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Vegetative and Reproductive Development of Corn (*Zea mays* L.) at Four Spring Planting Dates

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DEVELOPPEMENT VEGETATIF ET REPRODUCTIF DU MAIS (*Zea mays* L.) A QUATRE DATES DE SEMIS AU PRINTEMPS.

Par : N'guettia René YAO

Résumé

Les rendements en grain du maïs sont influencés par plusieurs facteurs y compris les caractéristiques physicochimiques du sol, les facteurs climatiques, les techniques culturales, le potentiel génétique des hybrides, la résistance aux maladies et le contrôle des ennemis de la plante. Nous devons développer une meilleure compréhension des mécanismes par qui ces différents facteurs influencent le rendement si nous voulons apporter une amélioration systématique à ce rendement de maïs. Un essai a été mis en place en 1979 à la Ferme agronomique de "Pennsylvania State University" près de Rock Springs avec du maïs provenant de deux groupes de maturité différente pour étudier la croissance végétative et le développement de la production dans différents environnements associés au retard du semis au printemps. Ensuite pour déterminer le mécanisme par lequel le retard du semis au printemps conduit à des rendements en grain reduits. Les résultats de cette étude étaient utilisés pour aider à identifier les facteurs qui s'associent pour réduire les rendements pour des semis à des périodes recommandées.

L'étude avait deux buts :

1) déterminer les relations entre la température de l'air et le développement de la plante de maïs pendant plusieurs stades de croissance ;

2) déterminer comment les intéractions temps-température entraînent la réduction du rendement en grain observé avec des semis tardif.

Un hybride hatif (Cornell 281) et un hybride semi tardif (Pioneer 3780) de maïs ont été semés manuellement à quatre dates, du 12 mai au 22 juin et demariés à 86500 et 66500 plants/ha respectivement pour C281 et P3780 afin d'obtenir des indices foliaires (LAI) équivalents. Les températures du sol et de l'air, le rayonnement solaire et les précipitations avaient été horairement enregistrés. Des relevés de température et d'humidité de sol ont été faits deux ou trois fois par semaine dans le champ expérimental et des échantillons de plantes régulièrement collectés pour caractériser le développement végétatif et reproductif.

La durée du semis à la levée a varié entre 6 et 8 jours et est plus courte quand la germination et la période de levée ont coïncidé avec des jours de température moyenne élevée. La durée en jour de la levée à l'initiation des fleurs mâles décroît avec le retard du semis.

L'accumulation de surface foliaire par plante et le développement de l'indice foliaire sont une fonction linéaire de la somme des degrés jours (GDD). La distribution de la matière sèche dans les différentes parties de la plante est identique pour les deux hybrides à toutes les dates de semis ; les taux presque constants de 17, 31 et 52 % étant observés respectivement pour les graines ; les limbes et les tiges avant la mi-floraison.

Le nombre de double-lignes de grains par épi est significativement supérieur ($P < 0,05$) pour P3780 (7,54) que pour C281 (7,39) quand la moyenne est faite sur toutes les dates de semis. Le nombre d'ovules par épi croit linéairement pendant le développement de l'épi, atteignant son maximum près de l'émission des soies puis décroit légèrement. Le nombre maximum d'ovules par double ligne est identique pour les deux hybrides à toutes les dates de semis variant entre 92 et 109. Le taux de grains effectivement remplis a varié entre 50 et 67 % du nombre d'ovules présents à l'émission des soies. Le rendement décroit avec des semis plus tardifs de 8,16 à 2,75 tonnes/ha pour C281 et de 8,85 à 1,63 tonnes par ha pour P3780. Les rendements très faibles enregistrés pour les deux dernières dates de semis sont en grande partie dûs à une faible pollinisation causée par des dégâts d'insectes sur les soies.

L'accumulation de matière sèche dans le grain est une fonction linéaire à la fois du temps en jours et de la somme des degrés jours. Le taux de remplissage des grains par jour ou par degré jour est identique pour les deux hybrides et à toutes les dates de semis. La période effective de remplissage des grains, dans la majorité des cas, décroit avec des semis plus tardifs ; variant entre 45 et 25 jours ; cependant, la période apparente de remplissage (de l'émission des soies à la formation de la couche noire) augmente. Cette augmentation est due à un retard dans la formation de la couche noire à la fin de la période de remplissage. Le remplissage des grains a été prématurement arrêté par le gêle pour les deux dernières dates de semis. Nous avons conclu que la diminution de la période effective de remplissage avec des semis plus tardifs est la principale cause de la réduction du rendement en grain. Puis que le rendement en grain du maïs décroit avec des semis plus tardifs et que la production d'ovules et l'accumulation de matière sèche sont des fonctions linéaires à la fois de la somme des degrés jours et de la durée en jours ; l'effet de la température n'a pu être dissocié. Trente à cinquante pour cent du potentiel d'ovules ne sont pas remplis en grains mûrs. Un travail de recherche doit être fait à l'avenir pour utiliser ce potentiel important d'ovules afin de maximiser le rendement du maïs.

The signatories below indicate that they have read and approved the thesis of N'guettia René Yao.

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ABSTRACT

Corn grain yields are influenced by many factors including soil physical and fertility characteristics, climatic factors, soil and crop management, hybrid genetic potential, disease resistance, and pest control. We must develop better understanding of the mechanisms by which these varied factors influence yield if we are to make systematic improvement in corn yields. A field experiment with maize from two maturity groups was conducted in 1979 at The Pennsylvania State University Agronomy farm near Rock Springs to study corn vegetative growth and yield development under the different environments associated with delayed spring planting. In addition to determining the mechanism whereby delayed spring planting leads to reduced grain yields, results of this study were used to help identify factors that combine to limit grain yields with planting at recommended periods.

The study had two objectives: (1) to determine the relationships between air temperature and corn plant development during several growth stages; and (2) to determine how these time-temperature effects bring about the reduction in yield observed with late planting.

An early (Cornell 281), and a mid-season (Pioneer 3780) corn hybrid, were each hand planted at four dates, from 12 May to 22 June and thinned to 86,500 and 66,500 plants/ha for C281 and P3780, respectively, to produce equivalent leaf area indexes (LAI). Soil and air temperatures, radiation, and precipitation were recorded hourly. Soil temperature and moisture block readings were also made two to three times per week at the experimental field. Plant samples were collected frequently to characterize vegetative and reproductive development.

Time to emergence ranged from 6 to 8 days and was shorter where the germination and emergence period consisted of days with higher daily average temperatures. Time (calendar days) from emergence to tassel initiation decreased with delayed planting.

Leaf area accumulation per plant and LAI development was found to be a linear function of growing degree days (GDD). The distribution of plant dry weight among different plant parts was similar between hybrids and among planting dates. Nearly constant percentages of 17, 31, and 52% were observed for sheaths, blades, and stalks, respectively, before mid-silk.

The number of double kernel rows per cob was significantly higher ($P < 0.05$) for P3780 (7.54) than C281 (7.39) when averaged over planting dates. Number of kernel sites per ear increased linearly during ear shoot development, reached a maximum near silking, and then declined slightly. The maximum number of kernel sites per double row was found to be similar for both hybrids at all dates and ranged from 92 to 109. The percentage of kernels that actually filled ranged from 50% to 67% of the number of kernel sites present at silking. Final grain yield decreased with late planting from 8.16 to 2.75 tons/ha for C281 and from 8.85 to 1.63 tons/ha for P3780. The very low yields in the last two planting dates were in a large part caused by poor pollination which, in return, was caused by insect damage to ear silks during pollination.

Kernel dry matter accumulation was a linear function of both GDD and calendar days. Kernel growth rate for GDD and calendar days was similar for all planting dates and hybrids. The effective filling period in most cases decreased with delayed planting, ranging from 45 to 25 days. The apparent filling period, from silking to blacklayer, however, increased with late planting due to delayed blacklayer formation at the end of the filling period. Grain filling was halted prematurely by frost at the two last planting dates. It was concluded that the decrease in effective filling period with delayed planting was the primary cause of reduced grain yield.

Since corn grain yield declined with delayed planting and kernel site production and kernel dry matter accumulation were linear functions of both GDD and Julian days, the temperature effect remained undetermined. Thirty to fifty percent of the potential kernel sites did not fill to mature kernels. Future research work should be done to utilize the large number of potential kernel sites for higher grain production.

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CHAPTER I

INTRODUCTION

Date-of-planting experiments not only allow one to evaluate the performance of hybrids from different maturity classes, but also to investigate developmental aspects of corn in the environment. Significant differences in corn plant development are likely to occur in different environments created by various planting dates. Characterization of these differences should contribute to a better understanding of corn plant development and of the influences of certain aspects of the environment on it. From a practical viewpoint, farmers frequently have to delay corn planting when spring weather conditions are poor for early field work or early seeding. In addition, replanting is often necessary when poor germination resulting in a poor plant population is likely to drastically reduce crop yield. A better understanding of plant response to late planting could lead to management practices that encourage late planting of corn in certain cropping systems.

The influence of delayed planting on corn (Zea mays L.) growth and yield has been studied by a number of workers. Benoit, Hatfield, and Ragland (1966) concluded from their research work in Kentucky that corn final yields indeed decreased with late planting. Decreases in yield with delayed planting are commonly reported in Pennsylvania and in many other states (1980 Agronomy Guide, The Pennsylvania State University). The 1980 Agronomy Guide of The Pennsylvania State University states: the "Ideal planting time is only a few days in duration. In most years, each day's delay past this period reduces yields by up to one bushel per acre per day." The concept of critical periods of planting for optimum corn yields is generally accepted throughout the country (Shaw, 1975). There is little evidence that demonstrates why late planting results in reduced yields.

Various researchers including Hunter et al. (1974) and Carr (1976), have pointed out that corn development and grain yields are influenced by many factors such as soil physical and fertility characteristics, climatic factors, and soil and crop management. A single factor or a combination of factors could result in yield reduction or increases. It is likely that different factors contribute to yield reductions from year to year and location to location so that the biological mechanisms responsible for reduced yields are difficult to identify and characterize.

One way to try to understand what happens to grain yield at the end of the growing season is through the analysis of the development and size of the components of yield. An intensive investigation of plant vegetative development and yield components (plants/ha, ears/plant, kernels/ear, dry weight/kernel) throughout the growing season should help identify the factors contributing to an eventual decrease in yield. The major environmental factors affecting yield development are solar radiation, temperature, and moisture. Although there have been many studies conducted to examine the effects of temperature and solar radiation on corn, little has been done to try to understand the mechanisms through which delayed planting, temperature, and radiation interactions lead to a decline in yield. In order to develop an understanding of the mechanisms in which late planting and temperature influence plant development and grain yield, a field study was conducted during the 1979 growing season at The Pennsylvania State University Agronomy Farm with two objectives:

(i) To determine the relationship between air temperature and various periods of corn plant development (tassel initiation, leaf development, ear shoot development, silking, and kernel filling); and

(ii) To determine how these time-temperature effects bring about the reduction in yield observed with late plantings.

CHAPTER II

LITERATURE REVIEW

The literature on corn growth and grain production has developed over many years. Climatic factors, such as temperature and radiation, affecting corn development have been well studied. A review of important findings on effects of environmental factors on developmental aspects of corn yield will help develop a background for the present research work. In this chapter, I will review results of research work about: (1) the different parts of the corn plant, their relations to yield, and how they are affected by factors of their environment; and (2) the concept of heat unit and growing degree days used in work involving temperature.

A. Developmental Aspects of Corn

1. Date for Corn Planting in Pennsylvania

In regions where weather conditions limit the development of crop plants, some of the factors to look at, before establishing any crop, are the length of the growing season (period safe from frost: temperature > $0^{o}C$ or $32^{o}F$), and the ideal date for planting. Early planting is commonly recommended to encourage good canopy development coincident with the period of high solar radiation and long photoperiods. Early planting is also recommended so that full season hybrids which commonly produce more leaf area per plant than short season hybrids can be grown.

A study conducted at State College, Pennsylvania (central Pennsylvania) over a 30-year period (Table 1) indicates the variation usually observed in growing season parameters. This report of 30 years of

Table 1. Summary of the results from a 30-year period (1926-1955) study at State College (central Pennsylvania) on the probability of frost in spring and fall. (Adapted from Kauffman and Butler, 1961.)

Probability of Frost	Season	
	Spring	Fall
.90	April 16	October 30
.75	" 21	" 23
.67	" 23	" 10
.33	May 01	" 06
.25	" 03	" 03
.10	" 08	September 24

records (Kauffman and Butler, 1961), shows that the frost free growing season in State College extends roughly from May 8 to September 24. The growing season in Pennsylvania varies from 90 to 130 days with the location (see Pennsylvania corn maturity zone map: Figure 1, and Table 2) (1980 Agronomy Guide, The Pennsylvania State University). A report by Shaw (1975) on the Growing-Degree Units for Corn in the North Central Region of the United States of America, shows an ideal average planting date to be safe from frost. This date varies with each zone and ranges from April 18 (in south Missouri) to June 6 (in Minnesota). It has been reported that corn can be safely planted 10 to 14 days before the average date of the last killing frost in the spring (Shaw, 1975 and 1980 Agronomy Guide, The Pennsylvania State University). Corn should be planted as early as possible to allow the completion of the grain filling before the frost in fall. Adequate hybrid selection based on both the length of the corn development cycle and the length of the growing season should be made.

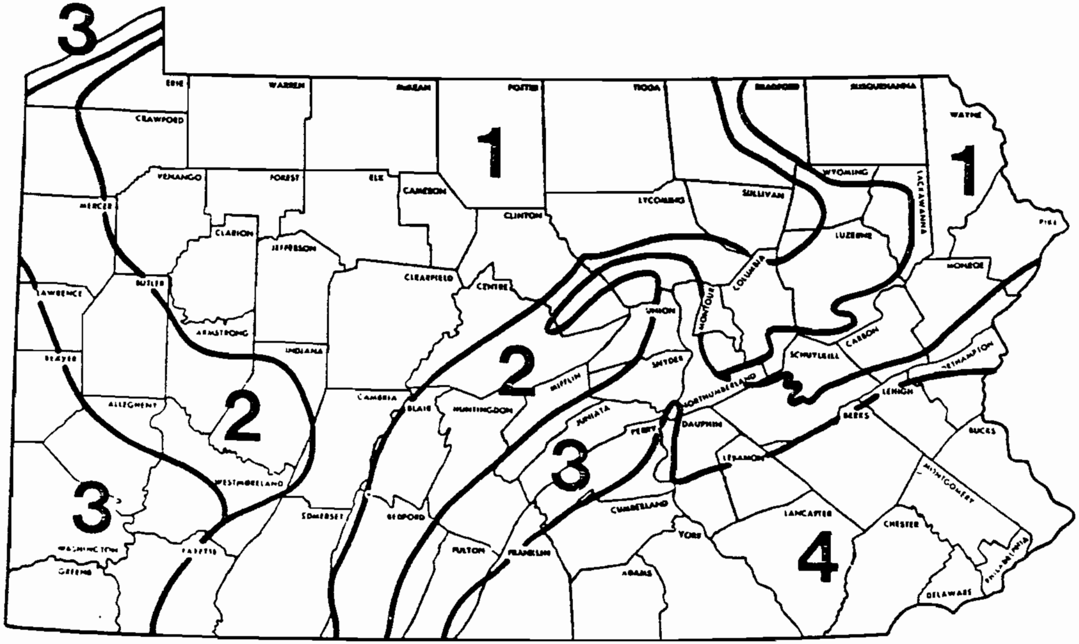


Figure 1. Pennsylvania corn maturity zones; 1, 2, 3, and 4 are the different zones.

Table 2. Pennsylvania corn maturity zones and their characteristics with respect to Days to Maturity and Growing Degree Days (GDD). (Adapted from 1980 Agronomy Guide, Pennsylvania State University.)

Pennsylvania Maturity Zone	Approximate Days to Maturity	GDD*
1	90-95	1600
	96-100	1825
2	101-105	2025
	106-110	2275
3	111-115	2500
	116-120	2725
4	121-125	2950
	126-130	3175

*GDD calculated with "National Weather Bureau" system (^{O}F system).

2. Emergence

Early growth of corn seedlings depends mainly on the conditions of emergence. This early growth, as one would expect, has an important influence on final corn grain yield.

Hanway (1966) reported that the corn embryo in the seed has five or more leaves and that the primary roots have been initiated. After planting, the seed absorbs water and the young plant begins to grow. The first internode elongates until the coleoptile emerges above the ground and so brings the plant under the influence of light which suppresses coleoptile growth and stimulates the formation of chlorophyll and leaf development. Under moist and warm conditions, the plants emerge within 5 days, but 2 weeks or longer may be required under cool and dry conditions (Hanway, 1966). Depth of planting has been reported to influence the length of time from planting to emergence. Blacklow in 1972 described the influence of temperature on germination and emergence of maize (Blacklow, 1972a and 1972b). He found that optimum growth during seedling establishment occurred at 30°C. A low temperature of 9°C led to a cessation of growth while a constant 40°C was lethal for corn plants. Blacklow (1973) developed a prediction model for germination and emergence that gave good agreement with measured values under fluctuating temperatures in controlled environments and in the field. He also pointed out that the verified model supported the hypothesis that the germinating seed and its elongating axes respond to prevailing temperatures with no adaptation to preceding conditions, and that the system responds within minutes to changes in temperature. Iremiren and Milbourn (1979), investigating soil temperature effects on corn emergence, reported that the initial effect of a clear polyvinyl chloride (PVC) mulch treatment was to shorten the interval between sowing and emergence and to improve germination. They pointed out that maize development was accelerated from emergence through to the grain maturity stage by an increase in soil temperature.

In conclusion to this section, two things need to be noted: (i) an improvement in germination and emergence can lead to better yield per unit land area; and (ii) adequate water supply and warm temperatures near 30°C are the ideal conditions for better germination and plant emergence.

3. Tassel Initiation

The importance of tassel initiation in corn plant development is due to the fact that leaf and ear primordia initiation are stopped at that stage. Therefore, one would expect a greater number of leaves per plant if any factor delays tassel initiation without affecting the leaf initiation rate. Temperature and photoperiod are two such factors that have been investigated.

There are reports that the ear shoot and the tassel begin to form when the plant has 8 or more leaves (Hanway, 1966). The tassel and its parts differentiate when the internodes of the stem start to elongate. Bonnett (1966) reported that tassel development was completed when anthers dehiced. There is evidence for a consistent decrease in time to tassel initiation as temperature increases from 15°C to 25°C regardless of photoperiod (Coligado and Brown, 1975). However, no difference in tassel initiation time has been reported at temperatures from 25°C to 30°C, suggesting that the optimum temperature is between 25-30°C. They reported an increase in leaf number due to a delay in tassel initiation with long photoperiods. A similar increase in leaf number due to delayed tassel initiation was reported with cool compared to warm temperature treatments. Hunter et al. (1974) found that the time to tassel initiation in a growth chamber experiment increased up to 5 days when the photoperiod was increased from 10 to 20 hours, and that this response occurred at all temperatures studied. However, the magnitude of the response was reported to be less at high temperature. Their findings on the time to tassel initiation were confirmed a year later by Coligado and Brown (1975). These researchers reported however that the relationship was nonlinear. Coligado and Brown (1975) also reported an interaction between temperature and photoperiod effects on the time to tassel initiation. The delay in tassel initiation with long compared to short photoperiods (20 vs. 10 hours) and the associated increase in leaf number helped explain the increase in the amount of vegetative dry matter present at tassel initiation in the long photoperiod treatments. Iremiren and Milbourn (1975) conducted a mulching experiment to study the influence of soil temperature on growth and development in maize. They reported that soil rather than air temperatures during the first 5 to 6 weeks after sowing had the most dominant effects on corn plant growth and subsequently on tassel initiation. This report confirmed results obtained by Watts (1972) and later supported by Carr (1977), and Cooper and Law (1977).

In conclusion, soil temperature and photoperiod should be recognized as two major environmental factors affecting the time to tassel initiation. In addition, this time to tassel initiation is very important in determining leaf number and leaf area per plant in some environments.

4. Leaf Development

Leaf number and leaf development are important in light interception and photosynthate production by the plant canopy. Like the other parts of the corn plant, leaf initiation and expansion are influenced by climatic factors such as temperature and photoperiod.

a. Rate of leaf initiation and leaf appearance. One should make a distinction between leaf initiation rate and the rate of leaf appearance. The former concerns the rate of leaf primordia initiation. Leaf initiation stops with tassel initiation. Therefore, a greater number of leaf initials is expected with delay in tassel initiation as reported earlier in this chapter. Milthorpe and Moorby (1974) defined plastochron as the time interval between the appearance of successive leaf primordia. There is evidence that leaf initiation rate increases with temperature. In 1975, Coligado and Brown reported a relative small decrease in leaf initiation rate with an increase in photoperiod. Leaf appearance rate describes leaf unfolding from the terminal enclosing sheaths. It usually occurs at a lower rate than that of primordia initiation because leaves require longer than one plastochron to unfold. Brouwer et al. (1973) reported that temperature appeared to be a major factor in determining the rate of leaf appearance, while light quality and intensity were found to have minor effects. They pointed out that up to the time of formation of the 8th visible leaf, root temperature controlled the rate of leaf appearance, but that air temperature gradually took over the control of leaf growth. Cooper (1979) reported a linear relationship between the rate of leaf emergence and soil temperature up to the 12th leaf stage. Thereafter, he found that the minimum temperature for leaf emergence was 9°C (48°F).

