to 1970 (NOAA)*. Rainfall was 4.5, 5.38, 9.2, 5.4, 32.8, 24.8, and 2.8 centimeters for the same

*National Oceanic and Atmospheric Administration.

months and the total also was considered normal, according to NOAA analysts.

3.2 The Genetic Material

This study utilized ten corn inbred lines and five of their single cross hybrids. They varied in relative maturity from about 80 days to 115 days, reflecting the corn maturity range in Wisconsin. The inbreds included:

W59M	W153R
W117	A619
W37A	C123
W64A	A634
W182E	Mo17

The single cross hybrids are listed in Table 1.

The plots were hand planted on May 21, 1980, with hand jabbers at the rate of two kernels per hill. When they were about 3 to 4 weeks old, they were thinned to one plant per hill.

Each plot consisted of three rows, of which the outer two were regarded as guard rows. A perfect stand was 24 plants to a row after thinning, but some rows had one or two plants fewer where some damage occurred. This was taken into consideration in computing the actual and expected yields. Within-row spacing was 20 cm, and there was 76 cm between rows in all plots, giving an expected population of 65,787 plants per hectare. Rows were 5 meters long. However, as noted above, all plots did not achieve 100% germination and therefore the actual population was

Table 1. The genetic material grown and days from planting to silk in 1980.

	Replication I	II	III	$\bar{X}$
Inbreds				
1. A634	72	71	71	71.3
2. W153R	66	65	66	65.7
3. W37A	68	69	68	68.3
4. W182E	65	65	65	65.0
5. W59M	62	63	62	62.3
b. Mo17	76	76	76	76.0
7. C123	78	78	78	78.0
8. W64A	68	68	67	67.7
9. W117	68	66	69	67.7
10. A619	71	71	71	71.0
Single crosses				
1. W59M x W117	61	66	61	62.7
2. W64A x W37A	63	63	64	63.3
3. A619 x C123	66	61	68	65.0
4. Mo17 x A634	69	62	69	67.0
5. W182E x W153R	64	64	65	64.0

slightly lower than this. The plots were weeded to ensure weed free conditions. This was done with chemicals, as well as hand weeding.

The experimental design was a randomized complete block design (RCBD). Each block had a complete set of ten inbreds and five single crosses. The blocks were replicated six times. Three blocks were used for a yield trial, while the other three were used for sampling purposes. The layout is shown in Appendix I.

No serious abnormal growth was noted, except for inbred W182E, which lodged after a wind storm but recovered within a short period.

3.3 Data Collection

A close watch was maintained in order to note the date of tasseling and silking. As soon as any plants in a plot showed tassels or silks, a daily check was made, and the number of plants with tassels and shedding pollen was recorded. This was continued until at least 50% of the plants in a plot were shedding pollen and that date was recorded as the 50% tasseling date. A similar watch was kept for silking, and as soon as one-half of the number of plants in a row were in silk, the date was recorded. This procedure has been followed by many corn research workers (9, 11, 18, 34, 37).

Six weeks after the silking/tasseling date, kernel samples were taken for moisture determination as well as for black layer detection. (On this date a dark yellow coloring was developing in sliced kernels from inbreds W182E and W59M.) The sampling procedure involved taking three ears at random from each plot and therefore a total of nine ears per treatment, in order to represent the three replications. The samples were collected usually in the evening and placed in plastic bags and taken to the laboratory immediately for analysis. The sampling was done every third day in a procedure similar to that adopted by Rench and Shaw (34). Most corn workers have reported at least three days as the duration required for black layer development (9, 11, 34). The sampling procedure continued until all samples for each entry showed a 100% black layer formation in the kernels examined.

In the laboratory the husks were removed from each ear and 12 kernels each from the tip, middle and base of the ear examined for black layer formation (9). Each ear was considered to have reached maturity when 50 to 100% of the kernels examined showed a visible black layer development. These randomly selected kernels from each sample were split lengthwise on the center of the germinal-abgerminal plane and evaluated for black layer development, a method used by Daynard and Duncan (11), Daynard (9), and Rench and Shaw (34). The split kernels were grouped into one of the following three phases for convenience.

Phase I

When kernels were milky, or non milky, but did not have a brown area opposite the embryo (corresponds to Phases I and II in classification by Shaw et al. (34).

Phase II

A thin brown line had developed, from the side opposite the embryo, to half way across the funiculum, or completely across the base of the kernel. This is the beginning of black layer formation.

Phase III

In this category, all kernels had darkened to a black layer and the black layer development was complete.

When 95 to 100% of all kernels examined had formed a black layer, 95% black layer maturity (BLM) was recorded. A similar classification was made for 50% black layer maturity when at least 50% of the kernels examined had a black layer. This was done in order to compare whether any significant differences in dry matter accumulation and heat unit accumulation existed between these two maturity classifications.

The remaining rows of each ear were shelled and mixed thoroughly with kernels from the other two ears from the same plot. A sample weighing about 100 grams was taken. Actual weight of the kernels plus the weight of the paper bags in which the moisture samples were weighed, was recorded. All weighing was done at least to .01 of a gram. The samples were placed in hot air driers at a temperature of about 49°C for a week and then for at least four days at 55°C, during which a constant weight was reached. Moisture content was expressed as a percentage on a wet weight basis.

For computation of growing degree days (GDD), the daily maximum and minimum temperature recordings taken at the UW Arlington Experimental Farm were obtained from the National Oceanic and Atmospheric Administration (NOAA), National Climatic Center, Asheville, N.C. The growing degree days were computed according to the formula given by NOAA for the duration of the experimental period. This formula is based on heat unit accumulation from planting to the date of 50%, or 95% black layer maturity (5, 17, 40) for each entry. Thus

$$GDD = \sum_{i=1}^{n} [(T_{max} + T_{min})/2 - 10]$$

where

GDD is the Growing Degree Days,

T_{max} is the daily maximum temperature in degrees Celsius,

T_{min}* is the minimum temperature in degrees Celsius for the particular day,

i=1...n denotes each day from planting to the appropriate termination point.

*Temperatures below 10°C were treated as 10°C in calculation as suggested by Gilmore and Rogers (17). If both Tmax and Tmin were below 10°C, no GDD were computed for that day, since 10°C is the minimum temperature required for the growth of corn.

3.4 Yield Data

When it had already been determined that all varieties had reached maturity, as shown by black layer formation, the yield trial plots were harvested. This was on October 23, 1980. The number of plants at harvest and number of ears were recorded. The ears were placed in plastic bags and sampled for moisture determination. The ears were dried in hot air driers and finally shelled. Further moisture content samples were taken on the day of shelling. The plot samples were weighed and calculations were made to establish the yields per plot and then on a per hectare basis (i.e., kg/ha or m. tons/ha).

3.5 Statistical Analysis

All the statistical analyses were performed in accordance with the accepted standard procedure as presented by Steel and Torrie (46) and Cochran and Cox (47). A random linear additive model was considered suitable for the analysis of variance, for example, for yield:

$$Y_{ij} = \mu + T_i + \beta_j + \epsilon_{ij}$$

where

Y is the grain yield in metric tons per hectare

μ is the population mean yield

τ_i is the effect of the ith entry

β_j is the effect of the jth replication

ϵ_{ij} is the random effect associated with an observation in the jth replication of the ith entry

Orthogonal contrasts were used to compare the preplanned tests.

4. RESULTS AND DISCUSSION

The results of this study are recorded in a series of tables that will be referred to constantly.