Bonaparte (1975) reported that leaves emerged at faster rates at higher temperatures, and under conditions of high soil fertility. He observed a reduction in leaf number in shorter daylength regimes as reported by many other workers. He also pointed out that the influence of photoperiod on leaf number was greater with cool nights than warm nights.

b. Leaf expansion. Cell division continues after leaf unfolding but at a declining average rate until the leaf is 25-75% of its final size (Humphries and Wheeler, 1963). These workers observed that cell division and leaf expansion ceased first at the leaf tip. Light and temperature were reported to influence cell division in the leaf primordia so that complete darkness or low irradiance led to an extremely slow rate of division (Evans, 1963). There is evidence that soil nutrients also affect leaf expansion. For example, high nitrogen supplies usually lead to large leaves (Elias *et al.*, 1979). Cooper and Law (1977) in Kenya found that soil temperature differences caused by mulching had an effect on leaf primordia initiation. They reported that higher soil temperature led to greater leaf area production during early growth and subsequently more leaf area per plant at tasselling. Brouwer *et al.* (1970) suggested that leaf expansion could be influenced by soil temperature by affecting the water supply to the leaf tissue. However, Kleinendorst and other workers (1970) indicated that the temperature of the shoot apical meristem may be more important in early leaf expansion than that of the root system. Watts (1971) reported that water stress led to a sharp decline in leaf elongation at temperatures below 5°C (41°F), and that the temperatures of the root and of the meristematic region interacted in the regulation of leaf expansion (Watts, 1971).

A number of researchers including Chabot et al. (1979) reported that variation in the light environment produce changes in leaf anatomical and biochemical structure which determine net photosynthetic CO_2 fixation. In this regard, Chabot et al. (1979) suggested that leaf adaptation is determined by integrated light energy rather than instantaneous flux intensity.

c. Leaf area (LA) and leaf area index (LAI). One criterion that should be met in grain yield comparison among hybrids of differing maturity is that the different corn hybrids should have the same potentiality for solar radiation interception on a land area basis. The crop should therefore have an equivalent leaf area per unit land area, in order to intercept the same amount of radiation reaching the canopy. The evaluation of leaf area index (LAI) was used to meet the criteria stated above. LAI is defined as the total area of one side of all leaves divided by the land area subtending these leaves. The concept was first introduced by Watson (1947, 1952) in research on the analysis of plant growth and yield. Leaf area index (LAI) is the ratio of the total leaf area (LA) over the land area (A).

$$\mathrm{LAI} = \frac{\mathrm{LA}}{\mathrm{A}}$$

Duncan (1972) stated that interception of light is the primary function of corn canopies, but the intercepted light should be used efficiently and this is a function of leaf angle. He pointed out that between LAI of 3 and 4 flat leaves intercept 90% of the light while leaves at a 15° angle intercept only 75 to 80%. Hoyt and Bradfield (1962) reported that "the net assimilation rate of corn was linear to leaf area index when this was less than 2.7 but declined rapidly when it was above that value. In a stand with a LAI of 3.3, drymatter produced per square meter of leaf area from grain initiation to maturity by the top, middle, and bottom leaves was of the ratio 4:2.2:1." Eik and Hanway (1966) also reported a linear relationship between corn grain yield and LAI at midsilk. They pointed out, however, that the relationship does not continue beyond LAI of 3.3.

Formulas have been developed for easy determination of corn leaf area (McKee, 1964). Many other methods such as photoelectric and comparison techniques have been used for leaf area estimation. The belt-type photocell leaf area meter and air flow planimeter have also been used.

In conclusion, leaf area is important in corn development and production because it functions in interception of solar energy for photosynthate production. Sufficient leaf area is needed to intercept most of the available solar energy if high productivity per unit land area is to be realized. Canopy leaf area is a function of leaf area per plant and plant population. Plant leaf area development is influenced by temperature, photoperiod, and light during the leaf initiation period or later during the leaf expansion.

5. Ear Shoot Development

Soon after leaf initials form during differentiation of the apical meristem, auxiliary shoot buds or ear primordia develop in acropetal succession (Kiesselbach, 1949). Initiation of these auxiliary shoot buds ceases, however, when tassel formation begins, as indicated by elongation of the shoot apex (Bonnett, 1966). Lateral projections initiate from the central axis of the ear primordium; these projections are the primordia from which the spikelet primordia differentiate. Ear shoot development was reported to start 5 weeks after plant emergence (Hanway, 1966). Sass and Loeffel (1959) conducted two field experiments in 1954 and 1955 to determine the relationship between the development of auxiliary buds in maize and barrenness. They reported that the first evidence of floral transition in the auxiliary buds occurred 43 days after planting. They cited in their report that the lowest bud, in the axil of the first foliage leaf, is well defined 2 to 3 days after the beginning of germination.

Hunter et al. (1977) reported only a slight influence of photoperiod on spikelet number per ear; Ragland et al. (1966) also observed a slight increase in number of kernel rows per ear and a 10% increase in the number of kernels per row at 14 days after silking with long photoperiods produced by supplementary radiation during the middle of the night. Cooper and Law (1977) conducted a 4-year field experiment in Kenya to investigate the effect of importance of soil temperature in determining the early growth vigor and final grain yields of corn hybrids. They planted each year at varying time intervals to generate differences in growth temperatures. They reported that soil temperatures early in the plant life had played an important role in determining the number of potential grain sites initiated without explaining the relationship in detail. Hanway (1966) reported that during flowering and the period of rapid grain filling, moisture stress or nutrient deficiency might result in poor pollination and unfilled kernels.

In summary, ear shoots are initiated early in the plant lifetime. Their development, which starts approximately 5 weeks after emergence, is influenced strongly by temperature and slightly by photoperiod.

6. Tasselling and Silking

Flowering in maize is indicated by the extrusion of anthers from the spikelets on the tassel and the emergence of silks from the husks. Bonaparte (1975) showed that the tassels on plants which experienced no period of water stress emerge a few days earlier than those which were subjected to soil moisture stress. He reported the association between total light energy and daylength contributed to the variation in the time of tassel emergence. High plant density was also reported to result in the lengthening of the interval between anthesis and silking; the delay in flowering was found to have a negative effect on the grain yield (Buren *et al.*, 1974). Prine (1971) showed that second ear abortion occurred during and just after silk emergence of the top most ear. Nishikawa and Kudo (1973) found that 60% of eventually barren plants (plants which failed to produce mature ears) had normal ear development until silk emergence. Tollenaar (1977) suggested that the irradiance intercepted per plant during the flowering period is a dominant factor determining the continuation of ear growth. Low amount of intercepted irradiance associated with low photosynthate production resulting in poor kernel filling, was found to contribute to a high percentage of barrenness (Tollenaar, 1977). There is evidence that ear abortion is also related to intraplant competition for photosynthate during the flowering period (Hanway, 1962). The flowering period is a critical stage where care is needed for better grain dry matter accumulation.

7. Kernel Filling

Kernel filling is an important process in the determination of grain yield. The kernel filling period is normally considered to start at midsilk and end at the blacklayer stage. The blacklayer stage indicates that the kernel has reached physiological maturity. A blacklayer forms at the base of the kernel and it is associated with the cessation of carbohydrate flow from the pedicel to the kernel. During the kernel filling period two important factors, kernel filling rate and the duration of filling, affect the final grain dry weight as we will see later in this section.

Studies indicate that the period from silking to blacklayer formation contains three different phases of kernel grain development: (i) a period (first lag period) of low dry matter accumulation, which was found to begin at pollination and last for 2 to 3 weeks; (ii) a period of linear grain filling which accounts for 90 percent of the dry matter accumulated; and (iii) a period (second lag period) in which the dry matter accumulation is not significant, and terminated at blacklayer formation (Johnson and Tanner, 1972; Shaw and Thom, 1951). Final grain yield is a resultant of rate and duration of dry matter accumulation. There are two methods of measuring corn filling period. The first method is the procedure described by Duncan and Hatfield (1964), in which kernels from the same ear are removed, dried, and weighed periodically throughout the grain filling period. The effective filling period duration (EFPD) is calculated by dividing rates of kernel dry weight accumulation, during the linear growth period, into mature kernel dry weights. The second method involves a technique based on blacklayer development. Daynard and Duncan (1969) reported that a blacklayer formed at the base of corn kernels at maturity and represented a visible signal that kernel dry matter accumulation had ceased. The apparent grain filling period duration (AFPD) can be defined, then, as the length of time interval, on an individual ear basis, from silk emergence (at the time fertilization occurs) to blacklayer formation. Several reports have indicated that a positive relationship exists between the length of the period from silk to grain maturity and grain yield (Hanway and Russell, 1969; Daynard, Tanner, and Duncan, 1971; Daynard and Kannenberg, 1976). Daynard and Kannenberg (1976) suggested that the EFPD might be even more closely related to yield than the AFPD (Daynard, Tanner, and Duncan, 1971).

Both length of the filling period and rate of grain growth have been reported to be affected by environmental factors. Breuer, Hunter and Kannenberg (1976) indicated that air temperature had the principal effect on grain filling period duration. However, they observed a photoperiod by temperature interaction on kernel grain filling. The interaction was confirmed a year later by a growth chamber study conducted by Hunter, Tollenaar, and Breuer (1977). They found that a longer photoperiod (photoperiods tested were 10 and 20 hours) and cooler temperature (the temperature was varied from 15 to 30°C) treatment led to highest final plant dry weight. They argued that the long photoperiod led to more leaf area per plant, suggesting a greater photosynthate production per plant in their experiments. They also pointed out that under cooler temperature there was a longer duration of dry matter accumulation. It is important to note that these last two experiments referred to were conducted in growth chambers so that low irradiance compared to out-of-doors conditions may have contributed to the observed results. A study with other cereals such as spring oats showed significant correlation between grain yield and accumulated solar and sky radiation during the grain filling period (McKee et al., 1979). Carter and Poneleit (1973) found significant yearly differences in number of growing degree days required to complete the effective grain filling period. They also observed a significant inbred by year interaction for the rate of grain dry matter accumulation. Similar findings were reported early in 1971 by Cerning and Guilbot. Plant density was reported to affect the EFPD to a limited extent, while both the EFPD and the kernel growth rate were found to be under genetic control (Poneleit and Egli, 1979). These authors indicated that the greater yield of the hybrid compared to that of the inbred was mainly due to the higher number of kernels per cob of the hybrid. Hanway and Russell (1969) reported that the rate of dry matter accumulation in the grain was similar for all hybrids, years, and populations tested. They also confirmed that the EFPD varied with hybrids and that the number of kernels per unit land area varied with consistent differences among different hybrids. A number of workers including Hunter et al. (1969) reported increases in grain yield when tassels were removed at or prior to silking. Solar energy that would be intercepted by the tassel reached the leaves for photosynthate production.

Based on these reports, it is apparent that corn grain yield depends on the rate and the duration of kernel filling and the number of kernels filled. These three components vary widely with management of environmental factors such as variety, plant population, temperature, light, photoperiod, soil moisture content, and soil fertility, resulting in more or less grain yield. No consistent relationship between these factors has been identified.

8. Whole Plant Dry Matter Accumulation in Corn

For a better understanding of the partitioning of photosynthate within the corn plant, one must evaluate dry matter accumulation in the other parts (stalks, leaf blades, and leaf sheaths) of the corn plant in addition to the grain. Paddick (1944) found that comparable plant parts were larger at maturity in the hybrid than in the inbred, and that the hybrids developed faster than their inbred parents. A number of workers including Hanway (1962 , 1966) reported that differences in soil fertility resulted in different rates of dry matter accumulation, but did not markedly influence the relative proportions of the different plant parts. Bryant and Blaser (1968) reported that the relative proportion of the different parts at maturity, varied between an early and a late hybrid, but was influenced only slightly by differences in plant populations or row spacing. Hanway and Russell (1969) observed similar patterns of dry matter accumulation in the total, above-ground plant parts in 11 hybrids studied and at different plant densities. They pointed out that the relative weights of the different plant parts at any given stage of plant development were essentially the same for the different hybrids. Hanway and Russell (1969) indicated that the leaves, leaf sheaths, stalks, and husks attained their final mature weights at about growth stages (Hanway growth stage system, 1966) 4.0 (48 days), 4.5, 5.0 (66 days), and 5.5, respectively. The cob and ear shank were reported to reach their maximum dry weight at about stage 6.5 (about 18 days after silking) and to show no later decrease in weight. The relative proportions of grain and nongrain plant weights were found to vary widely among hybrids and years, but only slightly with plant populations, with the grain varying from 35 to 52% of the total plant weight. The proportion of grain in most hybrids decreased slightly as the plant population increased from 38,700 to 58,100 plants/ha (Hanway and Russell, 1969). Elias, Gagianas, and Gerakis (1979) confirmed that plant density influenced crop growth, grain yield, and total biomass per unit land area. In their experiment, three plant densities (40, 80, and 120,000 plants/ha) and two levels (80 kg of N/ha and 170 kg of N/ha) of nitrogen were used. They found that the highest biomass (18.9 t/ha) was accumulated by the heaviest fertilized very high density treatment.

B. Heat Unit and Growing Degree Day

In an attempt to find better ways of estimating temperature effects on crop growth and yields, various thermal unit formulas have been developed to provide appropriate interpretation of agronomic experimental data. The "National Weather Service" method uses the following formula (Cross and Zuber, 1972; Shaw, 1975; Coelho and Dale, 1980).

$$\mathrm{GDU} = \frac{(\max + \min)}{2} - 50\ \mathrm{F}$$

Where GDU = Growing degree day unit

max = daily maximum temperature ($^{\circ}$F)

min = daily minimum temperature ($^{\circ}$F)

50 = the base temperature for plant growth

It has been suggested that it would be more accurate to set the temperature at 50 F when the minimum is below the base (Shaw, 1975). This allows days with maximum values above the base, but with minima below the base to accumulate GDU. A number of workers including

Gilmore and Rogers (1958) found that 30°C (86°F) was the optimum maximum temperature value for corn growth so that temperature values higher than 86°F should be set to 86°F. Cross and Zuber (1972) compared 22 different formulas for computing growing degree units proposed by different researchers. One of those is the hourly adjusted average system.

$$GDD = \sum_{i=1}^{n} \left(\sum_{j=1}^{24} X_{ij}^{hr'}\right)/24$$

Where GDD = Growing degree days

$X_{ij}^{hr'}$ = hourly adjusted temperature values

$= X_{ij}^{hr}$ if $X_{ij}^{hr} < 86$ and $X_{ij}^{hr} > 50$

$= 86$ if $X_{ij}^{hr} > 86$

$= 50$ if $X_{ij}^{hr} < 50$

X^{hr} = actual hourly temperature value

j = the hour during the day

i = the day during the growing period

n = total number of days of the experiment

(See Cross and Zuber, 1972, for the entire list of the 22 formulas.) They found that the adjusted average formulas when computed on either an hourly or a daily basis explained over 95% of the variation in flowering date in maize. Both the Ontario heat unit and heat stress systems use a quadratic equation to adjust the high temperature to fit a curvilinear growth response. When based on average thermal units the Ontario method was superior for only one of the 23 entries studied by Cross and Zuber (1972). They pointed out that the hourly heat stress system appeared to be the best method but the advantage over the other systems was slight. They did not indicate in their research report, however, what effect hybrid and variable growth conditions might have on the results presented.

Mederski, Miller, and Weaver (1973) studied the accumulated heat unit (AHU) method and the calendar day method for classifying the maturity of corn hybrids and predicting of occurrence of phenological events, and indicated that the AHU method of classifying corn hybrids was superior to calendar days. Sophisticated methods involving not only temperature function but also radiation, potential evapotranspiration, and leaf area index, have been developed recently for a better characterization of corn growth and development (Coelho and Dale, 1980).

C. Statement of Hypothesis

Based on the findings reviewed in this chapter, three hypothesis were proposed for the investigation of decline in corn grain yield with late plantings. The first hypothesis was that early and medium season corn will yield the same amount of grain per ha if both are planted at the same date and at appropriate population to obtain canopy LAI sufficient to intercept 95% or more of the available solar radiation. The second hypothesis was that air temperatures during ear shoot development and at silking combine to limit kernel number and subsequent grain yield of late compared to early planted corn. The third hypothesis was that rate of grain filling is slower for late compared to early planted corn and that duration of the grain filling period of late planted corn is halted prematurely due to cool fall temperatures.

CHAPTER III

MATERIALS AND METHODS

A. Location of the Experimental Field

The experiment was established during May and June 1979 on The Pennsylvania State University Agronomy farm at Rock Springs, at approximately 358 m (1175') altitude, 41°N latitude, and 78°W longitude. The field was in a large, east-west valley with a ridge (469 m) on the south side. The predominant soil type was a Hagerstown silt loam (Typic Hapludalf; fine, mixed, mesic). The area surrounding the field plots was covered mainly by corn, alfalfa, and grass.

B. Experimental Design

The experimental field covered 0.16 ha (0.4 acre) of land. A split-plot design, with four replications, was employed. The main plots consisted of 4 planting dates while the sub-plots included two corn hybrids. Each plot consisted of 8 rows that were 6.7 m (22') long with 76.2 cm (30") between rows.

C. Plant Establishment

An early (Cornell 281) and an early-medium season (Pioneer 3780) corn hybrid, classification based on the Pennsylvania maturity zone classification system (McGahen and Johnson, 1978), were grown. However, at The Pennsylvania State University Agronomy farm, Cornell 281 and Pioneer 3780 are relatively early-medium and full season hybrids, respectively. Each hybrid was hand planted at approximately 2-week intervals, beginning in the normal recommended planting period for the area and extending to late June. Actual planting dates of 12 and 30 May, 8 and 22 June, deviated from the intended 2-week interval because of inclement rainy weather. In an effort to obtain a mature plant canopy with a leaf area index (LAI) of approximately 4, two seeds were planted per hill at a distance of 13.3 cm (5.25") for Cornell 281 (C281) and 18.4 cm (7.25") for Pioneer 3780 (P3780). The target LAI of 4 was chosen based on a study by Duncan (1972) in which he found a LAI of 4 to be near optimum for solar radiation interception in maize. Earlier experiments at the Agronomy farm within various research projects established the approximate plant population necessary to obtain the desired LAI on P3780 (M. Boyle, M.S. Thesis, Pennsylvania State University). Information on yield, standability, and barrenness of C281 was obtained from the 1978 Pennsylvania Commercial Hybrid Corn Tests Report by McGahen and Johnson. The crop was hand-thinned to one plant per hill to obtain plant populations of 86,500 and 66,500 plants/ha for C281 and P3780, respectively. Thinning dates were 25 June, 6 and 18 July, and 6 August for the planting dates 1, 2, 3, and 4, respectively.

Muriate of potash (60% K) and ammonium nitrate (34% N) were broadcast at 235 kg/ha (210 lbs/acre) and 684 kg/ha (600 lbs/acre), respectively, before spring plowing; a 15-15-15 starter mix of 168 kg/ha (150 lbs/acre) was placed in the row with a tractor mounted, conventional corn planter, before hand seeding. The soil test report obtained before fertilizer was applied in 1979 was pH 7.2, 96 kg/ha of bray P_1 extracted P (86 lbs/acre); 0.28, 0.5, and 12.5 meq/100 g for K, Mg, and Ca, respectively. The CEC was 13.3 meq/mg. Percentage of CEC saturation was 2.1, 3.8, 93.9 for K, Mg, and Ca, respectively. The soil test results indicate that P was medium, K was low-medium, Ca was excessive, and Mg was low. Furadan 10G was banded over the row at 13.5 kg/ha (12 lba/acre) for insect pest control. Weeds were controlled by an application of atrazine at 2.8 kg/ha active ingredient (2.5 lbs/acre).

Eight moisture blocks (gypsum) were put in the field to monitor soil moisutre status. These moisture blocks were placed at 23 cm (9 inches) depth in the row. The selection of this depth was based on Bouyoucos et al. (1940) and Bouyoucos (1950) suggestions that the moisture block should be placed in the root zone where the water absorption is maximum. The actual depth of 23 cm was used to correspond with that suggested in the Splinter corn growth model (Splinter, 1973). The location of each moisture block throughout the field was chosen such that the coverage was approximately uniform over the experimental site, and also that each planting date treatment contained 2 blocks. They were monitored at least 3 times a week. The readings were taken in ohms (resistance) and then were converted to bars by the use of standard curves specific to each moisture block. The plots were irrigated when the soil water potential declined below -2 bars. The field was irrigated only once on June 26.

D. Plant Sampling

Two different types of measurements were taken during the experiment: (1) measurements concerning the biological and physiological aspects of the corn plant; and (2) the environmental factors which were thought to be associated with corn yield. Plant measurements included kernel site number and number of kernel rows per cob; stalk, leaf sheath, leaf blade, and kernel dry weights; and leaf area and plant height.

The two central rows of each plot were reserved for the final plant and grain harvest. The 6 other rows were used for the different samplings. The outside rows were sampled only when the plants were young and, therefore, the border effect was still negligible. Plants were sampled to determine time of tassel initiation before hand thinning by carefully digging out one of the two plants per hill. Four consecutive plants were sampled per plot beginning 13, 10, 8, and 6 days after emergence for the planting dates 1, 2, 3, and 4, respectively, and continued daily until tassel initiation was observed. The plants had 4 to 5 displayed leaves when sampled. Dug plants were placed in labelled paper bags, transported to the laboratory on campus, and dissected under a binocular microscope. The tassel was considered to be initiated if 50 percent of the observations per hybrid (average over the 4 replications) satisfied Bonnett's (1966) criteria for tassel formation. Every second plant, a total of 4 plants, was sampled per plot for dry matter accumulation by the different parts of the plant (stalks, leaf sheaths, leaf blades). Samples were taken twice a week. In order to avoid canopy opening, plants were selected on alternative rows starting from the outside rows towards the inside rows. In the laboratory the plants were separated into stalk, sheath, and blade components, put into labelled paper bags, and dried in a forced draft dryer at $69^{o}C$ ($157^{o}F$) for 1 to 3 weeks, depending on the amount of tissue being dried. A preliminary experiment consisting of a series of drying and weighing cycles was used to determine appropriate drying time. Dried plant samples were weighed to the nearest centigram.

Leaf area was determined by measuring the length and width of leaves on four different plants per plot twice a week from 3 weeks after emergence to 1 week after midsilk. Leaf area (LA) was calculated with the formula developed by McKee (1964).