4.1 Silking and Tasseling

The dates at which the various genotypes achieved 50% silking and 50% pollen shedding are recorded in Table 2. The data show a good agreement within plots, with standard deviation varying from 0 to 1.53 days from the median date in inbreds. However, in the single cross hybrids, there was more variation among plants in a plot, which showed standard deviation from 0 in W182E x 153R to 4 days in Mo17 x A634. In almost all cases, tasseling and 50% pollen shedding occurred before or about the same data as 50% silking. However, a reversal was noted in inbred W182E, where 50% silking occurred one day earlier than the 50% pollen shedding. This may not affect the pollination, as corn is largely wind pollinated and the difference is not likely to deter self pollination, when this is desired.

Days from planting to mid silking varied from 62.3 (W59M) in inbreds and 62.7 in single cross hybrids (59M x W117) to 78 and 67 in inbreds (C123) and single cross hybrids (Mo17 x A634), respectively. The mean for this period was 64.4 + 1.7 days among the single crosses and 69.3 + 4.9 days for inbreds. This suggests a reduction

Table 2. Mid silking and mid pollen shedding dates for inbreds and hybrids.

	Date					
	50% pollen shedding Replications			50% silking Replications		
	1	2	3	1	2	3
(i) Inbreds						
A634	July 30	29	30	July 31	30	30
W153R	July 25	24	25	July 25	24	25
W37A	July 23	25	24	July 27	28	27
W182E	July 25	25	25	July 24	24	24
W59M	July 20	21	20	July 21	22	21
Mo17	Aug. 1	1	1	Aug. 4	4	4
C123	Aug. 4	4	3	Aug. 6	6	6
W64A	July 27	27	26	July 27	27	26
W117	July 21	21	22	July 27	25	28
A619	July 27	27	27	July 30	30	30
(ii) Single cross hybrids						
W59M x W117	July 19	22	19	July 20	25	20
W64A x W37A	July 21	21	22	July 22	22	23
A619 x C123	July 22	20	22	July 25	20	27
Mo17 x A634	July 28	21	28	July 28	22	28
W182E x W153R	July 20	22	20	July 23	23	23

of days to silking by cross pollination. Dessureaux et al. (13) reported that cross pollination hastened maturation 4 or 5 days, with the more rapid rate of moisture depletion in grain. Hallauer and Russell (19), on comparing inbreds, single crosses and the segregating F_3, BS_1* and BS_2* populations, noted little heterotic effect (2.3% on the basis of mid-parent) for hastening maturity. In this study, reduction in days to mid silking, which has often been used as a criterion of maturity (2), was 2.3 days in single cross 59M x W117, compared to its constituent inbreds, and 9.5 days in A619 x C123, compared to its late maturing inbred parents, A619 x C123.

Aldrich (2) reported that silking date is highly indicative of relative maturity. He found correlation coefficients between days from seedling emergence to silking and the percentage of dry matter in the grain at harvest time varying from -0.528 to -0.873. In this study, a correlation coefficient, r = -0.338 (which was not significant at the 5% level) was found between days to silk and grain yield among the inbreds. There was a highly significant r value of 0.90 between days to silk and yield among the hybrids at harvest, suggesting that days to silk were indicative of yield levels in the material used in this study. Further, a coincidence of maximum dry matter and the date

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*BS_1 and BS_2 = selfed backcross progenies to B14 and OH45, respectively.

of formation of a black layer was noted. Since the black layer formation was used as a criterion of physiological maturity defined as the date of maximum dry matter accumulation, then the correlation between yield and days to silking appears to support earlier observations by Aldrich (2). Snelling and Hoerner (39) reported a significant correlation between silking date and percentage of dry matter in the grain for sampled collected on September 14, but not significant on the harvesting date (October 21, 1940).

4.2 Yield

There was considerable variation in yield in the material studied, as shown in Table 3. This ranged from 3646 kg/ha (3.65 metric tons/ha) in inbred C123 to 6109 kg/ah (approximately 6.10 metric tons) in inbred A619 and 7862 kg/ha in W182E x W153R, to over 12,000 kg/ha in Mo17 x A634 among the hybrids. The mean yield, as expected, was higher for the single hybrids (9369 kg/ha) than for the inbreds (4737). Analysis of variance indicated highly significant differences (1% level) for both the inbreds and hybrids. Since block effects were not significant (5% level), much of the variation probably was genetic, because all of the experiments were carried out in a similar environment, except for possible differences in genotype-environment interactions. The increased yield in the hybrids over their respective inbreds may be attributed to

Table 3. Corn grain yields in metric tons per hectare for inbreds and hybrids.

	Replications				(Expected
	I	II	III	$\bar{X}$	$\bar{X}$) [1/]
a) <u>Inbreds</u>					
A634	3.47	5.09	4.45	4.34	4.51
W153R	5.61	5.06	6.18	5.62	5.39
W37A	4.66	4.92	4.43	4.67	5.25
W182E	4.39	5.35	4.49	4.74	4.95
W59M	3.43	4.21	4.20	3.95	4.30
Mo17	4.24	3.27	4.45	3.99	4.61
C123	3.69	3.78	3.47	3.65	3.87
W64A	5.58	5.52	5.73	5.61	6.15
W117	4.55	4.78	4.79	4.70	5.07
A617	7.13	5.17	6.03	6.11	6.35
b) <u>Hybrids</u>					
59M x W117	9.22	7.93	7.93	8.36	8.73
W64A x W37A	8.68	8.48	9.30	8.82	9.23
A619 x C123	10.89	8.21	10.09	9.73	10.52
Mo17 x A634	12.37	11.22	12.67	12.09	12.25
W182E x W153R	7.64	7.95	7.68	7.86	9.19

[1/] Expected on the basis of 24 plants per plot.

heterotic effects, which have been firmly established and for which plausible theories have been advanced.

In Table 3, a column has been included for the expected mean yields on the basis of 24 plants per plot. This takes into consideration the plants that died or did not grow to produce grain for whatever reason.

4.3 Black Layer Formation and the Grain Filling Duration (Tables 4-19)

The first samples showing the formation of a black layer in the tip of the kernels that were sliced, were inbreds W182E and W59M on September 11, 1980, and black layer formation was almost complete in both inbreds and hybrids on October 8. The exceptions were the two late maturing inbreds, Mo17 and C123, and their hybrid (Mo17 x C123). There was considerable variation in duration taken to form the black layer among the genotypes, and no attempt was made to follow up the formation within individual plants, but rather it was followed within plots by sampling an equal number of ears from each plot at intervals indicated earlier. This period, taken as the number of days since the first black layer kernels were detected, to 100% black layer formation in kernels sampled within an entry, varied from 3 days to about 22 days. This compared to 3 to 4 days in some hybrids and 15 to 20 days in others, as reported by Carter et al. (6). Daynard (11) reported a duration of 2-3 days in one study and 5-8 days for black layer development,

Table 4. Analysis of variance for yield (ton/ha).

Source of variation	df	Sum of squares	Mean square	F
(i) <u>Inbreds</u>				
Lines	9	17.9437	1.9937	6.36**
Blocks	2	0.1160	0.0580	0.19ns
Error	18	5.6398	0.3133	
Total	29	23.6995		
CV = 11.8%				
(ii) <u>Hybrids</u>				
Hybrids	4	34.3200	8.58	18.40**
Blocks	2	2.7602	1.38	2.96 ns
Error	8	3.7301	0.47	
Total	14	40.8103		
CV = 7.3%				

**Significant at 1% level.

ns - not significant at 5% level.

Table 5. Dates of 50% (A) and 95% (B) black layer formation among inbreds and hybrids.