McKee (1964) developed two formulas for corn leaf area determination based on non destructive leaf measurements. The equations are as follows:

(1) $LA = \Sigma(L \times W)0.73$

(2) $LA = (\Sigma L)6.67$

Where L = the over-all length of the leaf

W = maximum width of the leaf

The mean leaf area coefficient (0.73) in Equation 1 was based on measurements of 1,128 leaves from 8 corn hybrids. McKee found that there was no significant difference in the leaf area coefficient due to plant population or plant variety. He reported little consistent effect of age and position on the plant on the leaf area coefficient. He also proposed using the same leaf area coefficient for plants grown both indoors in the greenhouse and outdoors. He found that the correlation coefficient between measured leaf area per plant and the leaf area of a rectangle represented by $\Sigma(L \times W)$ was 0.9985*** ($r_{.001} = 0.3211$). McKee reported that the leaf area coefficient in Equation 2 gave less precise, but adequate results. He found that the ΣL for each plant was significantly correlated with ΣW, $r = 0.9011$***, and with the measured leaf area, $r = 0.9439$*** ($r_{.001} = 0.3211$). Leaf area index (LAI) was calculated with the following formula:

$$LAI = \frac{LA/plot\ (cm^2)}{0.445 \times 10^6\ (cm^2)} \qquad [1]$$

Where 0.445×10^6 (cm^2) = area of each plot

LA/plot = (average leaf area/plant)(plant population/plot).

Plant height was measured to the whorl before tasselling and to the tip of the tassel after tassel emergence. The measurements were taken twice a week on the 4 plants used for leaf area determination. When the topmost ear was visible, the number of leaves above this was recorded.

Reproductive development was assessed by ear shoot development before silking and by grain development after silking. For ear shoot development, observations were made on two of the four plants sampled for measurement of dry matter accumulation, starting about six weeks after emergence. The two topmost ear shoots were studied under the binocular microscope described earlier. Number of double rows per ear shoot and the number of kernel sites per double row were counted. It was decided to make the observations on the double row basis because the initial spikelet primordia started dividing from the base of the ear shoot giving a pair of rows. Meanwhile, the row stayed single at the tip of the ear shoot so that it was easier to count the kernel sites per paired rows. Ear length, excluding the shank, was also measured.

Tasselling and midsilk dates were determined by counting the number of plants with visible tassel rising from the whorl or visible silks appearing from the husks, in the two central rows per plot. Fifty percent tasselling and midsilk dates were reported when 50 percent of the plants averaged over the 4 replications had tassels or silks.

Samples were collected for evaluation of the kernel grain filling period weekly starting approximately 20 days after silking. For these observations, six ears per plot were sampled once a week on consecutive plants starting from the outside rows towards the inside rows. Number of double rows and the number of filled kernels per double row were counted. Total ear length was measured to the nearest 1 mm, then the six ears were put in a labelled cloth bag and dried at 69°C (157°F) in the dryer described earlier. Dry weight (DWt) of the ear (cob + kernels) was determined right after removal from the dryer, three to four weeks after sampling. Grain from the central part of each ear was shelled separately. Seventeen kernels from each of the six ears/plot were bulked to give 102 kernels, weighed, redried at 104°C (219°F), and reweighed. The remaining kernels from the six ears were bulked and weighed without additional drying. These weights were adjusted to dryness (104°C) based on percentage moisture calculated for the 102 kernels dried at 104°C. A coefficient of correction between dry weights at 69°C and DWt at 104°C was calculated. The coefficient was then used to calculate the total grain DWt at 104°C from the DWt at 69°C.

Fifty percent blacklayer was determined by looking at 4 kernels per ear from two ears per plot. The sampling started when blacklayer was observed on the same hybrid planted earlier in an adjacent experimental field. The hybrid was considered to be at 50 percent blacklayer when four of the eight kernels observed, averaged over the replications, reached blacklayer.

At blacklayer, plants were harvested to determine final grain and plant weight, and harvest index (HI). Ears were harvested from all plants within two successive six-foot sections in the middle of one of the center rows of each plot. This allowed a five-foot border on each end of the harvested row. In addition, six consecutive plants were sampled from the middle section of the second center row in each plot. The plants were cut at ground level, bulked in burlap bags, and dried at 69°C (157°F) in a forced draft oven. Final plant DWt and final grain DWt per plant were determined by weighing the samples after removal from the dryer. The ears were shelled and 102 kernels subsampled as described earlier for grain dry weight determination at 104°C. The number of barren plants (plants which failed to produce ears) was determined by counting the total plants in the row harvested and the number of plants with ears. The difference between the two numbers recorded gave the total number of barren plants. Some of the plants had apparent ears but failed to produce any grain leading obviously to an underestimation of the percentage of barrenness. The barrenness index (BI) was computed as the ratio of barren plants over total plants. From the preceding data, the final grain yield was cacualted in two ways using: (i) the average grain dry weight per 6 feet of row adjusted to a unit land area basis, and (ii) the average kernel dry weight, the number of kernels per ear, and the plant population with an adjustment for percentage barrenness. The harvest index was calculated using the following equation:

$$HI = \frac{GW}{PW} \qquad [2]$$

Where HI = Harvest Index

GW = total grain dry weight from 6 plants

PW = total plant dry weight (vegetative and reproductive parts from the same 6 plants)

E. Weather Data

The weather data were collected at the Agronomy farm of The Pennsylvania State University Weather Station, near Rock Springs, 11 km (6 miles) from campus, at approximately 41°N latitude, 78°W longitude, and 358 m (1175') altitude. The station was located in the middle of the farm, about 300 m (≃ 1000') from the experimental site. Soil data were collected on both bare and sod covered plots. The following parameters were measured hourly: soil and Weather Bureau Shelter air temperatures, soil water potentials, precipitation, and global solar radiation. All the instruments were connected to a Campbell Scientific CR5 data logger which stored recorded data on printed paper tape and on audio cassette tape for computer processing.

Thermocouple thermometers (Cu-Cn) were used to measure shelter air temperature and bare and sod soil temperatures at 5 cm (2 inches) depth. Hollinger and Reetz, Jr. (1979 Agronomy Abstracts) reported differences (up to 6.1°C) between weather station and crop canopy temperatures when measured hourly. The differences however were small when the temperature hourly measurements were averaged over 24 hours (day and night). Soil temperature was monitored manually at least twice a week in the experimental field plots at 5 cm depth. Eight thermocouples used for this purpose were placed at the same locations as the moisture blocks described earlier. Let us point out that these thermocouples and moisture blocks were placed after the second corn planting resulting in missing data at the beginning of the growing season. The 5 cm depth was chosen for soil temperature measurement because of the importance of soil temperature near the seedling terminal growing point on plant emergence and seedling growth (Van Wijk, 1965). Soil temperature data from the field site were used to evaluate whether the weather station soil data was representative of the experimental site.

Gypsum blocks were used for measuring the soil moisture status. Both bare and sod plot soil water potential was measured at depths of 5 cm (2"), 15 cm (6"), and 30.5 cm (12").

A standard rain gage, tipping bucket transmitter Ne562, marketed by Science Associates, Inc., was used to measure rainfall.

An Eppley black and white pyranometer was used for global solar radiation measurement. The Eppley 180° pyranometer, 50 junction model, used in the study was recalibrated on May 10, 1979 (by the meteorology department of the Pennsylvania State University) and observed to generate an emf of 6.92 mV/ly.

The hourly shelter temperature and the following formula were used to compute growing degree days (GDD).

$$GDD = \sum_{i=1}^{n} \left(\sum_{j=1}^{24} T'_H\right)/24 \qquad [3]$$

Where T'_H = adjusted hourly temperature (^{o}C)

$= T_H$ when $10 \leq T_H \leq 30^{o}$C

$= 30$ if $T_H > 30^{o}$C

$= 10$ if $T_H < 10^{o}$C

T_H = the actual hourly temperature

n = total length of period (days) investigated

j = number of hours during the day

i = days investigated

Two different periods were investigated: (i) time from emergence to midsilk for the vegetative development; and (ii) time from midsilk to blacklayer for grain filling. This method for calculating growing degree days was described and evaluated by Cross and Zuber (1972).

F. Statistical Methods

Statistical analysis and data conversions were carried out by the use of library programs, compiled for the IBM computer, model 3033, as operated by the Computation Center at The Pennsylvania State University. The Statistical Analysis System (SAS) mean procedure was used for the computation of the hourly adjusted temperature average needed for the GDD calculations. The SAS split-plot method of analysis of variance (ANOVA) and Duncan's multiple range test procedures were used in analyzing the experimental data and in describing the statistical significant differences. The SAS General Linear Models procedure (GLM) was used in running linear regression on some of the data (kernel dry-matter accumulation, accumulation of kernel sites). Homogeneity of regression coefficients was tested by the use of the sum of squares term of the interaction between the independent variable and the class (treatment).

CHAPTER IV

RESULTS AND DISCUSSION

A. Microclimate Data

Appendix A, Table 45, contains a summary of the weather data which includes the adjusted average, the minimum and maximum shelter air temperatures in ^{o}C, global solar radiation (ly/day), and the rainfall in mm/day. The plot of these different data is shown in Figure 2. The highest shelter air temperature (32^{o}C) of the season was recorded in May. In July and August maximum and minimum temperatures were mostly higher than 23^{o}C and 12^{o}C, respectively. Low radiation was recorded in late May and early June, and in late September and early October. The rainfall totaled 521 mm from May through October 15 and was fairly well distributed during the growing season. The crop received only one application of 25 mm irrigation water on June 26.

Appendix A, Table 46, summarizes soil temperatures (5 cm depth) at the two locations (weather station bare plot and the experimental field) for approximately the same time of the day. The t-test (Table 3) showed that there was no significant differences between soil temperatures at 5 cm depth recorded both in the weather station and in the experimental field. Since there was no difference in soil temperature between the two locations the microclimate data from the weather station were considered appropriate for the study in the field.

Tables 4 and 5 contain the growing degree days computed, respectively, from emergence and midsilk. The cumulative growing degree days over 5-day intervals, from 1 May to 15 October, are plotted on Figure 3. The rate of heat accumulation declined late in the growing season

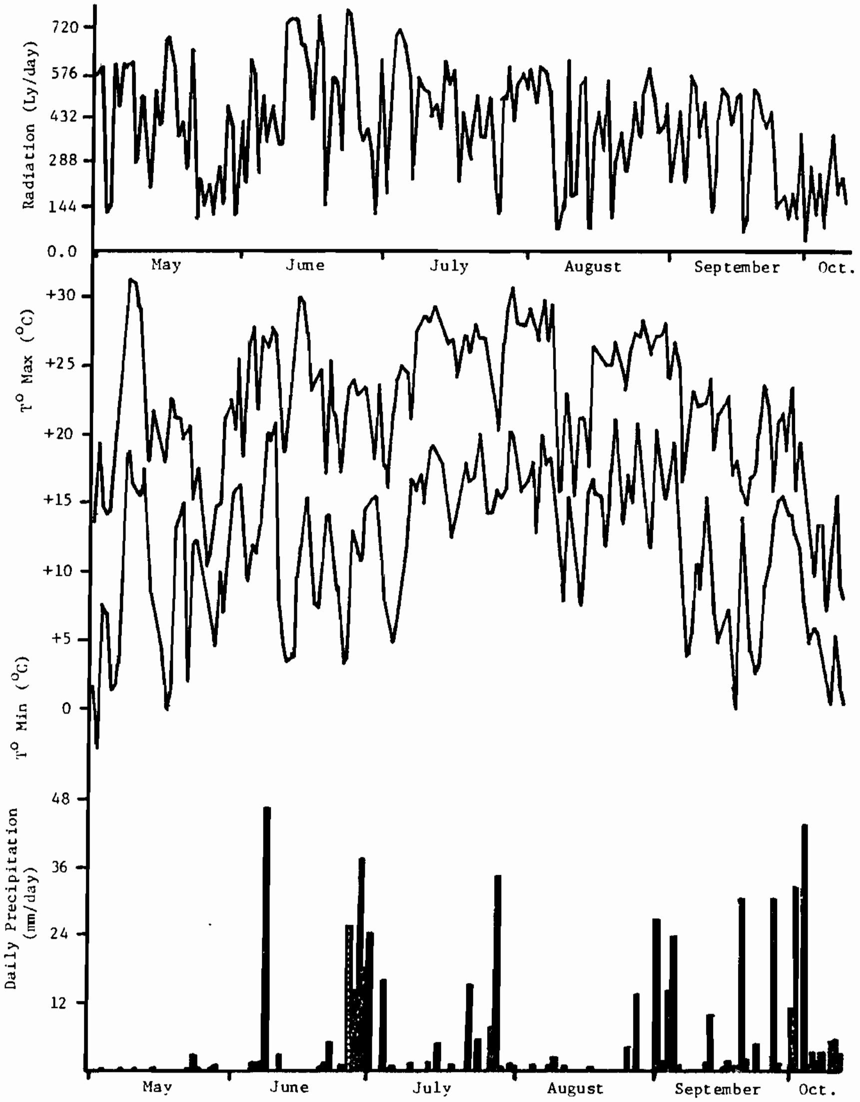

Radiation (Ly/day)
720
576
432
288
144
0.0
May
June
July
August
September
Oct.
T° Max (°C)
+30
+25
+20
+15
+10
+5
0
T° Min (°C)
Daily Precipitation (mm/day)
48
36
24
12
May
June
July
August
September
Oct.

Table 3. Summary of the t-test used in the comparison of soil temperature at 5 cm depth between the Weather Station and the experimental field; data used in this test were recorded from 6 June to 6 July 1979.

Location	Mean Temperature	Standard error	Variances	T	DF	Prob > |T|
Field	22.3	0.807	Unequal	0.767	20	0.4524
Weather Station	21.4	0.770	Equal	0.767	20	0.4524

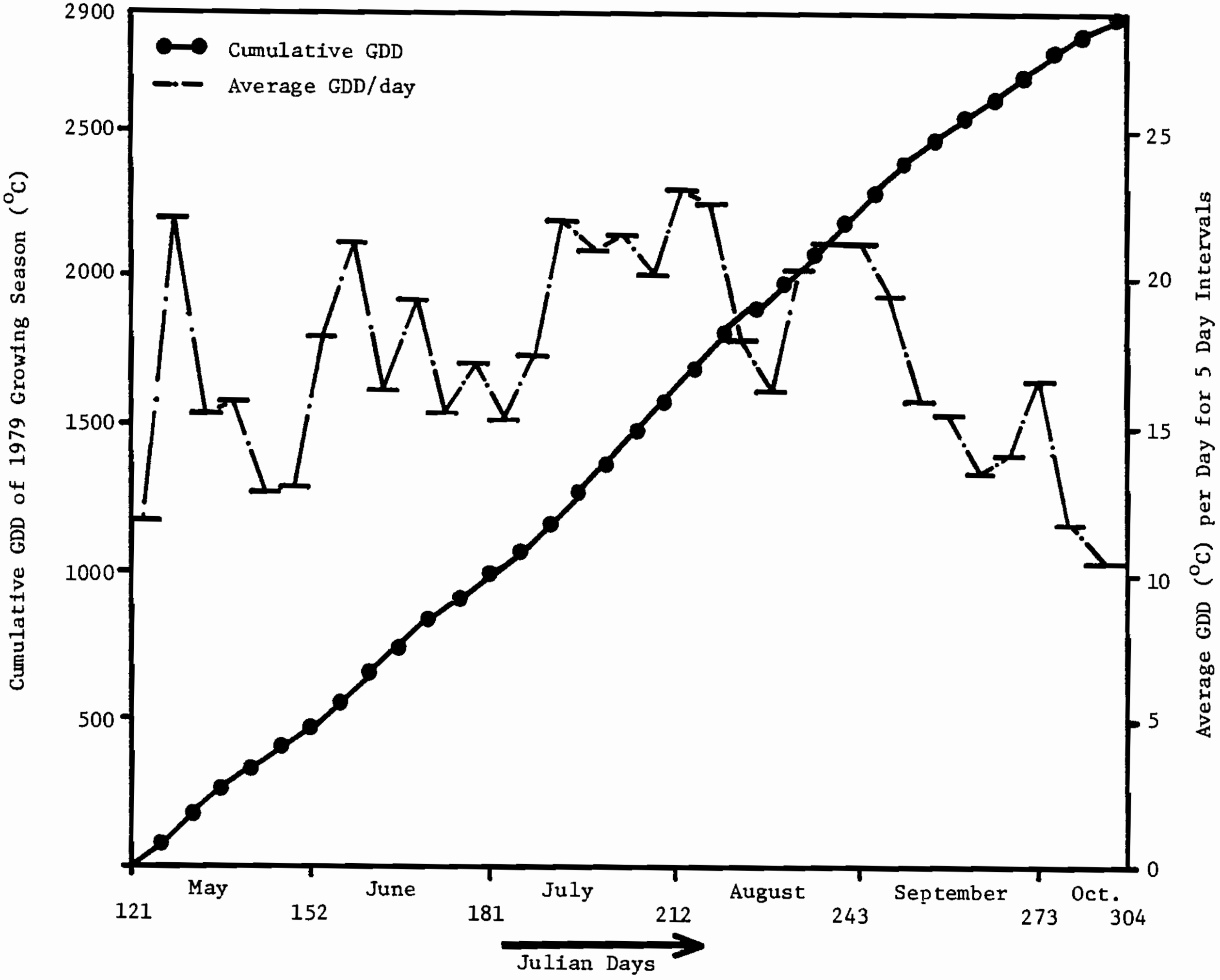
For H_0: Variances are equal, F' = 1.10 with 10 and 10 DF, Prob > F' = 0.8847

Table 4. Growing degree days (GDD) from emergence to successive harvest dates, computed from shelter air temperature, for use in the analysis of the vegetative growth.

1979 Date	Julian Day	Emergence Date 5-20-79	 6-5-79	 6-14-79	 6-29-79
		GDD			
22 June	173	548	331	167	--
03 July	184	727	511	347	86
05	186	752	535	371	110
06	187	767	550	386	125
09	190	821	604	441	179
10	191	840	623	459	198
13	194	904	688	524	263
16	197	972	755	591	330
19	200	1035	818	654	393
23	204	1118	901	737	476
25	206	1162	946	782	521
26	207	1185	969	805	543
31	212	1285	1069	905	644
02 August	214	1334	1118	954	630
05	217	1401	1185	1021	760
07	219	1444	1228	1064	803
10	222	1513	1296	1133	871
13	225	1561	1344	1181	919
16	228	1608	1392	1228	966
20	232	1682	1465	1301	1040
22	234	1719	1503	1339	1077
23	235	1740	1523	1359	1098
26	238	1803	1587	1423	1162
27	239	1825	1608	1444	1183
29	241	1869	1652	1488	1227
30	242	1891	1674	1510	1249
31	243	1911	1694	1530	1269
06 September	249	2039	1822	1658	1397
12	255	2119	1902	1738	1477
17	260	2215	1998	1834	1573
20	263	2257	2041	1877	1616
27	267	2310	2232	1929	1668
30	270	2353	2136	1972	1711

Table 5. Growing degree days (GDD) from midsilk to successive harvest dates, computed from shelter air temperatures, for use in the analysis of kernel dry matter accumulation.

		Midsilk Date							
		C281				P3780			
1979 Date	Julian	7-31-79	8-8-79	8-18-79	8-29-79	8-2-79	8-10-79	8-20-79	8-31-79
		GDD							
31 July	212	0	0	0		0	0	0	
23 August	235	454	271	100		405	227	58	
27	239	539	356	185	0	491	312	143	
30	242	605	422	251	22	556	378	209	0
05 September	248	731	548	377	148	682	504	335	106
06	249	753	570	399	170	704	526	357	128
10	253	801	618	446	218	752	573	405	176
12	255	833	650	479	250	784	606	437	208
17	260	929	746	574	346	880	702	533	304
20	263	972	789	617	389	923	744	576	347
27	267	1024	841	670	441	976	797	628	399
30	270	1067	884	713	484	1018	840	671	442
07 October	277	1181	998	826	598	1132	953	785	556
11	281	1224	1041	869	641	1175	996	828	599
13	283	1245	1062	890	662	1196	1017	848	620



Cumulative GDD
Average GDD/day
Cumulative GDD of 1979 Growing Season (^oC)
2900
2500
2000
1500
1000
500
Average GDD (^oC) per Day for 5 Day Intervals
25
20
15
10
5
0
May
June
July
August
September
Oct.
121
152
181
212
243
273
304
Julian Days

(September and October) due to the low solar beam incident angle and shorter photoperiod during that period in the Temperate Zone of the Northern Hemisphere. A relative constant heat accumulation rate was recorded from mid July to early August leading to a linear increase in growing degree days. This result is evident in the diagram presented in Figure 3. During the period of study (1 May to 15 October), a total of 2900 growing degree days (base 10^o, 30^oC) was accumulated.

B. Corn Plant Sampling Results

1. Time to Emergence

The time from sowing to plant emergence and the growing degree days (GDD, base 10^o, 30^oC) computed from the available soil temperatures measured at 5 cm (2") depth are shown in Table 6. The time to emergence was similar for both Cornell 281 (C281) and Pioneer 3780 (P3780); however, there was a slight difference between times to emergence associated with planting date. The time was 6 days (average soil temperature = 23.1^oC) for the third planting and 7 days (average soil temperature = 22.6^oC) for the fourth planting date. Higher daily average soil temperature was associated with a shorter time to emergence, which agrees with earlier findings by Iremiren and Milbourn (1979). Number of soil GDD varied with time to emergence showing that the young plant did not have to accumulate a certain amount of growing degree days before rising above the ground level. The average daily soil temperature, therefore, is more significant for characterizing the time to emergence than the GDD based on soil temperature.

Table 6. Time in days and GDD from planting to emergence of both Cornell 281 and Pioneer 3780 planting at successive dates.

1979 Planting Date	Time to Emergence (days)	GDD (soil) Sowing-Emergence at 5 cm	Average Daily Temperature °C
May 12	8	--	
May 30	6	--	
June 8	6	138.5	23.1
June 22	7	158.1	22.6

Table 7. Time in days and GDD from emergence to tassel initiation of both Cornell 281 and Pioneer 3780 planted at successive dates.