	A. Replication			B. Replication		
	1	2	3	1	2	3
(i) Inbreds						
A634	9/28[1/]	9/26	9/26	10/4	10/4	10/4
W153R	9/25	9/29	9/26	10/8	10/8	10/8
W37A	9/24	9/26	9/26	10/4	10/8	10/4
W182E	9/15	9/19	9/22	10/4	10/1	10/4
W59M	9/24	9/26	9/24	10/8	10/8	10/8
Mo17	10/6	10/7	10/6	10/19	10/19	10/19
C123	10/11	10/9	10/10	10/19	10/19	10/19
W64A	10/5	9/30	10/5	10/8	10/8	10/8
W117	9/19	9/26	9/28	10/4	10/4	10/4
A619	10/3	10/3	10/3	10/4	10/4	10/4
(ii) Hybrids						
W59M x W117	9/20	9/17	9/17	10/1	10/4	10/1
W64A x W37A	9/15	9/19	9/15	10/4	10/1	10/4
A619 x C113	10/3	10/16	10/3	10/8	10/8	10/8
Mo17 x A634	10/6	10/3	10/6	10/11	10/11	10/8
W182E x W153R	9/27	9/27	9/27	10/4	10/8	10/4

[1/] Month/date

A Dates for 50% BLF.

B Dates for 95% BLF.

Table 6. Grain filling period in days (silking to black layer formation) for inbreds and hybrids.

Variety	Days 1	2	3	X̄
(i) Inbreds				
A634	66 (60)	67 (59)	67 (59)	66.7 (59.3)*
W153R	76 (63)	75 (66)	75 (63)	75.3 (64.0)
W37A	69 (59)	68 (56)	69 (61)	68.7 (58.7)
W182E	72 (53)	69 (57)	72 (60)	71.0 (56.7)
W59M	78 (62)	77 (65)	78 (64)	77.7 (63.7)
Mo17	76 (63)	76 (64)	76 (63)	76.0 (63.3)
C123	74 (66)	74 (64)	74 (63)	74.0 (64.3)
W64A	73 (70)	73 (65)	74 (69)	73.3 (68.0)
W117	69 (64)	71 (63)	70 (64)	70.0 (63.7)
A619	66 (65)	66 (65)	66 (65)	66.0 (65.0)
(ii) Hybrids				
W59M x W117	73 (62)	71 (54)	73 (59)	72.3 (58.3)
W64A x W37A	74 (55)	71 (60)	73 (54)	72.7 (56.3)
A619 x C123	75 (70)	80 (79)	73 (68)	76.0 (72.3)
Mo17 x A634	75 (70)	81 (73)	72 (70)	76.0 (72.3)
W182E x W153R	73 (66)	77 (66)	73 (67)	74.3 (66.3)

*Duration to 50% black layer formation is shown in brackets, other figures refer to 95% black layer.

Table 7. The grain filling period (days) and yield comparisons for inbreds and hybrids.

Entry	Yield kg/ha	Days for grain filling 50% BLF	95% BLF
(i) Inbreds			
A634	4337.1	59.3	66.7
W153R	5615.4	64.0	75.3
W37A	4668.9	58.7	68.7
W182E	4744.3	56.7	71.0
W59M	3946.9	63.7	77.7
Mo17	3987.3	63.3	76.0
C123	3646.4	64.3	74.0
W64A	5613.1	68.0	73.3
W117	4704.9	63.7	70.0
A619	6108.7	65.0	66.0
	$\bar{X}$ = 4737.4	$\bar{X}$ = 62.7	$\bar{X}$ = 71.87
(ii) Hybrids			
W59M x W117	8356.7	58.3	72.3
W64A x W37A	8818.6	56.3	72.7
A619 x C123	9728.2	72.3	76.0
Mo17 x A634	12087.4	72.3	76.0
W182E x W153R	7862.4	66.3	74.3
	$\bar{X}$ = 9369.45	$\bar{X}_1$ = 65.1	$\bar{X}_1$ = 74.26

Table 8. Regression analysis of yield on the duration of grain filling.

(i) Inbreds: Filling period to 50% black layer formation.

Source	df	Sum of squares	Mean square	F
Regression	1	550,310.80	550,310.8	0.81 ns
Deviation	8	5,411,744.84	676,468.1	
Total	9	5,962,055.64		

R^2 = 9.23%

(ii) Inbreds: Regression of yield on days from 50% silking to 95% black layer maturity.

Source	df	Sum of squares	Mean square	F
Regression	1	908,801.30	908,801.30	1.44 ns
Deviation	8	5,053,254.34	631,655.79	
Total	9	5,962,055.64		

R^2 = 15.24%

Table 9. (i) Hybrids: Regression of yield on grain filling period to 50% black layer maturity.

Source	df	Sum of squares	Mean square	F
Regression	1	4,512,270.92	4,512,270.92	2.05 ns
Deviation	3	6,610,737.65	2,202,579.219	
Total	4	11,123,008.58		

R^2 = 40.57%

(ii) Hybrids: Regression of yield on grain filling period to 95% black layer maturity.

Source	df	Sum of squares	Mean square	F
Regression	1	5,382,159.77	5,382,159.77	2.81 ns
Deviation	3	5,740,848.80	1,913,616,27	
Total	4	11,123,008.58		

R^2 = 48.39%

Table 10. Percentage grain moisture content at black layer formation.

	Replications 1	2	3	$\bar{X}$
(i) Inbreds				
A634	33.5 (37.3)	33.3 (36.0)	30.5 (36.7)	32.4 (36.7)*
W153R	28.0 (36.6)	29.0 (36.3)	26.5 (33.9)	27.8 (35.6)
W37A	24.6 (28.3)	29.9 (31.9)	31.3 (30.6)	28.6 (30.3)
W182E	29.8 (38.3)	31.7 (39.9)	31.0 (35.5)	30.8 (37.9)
W59M	28.0 (35.8)	29.7 (35.5)	29.3 (35.5)	29.0 (35.6)
Mo17	33.7 (37.5)	34.8 (38.0)	36.3 (38.7)	34.9 (38.1)
C123	27.5 (42.8)	28.3 (39.4)	29.9 (41.4)	28.5 (41.2)
W64A	28.8 (31.5)	30.1 (32.6)	28.8 (32.1)	29.2 (32.1)
W117	32.4 (35.1)	30.0 (35.9)	29.2 (37.4)	30.5 (36.1)
A619	38.1 (36.6)	37.2 (37.2)	39.6 (39.6)	38.3 (37.8)
(ii) Hybrids				
W59M x W117	28.2 (34.6)	26.6 (36.0)	28.8 (35.2)	27.9 (35.2)
W64A x W37A	30.0 (36.2)	32.1 (34.7)	28.4 (38.8)	30.2 (36.6)
A619 x C123	35.0 (36.6)	34.6 (34.7)	35.9 (35.7)	35.2 (35.7)
Mo17 x A634	27.2 (35.2)	29.2 (36.0)	31.9 (34.6)	29.4 (35.3)
W182E x W153R	33.5 (37.1)	27.6 (34.8)	28.7 (35.8)	29.9 (35.9)

*Figures in brackets: Moisture content at 50% black layer maturity. Those not enclosed refer to moisture content at 95% black layer.

Table 11. Analysis of variance for grain moisture at 95% and 50%[1] black layer maturity.

Source of variation	df[2]	Sum of squares	Mean square	F
(i) Inbreds				
Inbreds	9	324.46 (261.35)	36.05 (29.04)	13.68** (14.37)**
Blocks	2	5.77 (0.42)	2.89 (0.21)	1.09 ns (0.10) ns
Error	18	47.44 (36.37)	2.64 (2.02)	
Total	29	377.67 (298.14)		
CV = 5.23%				
(ii) Hybrids				
Hybrids	4	90.84 (10.8033)	22.71 (2.70)	4.62* (3.70)*
Blocks	2	1.83 (1.84)	0.91 (0.92)	0.185 ns (1.25) ns
Error	8	39.34 (5.80)	4.92 (0.74)	
Total	14	132.01 (18.53)		
CV = 7.27%				

**Significant at 1% level, *significant at 5% level.

ns - not significant at 5% level.

[1] Figures in brackets refer to ANOVA for grain moisture at 50% black layer formation.

[2] Degrees of freedom refer to both 95% and 50% black layer formation.

Table 12a. Heat units (Growing Degree Days) accumulated from planting to 95% black layer maturity.

	Replication			
	1	2	3	$\bar{X}$
(i) Inbreds				
A634	1365.63	1365.63	1355.63	1362.30
W153R	1378.97	1378.97	1378.97	1378.97
W37A	1365.63	1378.97	1365.63	1370.08
W182E	1365.63	1363.13	1365.63	1364.80
W59M	1378.97	1378.97	1242.31	1333.42
Mo17	1400.65	1400.65	1400.65	1400.65
C123	1400.65	1400.65	1400.65	1400.65
W64A	1378.97	1378.97	1378.97	1378.97
W117	1365.63	1365.63	1365.63	1365.63
A619	1365.63	1365.63	1365.63	1365.63
(ii) Hybrids				
W59M x W117	1363.13	1365.63	1363.13	1362.96
W64A x W37A	1365.63	1389.25	1398.97	1384.62
A619 x C123	1378.97	1378.97	1378.97	1378.97
Mo17 x A634	1392.59	1392.59	1428.97	1404.72
W182E x W153R	1365.63	1378.97	1365.63	1370.08

Table 12b. Heat units (Growing Degree Days) accumulated from planting to 50% black layer maturity.

	Replication			
	1	2	3	$\bar{X}$
(i) Inbreds				
W634A	1343.99	1334.00	1324.00	1334.00
W153R	1332.44	1350.11	1334.00	1338.83
W37A	1329.06	1334.00	1334.00	1332.35
W182E	1283.74	1299.89	1324.62	1302.75
W59M	1329.06	1334.00	1334.00	1332.35
Mo17	1365.91	1399.81	1365.91	1377.21
C123	1392.59	1385.36	1389.53	1389.16
W64A	1365.63	1356.74	1365.63	1362.67
W117	1350.11	1334.00	1343.99	1342.70
A619	1365.63	1365.63	1365.63	1365.63
(ii) Hybrids				
W59M x W117	1310.17	1289.58	1289.58	1296.44
W64A x W37A	1283.74	1299.89	1283.74	1289.12
A619 x C123	1365.63	1363.91	1365.63	1365.06
Mo17 x A634	1365.91	1365.63	1365.91	1365.82
W182E x W153R	1339.27	1339.27	1343.99	1340.84

Table 13. Growing Degree Days (GDD) for inbreds and hybrids from day of planting to mid silking.

	Replications			
	1	2	3	$\bar{X}$
(i) Inbreds				
A634	789.89	776.55	766.55	777.66
W153R	727.94	714.88	727.94	723.59
W37A	744.05	754.05	744.05	747.38
W182E	714.88	714.88	714.88	714.88
W59M	682.66	694.33	682.66	686.55
Mo17	841.00	841.00	841.00	841.00
C123	867.11	867.11	867.11	867.11
W64A	744.05	744.05	744.05	744.05
W117	744.05	727.94	754.05	742.01
A619	776.55	776.55	776.55	776.55
(ii) Hybrids				
W59M x W117	668.21	668.21	668.21	668.21
W64A x W37A	694.33	704.05	704.05	697.57
A619 x C123	727.94	727.94	744.05	733.31
Mo17 x A634	754.05	754.05	754.05	754.05
W182E x W153R	704.05	704.05	704.05	704.05

Table 14. Analysis of variance for GDD from planting to mid silking for inbreds and hybrids.

Source	df	Sum of squares	Mean square	F
(i) Inbreds				
Entries	9	84,209.96	9,356.66	193.52**
Replications	2	22.29	11.15	0.23 ns
Error	18	870.22	48.35	
Total	29	85,102.47		
CV 0.9%				
(ii) Hybrids				
Entries	4	13,229.19	3,307.30	179.94**
Replications	2	88.96	44.48	2.42 ns
Error	8	147.05	18.38	
Total	14	13,465.20		
CV 1%				

**Significant at 1% level.

ns - not significant at 5% level.

Table 15. Growing Degree Days (GDD) from mid silking to 50% black layer formation for inbreds and hybrids.

	Replications			
	1	2	3	$\bar{X}$
(i) Inbreds				
A634	554.10	557.45	557.45	556.33
W153R	604.46	635.22	606.06	615.25
W37A	585.01	579.95	589.95	584.97
W182E	568.86	585.01	609.74	587.87
W59M	646.40	639.67	651.34	645.80
Mo17	524.91	631.30	524.91	560.37
C123	525.48	518.25	522.42	522.05
W64A	621.58	612.69	621.58	618.62
W117	606.05	606.06	589.94	600.68
A619	589.08	589.08	589.08	589.08
(ii) Hybrids				
W59M x W117	641.96	621.37	621.37	628.23
W64A x W37A	589.41	605.56	579.69	591.55
A619 x C123	637.69	635.97	621.58	631.75
Mo17 x A634	611.86	611.58	611.86	611.77
W182E x W153R	635.22	635.22	639.94	633.79

Table 16. Analysis of variance for GDD from mid silking to 50% black layer formation for inbreds and hybrids.

Source	df	Sum of squares	Mean square	F
(i) Inbreds				
Entries	9	33,922.57	3,769.17	7.99**
Replications	2	880.43	440.24	0.93 ns
Error	18	8,491.24	471.74	
Total	29	43,294.29		
CV 4%				
(ii) Hybrids				
Entries	4	4,094.35	1,023.59	13.79**
Replications	2	201.57	100.78	1.36 ns
Error	8	594.01	74.25	
Total	14	4,889.93		
CV 1.4%				

**Significant at 1% level.

ns - not significant at 5% level.

Table 17. Growing Degree Days (GDD) from mid silking to 95% black layer formation for inbreds and hybrids.

	Replications			
	1	2	3	$\bar{X}$
(i) Inbreds				
A634	575.74	589.08	589.08	584.63
W153R	651.03	664.09	651.08	655.38
W37A	621.58	624.92	621.58	622.69
W182E	650.75	648.25	650.75	649.92
W59M	696.31	684.64	696.31	692.42
Mo17	559.65	559.65	559.65	559.65
C123	533.54	533.54	533.54	533.54
W64A	634.92	634.93	634.92	634.92
W117	621.58	637.69	611.58	623.62
A619	589.08	589.08	589.08	589.08
(ii) Hybrids				
W59M x W117	694.92	697.42	694.92	695.75
W64A x W37A	671.30	694.92	694.92	687.05
A619 x C123	651.03	651.03	634.92	645.66
Mo17 x A634	638.54	638.54	674.92	650.67
W182E x W153R	661.58	674.92	661.58	666.03

Table 18. Analysis of variance for GDD from mid silking to 95% black layer formation for inbreds and hybrids.