1979 Planting Date	Hybrid					
	C281			P3780		
	Days	GDD*		Days	GDD	
		at 5 cm D	at surface		at 5 cm D	at surface
12 May	17	--	--	17	--	--
30 May	11	223.7	224.8	12	248.5	248.2
08 June	9	198.8	189.5	10	215.6	208.9
22 June	6	103.6	111.6	7	120.5	120.8

*GDD computed from soil temperature
D = depth

2. Time from Emergence to Tassel Initiation

The time from emergence to tassel initiation (Table 7) varied from 6 to 17 days with planting dates. However, the differences between C281 and P3780 within planting dates was only 1 day. The time from emergence to tassel initiation was found to decrease with late planting. Number of accumulated GDD (base 10^{o}, $30^{o}C$) calculated from soil temperatures (5 cm) for the same period declined also with late planting. Accumulated GDD at 5 cm depth were 223.7, 198.8, and 103.6 for C281, and 248.5, 215.6, and 120.5 for P3780 at dates 2, 3, and 4, respectively. There were no large differences between the GDD (Table 7) computed from soil temperatures recorded at the surface and at 5 cm depth. This small difference suggests that soil surface temperatures did not influence early seedling growth any more than soil temperatures at 5 cm depth. The average daily soil temperature (5 cm) during each growth period was higher for the third planting date in both hybrids. They were 20.3, 22.1, and $17.3^{o}C$ for C281 and 20.7, 21.6, and $17.2^{o}C$ for P3780 at dates 2, 3, and 4, respectively. This decline in time to tassel initiation while the soil temperature decreased, as observed from dates 3 to 4, disagrees with an earlier finding by Coligado and Brown (1975) that there was a consistent decrease in time to tassel initiation as temperature increased from 15^{o} to $25^{o}C$ regardless of photoperiod. It is important to point out, though, that their experiments were conducted in growth chambers at constant temperature while my results were observed in the field, where temperature and irradiance levels vary widely.

The total irradiance accumulated between emergence and tassel initiation decreased with late planting. The daily average irradiance (ly/day) during each period was 519.7, 432, and 501.6 ly/day for C281, and 531.6, 445.0, and 495.8 ly/day for P3780 at dates 2, 3, and 4, respectively. Neither temperature nor radiation provide a clear explanation of the decline observed in the time to tassel initiation with delayed planting.

3. Plant Development

a. Plant population. The plant stand at harvest varied between the different planting dates (Table 10). The number of plants per row deviated from the expected fifty for C281 and thirty-six for Pioneer 3780 in most cases. The reduction in plant stand was mainly due to poor emergence resulting from dry soil surface early in the season. The average plant population was 86,500 plants/ha for C281 and 66,500 plants/ha for P3780.

b. Leaf development. A summary of the averages of leaf area per plant and leaf area index (LAI) per planting date are shown in Appendix B, Tables 47 and 48. The LAI data plotted in Figure 4 show that the LAI increased linearly with growing degree days after an early phase of increasing LAI accumulation rate, reached a maximum, and then declined slowly. The analysis of regression (Tables 8 and 9), which only includes data from the linear part of the graph, gave a single regression line for all planting dates of each hybrid. The regression equations are as follows:

$$\text{LAI} = 0.00451\ \text{GDD} - 1.644 \qquad \text{for C281} \qquad [4]$$

$$\text{LAI} = 0.00433\ \text{GDD} - 1.987 \qquad \text{for P3780} \qquad [5]$$

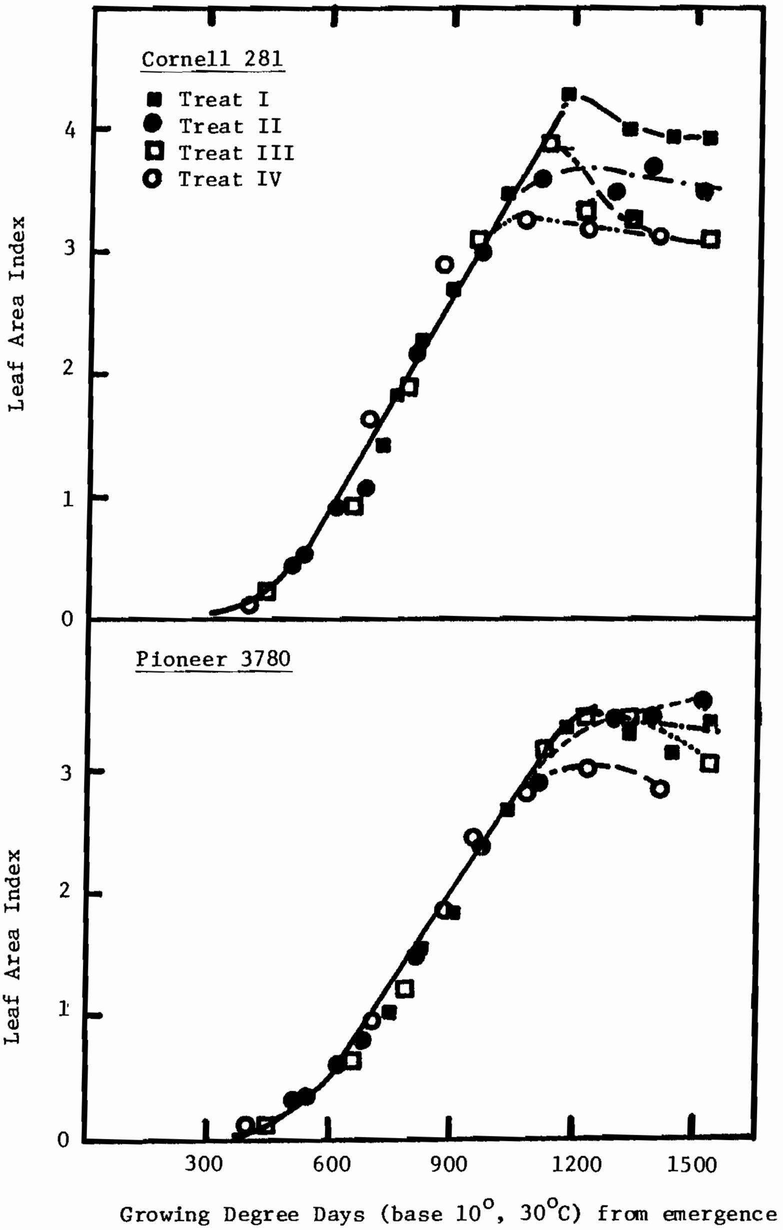

Cornell 281
■ Treat I
● Treat II
□ Treat III
○ Treat IV
Leaf Area Index
0
1
2
3
4
Pioneer 3780
Leaf Area Index
0
1
2
3
300
600
900
1200
1500
Growing Degree Days (base 10°, 30°C) from emergence

Table 8. Regression analysis on Leaf Area Index versus growing degree days for two corn hybrids (C281, P3780). The points from the linear accumulation were used in this analysis.

Hybrid	Intercept	Regression Coefficient	F ratios Significance	R-square	C.V.
Cornell 281	-1.644	0.00451	***	0.870	19.49
Pioneer 3780	-1.987	0.00433	***	0.967	11.36

*** Significant at 1 percent level of probability.

Table 9. Test of homogeneity on the regression coefficients shown in Table 6.

Source of Variation	d.f.	Significance of F-ratios Type IV
Hybrid	1	NS
GDD	1	***
GDD* Hybrid[†]	1	NS

*** Significant at 1 percent level of probability.

NS Non-significant at 10 percent level of probability.

[†] The interaction GDD* Hybrid SS were used to test the homogeneity of the regression coefficients.

The model was significant at the 1 percent level of probability for both hybrids. The respective coefficients of determination and the coefficients of variation were 0.870 and 19.49 for C281, and 0.967 and 11.36 for P3780. The test of homogeneity of regression coefficients shows that there was no significant difference between the rates of LAI accumulation for the two hybrids. The significance of the sum of squares due to GDD effects at the 1 percent level of probability suggests that cumulative heat units were an important factor influencing leaf development. Essentially 87.0 percent of the variation in LAI of C281 was associated with the GDD while 96.7 percent of the variation in LAI of P3780 was associated with the GDD. However, some other environmental factors such as radiation, has been reported to strongly affect leaf development (Evans, 1963). Watts (1971) reported a sharp decline in leaf elongation caused by water stress. Soil fertility was found also to have an important influence on leaf expansion (Elias _et al._, 1979). The LAI was found to reach its maximum at the midsilk growth stage. Average values ranged from 3.2 to 4.1 for C281, and from 3.0 to 3.4 for P3780 (Table 10). Contrary to expectations, there were some differences in the LAI mostly associated with the variation in plant stand. Figure 4 showed that the leaf growth was strongly associated with the growing degree days while the lower senescence was independent of the GDD at the end of the growing season.

Table 10. Leaf Area Index at midsilk, actual number of plants per row (# P/R), and average number of leaves above the topmost ear* for two corn hybrids (C281 and P3780) planted at 4 dates in the spring of 1979.

1979 Planting Date	Hybrid					
	C281			P3780		
	LAI	# P/R	#L	LAI	# P/R	#L
12 May	4.1	48	5.9	3.3	36	6.4
30 May	3.5	46	5.7	3.4	35	6.3
08 June	3.3	41	5.8	3.4	32	6.2
22 June	3.2	43	5.6	3.0	33	6.0

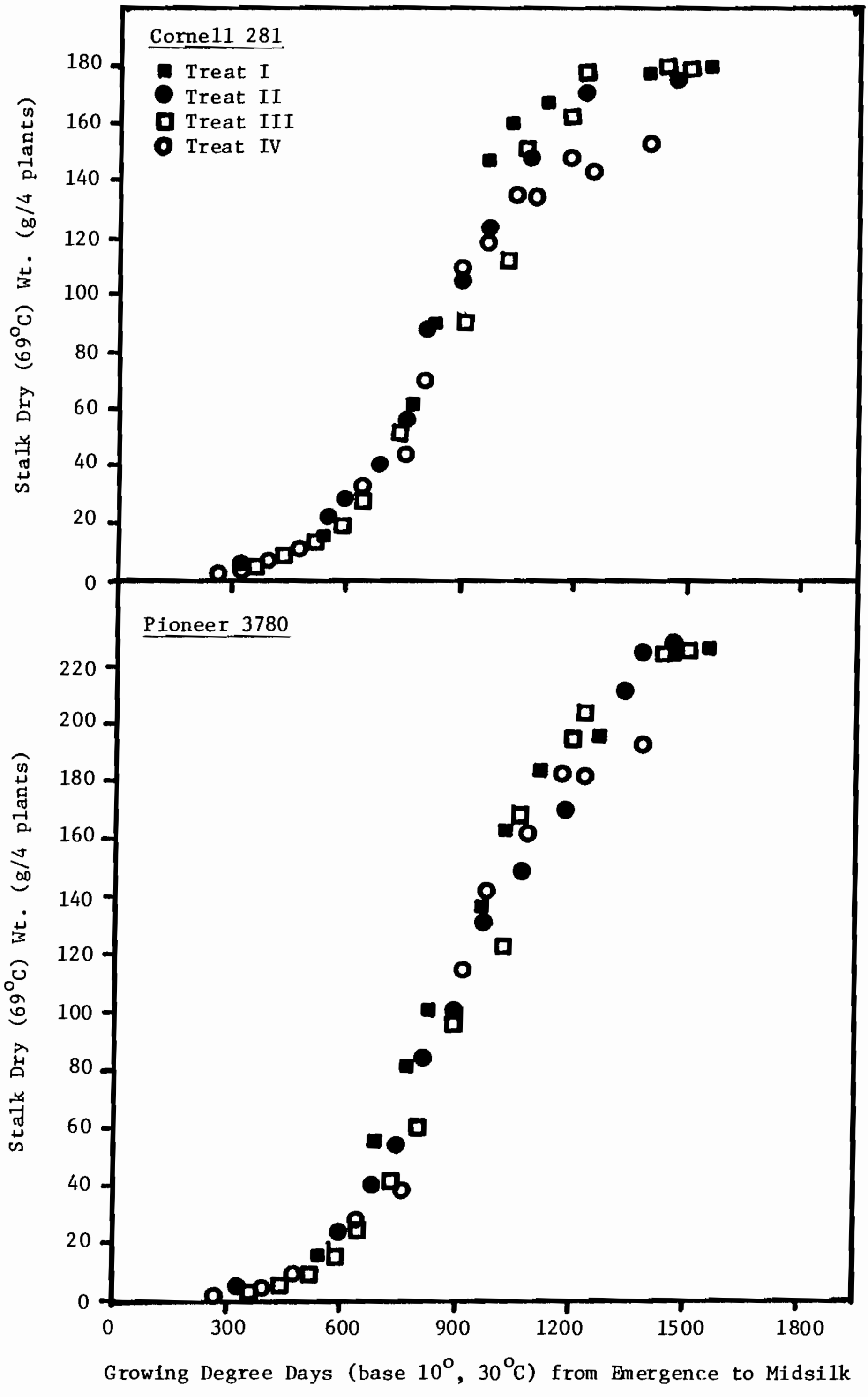
*For all planting dates and hybrids the range in number of leaves above the ear was 5-7.

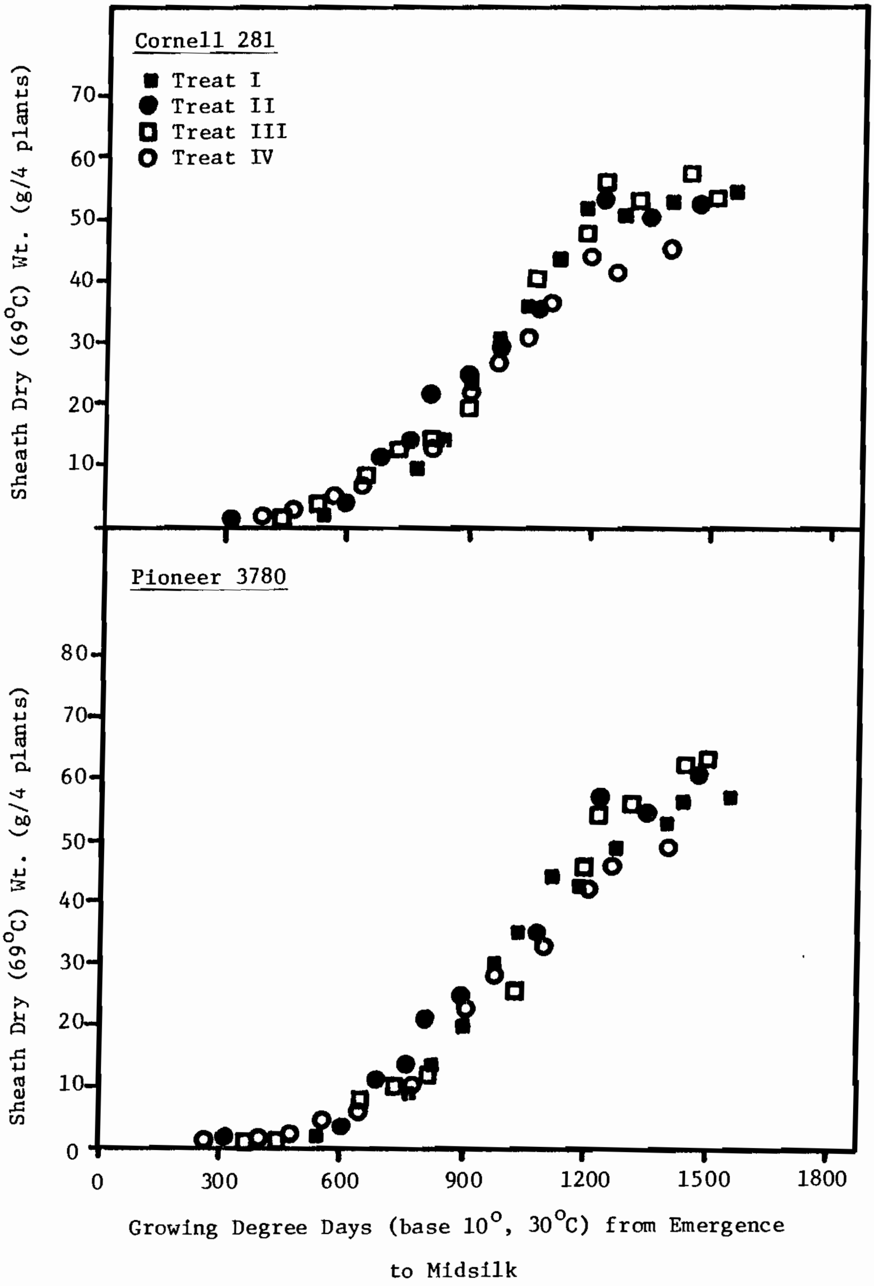
Table 11. Percentage of total shoot dry matter in plant parts (leaf sheaths, leaf blades, and stalks) at midsilk for two corn hybrids (C281 and P3780) planted at successive dates in the spring of 1979.

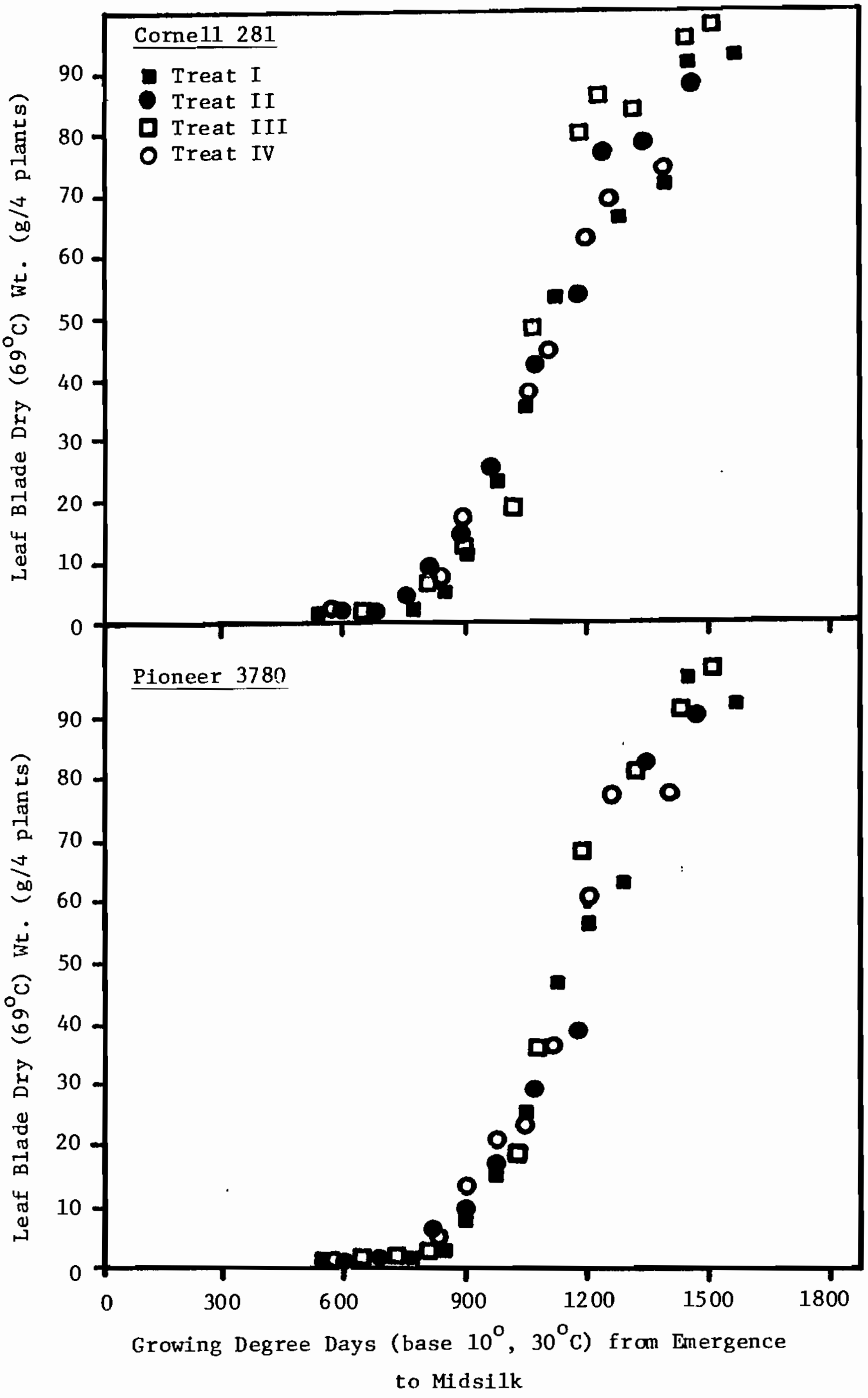
Hybrids	Plant Parts	1979 Planting Date				Average
		12 May	30 May	08 June	22 June	
		%				
	sheaths	18.6	17.6	17.4	14.9	17.1
C281	blades	33.0	26.9	28.7	28.9	29.4
	stalks	48.4	55.5	53.9	56.3	53.5
	sheaths	18.0	16.9	17.0	15.7	16.9
P3780	blades	35.3	31.5	32.6	31.1	32.6
	stalks	46.7	51.6	50.4	53.2	50.5

The number of leaves above the topmost ear was slightly higher for P3780 (6.4, 6.3, 6.2, and 6.0 leaves) than for C281 (5.9, 5.7, 5.8, and 5.6 leaves) (Table 11). The actual number of leaves above the topmost ear ranged from 5 to 7 for all dates and hybrids. It has been shown in research work that these leaves above the ear are the main source of photosynthate providing the carbohydrate for kernel fill (Eastin, 1969).

c. Plant dry matter accumulation during the period from emergence to silking. Dry (69°C) weights for the different parts of the plant above the ground are summarized in Appendix C, Tables 49, 50, and 51. The dry (69°C) weights of stalks, sheaths, and blades are plotted against the growing degree days in Figures 5, 6, and 7, respectively. Like dry matter accumulation by plant parts on a calendar day basis (Hanway and Russell, 1969), the general curve of dry matter accumulation by the stalk, leaf sheath, and leaf blade was sigmoid in shape. The plotted data showed that the dry weight accumulation rate per degree day in the sheath (Figure 6) was lower (lower slope) than the dry matter accumulation rate in the stalk (Figure 5) and the blade (Figure 7). The graphs also show that the rate of accumulation was relatively higher in the stalk than in the blade. At midsilk there was less variation among planting date treatments in the percentage of total plant dry weight associated with sheaths than with stalks and blades (Table 11). Averaging over planting dates and hybrids, 17, 31, and 52 percent of the total plant dry matter at midsilk was associated with sheaths, blades, and stalks, respectively. Total plant dry matter (Appendix C, Table 52) determined at 104°C by a correction of the dry weights


Cornell 281
■ Treat I
● Treat II
□ Treat III
○ Treat IV
Stalk Dry (69°C) Wt. (g/4 plants)
0
20
40
60
80
100
120
140
160
180
Pioneer 3780
Stalk Dry (69°C) Wt. (g/4 plants)
0
20
40
60
80
100
120
140
160
180
200
220
0
300
600
900
1200
1500
1800
Growing Degree Days (base 10°, 30°C) from Emergence to Midsilk


Cornell 281
■ Treat I
● Treat II
□ Treat III
○ Treat IV
Sheath Dry (69°C) Wt. (g/4 plants)
70
60
50
40
30
20
10
Pioneer 3780
Sheath Dry (69°C) Wt. (g/4 plants)
80
70
60
50
40
30
20
10
0
0
300
600
900
1200
1500
1800
Growing Degree Days (base 10°, 30°C) from Emergence
to Midsilk


Cornell 281
■ Treat I
● Treat II
□ Treat III
○ Treat IV
Leaf Blade Dry (69°C) Wt. (g/4 plants)
0
10
20
30
40
50
60
70
80
90
Pioneer 3780
Leaf Blade Dry (69°C) Wt. (g/4 plants)
0
10
20
30
40
50
60
70
80
90
0
300
600
900
1200
1500
1800
Growing Degree Days (base 10°, 30°C) from Emergence to Midsilk

obtained at 69°C from the different plant parts (see correction factor, Appendix C, Table 53) is plotted on Figures 8 and 9. The plot shows a slow increase in plant dry weight with growing degree days during the early growth of the crop, which reached a constant growth rate at about 700 GDD. The same results were obtained by Hanway and Russell (1969) on a calendar day basis. These authors found that maximum dry matter was reached first in the blades, then the sheaths, and later the stalks. In my study, plant part dry weights balanced each other in such a way that the bulk growth rate was essentially constant over much of the growing season producing a linear relationship with GDD. There were some differences in the linear rates of total plant dry weight accumulation versus growing degree days with respect to planting dates (Figures 8 and 9). The rates for both hybrids ranked by planting treatment were as follows: 3rd > 2nd > 1st > 4th. The average plant dry weights (104°C) at midsilk were 69, 70, 80, and 60 grams/plant for Cornell 281, and 72, 79, 84, and 64 grams/plant for Pioneer 3780 at dates 1, 2, 3, and 4, respectively. Plant dry weight at midsilk increased with delayed planting up to the third date and then decreased substantially with the fourth planting. The warm temperatures recorded in July and early August (Figures 2 and 3) apparently provided a better environment for vegetative growth of the second and third planting date treatment, thereby leading to a high amount of dry matter accumulated by midsilk. The data showed that Pioneer 3780 had consistently higher dry matter per plant than Cornell 281 at all growth stages. This agrees with the earlier statement made in Chapter III that Pioneer 3780 is a larger hybrid than Cornell 281.