Source	df	Sum of squares	Mean square	F
(i) Inbreds				
Entries	9	61,997.11	6,888.57	199.61**
Replications	2	60.60	30.30	0.88 ns
Error	18	621.23	34.51	
Total	29	62,678.93		
CV 1%				
(ii) Hybrids				
Entries	4	5,793.26	1,448.32	8.80**
Replications	2	206.78	103.39	0.63 ns
Error	8	1,316.68	164.59	
Total	14	7,316.72		
CV 2%				

**Significant at 1% level.

ns-not significant at 5% level.

Table 19. Correlation coefficients of days to mid silking, grain filling period, heat unit accumulation and yield for hybrids and inbreds.

Correlation between	r
Days from planting to mid silking and yield in ... (1) inbreds	-0.34ns
(2) hybrids	0.91**
Grain filling days to 50% BLF and yield (inbreds)	0.30ns
Grain filling days to 95% BLF and yield in inbreds	-0.40ns
Grain filling days to 50% BLF and yield in hybrids	0.64*
Grain filling days to 95% BLF and yield in hybrids	0.70*
Heat unit accumulation in inbreds to 50% BLF and yield	-0.13ns
Heat unit accumulation in inbreds to 95% BLF and yield	-0.07ns
Heat unit accumulation in hybrids to 50% BLF and yield	0.78**
Heat unit accumulation in hybrids to 95% BLF and yield	0.57ns

ns - not significant.

* - significant at 5% level.

**- significant at 1% level.

in a later study (9), and noted considerable variability within hybrids for this trait. In both studies by Daynard and Carter et al., the reported period of black layer formation was based on an individual ear basis and had its termination point as 50% black layer formation, i.e., where at least 50% of the kernels sampled showed a black layer at their tips. This study seems to suggest considerable variability in the time taken to develop a black layer.

The color of the black layer varied from charcoal black to a deep brown color in some entries, especially C123. However, the majority of the inbreds and all hybrids showed the charcoal black color of the black closing layer. It was more difficult to determine the end point in those entries forming a brown colored closing layer, which also happened to be the late maturing ones. Carter and Poneleit (6) had similar difficulty with late maturing inbreds.

Black layer formation occurred in all the entries examined in this study and appeared to be a common feature in all inbreds and hybrids of corn that have been studied (6, 9, 11, 34, 37). It was also noted that for all inbreds and hybrids, black layer was formed during the period of maximum dry matter accumulation. This is depicted on the graph showing the dry matter accumulation of 100 kernels in relation to the time of black layer formation. This

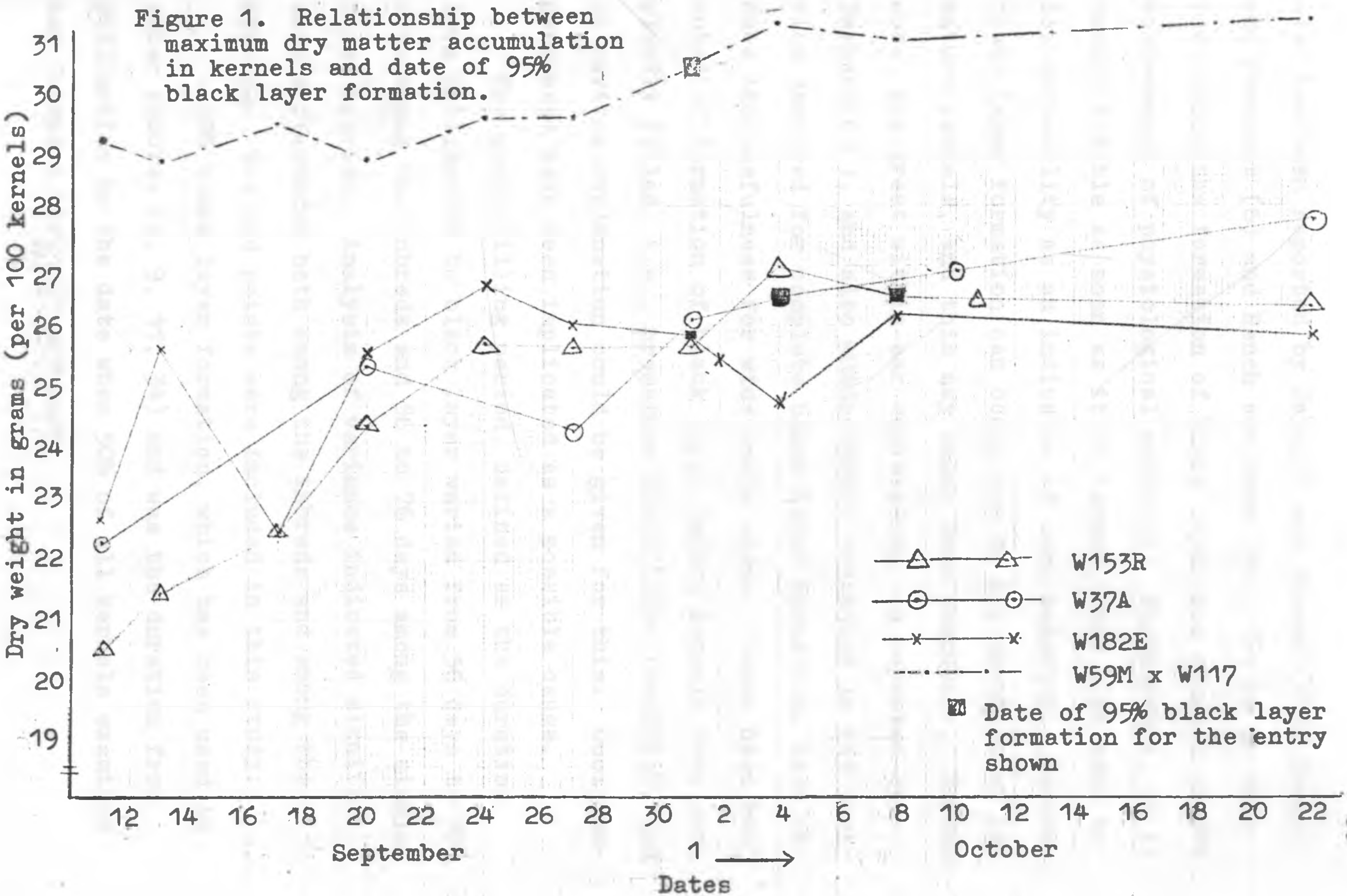

Figure 1. Relationship between maximum dry matter accumulation in kernels and date of 95% black layer formation.

also has been reported by Daynard and Duncan (11), Carter and Poneleit (6) and Rench and Shaw (34). It is on this basis that the formation of black layer was equated to the achievement of physiological maturity. Furthermore, it is easily visible as soon as it is formed; this also adds to its suitability as an indicator of corn maturity. However, black layer formation can occur due to the abortion of immature kernels, and this may cause some confusion. Furthermore, the great within-ear variability, as reported by Daynard (9), and also within-hybrid variation in the duration required for complete black layer formation, does reduce its usefulness for wide scale usage. Cases have been noted of formation of black layer before kernels have completely filled, i.e., premature black layer formation, and no obvious explanation could be given for this. Cool temperatures have been implicated as a possible cause.

The grain filling period, defined as the duration from pollination to black layer varied from 56 days to 77 days among the inbreds and 56 to 76 days among the single cross hybrids. Analysis of variance indicated significant differences both among the inbreds and among the hybrids. Two end points were included in this study:

--50% black layer formation, which has been used in other studies (6, 9, 11, 34) and was the duration from pollination to the date when 50% of all kernels examined had formed a black layer, and

--95% black layer, when 95% or more, of all kernels examined in a sample showed complete black layer formation. Both end points were related to yield in a regression analysis of yield on grain filling period. In all four cases the regression of yield on the filling period was not significant (Tables 8,9). This was true for both inbreds and hybrids. In relating the filling period (to 50% black layer formation) to yield among the inbreds, it was noted that only 9.23% of the differences in yield could be explained by the length of the total grain filling period. Using 95% BLF (black layer formation) as the end point in the same analysis, only 15.24% of the yield differences among the inbreds could be attributed to differences in length of the filling period. Since the inbreds were all grown in a similar environment and with the same planting date, it appears that a considerable proportion of the yield difference was due to the genetic constitution of those inbreds.

Among the hybrids, with 50% BLF as the end point of the filling period, 40.57% of the yield differences could be explained by differences in grain filling period. This increased to 48.4% when a regression analysis was performed with 95% BLF as the end point of the grain filling period.

The grain filling period found in this study can be compared to 57 to 70 days found by Hallauer et al. (19)

and Daynard (10), and longer than the duration first suggested by Shaw et al. (36). Data from the latter study were not supported by later work. It is also notable that there seems to be considerable variability in corn for this characteristic, and the period seems longer for the later maturing entries, as was noted by Gunn and Christensen (18), but with exceptions. Hanway and Russell (19) also found that considerable yield differences could be due to differences in the grain filling period. While this was true in this study for hybrids, it was not for inbreds. Daynard, Turner and Duncan (12) found a significant linear relationship in corn hybrids between grain yield and what they termed effective filling period duration (EFPD). However, they did not use black layer maturity as the end point, and they were not able to establish the actual (or total) filling period.

From this study and others noted above, it appears that there is some relationship between the filling period and grain yield in corn. However, it must be noted that the filling period has been defined in different ways. Daynard et al. (12) defined their EFPD as the grain yield divided by the average rate of grain weight accumulation during the linear period of grain formation, and therefore is a relative measure of the filling period. Johnson and Turner (26) noted a lag period of 7 to 14 days before the linear phase of grain filling occurs in corn. The relationship between the effective filling period and actual filling period is poorly understood and so is the effect of selection on the basis of filling period. Apparently more detailed work is required to characterize in more detail the relationship of this filling period and yield, before a meaningful selection program can be embarked on. If indeed a firm genetic relationship is established in all genotypes of corn, then selection programs in this area will be fruitful. Positive correlations were found between yield and the filling period to 50 and 95% BLF. (Table 19).

4.4 Moisture at Black Layer Formation

Table 10 gives a detailed record of grain moisture contents at black layer maturity. Again these were determined at 50% BLF and 95% BLF for both inbreds and hybrids. At 95% BLF, moisture contents varied from 28 to 38% among the inbreds and 28 to 35% in the hybrids, with means of 31% and 30.5%, respectively.

At 50% BLF, the moisture contents were slightly higher than at 95%, reflecting the drop in moisture during the maturation period. The grain moisture ranged from 30 to 41% among the inbreds and 35 to 36% among hybrids, with mean of 36.1 and 35.7%, respectively. Higher moisture contents were recorded for the late maturing inbreds, for example, C123 with 41.2% and A619 with 38.3%. Early maturity inbreds had a lower moisture content, for example W153 had 27.8% and W37A had 24.6%. These differences are likely to be partially environmental, because the earlier inbreds and/or hybrids reached their maturity while it was still warmer.

The analysis of variance showed highly significant differences in moisture content among inbreds and hybrids at 95% and 50% BLF. These results also indicated considerable variation in moisture contents both within and between entries; for instance, the hybrid, W182E x 153R, had a mean moisture content of 33.5% in one trial and 28.7% in another, the inbred, W37A, had 24.6% as mean moisture content in one trial and 31.3% in another. The moisture contents found in this study fall within the range that has been reported by other workers, as Daynard (9) who reported 30 to 37% in some hybrids, and 39 to 42% in others at black layer maturity, Sutton et al.(40) 22.6 to 32.9% at black layer, and Carter et al. (6) 15 to 35%. It would appear that some variation exists in moisture content at physiological maturity, both within and among individual hybrids or inbreds. This suggests that moisture content alone cannot be a satisfactory criterion of corn maturity. However, moisture content is an important consideration when harvesting corn, and, depending on the drying facilities available to a farmer, different grain moisture contents are likely to be chosen as suitable for corn harvesting. However, it is unlikely that, unless for high moisture corn, a farmer will harvest grain corn before the formation of a black layer. Since the black layer is much easier to detect than measuring the grain moisture content, it looks reasonable that the black layer be detected on samples collected from a field before moisture content can be determined. The use of both these two criteria appears a better 'joint' criterion than either of them alone. Thus a farmer will ensure no dry matter loss as the physiological maturity will have been reached, and there should not be excessive moisture in the corn.

There was an increase in kernel dry weight from the first day of sampling (September 11), which gradually levelled off at or around the black layer maturity. Seven of the 10 inbreds lost dry weight after the dates of BLF and moisture decreased after the same dates. The loss of dry weight after black layer appeared to indicate that maximum dry weight was attained at or near BLF, and this further supports the use of black layer as an indicator of physiological maturity in inbreds as it has been used in hybrids. Carter et al. (6) made a similar observation.

4.5 Heat Units

The results of measurements of heat units from planting to the two end points are recorded in Tables 12 and 18. On a 95% BLF basis, the growing degree days (GDD) required for inbreds ranged from 1333 to 1400, with a mean of 1372.1 ± 19.6 and CV = 1.43%. Among the hybrids, the GDD ranged from 1353 to 1404 GDD, with a mean of 1375 GDD, a standard deviation of ±27 heat units and CV = 1.96%. It would appear that the heat unit requirements for inbreds were only slightly less than for hybrids and standard deviations were not similar. The small differences may be due to uniform growing conditions and a narrow range in relative maturity of the experimental material, i.e., most arrived at the 95% BLF between October 1 and 10, when temperatures were relatively low and hence small heat unit accumulation. The maturity range for inbreds was longer than for hybrids, i.e., from October 1 to 19 for hybrids compared to mid-September to October 19 for inbreds.

On the basis of 50% BLF as the end point, the heat unit accumulation ranged from 1332 to 1404 GDD, with a mean of 1357 units, a standard deviation of ±25.4 units and a coefficient of variation of 1.8% among the inbreds. For the hybrids, the values were 1289 to 1365 GDD, with a mean of 1343, a standard deviation of ±36.8 units, and a coefficient of variation of 2.8%. This indicated more variation among the hybrids than among the inbreds on this criterion of maturity, as was the situation with 95% BLF. This could be due to low heat unit accumulation towards the end of the growing season for inbreds and hybrids, which tended to make uniform the accumulated GDD.

The analysis of variance indicated highly significant differences in heat units accumulated both among the inbreds and hybrids, suggesting considerable variation in this trait in both the inbred lines and hybrids. The number of growing degree days required among the inbreds from planting to mid silking ranged from 686 to 841 with a mean of 762. For the same period, the hybrids required 668 to 754 GDD with a mean of 711 (Table 13). The differences among the inbreds and among the hybrids were highly significant. Similarly, the GDD required during the grain filling period to either 50% BLF or to 95% BLF were highly significant, except for some inbreds where significance was detected at the 5% level only (Tables 16 and 18).

These results are in agreement with those reported by Carter and Poneleit (6), working on corn inbreds. Further, a significant negative correlation was obtained for growing degree days required during the grain filling period and moisture content at BLF for inbreds but not for hybrids. These correlations are largely genetic, since all the plots were in similar environments, except for possible genetic x environmental interaction. The significant differences for growing degree days at black layer maturity and filling period in this study suggest that an absolute value, applicable over all environments, cannot be assigned for either inbreds or hybrids. Studies (6) have indicated year-to-year variation even within the same genotype, though some genetic constant can still be established. Levels of minerals, like phosphorus and potassium, and the time of planting, have been shown to influence GDD from planting to black layer maturity as well as GDD in the filling period. This would still introduce more variability.