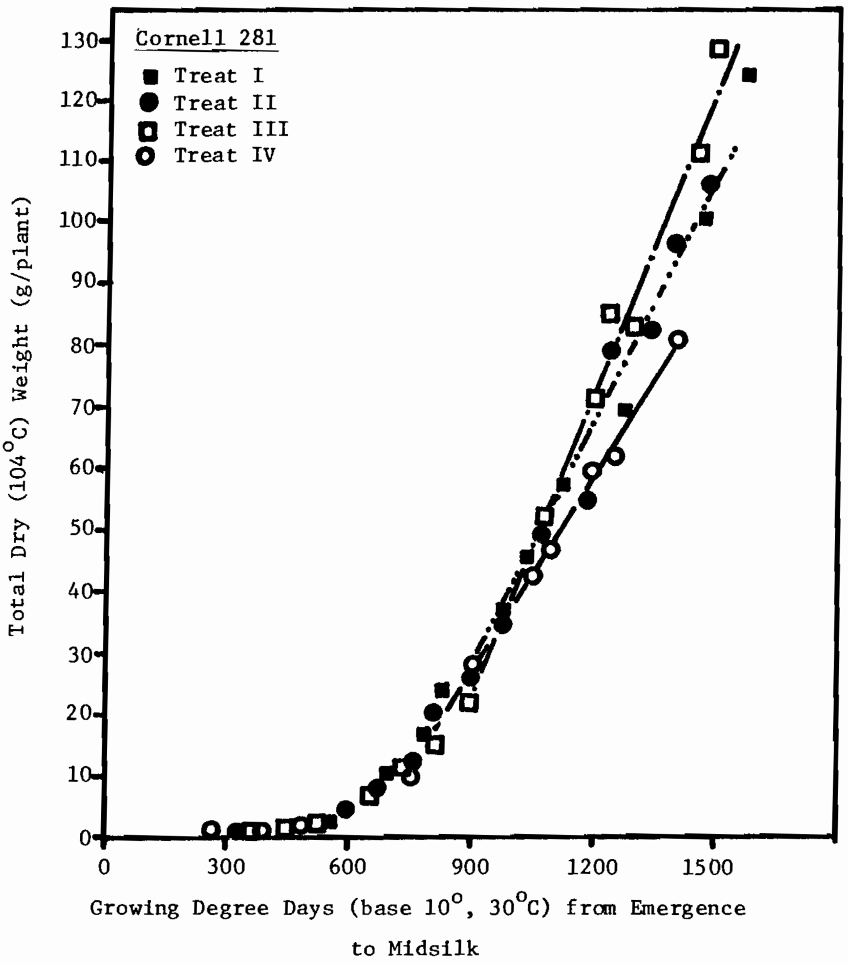


Figure 8. Relationship between total plant dry (104°C) weight (g/plant) for Cornell 281 planted at four dates in the spring of 1979, and the growing degree days (base 10°, 30°C).

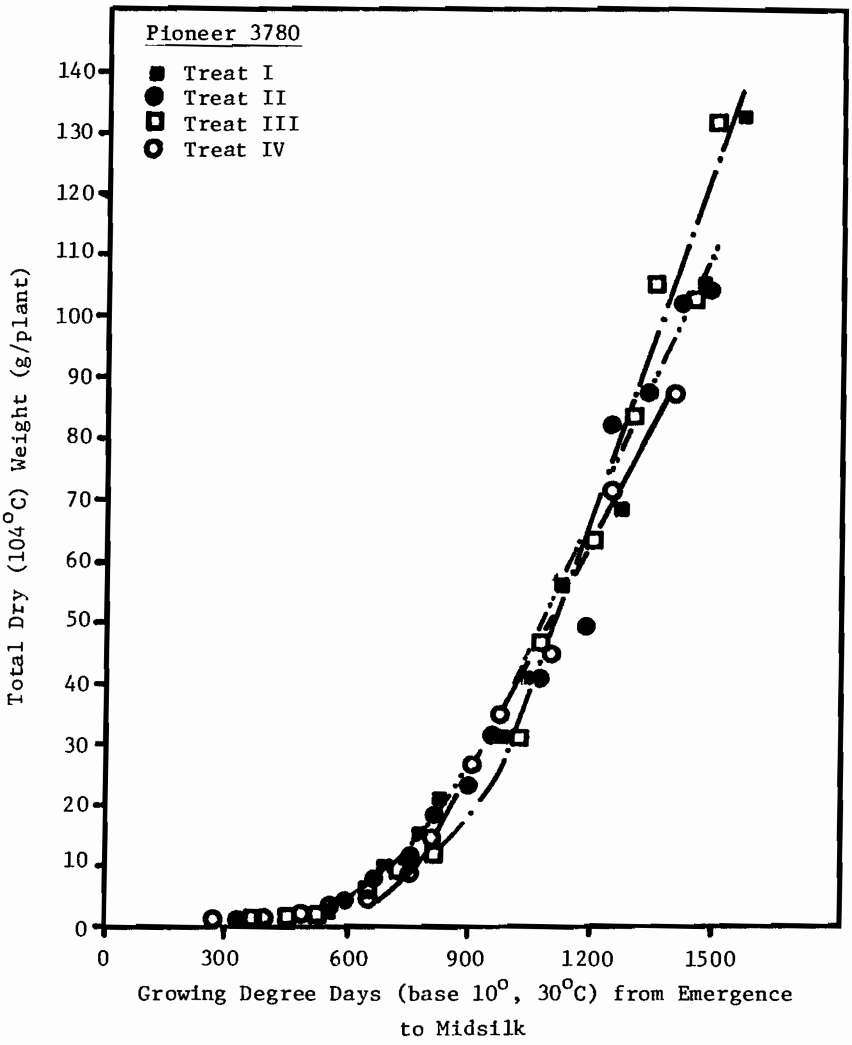


Figure 9. Relationship between total plant dry (104^{o}C) weight (g/plant) for Pioneer 3780 planted at four dates in the spring of 1979, and the growing degree days (base 10^{o}, 30^{o}C).

At maturity, total plant dry (69^oC) weight ranged from 18.9 to 9.8 mT/ha for C281 and from 16.2 to 8.9 mT/ha for P3780. It is important to point out that plants from the last two planting dates did not reach blacklayer before the frost. Total plant dry weight per unit land area at maturity declined with delayed planting (Table 12). The reduction in total plant dry matter per ha with late planting was due to the decrease in grain dry weight as we will see later in this report.

The analysis of variance on the total biomass (Table 13) shows that both the planting treatment and the hybrid effects on the total plant weight per unit land area were significant at the 1% level. The interaction between planting dates and hybrids was non-significant indicating that the dry matter accumulation response of both hybrids to delayed planting was the same. Duncan's multiple range test shows that there was a significant difference at the 5% level, between Cornell 281 (14.3 mT/ha) and Pioneer 3780 (12.3 mT/ha) when the total plant weight per ha was averaged over planting date (Table 12).

d. Plant height. Plant height measured in cm (see Appendix D, Table 54) was plotted against growing degree days in Figure 10. These data produced sigmoid curves for both hybrids at all dates. The plant elongation rate was essentially the same for both hybrids at all dates (Figure 10); however, the fourth planting corn was consistently taller while the first planting corn was consistently shorter when exposed to the same number of GDD. Even though P3780 had a greater dry matter per plant it was shorter than C281 plant. At maturity Cornell 281 measured 2.70 m while Pioneer 3780 was 2.40 m long. This difference in plant size might be due to the difference in plant population. At a population of 86,500 plants/ha, C281 plants were so close together that stalk

Table 12. Total plant dry (69°C) matter per unit land area for two corn hybrids (C281 and P3780) planted at four dates in spring of 1979. Plants were sampled at blacklayer for early plantings and at frost for late plantings.

1979 Planting Date	Hybrid*	
	C281	P3780
	-mT/ha-	
12 May	18.9 a	16.9 a
30 May	14.8 b	14.3 b
08 June**	13.9 c	10.1 c
22 June**	9.8 d	8.9 d
Average†	14.3	12.3

*Dry weight followed by the same letter within and between columns are not significantly different ($P < 0.05$).

**Plants did not reach blacklayer before frost in the fall.

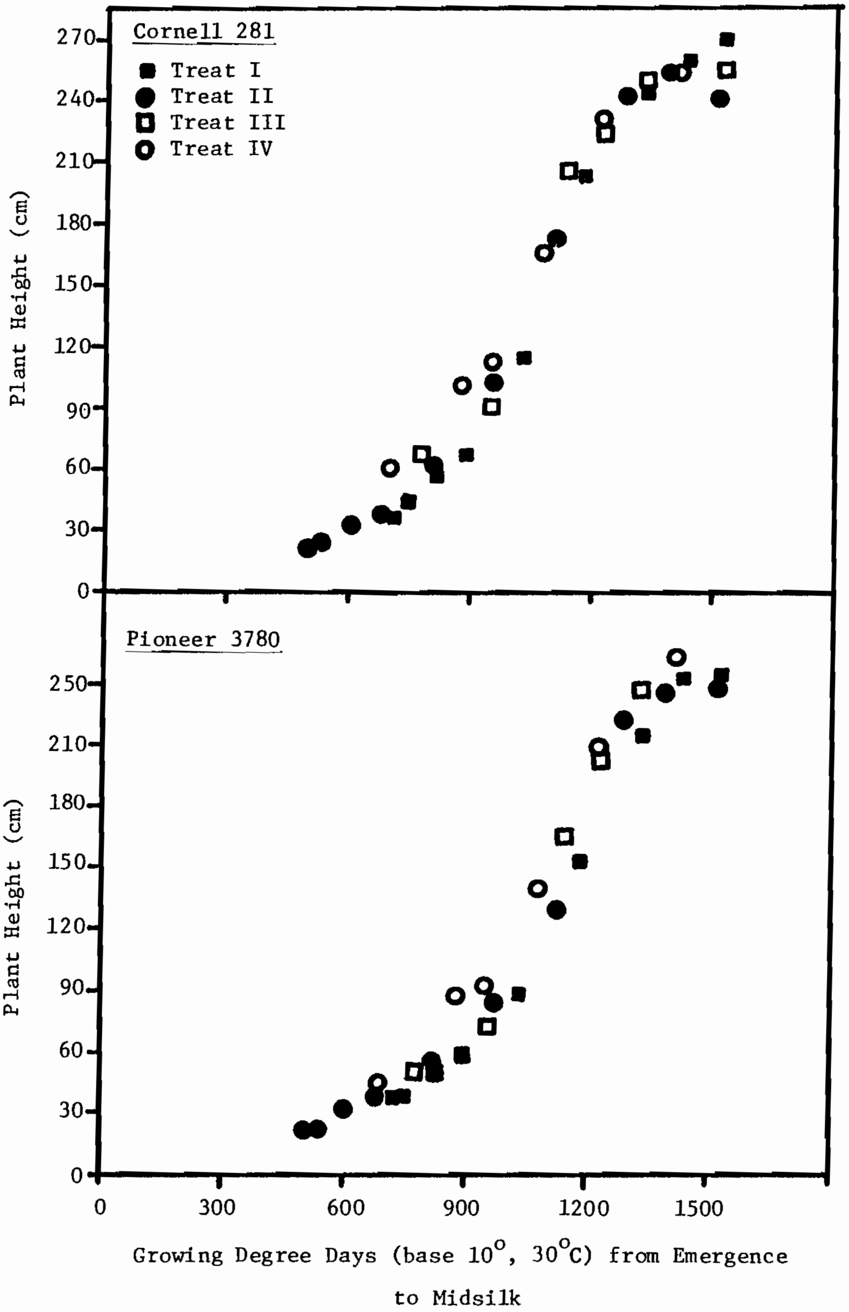
†Hybrids are significantly different at $P < 0.05$.

Table 13. Summary of significance of F-ratios and degrees of freedom for analysis of variance of total plant dry weight per ha for C281 and P3780 planted at 4 dates in the spring of 1979.

Source of Variation	d.f.	Significance of F-ratios
Hybrid	1	***
Planting date	3	***
Hybrid * Planting date	3	NS
Error	24	
Corrected total	31	

***Significance at the 1% level.

NS non-significant


Cornell 281
■ Treat I
● Treat II
□ Treat III
○ Treat IV
Plant Height (cm)
270
240
210
180
150
120
90
60
30
0
Pioneer 3780
Plant Height (cm)
250
210
180
150
120
90
60
30
0
0
300
600
900
1200
1500
Growing Degree Days (base 10°, 30°C) from Emergence to Midsilk

elongation may have been stimulated by interplant competition for solar energy.

4. Reproductive Events

The timing of reproductive growth stages including tasselling, silking, and blacklayer formation dates, are summarized in Table 14. The time from emergence to midsilk was 87, 64, 65, and 61 days for C281 and 89, 66, 67, and 63 days for P3780 at successive planting dates. Except for the first planting date which had an emergence to silking time interval of nearly 90 days for both hybrids, there was little difference in time from emergence to midsilk between planting dates for either hybrid. The time from midsilk to blacklayer which is considered to be the apparent kernel filling period, will be discussed in detail later in the report.

C. Factors Influencing Corn Grain Yield

The decline observed in corn grain yield with late planting might be due to many factors such as: number of double rows per ear shoot, rate and duration of kernel site development which affects kernel number, and rate and duration of kernel filling. These factors will be discussed separately.

1. Number of Double Rows (DR) per Cob

The number of double rows (DR) observed per cob are presented in Table 15. The DR tended to be higher for P3780 than for C281 at the same date. The averages ranged from 7.1 to 7.6 DR/cob for C281 and from 7.4 to 7.8 DR/cob for P3780. The actual number ranged from 6 to 10 DR/cob for all hybrids and planting dates. The analysis of variance

Table 14. Visually identifiable reproductive growth stages of two corn hybrids (Cornell 281 and Pioneer 3780) planted in spring of 1979 at four dates.

1979 Planting Date	Hybrid					
	C281			P3780		
	50% tas.	50% silk	50% black	50% tas.	50% silk	50% black
	date					
12 May	26 Jul	31 Jul	27 Sept	1 Aug	2 Aug	8 Oct
30 May	4 Aug	8 Aug	10 Oct	8 Aug	10 Aug	frost
08 June	13 Aug	18 Aug	frost	20 Aug	20 Aug	frost
22 June	26 Aug	29 Aug	frost	29 Aug	31 Aug	frost

tas. = tasselling
Jul = July
Aug = August
Sept = September

Oct = October
frost = Plants did not reach blacklayer before frost in the fall

Table 15. Number of double rows (DR) per cob for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Hybrid		Means
	C281	P3780	
12 May	7.4 b*	7.5 c	7.45 b
30 May	7.6 a	7.8 a	7.70 a
08 June	7.4 b	7.4 b	7.40 b
22 June	7.1 c	7.4 b	7.25 c
Average**	7.39	7.54	

*Duncan's multiple range test within column ($P < 0.05$).

**Hybrid averages significantly different at $P < 0.05$.

Table 16. Summary of significance of F-ratios and degree of freedom for analysis of variance of number of double rows for two corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Source of Variation	d.f.	Significance of F-Ratios
Corrected Total	111	
Model	7	***
Hybrid (H)	1	***
Planting date (PD)	3	***
H * PD	3	NS
Error	104	

***Significant at 1% level
NS Non-significant at 10% level

(Table 16) showed that the planting date and hybrid effects on the number of double rows per cob were significant at the 5 percent level of probability. The 30 May planting date had the highest number of double rows per cob for both hybrids. A study of the microclimate data recorded during the week prior to the beginning of kernel site accumulation, showed that the higher number of double rows was associated with higher irradiance (ly/day) (Figure 11) but not with higher temperature (GDD/day). The beginning of kernel site accumulation was determined by extrapolating the kernel site accumulation lines (Figures 12 and 13) to zero kernel site numbers. It was estimated that the number of double rows per cob was initiated within 7 days prior to the beginning of kernel site accumulation. The results of these investigations did not reveal a clear relationship between temperature and kernel row number. Duncan's multiple range test gave three classes for each hybrid (Table 15). This test indicated that there were significant differences at the 5% level of probability between planting dates with hybrid. The interaction between planting dates and hybrids was non-significant indicating that hybrid response was the same across planting dates. When averaged over dates, I observed 7.39 DR/cob for C281 and 7.54 DR/cob for P3780. These averages were significantly different at the 5% level (DF = 104, MS = 0.0564639). The data used in computation of these averages are shown in Appendix E, Table 55.