4.6 Contrasts between Hybrids and Their Constituent Inbreds (Table 20a-e)

Orthogonal contrasts of yield in the hybrids and their constituent inbreds, indicated highly significant differences in all five cases. The hybrids thus expressed a heterotic effect over their inbreds. The genetic basis of this is still controversial and no attempt will be made to present the theories advanced. The contrasts indicated a significant decline in moisture contents of hybrids in only 3 of the 5 cases (Table 20d). This was at the 50% black layer maturity. At 95% black layer maturity, only one (Mo17 x A634) of the three indicated a significantly lower moisture in the hybrids compared to its constituent

Table 20a. Orthogonal contrasts between hybrids and their constituent inbreds for yield (tons/ha).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\Sigma c^2$	SS(Q)	F
Treatment totals	13.01	16.84	14.0	14.23	11.84	11.96	10.93	16.83	14.11	18.32	24.39	26.45	29.18	36.26	23.27				
Contrasts																			
W59M x W117 vs W59M/W117	0	0	0	0	-1	0	0	0	-1	0	2	0	0	0	0	22.83	18	28.95	36.19**
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	22.07	18	27.06	33.83**
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	29.11	18	47.07	58.83**
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	47.55	18	125.60	157.00**
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	15.47	18	13.29	16.61**

**Significant at the 1% level.

Table 20b. Orthogonal contrasts for grain filling period (50% BLF).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\Sigma c_i^2$	SS(Q)	F
Treatment totals	178	192	176	170	191	190	193	204	191	195	175	169	217	213	199				
Contrasts																			
W59M x W117 vs W59M/W117	0	0	0	0	-1	0	0	0	-1	0	2	0	0	0	0	-32	18	56.89	8.18**
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	-42	18	98.00	14.09**
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	46	18	117.56	16.89**
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	58	18	186.89	26.86**
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	36	18	72.00	10.35**

**Significant at 1% level.

Table 20c. Orthogonal contrasts for grain filling period (95% BLF).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\Sigma c_i^2$	SS(Q)	F
Treatment totals	200	226	206	213	233	228	222	220	210	198	217	218	228	228	223				
Contrasts																			
W59M x W117 vs W59M/W117	0	0	0	0	-1	0	0	0	-1	0	2	0	0	0	0	-9	18	4.50	1.35ns
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	10	18	5.55	1.667ns
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	36	18	72.00	21.63**
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	28	18	43.56	13.09**
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	7	18	2.72	0.82ns

ns - Not significant

**Significant at 1% level.

Table 20d. Orthogonal contrasts for grain moisture (50% BLF).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\sum c_i^2$	SS(Q)	F
Treatment totals	110.0	106.8	90.8	113.7	106.8	114.2	123.6	96.2	108.4	113.4	105.8	109.7	107.0	105.8	107.7				
Contrasts																			
W59M x W117 vs W59M/W117	0	0	0	0	-1	0	0	0	-1	0	2	0	0	0	0	3.6	18	0.72	0.39ns
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	32.4	18	58.32	31.65**
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	-23.0	18	29.40	15.96**
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	-12.60	18	8.82	47.87*
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	-5.10	18	1.45	0.78ns

ns - Not significant at 5% level.

**Significant at 1% level.

*Significant at 5% level.

Table 20e. Orthogonal contrasts for grain moisture (95% BLF).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\sum c_i^2$	SS(Q)	F
Treatment totals	97.3	83.5	85.8	92.5	87.0	104.8	85.7	87.7	91.6	114.9	83.6	90.5	105.5	88.3	89.8				
Contrasts																			
W59M x W117 vs W59M/W117	0	0		0	-1	0	0	0	-1	0	2	0	0	0	0	-11.4	18	7.22	2.19*
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	7.5	18	3.12	0.95ns
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	10.4	18	6.00	1.82ns
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	-25.5	18	36.13	10.97*
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	3.60	18	0.72	0.22ns

ns - Not significant at 5% level.
*Significant at 5% level.

inbreds. In view of this result, it's difficult to make a general statement.

Highly significant results were obtained on contrasting the hybrids with their inbreds for the length of grain filling period from pollination to 50% black layer maturity. Of these, the hybrids 59M x W117 and W64A x W37A showed a significant decrease in the filling period, compared to their respective inbreds. Hybrids A619 x C123, Mo17 x A634, and W182E x W153R indicated significantly longer filling periods and yields over their constituent inbreds. At 95% black layer maturity, only two of the five hybrids, i.e., A619 x C123 and Mo17 x A634, showed significantly longer filling periods than their respective inbreds. In all cases, an increase in yield of hybrids over the inbreds supported the results of the regression analysis that the length of the filling period accounts for different percentages of yield variance in different inbreds and hybrids. These results may be partially due to the differences in the lag period which occurs before the linear grain filling phase. Thus Johnson and Turner (26) found two inbreds and their single cross progeny differing in the length of the total filling period by 3 days but differed by 8 days in the length of the grain filling period, due to a 5-day difference in the lag period.

4.7 Summary

The conclusion from this study is that three criteria, moisture percentage, GDD and black layer formation, are not adequate to measure corn maturity, although they differ in suitability. The close association of BLF with maximum dry weight, and hence the physiological maturity and the ease of detection, gives it an advantage over the other two. However, cases of premature black layer formation are a pitfall and care should be taken in using this criterion of maturity. A combination of the determination of moisture content after black layer detection would save unnecessary sampling when moisture content is high and filling is not complete. Further, the growing degree days would support the other two in guiding the planning of the crop growing in a given environment, so that on the basis of expected temperature (GDD), a rough estimate of a sampling date could be made. The data indicate a relatively small GDD variation within an inbred or hybrid in a specific environment. Thus, this third criterion would support a combination of the first two.

The negative association of GDD from planting to pollination with GDD in the filling period suggests genes causing an increased GDD for filling period also would decrease GDD from planting to pollination. If indeed the extension of the filling period would increase the yield, this would look like a favorable situation. However, further studies are required to support this view. From this study it is also clear that there is a positive correlation between the grain filling period and yield in hybrids, but a negative relationship in inbreds. It appears that selection for longer grain filling period may be beneficial, but there is need to study this relationship in several environments and years as well as establish its genetic basis.

Days to silk were also found highly indicative of yield in the hybrids used in this study.

Table 20a. Orthogonal contrasts between hybrids and their constituent inbreds for yield (tons/ha).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\Sigma c_i^2$	SS(Q)	F
Treatment totals	13.01	16.84	14.0	14.23	11.84	11.96	10.93	16.83	14.11	18.32	24.39	26.45	29.18	36.26	23.27				
Contrasts																			
W59M x W117 vs W59M/W117	0	0	0	0	-1	0	0	0	-1	0	2	0	0	0	0	22.83	18	28.95	36.19**
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	22.07	18	27.06	33.83**
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	29.11	18	47.07	58.83**
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	47.55	18	125.60	157.00**
W182E x W153R vs W182R/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	15.47	18	13.29	16.61**

**Significant at the 1% level.

Table 20e. Orthogonal contrasts for grain moisture (95% BLF).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\sum c_i^2$	SS(Q)	F
Treatment totals	97.3	83.5	85.8	92.5	87.0	104.8	85.7	87.7	91.6	114.9	83.6	90.5	105.5	88.3	89.8				
Contrasts																			
W59M x W117 vs W59M/W117	0	0		0	-1	0	0	0	-1	0	2	0	0	0	0	-11.4	18	7.22	2.19*
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	7.5	18	3.12	0.95ns
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	10.4	18	6.00	1.82ns
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	-25.5	18	36.13	10.97*
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	3.60	18	0.72	0.22ns

ns - Not significant at 5% level.
*Significant at 5% level.