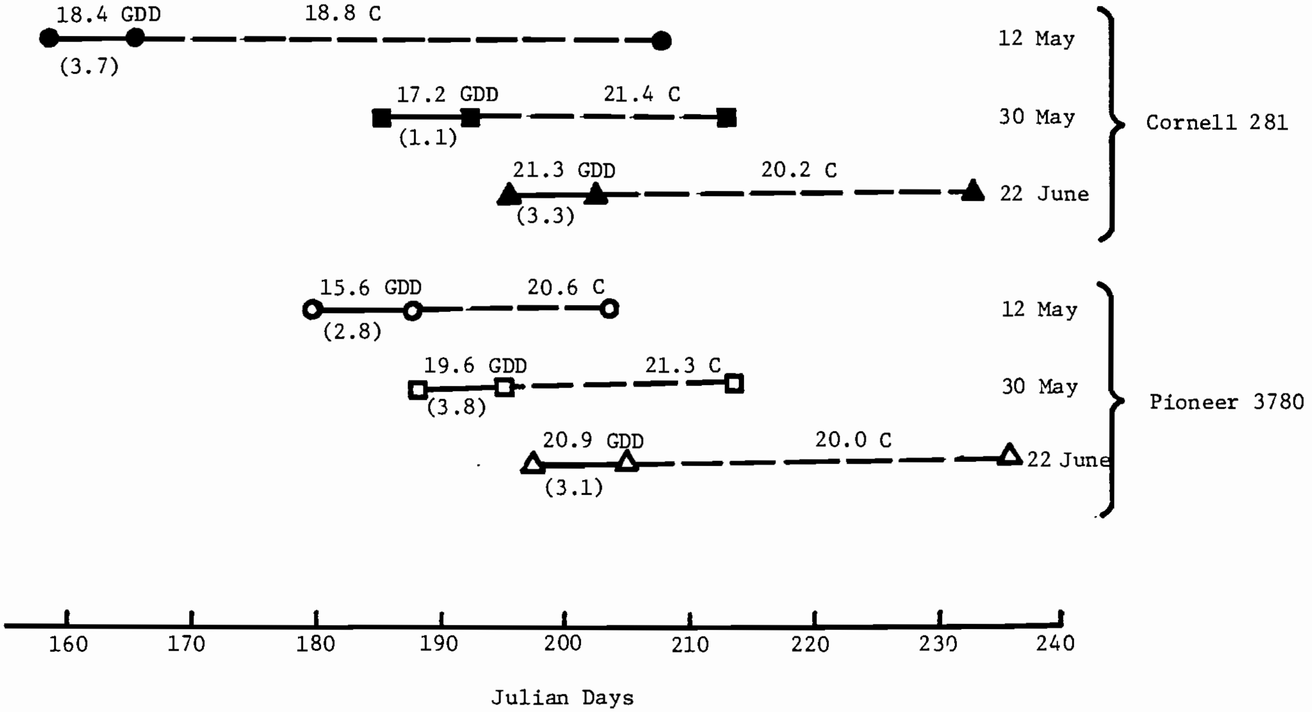


Figure 11. Week prior to the beginning of kernel site accumulation with its average GDD/day and its cumulative irradiance, 10^3 ly (in parentheses), in solid line; duration of linear kernel site accumulation with the average daily temperature during this period in dashed line for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

2. Kernel Site Accumulation

Kernel site accumulation data (Appendix E, Table 56) are plotted on Figure 12 for C281 and Figure 13 for P3780. Kernel site accumulation was linearly related to growing degree days. After reaching a maximum which was found to be near midsilk, kernel site number declined, but the decline was not consistent among planting date treatments. Similar graphs were obtained when plotting the data against calendar day. Regression lines were fitted to the points in the linear part of the curves. The analysis of regression (Tables 17, 19, 21a, and 21b) showed a high correlation ($r > .96$ in all cases) between the number of kernel sites accumulated and either the GDD or the calendar day. The coefficient of variation was less than 12.3 in both hybrids. The test of homogeneity of the regression coefficients (Tables 18 and 20) gave the grouping presented in Tables 17, 19, 21a, and 21b. On both a calendar day and a growing degree day basis, kernel site accumulation rates were non-significant between dates 1 and 2 for P3780 while the 30 May planting was significantly different from dates 1 and 4 for C281. The third planting date was not included because there were not enough data taken during the linear accumulation period to calculate an accumulation rate. The results showed that kernel site accumulation rate was highly correlated with and linearly related to either GDD or calendar day over most of the accumulation period. Even though there was a high correlation between number of kernel sites accumulated and GDD, differences in rate of accumulation were observed among planting dates. This suggests that the GDD temperature function used was not appropriate for all planting dates or that other factors interacted with the thermal unit response or operated independently to influence

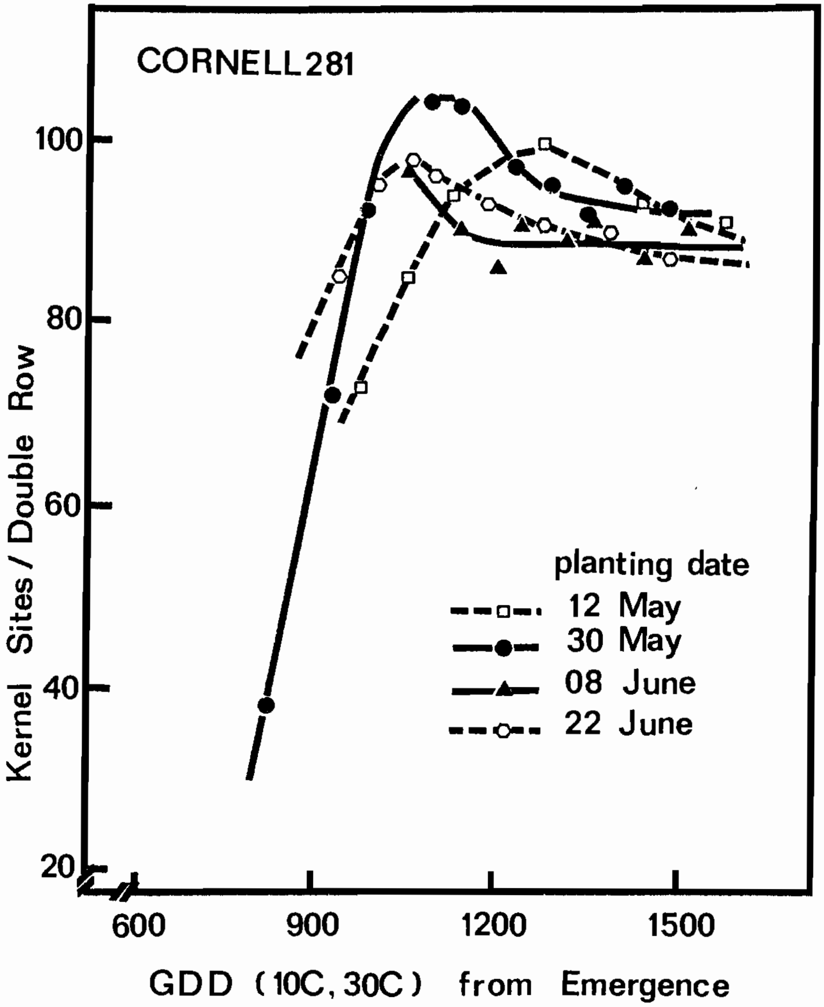


Figure 12. Relationship between the number of kernel sites per double row for Cornell 281 (planted at 4 dates) and the growing degree days (base 10^o, 30^oC) from emergence, calculated with shelter air temperatures.

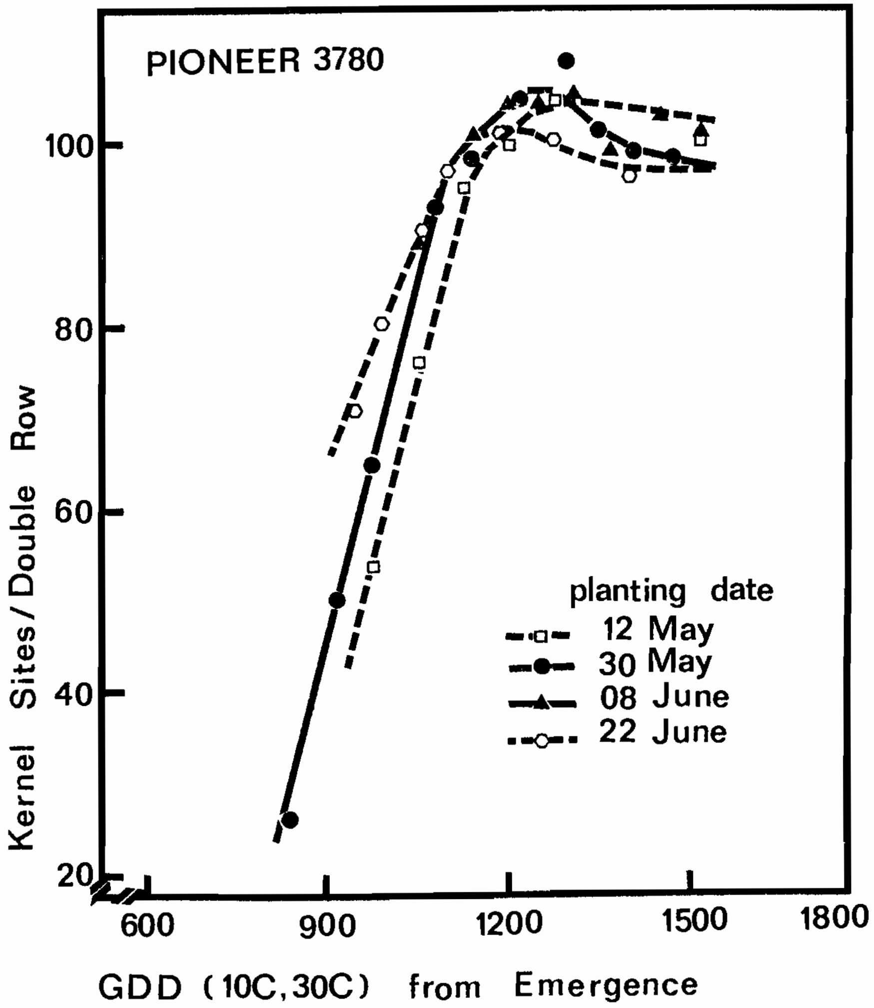


Figure 13. Relationship between the number of kernel sites per double row for Pioneer 3780 (planted at 4 dates) and the growing degree days (base 10°, 30°C) from emergence, calculated with shelter air temperatures.

Table 17. Regression analysis of kernel site accumulation against GDD from emergence, for C281.

Planting Date	Intercept	Regression Coefficient	F-ratio Significance	R-Square	C.V.
12 May	- 63.53	0.141 b	***	0.999	0.2
30 May	-167.67	0.255 a	**	0.929	12.1
08 June††	--	--	--	--	--
22 June	- 75.44	0.171 b	***	--	--

*** Significant at 1 percent level.
** Significant at 5 percent level.
†† Not enough data for the third planting date.
The regression coefficients followed by the same letter are not significantly different.

Table 18. Test of homogeneity on the regression coefficients of kernel site accumulation for C281 and P3780 (GDD basis).

Source of Variation	d.f.	Significance of F-ratios Type IV C281	 P3780
Planting dates	2	NS	***
GDD	1	*	***
GDD* Planting dates†	2	NS	***

*** Significant at 1 percent level of probability.
† GDD* Planting dates SS were used to test the homogeneity of regression coefficients.

Table 19. Regression analysis on the kernel site accumulation against GDD from emergence for Pioneer 3780.

Planting Date	Intercept	Regression Coefficient	F-ratio Significance	R-Square	C.V.
12 May	-223.288	0.285 a	**	0.999	1.0
30 May	-171.504	0.239 a	***	0.994	4.1
08 June††	--	--	--	--	--
22 June	- 77.675	0.159 b	***	0.999	0.6

*** Significant at 1 percent level.

** Significant at 5 percent level.

†† Not enough data for the third planting date.

Table 20. Test of homogeneity of the regression coefficients of kernel site accumulation for C281 and P3780 (calendar day basis).

Source of Variation	d.f.	Significance of F-ratios Type IV	
		C281	P3780
Planting dates	2	NS	***
GDD	1	*	***
GDD* Planting dates†	2	NS	***

*** Significant at 1 percent level of probability.

** Significant at 5 percent level of probability.

NS Not significant.

† GDD* Planting date SS were used to test the homogeneity of the regression coefficients.

Table 21a. Regression analysis of kernel site accumulation against calendar day for C281.

Planting Date	Intercept	Regression Coefficient	F-ratio Significance	R-square	C.V.
12 May	- 506.277	2.942 b	***	0.999	0.3
30 May	-1042.904	5.416 a	**	0.926	12.3
08 June††	--	--	--	--	--
22 June	- 493.995	2.563 b	***	--	--

*** Significant at 1 percent level.
** Significant at 5 percent level.
†† Not enough data for the third planting date.
Rate with the same letter within a column were not significantly different at the 5 percent level.

Table 21b. Regression analysis of kernel site accumulation against calendar day for P3780.

Planting Date	Intercept	Regression Coefficient	F-ratio Significance	R-square	C.V.
12 May	-1118.581	5.949 a	**	0.999	1.2
30 May	-1002.858	5.132 a	***	0.995	3.6
08 June††	--	--	--	--	--
22 June	- 567.946	2.826 b	***	0.990	1.6

*** Significant at 1 percent level.
** Significant at 5 percent level.
†† Not enough data for the third planting date.
Rate with the same letter within a column were not significantly different at 1 percent level.

kernel site accumulation. If the GDD temperature function applied over all environments tested or if temperature was the only factor affecting kernel site accumulation, the rate per GDD would be the same for all planting dates within a hybrid. However, different responses may have been observed between hybrids because corn hybrids could respond differently to the same temperature levels. The results show that at least the GDD function used in this study does not have any advantage over time function (calendar day) for kernel site production.

Maximum number of kernel sites per DR, number of kernel sites/DR at midsilk, and final number of kernels filled per DR are shown in Table 22. Maximum number of sites/DR ranged from 92.1 to 104.4 for C281, and from 101.8 to 108.8 for P3780. The analysis of variance showed a significant effect ($P < 0.01$) of delayed planting on potential kernel sites/DR for P3780 (Tables 23 and 24). Duncan's multiple range test showed that only the kernel sites/DR for the third date was significantly different ($P < 0.05$) from the others for C281 while the potential kernel sites per double row was not significantly different between all planting dates for P3780. The highest number for both hybrids was recorded on the 30 May planting date. This high number of potential kernel sites was associated with higher GDD/day during the kernel site accumulation period (Figure 11) with 21.4 ± 1.5 GDD/day for C281 and 21.3 ± 1.6 GDD/day for P3780. These values were 6% higher than the average GDD/day during kernel site development at the other planting dates. There were differences also in the duration of the kernel site accumulation period (Figure 11). However, there was no difference in the maximum number of kernel sites per DR between planting dates within hybrids, except for the third date for C281. This result suggests that

Table 22. Number of maximum kernel sites per double row (Max KS/DR), number of kernel sites per double row present at silking and number of filled kernels/DR for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Max KS/DR	KS/DR (Midsilk)	Final Kernel #/DR
	C281		
12 May	99.8 a	99.8 a	63.1 a
30 May	104.4 a	97.6 ab	54.5 ab
08 June	92.1 b	91.0 c	47.8 cb*
22 June	98.4 a	93.0 cb	43.0 c*
	P3780		
12 May	104.5 a	103.5 a	70.0 a
30 May	108.8 a	108.8 a	54.3 b
08 June	104.6 a	104.0 a	24.7 c*
22 June	101.8 a	100.5 a	22.6 c*

*Poor pollination due to insect feeding on silks.

Kernel numbers with the same letter within each column are not significantly different at the 5% level (Duncan's multiple range test).

Table 23. Summary of significance of F-ratios and degrees of freedom for analysis of variance of number of maximum kernel sites for C281 planted in the spring of 1979 at 4 dates.

Source of Variation	d.f.	Significance of F-ratio
Corrected total	39	
Planting dates	3	***
Error	36	

*** Significant at 1 percent level

Table 24. Summary of significance of F-ratios and degrees of freedom for analysis of variance of number of maximum kernel sites for Pioneer 3780 planted in the spring of 1979 at 4 dates.

Source of Variation	d.f.	Significance of F-ratio
Corrected total	35	
Planting dates	3	NS
Error	32	

NS = non-significant

the rate of spikelet (kernel site) production was not a limiting factor in the determination of the number of potential spikelets available for kernel filling in this experiment. In most cases the maximum number of spikelets was reached just before or at silking.

The observation data of number of kernels filled per double row on the topmost ear is shown in Appendix E, Table 57. The final number of kernels filled per DR are shown in Table 22. The number of filled kernels was significantly lower with late compared to early planting. The analysis of variance (Table 25) and Duncan's multiple range test showed significant differences ($P < 0.05$) between and within hybrids. Final kernel numbers ranged from 43.0 to 63.1 kernels/DR for C281 and from 22.6 to 70 kernels/DR for P3780. The two last planting dates in both hybrids had poor pollination due to insect feeding on silks. The extent of insect damage depended upon the timing of severe insect feeding and silking on an individual ear shoot basis. Since insect activity was not monitored quantitatively, the degree of poor pollination due to the insects cannot be quantified. However, it seemed that the third planting of C281 silked early enough to avoid most of the insect damage (Tables 27, 39, and 43). The difference in final kernel number between the two first planting dates in both hybrids, although non-significant for C281, was mainly due to the fact that spikelets at the tip of the cob failed to develop early in the filling period.

The analysis of variance on the total number of harvested kernels per hectare (Table 26) showed a significant effect of the time of planting for both C281 and P3780. Maximum number of kernel sites and number of filled kernels adjusted to a unit land area by taking into account the differences in plant population and hybrid barrenness are presented in

Table 25. Summary of significance of F-ratios and degrees of freedom for analysis of variance of number of kernels harvested for Pioneer 3780 planted in the spring of 1979 at 4 dates.

	C281		P3780	
Source of Variation	d.f.	F-ratio	d.f.	F-ratio
Corrected total	51		63	
Planting dates	3	***	3	***
Error	48		60	

*** Significant at 1% level.

Table 26. Summary of significance of F-ratios and degrees of freedom for analysis of variance of number of kernels harvested per ha for Cornell 281 and Pioneer 3780 planted in the spring of 1979 at 4 dates.

	C281		P3780	
Source of Variation	d.f.	F-ratio	d.f.	F-ratio
Corrected total	63		51	
Planting dates	3	***	3	***
Error	60		48	

*** Significant at 1% level.

Table 27. Maximum number of kernel sites and number of filled kernels per ha for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Hybrid			
	C281		P3780	
	Max	Harvested	Max	Harvested
	10^6/ha			
12 May	55.2	37.2 a	55.2	34.3 ab
30 May	63.1	30.1 bc	54.4	26.5 c
08 June[†]	56.8	28.0 c	49.8	12.0 d
22 June[†]	56.5	25.3 c	49.5	11.1 d

[†] Pollination reduced by insects feeding on silks.

Within and between columns, kernel number followed by the same letter are not significantly different ($P < 0.05$).

Table 27. Despite the population differences between hybrids, the maximum kernel site number per hectare was similar for both hybrids, 55.2×10^6 kernels/ha for planting date treatment 1. Duncan's multiple range test (Table 27) showed significant difference ($P < 0.05$) between the total number of kernels filled for the first two planting dates of both hybrids. The differences in harvested kernel number for the last two planting dates can be explained mainly by the insect damage on ear shoot silks resulting in poor pollination. For the first two planting dates in both hybrids where there was no insect damage, there was no significant difference ($P < 0.05$) in the number of kernels filled for C281 while the difference was significant for P3780. For the first two dates, the results presented in Table 27 show that 33% to 50% of the spikelets present at midsilk failed to produce mature grain. This result suggests that neither the maximum number of potential kernel sites nor the kernel site accumulation rate were limiting the final grain yield.

3. Ear Length

Ear length data (Appendix E, Table 58) are plotted in Figures 14 and 15 against growing degree days. All the data points fall essentially on one sigmoid curve. There was no difference in the rate of ear elongation (slope of lines) during most of the growth period, even though more GDD accumulated before ear shoot elongation began for the first planted corn than for ears at later plantings in both hybrids. The diagrams show that there was a high correlation between ear length and GDD. The final ear length was quite similar for all dates within and between hybrids. The average was 22.2 cm for C281 and 23.5 cm for P3780.

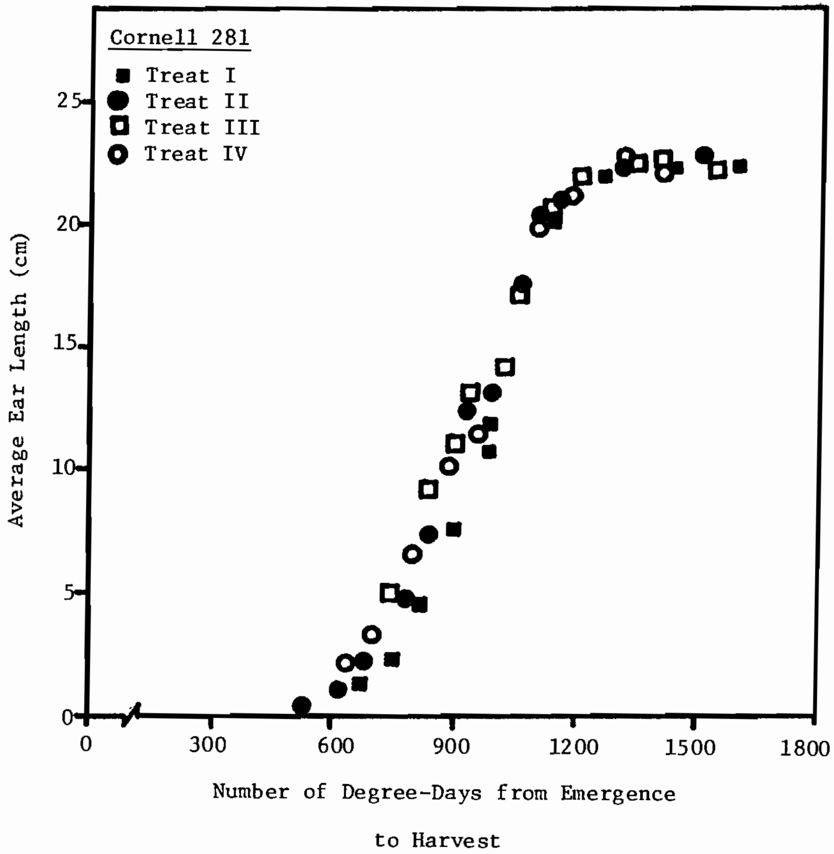


Figure 14. Relationship between the ear length (cm) of Cornell 281 planted at four dates, and growing degree days (base 10^{o}, 30^{o}C) from emergence.

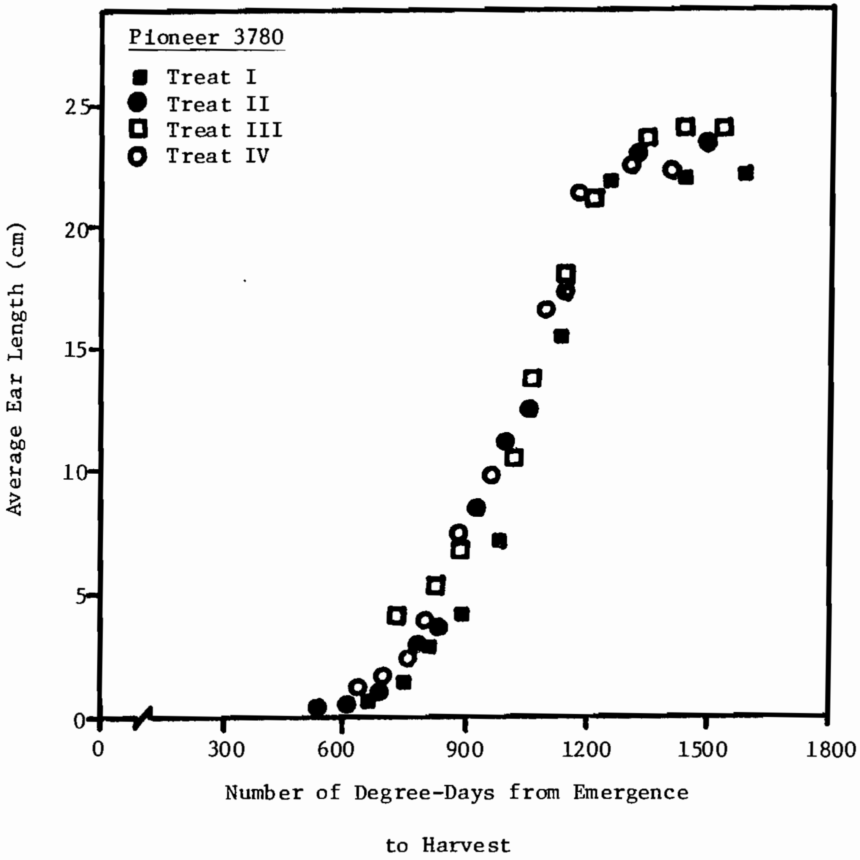
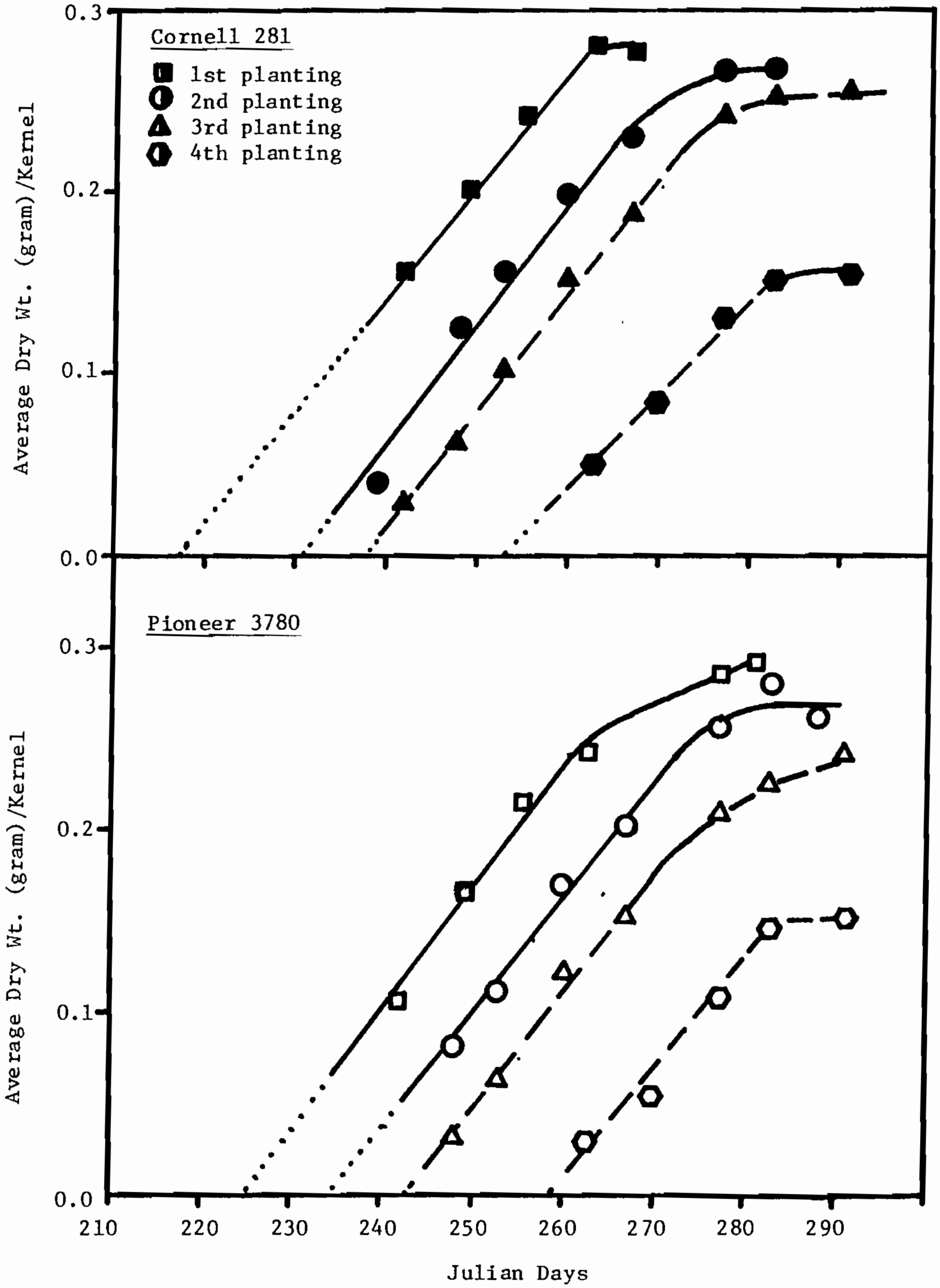


Figure 15. Relationship between the ear length (cm) of Pioneer 3780 planted at four dates, and growing degree days (base 10°, 30°C) from emergence.

4. Kernel Dry Weight Accumulation

The grain dry weight (104°C) data (Appendix E, Tables 59 and 60) are plotted against calendar days in Figure 16 and against growing degree days in Figure 17. Figure 16 shows a linear relationship between kernel dry matter accumulation and calendar days over most of the grain filling period. Linear regression lines were fitted to the data and the analysis results are summarized in Tables 28 and 30. A linear relationship was found also between the dry weight per kernel and growing degree days. The regression analysis results are shown in Table 32. All the F-ratios of the regression models were significant at the 1% level of probability. This means that there was a highly linear relation between kernel dry weight (104°C) and calendar day or GDD. The coefficient of determination (r^2) ranged, in all cases, from 0.968 to 0.999. This means that the linear models could explain 96.8 to 99.9 percent of the variation in kernel dry weight. On a calendar day basis, the coefficient of variation (C.V.) ranged from 2.15 to 11.51 for both hybrids, while on the growing degree day basis, it was 8.28 and 6.52 for C281 and P3780, respectively. As shown in Figure 17, all the kernel dry weight (104°C) data points fall on the same line for each hybrid, when plotted against GDD. The kernel growth rates observed during the linear phase of grain filling are summarized in Table 34. Tests of regression coefficient homogeneity (Tables 29, 31, and 33) showed that there were no significant differences between slopes within and between hybrids on both a calendar day and GDD basis. Calculated kernel growth rates were 0.36 mg/GDD ($r = 0.9864$, c.v. = 28.28) for C281 and 0.38 mg/GDD ($r = 0.9925$, c.v. = 6.25) for P3780. These results suggest that rate of kernel dry matter accumulation was


Cornell 281
■ 1st planting
● 2nd planting
▲ 3rd planting
⬢ 4th planting
Pioneer 3780
Average Dry Wt. (gram)/Kernel
0.0
0.1
0.2
0.3
210
220
230
240
250
260
270
280
290
Julian Days

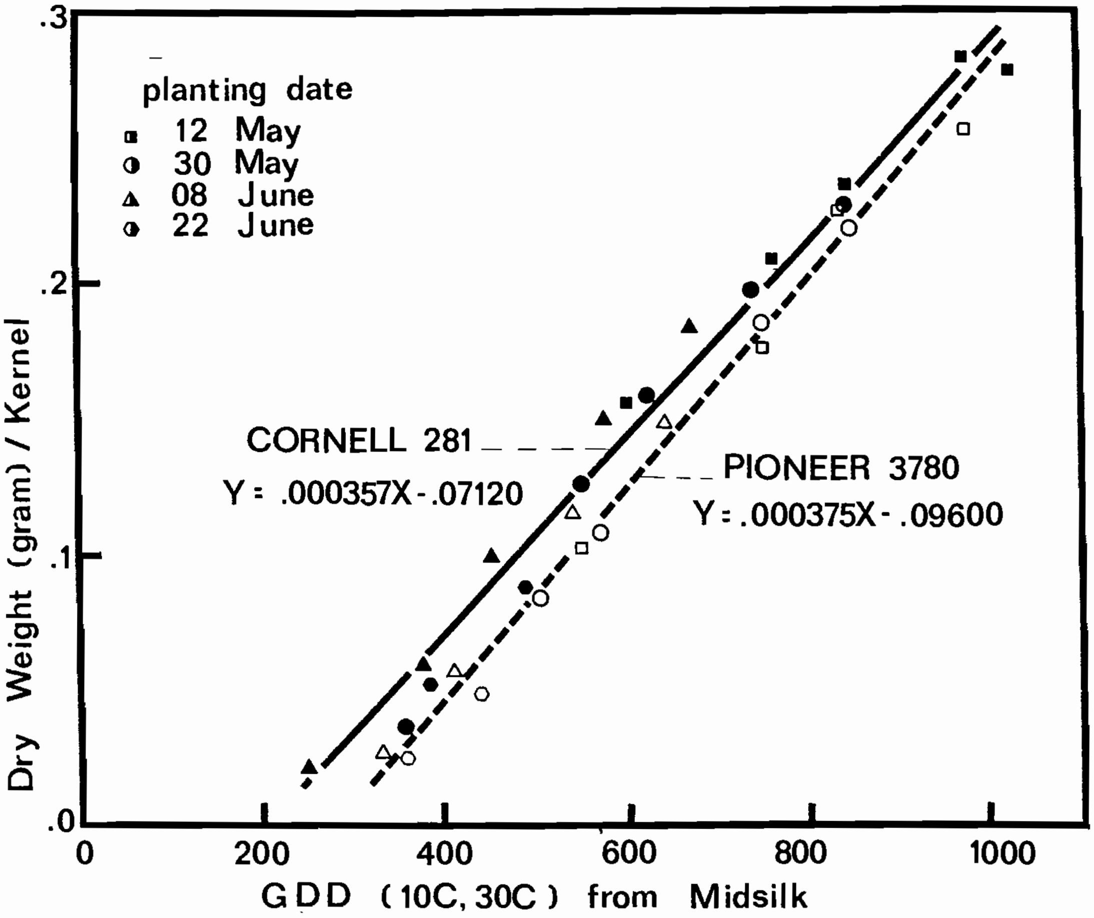

.3
.2
.1
.0
Dry Weight (gram) / Kernel
planting date
■ 12 May
● 30 May
▲ 08 June
◐ 22 June
CORNELL 281
Y = .000357X - .07120
PIONEER 3780
Y = .000375X - .09600
0
200
400
600
800
1000
GDD (10C, 30C) from Midsilk

Table 28. Regression analysis of kernel dry weight versus Julian day for Cornell 281.

Planting Date	Intercept	Regression Coefficient	F-ratio Significance	R-Square	C.V.
12 May	-1.425	0.00654 a	***	0.995	2.18
30 May	-1.559	0.00674 a	***	0.968	10.23
08 June	-1.577	0.00663 a	***	0.995	5.22
22 June	-1.290	0.00510 a	***	0.989	5.58

*** Significant at 1 percent level of probability.

a = There was no significant difference between the regression coefficients.

Table 29. Test of homogeneity of the regression coefficients of kernel dry weight accumulation for C281.

Source of Variation	D.f.	Significance of F-ratios Type IV
Planting date	3	NS
Julian day	1	***
Julian* Planting Date†	3	NS

*** Significant at 1 percent level of probability.

† Julian* Planting date SS were used to test the homogeneity of the regression coefficients.

Table 30. Regression analysis of kernel dry weight versus Julian day for Pioneer 3780.

Planting Date	Intercept	Regression Coefficient	F-ratio Significance	R-Square	C.V.
12 May	-1.464	0.00652 a	***	0.955	8.49
30 May	-1.431	0.00612 a	***	0.991	4.69
08 June	-1.579	0.00650 a	***	0.986	8.59
22 June	-1.571	0.00606 a	***	0.978	11.51

*** Significant at 1 percent level of probability

a = There was no significant difference between the regression coefficients.

Table 31. Test of homogeneity of the regression coefficients of kernel dry weight accumulation for P3780.

		Significance of F-ratios
Source of Variation	D.f.	Type IV
Planting date	3	NS
Julian day	1	***
Julian* Planting date†	3	NS

*** Significant at 1 percent level of probability

** Significant at 5 percent level of probability

† Julian* Planting date SS were used to test the homogeneity of the regression coefficients.

NS = Non-significant

Table 32. Regression analysis of kernel dry matter accumulation versus GDD (base 10°, 30°C) for 2 corn hybrids (Cornell 281 and Pioneer 3780).

Hybrid	Intercept	Regression Coefficient	F-ratio Significance	R-Square	C.V.
C281	-0.0712	0.00035729 a	***	0.973	8.28
P3780	-0.0960	0.0003732 a	***	0.985	6.52

*** Significant at 1 percent level of probability

a = There was no significant difference between the regression coefficients.

Table 33. Test of homogeneity on the regression coefficients of kernel dry matter accumulation on GDD basis for C281 and P3780.

Source of Variation	d.f.	Significance of F-ratios Type IV
Hybrid	1	*
GDD	1	***
GDD* Hybrid†	1	NS

* Significant at 10 percent level of probability

*** Significant at 1 percent level of probability

NS Not significant

† GDD* Hybrid SS were used to test the homogeneity of the regression coefficient.

Table 34. Kernel growth rates on calendar day basis (mg/day) and GDD basis (mg/GDD) for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Hybrid	
	C281	P3780
	---------------mg/day---------------	
12 May	6.5 a	6.5 a
30 May	6.7 a	6.1 a
08 June	6.6 a	6.5 a
22 June	5.1 a	6.1 a
	---------------mg/GDD---------------	
All dates	0.36	0.37

Within and between columns different letters indicate significant difference between the regression coefficients at the 5% level.

On the GDD basis there was no difference in grain dry matter accumulation rate.

not significantly limited by cooler fall temperatures associated with delayed planting (Figure 3). The test for significance among regression coefficients is a conservative test. The decline in kernel filling rate from 6.6 to 5.1 mg/day by C281 from the third to the fourth planting date (Table 34) suggests that cool fall temperatures may have started to influence grain growth. No such trend was observed for P3780.

The effective kernel filling period duration (EFPD) was computed in days and presented in Table 35 with the equivalent GDD. The EFPD declined in both hybrids from 43 to 30 days for C281 and 45 to 25 days for P3780. Number of GDD accumulated during the effective filling period declined also with late planting. As temperatures declined in the fall (Figure 3) the effective kernel filling period became shorter for the late plantings. The final grain dry weight per kernel declined with delayed planting in both hybrids from 290 to 150 mg (Table 36). It is obvious that the decline in EFPD had contributed to the reduction in the dry weight per kernel but no measurement was done on the initial size of kernel to determine whether the volume of the kernel was also limiting. The number of GDD accumulated per mg dry weight (Table 36) varied from 2.62 to 2.98 for C281 and from 2.67 to 2.83 for P3780. Although final dry weight per kernel and GDD accumulated during the EFPD declined with delayed planting, their relationship was inconsistent.

The apparent kernel filling period duration (AFPD) (Table 35) was found to increase up to the second planting date then declined rapidly in Cornell 281, while the AFPD declined steadily in P3780 with delayed planting. It should be noted that plants of the last two planting dates did not reach blacklayer formation before frost in the fall so the AFPD at these dates was shortened by frost.

Table 35. Effective kernel filling period duration in Julian days and GDD and apparent kernel filling period duration in days of two corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Hybrid					
	C281			P3780		
	AFPD	EFPD		AFPD	EFPD	
	Days	Days	GDD	Days	Days	GDD
12 May	58	43	827	67	45	742
30 May	63	40	728	66	45	788
08 June†	58	38	666	56	37	608
22 June†	47	30	460	45	25	370

† = Plants did not reach blacklayer before frost

EFPD = Effective filling period duration (period of rapid kernel dry weight accumulation)

AFPD = Apparent filling period duration (silking to blacklayer)

Table 36. Final dry (104°C) weight per kernel and GDD accumulated per mg dry weight grain per kernel for two hybrids (Cornell 281 and Pioneer 3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Hybrid			
	C281		P3780	
	mg	GDD/mg	mg	GDD/mg
12 May	279	2.96	290	2.56
30 May	268	2.72	278	2.83
08 June	254	2.62	240	2.53
22 June	154	2.98	150	2.47

There are two lag periods in the corn grain filling period. The first lag period is the time from midsilk to the beginning of rapid grain dry matter accumulation while the second lag period is the time from the end of the effective filling period to blacklayer formation. In this study the first lag was calculated by determining the time interval from midsilk date to projected zero grain dry weight date. The second lag was calculated by taking the difference between the projected date for final grain dry weight and the date of blacklayer formation. The calculated lag periods are shown in Table 37. The first lag period ranged from 7 to 13 days for Cornell 281 and from 11 to 17 days for Pioneer 3780. In a study with 20 hybrids of various maturity groups, Boyle (1980, M.S. Thesis, Agronomy Dept., The Pennsylvania State University) found that the estimated time from silking to the beginning of kernel dry matter accumulation was similar for all hybrids with an average of 11 days ± 2 days standard deviation. Hanway and Russell (1969) reported a value of 12 days for corn grown in Iowa. For Cornell 281 the shorter first lag period appeared to be associated with higher GDD accumulated per day (Table 37). The method for estimating lag periods in kernel growth are not precise, however, so actual relationships cannot be determined with my data. The second lag period ranged from 4 to 11 days for C281 and 3 to 11 days for P3780. The shorter second lag period for the fourth planting date was probably due to frost which prematurely stopped kernel filling.

D. Final Harvest

1. Final Grain Yields

The final grain harvest data are shown in Table 42 and Appendix F, Table 61. Final grain dry weight (104°C) per unit land area (ha) is

Table 37. GDD accumulation per calendar day and time from midsilk to beginning of effective grain filling (first lag) and from the end of the effective filling period to blacklayer formation (second lag) for C281 and P3780 planted at 4 dates in the spring of 1979.

1979 Planting Date	Hybrid					
	C281			P3780		
		1st lag	2nd lag		1st lag	2nd lag
	GDD/day	Days	Days	GDD/day	Days	Days
12 May	23.0	7	8	17.7	11	11
30 May	20.9	12	11	21.1	13	*
08 June	21.2	9	*	18.8	12	*
22 June	15.3	13	*	14.8	17	*

*Plants did not reach 50% blacklayer before frost.

Table 38. Final grain dry (104°C) weight (metric tons/ha) calculated on grain weight/1.83 m of row (method 1) of two corn hybrids (Cornell 281 and Pioneer 3780) planted in spring of 1979 at successive dates.

1979 Planting Date	Hybrid**	
	C281	P3780
	MT/ha	
12 May	6.0 b	8.0 a
30 May	6.1 b	6.4 b
08 June†	4.3 c	1.5 d
22 June†	2.0 d	1.1 d

** Within and between columns yields followed by the same letter are not significantly different ($P < 0.05$).

† Silks on ear shoot were damaged at pollination by insects.

summarized in Tables 38 and 39 for the two methods of calculation. The grain yield decreased from 6.1 to 2.0 mT/ha for C281 and from 8.0 to 1.1 mT/ha for P3780 in the first method (Table 38), and from 8.16 to 2.75 tons/ha for C281 and from 8.85 to 1.63 tons/ha for P3780 (Table 39). It is important to point out that insects damaged the silks as they emerged from plants of third and the fourth planting dates. Subsequent poor pollination resulted in the unexpected low grain yields recorded for both hybrids planted at dates 3 and 4. Plants of C281 from the third planting date silked a little before insect activity became significant so the yield reduction was smaller than for the fourth planting (Tables 38 and 39). Analysis of variance and mean separation test results for the data are summarized in Tables 38, 39, and 40. The F-ratios associated with the variation in yield associated with planting date and hybrid effects were significant at the 1% level of probability in the second method (using plant population) while only planting date had a significant effect on yield in the first method (which used number of rows/plot). These results mean that there was a significant variation in yield due to differences in planting dates and hybrids for the second method. The interaction between planting dates and hybrids was also significant at the 1% level in both methods suggesting that plant yield response was different among planting dates and hybrids. The significance of the hybrid effect and the interaction can be explained by the insect damage on the ear shoot silks at pollination for the third planting date. Plants from C281 of the third planting date silked before the insect damage became significant while plants from P3780 silked during the critical period of insect activity resulting in difference in pollination between the two hybrids at this date. The

Table 39. Final grain dry (104°C) weight (metric tons/ha) calculated from average grain weight/ear X population basis (method II) of two corn hybrids (Cornell 281 and Pioneer 3780) planted in the spring of 1979 at successive dates.

1979 Planting Date	Hybrid**	
	C281	P3780
	mT/ha	
12 May	8.16 a	8.85 a
30 May	7.13 b	7.39 b
08 June†	6.05 c	2.41 d
22 June†	2.75 d	1.63 e

These results differ from those in Table 38 (probably due to an underestimated barrenness factor).

** Within and between columns yields with the same letter are not significantly different at 5 percent level.

† Silks on ear shoot were damaged at pollination by insects.

Table 40. Summary of significance of F-ratios and degrees of freedom for analysis of variance of final grain yield of two corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

	1st Method		2nd Method	
Source of Variation	d.f.	F-ratios significance	d.f.	F-ratios significance
Corrected total	31		31	
Model	22		22	
Replication (rep)	3	NS	3	NS
Planting date	3	***	3	***
Rep* Planting date	9	NS	9	NS
Hybrid	1	***	1	NS
Hybrid* Planting	3	***	3	***
Hybrid* Rep	3	NS	3	NS
Error	9		9	

*** Significant at 1% level of probability

NS Non-significant

data in Tables 27, 38, 39, and 43 support the preceding argument by showing relatively high kernel number or yield or harvest index for the third planting date of C281 compared to the fourth planting date of C281 and the last two planting dates for P3780. Duncan's multiple range test at the 5% level of probability (d.f. = 9, MS = 0.779815) showed that there was significant difference in the yield between hybrids for the first planting date in the first method while the difference was non-significant in the second method. In addition the two methods gave different values of the yield. The yields reported in Table 39 were calculated from individual ear data from 6 consecutive plants and adjusted for population and barrenness percentages (Method II). Meanwhile, the yields reported in Table 38 were calculated from 6 feet row data and adjusted for length and number of rows per unit land area (Method I). The differences between the two methods of yield calculation suggest that the percentage of barrenness was underestimated, and that one must be careful when using the second method. As I pointed out in Chapter III, some plants had apparent ears but failed to produce mature kernels resulting in hidden barren plants. The differences in yields for the last two planting dates were partly due to insect damage on the ear shoot silks resulting in poor pollination.