Table 20d. Orthogonal contrasts for grain moisture (50% BLF).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\sum c_i^2$	SS(Q)	F
Treatment totals	110.0	106.8	90.8	113.7	106.8	114.2	123.6	96.2	108.4	113.4	105.8	109.7	107.0	105.8	107.7				
Contrasts																			
W59M x W117 vs W59M/W117	0	0	0	0	-1	0	0	0	-1	0	2	0	0	0	0	3.6	18	0.72	0.39ns
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	32.4	18	58.32	31.65**
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	-23.0	18	29.40	15.96**
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	-12.60	18	8.82	47.87*
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	-5.10	18	1.45	0.78ns

ns - Not significant at 5% level.

**Significant at 1% level.

*Significant at 5% level.

Table 20c. Orthogonal contrasts for grain filling period (95% BLF).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\Sigma c_i^2$	SS(Q)	F
Treatment totals	200	226	206	213	233	228	222	220	210	198	217	218	228	228	223				
Contrasts																			
W59M x W117 vs W59M/W117	0	0	0	0	-1	0	0	0	-1	0	2	0	0	0	0	-9	18	4.50	1.35ns
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	10	18	5.55	1.667ns
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	36	18	72.00	21.63**
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	28	18	43.56	13.09**
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	7	18	2.72	0.82ns

ns - Not significant

**Significant at 1% level.

Table 20b. Orthogonal contrasts for grain filling period (50% BLF).

Treatments	A634	W153R	W37A	W182E	W59M	Mo17	C123	W64A	W117	A619	W59M x W117	W64A x W37A	A619 x C123	Mo17 x A634	W182E x W153R	Q	$r\Sigma c_i^2$	SS(Q)	F
Treatment totals	178	192	176	170	191	190	193	204	191	195	175	169	217	213	199				
Contrasts																			
W59M x W117 vs W59M/W117	0	0	0	0	-1	0	0	0	-1	0	2	0	0	0	0	-32	18	56.89	8.18**
W64A x W37A vs W64A/W37A	0	0	-1	0	0	0	0	-1	0	0	0	2	0	0	0	-42	18	98.00	14.09**
A619 x C123 vs A619/C123	0	0	0	0	0	0	-1	0	0	-1	0	0	2	0	0	46	18	117.56	16.89**
Mo17 x A634 vs Mo17/A634	-1	0	0	0	0	-1	0	0	0	0	0	0	0	2	0	58	18	186.89	26.86**
W182E x W153R vs W182E/W153R	0	-1	0	-1	0	0	0	0	0	0	0	0	0	0	2	36	18	72.00	10.35**

**Significant at 1% level.

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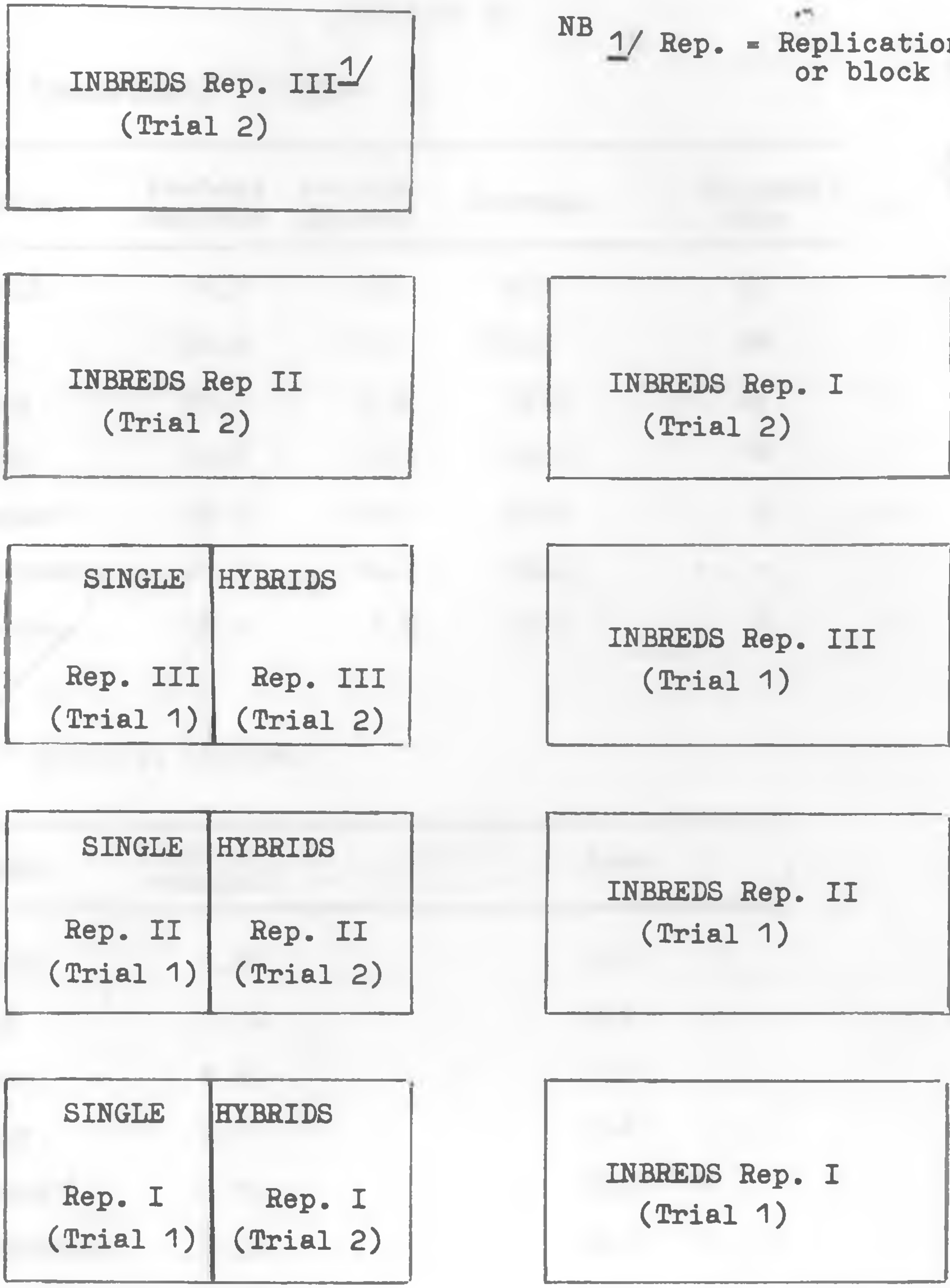
Appendix I. Field Layout.



NB 1/ Rep. = Replication or block

APPENDIX II

1. Temperature °Celsius

Month	Average maximum	Average minimum	Average	Highest date
April	14.7	1.8	8.3	22
May	22.9	8.3	15.6	28
June	25.4	11.8	18.6	27
July	29.8	16.1	22.9	18
August	27.2	15.7	21.4	8
September	21.7	10.7	16.2	-
October	12.4	1.6	7.1	8

2. Rainfall (inches)

Month	Total rainfall	Snow
April	1.79	1.0
May	2.12	0.0
June	3.62	0.0
July	2.11	0.0
August	12.92	0.0
September	9.75	0.0
October	1.09	0.0