2. Barrenness

Percentage barrenness was measured at final harvest of all plots (Table 41). The average barrenness percentages were 13.6, 8.0, 3.6, and 6.5 for C281 and 0.0, 3.7, 3.3, and 1.5 for P3780 at dates 1, 2, 3, and 4, respectively. The barrenness was higher in Cornell 281 than in Pioneer 3780 and the highest percentage was recorded with the highest

Table 41. Percentage barrenness at harvest and LAI at midsilk for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Hybrid			
	C281		P3780	
	%	LAI	%	LAI
12 May	13.6	4.1	0.0	3.3
30 May	8.0	3.5	3.7	3.4
08 June	3.6	3.3	3.3	3.4
22 June	6.5	3.2	1.5	3.0

Table 42. Whole plant and grain dry (104°C) weight at harvest for 6 plants for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Hybrid			
	C281		P3780	
	Whole Plants	Grain	Whole Plants	Grain
	grams/6 plants			
12 May	1278	640	1422	780
30 May	1002	525	1257	677
08 June	941	425	885	221
22 June	664	199	780	146

Table 43. Harvest indexes of 2 corn hybrids (Cornell 281 and Pioneer 3780) planted in the spring of 1979 at 4 dates.

1979 Planting Date	Hybrid*	
	C281	P3780
12 May	0.50 a	0.55 a
30 May	0.52 a	0.54 a
08 June†	0.45 a	0.24 bc
22 June†	0.31 b	0.19 c

* Duncan's multiple range test within and between hybrids ($P < 0.05$).

† Insect damage of silks and fall frost.

Table 44. Summary of significance of F-ratios and degrees of freedom for analysis of variance harvest index for 2 corn hybrids (C281 and P3780) planted at 4 different dates.

Source of Variation	d.f.	Significance of F-ratios
Corrected total	31	
Model	19	
Replication (rep)	3	NS
Planting date	3	***
Rep* Planting date	9	NS
Hybrid	1	***
Hybrid* Planting date	3	***
Error	12	

*** Significant at 1% level of probability

NS Non-significant at 10% level of probability leaf area index in C281 (Table 41). It should be pointed out that Cornell 281 had a higher plant density (86,500 plants/ha) compared to Pioneer 3780 (66,500 plants/ha). Sass and Loeffel (1959) conducted a two-year study (1954-1955) with 3 single crosses and 4 inbreds of maize and found that there was a marked differential response of single crosses and inbreds to plant populations (29,650 plants/ha, and 59,300 plants/ha) levels with respect to stalk barrenness. They concluded from their study that barrenness is the result of failure of silk emergence during the pollen-shedding period, rather than the failure of formation of floral organs.

3. Harvest Index

Table 42 contains the total plant and grain dry (104^{o}C) weight used in the calculation of the harvest index. A summary of the average harvest indexes is presented in Table 43 by hybrid and planting dates. The analysis of variance (Table 44) showed that the planting date and the hybrid effects on the harvest index were significant at the 1% level of probability. The interaction between planting date and hybrid was also significant at the 1% level showing that the two factors did not act independently of each other. This significant interaction could be explained by the fact that the last two planting dates for P3780 were severely damaged by insects while only the fourth planting date for C281 was severely damaged. Duncan's multiple range test (Table 43) showed non-significant difference between hybrids for the two first plantings at the 5% level of probability. The differences in harvest index for the third and fourth planting dates were mainly due to poor pollination associated with the insect damage on silks and eventually to the fall frost which prematurely halted the grain filling before blacklayer formation. Based on the first two planting dates which were safe from frost and insect damage, the average harvest index was 0.53. This means that at blacklayer (physiological maturity), 53% of the above ground bulk dry (104°C) weight of the corn plant consisted of grain dry matter.

CHAPTER V

GENERAL DISCUSSION

It was found in the experiment that the time to emergence varied between 6 and 8 days. Shorter times were associated with warmer soil temperatures obtained with delayed planting. This high soil temperature effect on time to emergence supports the findings by Iremiren and Milbourn (1979) that the initial effect of a polyvinyl chloride (PVC) mulch treatment was to shorten the interval between sowing and emergence. In their experiment, the PVC treatment led to increased soil temperature which was found to improve germination, compared with chalk mulch. The small difference in time to emergence was not considered to be an improtant factor in yield determination in this study.

Time from emergence to tassel initiation varied widely from 17 to 6 days from normal to delayed planting. The GDD computed for the period from emergence to tassel initiation was found to decline with delayed planting. The shortest time from emergence to tassel initiation was recorded with the lowest average soil temperature at the 5 cm depth but the temperature range was so small that I cannot say whether my result disagrees with the findings by Coligado and Brown (1975) in a growth chamber study that there was a consistent decrease in time to tassel initiation as temperature was increased from 15° to 25°C regardless of photoperiod. This result suggests, however, that growth chamber data cannot be systematically applied to field conditions. The reason for this shortening in time to tassel initiation remained undetermined.

Leaf area index was found to increase linearly with growing degree days over most of the leaf expansion period. There was no significant difference in the slopes (rate of leaf area accumulation) for the two hybrids (0.00451 LAI/GDD for C281 and 0.00433 LAI/GDD for P3780). These results show that the leaf development was closely related to temperature (GDD). Temperature influence on leaf development was reported in the literature by a certain number of workers such as Brouwer et al. (1973) and Cooper (1979). However, the importance of other environmental factors such as radiation for leaf development was also pointed out (Evans, 1963). As reviewd by Tollenaar (1977), leaf area index is one of the factors affecting total assimilate supply for crop growth. He reported that LAI attains its maximum value at or shortly after silking which was also true in this present study. Duncan (1972) in a study found that gross photosynthesis increased with LAI and tended to level off after LAI of 4.0. He pointed out the importance of having adequate crop canopies for the interception of light for photosynthate production. He reported a general relationship between planting rate and grain yield to be one in which there is an initial linear phase where yield rises in proportion to planting rate. He found that this is followed by a phase where yield per plant decreases and yield per ha climbs to a plateau. This occurs, as he pointed out, at whatever plant population is needed to give a leaf area index of approximately 4.0.

The number of leaves above the topmost ear was found to be slightly higher in P3780 than in C281. The difference, however, was not significant. The number of leaves above the topmost ear ranged from 5 to 7 leaves for all hybrids at all dates. Eastin (1969) reported that the leaves above the ear were the main source providing carbohydrate for kernel fill. The leaf area (green part) per plant (at midsilk) was 4751, 5232, 4478, and 4139 cm^2 for C281 and 5100, 5405, 5913, and 5059 cm^2 for P3780 for planting dates 1, 2, 3, and 4, respectively. Delayed planting did not affect leaf area per plant substantially. Therefore, a need for plant density adjustment with delayed planting within hybrids would not be necessary to obtain equivalent LAI.

Duncan (1972) pointed out that barrenness may occur in plants at a relatively low plant population, even below those needed for a LAI of 4.0. Sass and Loeffel (1959) reported an increase in barrenness with higher population. This is supported by my results showing a higher barrenness in C281 (86,500 plants/ha) than in P3780 (66,500 plants/ha). These authors found that barrenness was the result of failure of silk emergence during the pollen-shedding period, rather than the failure of formation of floral organs. The higher percentage barrenness in my study was also associated with higher LAI within hybrids. Apparently, factors contributing to barrenness in this study were strong enough to influence percentage barrenness with the differences in LAI observed among plots.

The analysis of dry matter accumulation in plant parts before silking showed a fairly constant percentage associated with leaf blades, leaf sheaths, and stalks over planting dates. There were small differences between the two hybrids (Table 11). Bryant and Blaser (1968) reported that the relative proportion of the different parts varied significantly between an early and a late hybrid. They observed only a slight influence of plant population on these proportions. Hanway and Russell (1969) observed similar patterns of dry matter accumulation in the total, above-ground plant parts in 11 hybrids studied and at different plant densities. The total plant dry weight at midsilk was found to increase with delayed planting up to the third date, then to decline for the fourth date. Final plant dry weight at physiological maturity, however, was found to decrease with each successive planting date (Table 12). Warmer temperatures and high irradiances in July could account for the difference in total plant dry weight obtained at midsilk while grain yield differences among planting dates explained the difference in results attained at maturity.

The time from emergence to silking was found to be relatively similar (61-67 days) for both hybrids at all dates. Up to silking, plant response was similar for both hybrids and all planting dates. However, significant differences were found in the final yields. I am ignoring the last two planting dates because of the insect damage discussed earlier. For the first method of measurement, the yield was the same for C281 while it decreased for P3780. The yield indeed decreased with delayed planting in the second method, averaging 8.16 and 7.13 tons/ha for C281, and 8.85 and 7.37 tons/ha for P3780 at dates 1 and 2, respectively. Duncan's multiple range test showed that there was significant difference in hybrid yields in the first method while the difference was non-significant in the second method. In addition, the second method overestimated the yield suggesting that the barrenness factor was underestimated. In conclusion the calculated yield values depend on the yield test used. A harvest over the row estimates better the barrenness percentage compared to a harvest of few ears from the row. Harvest index was found to be similar for both hybrids at planting dates 1 and 2, suggesting that at maturity the plants from the second planting were smaller compared to those from the first date.

Many parameters were investigated, in an attempt to try and explain why a decrease in yield was observed with late planting. It was found that number of double kernel rows per cob varied significantly at the 5% level with hybrid and planting date. The highest number of double kernel rows was not found to be associated with either air temperature or radiation recorded during the week prior to the beginning of kernel site accumulation (Figure 11). The cause of the observed response was not determined.

Spikelet accumulation rate per ear shoot was found to be a linear function of GDD. For C281, there was a significant difference between the kernel site accumulation rates of ears from the first, second, and fourth planting date. Kernel site accumulation rate was not calculated for the third planting date because of insufficient data points during the site accumulation period. Spikelet accumulation was highly correlated with temperature (GDD) in both hybrids. The differences in slope, however, suggest that either the temperature function used was not appropriate or some other factors interacted in the ear shoot development. Tollenaar (1977) reviewing sink-source relationships during reproductive development in maize, reported that development of upper ears, up until the cessation of spikelet initiation, is rather unaffected by environmental factors. However, Hunter _et al._ (1977) reported a slight influence of photoperiod on spikelet number per ear. Cooper and Law (1977) reported that soil temperatures early in the plant life had played an important role in determining the number of potential grain sites. I found that higher kernel site accumulation rates were associated with higher GDD per day (Figure 11). This result suggests that differences in temperatures led to differences in the plant response and subsequent kernel site accumulation rates. The maximum number of kernel sites was similar for both hybrids at all dates except for third planting of Cornell 281 which was significantly lower than the other sampling dates. The maximum number ranged from 92 to 109 sites/double row. There was no significant difference between the number of kernels harvested for C281 at dates 1 and 2 while the difference was significant at the 5% level for P3780 at the same dates. Only 50 to 67 percent of the spikelets present at midsilk produced grain, suggesting that at midsilk there were enough kernel sites such that spikelet development was not a limiting factor for grain yield in this experiment.

Both grain yield and number of kernels filled were related to the amount of radiation accumulated during the week prior to silking and the two following weeks. As the accumulated irradiance increased both the grain yield and the number of kernels filled increased. The accumulated irradiance during the three-week period was 9071 and 8649 ly for C281, and 8567 and 8360 ly for P3780 for planting dates 1 and 2, respectively. The amount of irradiance (ly) accumulated per ton of grain varied with planting dates, ranging from 968 to 1213 ly/ton of grain, suggesting that other factors besides radiation such as temperature, interacted for grain production. The increase in number of kernels filled and subsequent grain yield supports the suggestion that irradiance intercepted per plant during the flowering period is a dominant factor determining the continuation of ear growth (Tollenaar, 1977).

Ear length was found to be similar for all dates within hybrid and slightly different between C281 and P3780, 22.2 cm and 23.5 cm, respectively. Since the actual physical length of the ear shoot was similar for all treatments of both hybrids, ear length does not appear to be associated with observed grain yield differences.

Kernel dry matter accumulation was found to be a linear function of both calendar day and GDD. The slopes of the regression lines were not significantly different within and between hybrids on either a calendar day basis or a GDD basis. Johnson and Tanner (1972) reported that growth of a corn kernel starts immediately after fertilization as a non-linear function followed by a linear growth phase. They reported that up to 90% of the maximum kernel dry weight may accumulate during the linear phase. Duncan et al. (1965) found a significant correlation of temperature and kernel growth rate.

The equations derived from my data were:

$$\text{KDWt (gram)} = 0.00035729\ \text{GDD} - 0.0712 \qquad \text{for C281} \qquad [6]$$

$$\text{KDWt (gram)} = 0.0003732\ \text{GDD} - 0.0960 \qquad \text{for P3780} \qquad [7]$$

Where KDWt is the kernel dry weight (104°C) in grams.

My results suggest that the effective kernel filling period decreases with delayed planting. Daynard et al. (1971) found that corn grain yield was more closely related to the effective filling period duration than to the kernel growth rate. They reported the EFPD was not affected by plant density. Poneleit and Egli (1979) reported that EFPD, but not the rate of kernel growth, was influenced to a limited extent by plant density and both were under genetic control. The apparent kernel filling period from silking to blacklayer was found to increase with delayed planting but was prematurely halted by fall frost for later planting dates.

CHAPTER VI

CONCLUSIONS

1. Corn grain yield significantly declined with delayed planting.
2. When averaged over planting dates, the number of kernel rows per cob was significantly different between Cornell 281 and Pioneer 3780.
3. Kernel site accumulation was a linear function of temperature (growing degree days). Differences in the rates of site accumulation suggested that the temperature function used was not appropriate for ear shoot development, or that factors other than temperature significantly influenced the ear shoot development.
4. The large differences between maximum kernel sites and number of kernels filled suggest that at silking there were enough kernel sites such that the kernel site accumulation was not important in determining the final number of kernels.
5. Kernel dry matter accumulation was related to growing degree days (GDD) and calendar days. Kernel growth rate in both cases was not significantly different within and between Cornell 281 and Pioneer 3780.
6. Effective kernel filling period duration decreased with delayed planting.
7. The results of the present study do not agree with the second hypothesis stating that high air temperatures during ear shoot development and at silking combine to limit kernel number and subsequent grain yield of late planted corn. Ear shoot development and potential kernel sites were found not to be limiting. The differences in kernel number was mainly associated with insect damage, but not to temperatures at silking.

8. The results agree partially with the third hypothesis: Kernel filling rate was found not to be significantly different between planting dates as I stated; however, the duration of filling was halted prematurely due to cool fall temperatures and frost.

9. The final yield differences within hybrids at similar LAI were mainly due to:

   (a) The final kernel per ha, which was lower in late planted corn because of poor pollination.

   (b) The duration of the effective filling period, which was reduced by lower air temperatures.

   (c) The differences in barrenness, and also plant stand.

10. The results of this study reveal that future work should be done to determine why 30 to 50 percent of the potential kernel sites failed to produce grain. This future work should help determine how one can take advantage of the high potential kernel sites for maximum grain production.

APPENDIX A

Microclimate Data of 1979 Growing Season

Table 45. Microclimate data: maximum, minimum, and adjusted shelter air temperatures (°C); Radiation (Ly/day); and precipitation (mm/day) recorded during the growing season of 1979.

		Shelter				
Calendar day	Julian day	Adj. Average T* °C	min T °C	max T °C	Radiation Ly/day	Rain mm/day
May 1	121	10.9	1.4	13.8	562	0.0
	122	13.3	-3.1	19.6	590	0.0
	123	13.5	7.7	15.1	115	0.2
	124	10.4	7.4	14.1	144	0.0
	125	10.9	1.3	14.4	605	0.0
	126	13.7	2.7	20.0	461	0.0
	127	18.6	6.3	26.9	605	0.5
	128	23.9	18.2	29.9	590	0.0
	129	25.1	18.9	31.4	605	0.0
	130	21.1	16.0	30.9	274	0.2
	131	21.3	15.4	28.7	504	0.0
	132	20.1	17.6	23.7	274	0.0
	133	15.5	11.9	17.8	202	0.0
	134	15.4	8.2	21.8	518	0.2
	135	13.6	5.8	20.8	403	0.0
	136	12.6	4.1	18.0	590	0.0
	137	13.7	0.1	20.1	691	0.0
	138	15.0	1.2	22.6	590	0.0
	139	16.1	13.2	21.1	360	0.0
	140	17.3	13.9	21.3	418	0.0
	141	16.7	14.9	19.7	259	0.2
	142	14.3	2.8	20.6	648	0.2
	143	13.5	11.9	15.4	86	2.9
	144	14.4	12.4	17.5	230	0.2
	145	11.5	9.1	13.3	144	0.0
	146	10.0	7.3	10.3	216	0.0
	147	10.4	6.4	11.6	115	0.2
	148	11.5	4.6	14.6	274	0.5

Table 45 (Continued).

Calendar day	Julian day	Shelter Adj. Average T* °C	 min T °C	 max T °C	Radiation Ly/day	Rain mm/day
	149	12.6	10.1	15.8	144	0.0
	150	14.1	6.7	21.2	475	0.0
	151	16.2	11.5	22.7	389	0.0
June 1	152	18.2	15.7	20.3	115	0.0
	153	20.2	16.2	25.5	418	0.0
	154	16.2	14.2	18.1	216	0.0
	155	17.5	9.1	26.4	619	0.0
	156	18.2	12.0	27.9	562	1.0
	157	16.1	11.7	21.7	245	1.2
	158	21.2	14.2	27.4	504	0.0
	159	22.3	20.1	26.3	346	46.3
	160	23.2	19.3	27.8	475	0.0
	161	23.4	20.8	27.1	346	0.0
	162	14.4	7.1	22.0	346	2.4
	163	13.4	4.7	18.6	734	0.0
	164	14.6	3.3	21.5	749	0.0
	165	17.4	3.6	25.7	749	0.0
	166	21.3	10.3	30.0	662	0.0
	167	22.3	13.4	29.5	662	0.0
	168	21.2	15.3	27.6	590	0.0
	169	18.2	13.3	23.1	418	0.0
	170	17.0	7.5	24.2	763	0.0
	171	17.9	7.3	24.7	648	0.2
	172	15.5	14.0	17.0	144	1.2
	173	19.2	14.0	27.1	562	6.0
	174	16.2	10.5	21.3	547	0.0
	175	11.7	8.8	17.1	331	0.0
	176	14.3	3.0	21.3	778	0.2
	177	16.8	3.5	23.3	763	0.0
	178	18.2	13.0	24.1	634	0.0

Table 45 (Continued).

		Shelter				
Calendar day	Julian day	Adj. Average T* °C	min T °C	max T °C	Radiation Ly/day	Rain mm/day
	179	16.6	11.5	22.9	389	13.9
	180	15.7	10.7	23.3	346	37.2
July 1	181	18.5	14.4	23.3	389	17.8
	182	16.7	15.1	19.8	331	23.8
	183	16.1	15.3	18.1	115	0.0
	184	18.4	13.1	23.9	619	0.0
	185	12.3	8.6	17.7	187	15.4
	186	12.3	7.2	16.0	461	0.0
	187	15.0	4.5	21.6	691	0.2
	188	16.4	6.0	24.1	720	0.0
	189	18.0	8.9	25.1	662	0.0
	190	19.3	11.1	24.7	547	0.0
	191	18.5	16.7	20.8	230	7.2
	192	20.9	15.7	27.4	562	0.0
	193	21.9	17.1	28.3	518	0.0
	194	22.0	14.8	28.5	518	0.0
	195	22.4	18.8	28.2	432	1.0
	196	22.9	19.0	29.6	475	0.0
	197	21.8	18.4	28.4	389	4.6
	198	22.0	17.6	27.7	619	0.0
	199	20.9	15.4	26.7	533	0.0
	200	20.2	12.4	27.0	590	0.2
	201	19.7	14.5	24.1	230	0.0
	202	21.6	16.0	26.4	446	0.0
	203	21.7	18.0	27.1	346	0.0
	204	19.9	16.6	25.9	288	14.9
	205	21.9	16.8	28.1	504	0.0
	206	22.6	20.0	26.9	360	5.3
	207	22.9	17.2	27.0	360	0.0
	208	19.5	14.1	25.1	504	0.0

Table 45 (Continued).

Calendar day	Julian day	Shelter Adj. Average T* ^oC	Shelter min T ^oC	Shelter max T ^oC	Radiation Ly/day	Rain mm/day
	209	19.0	14.3	23.1	230	7.0
	210	18.3	15.8	20.2	115	33.8
	211	20.8	15.2	26.4	490	0.2
August 1	212	22.5	15.9	29.0	605	0.0
	213	24.4	20.1	30.6	418	0.7
	214	24.5	19.2	28.1	533	0.2
	215	21.9	15.7	28.1	576	0.0
	216	22.2	16.1	28.1	518	0.0
	217	22.9	16.7	29.2	590	0.0
	218	22.6	18.0	28.2	475	0.5
	219	20.5	12.7	26.9	590	0.0
	220	24.1	20.0	29.9	576	0.0
	221	22.2	17.8	26.8	504	0.0
	222	22.2	18.3	29.4	302	0.5
	223	18.0	15.7	20.4	72	2.2
	224	14.3	12.8	15.7	130	0.0
	225	15.7	7.5	22.9	619	0.5
	226	19.1	15.3	20.6	173	0.0
	227	13.4	12.0	15.3	187	0.0
	228	14.7	9.8	21.1	533	0.0
	229	15.0	7.3	21.2	572	0.0
	230	16.8	15.4	17.7	72	0.2
	231	21.1	16.7	26.6	374	0.0
	232	20.5	15.6	25.8	446	0.0
	233	19.4	15.6	25.6	389	0.0
	234	18.2	11.7	25.0	547	0.0
	235	20.4	15.3	25.0	115	0.0
	236	23.0	21.0	26.9	288	0.0
	237	21.7	16.7	25.0	374	0.0
	238	19.1	13.3	23.3	259	0.0

Table 45 (Continued).

Calendar day	Julian day	Shelter Adj. Average T* °C	 min T °C	 max T °C	Radiation Ly/day	Rain mm/day
	239	21.6	16.9	25.9	346	4.1
	240	21.0	14.9	27.3	475	0.2
	241	22.7	20.9	26.8	360	12.7
	242	22.1	16.8	28.2	504	0.0
Sept. 1	243	19.8	14.5	27.1	590	0.0
	244	19.4	11.5	25.8	504	0.0
	245	22.8	20.3	27.1	374	26.4
	246	22.0	17.2	27.1	403	1.0
	247	21.1	14.9	28.2	475	0.0
	248	20.9	17.6	23.9	216	17.8
	249	22.1	19.4	26.8	360	22.3
	250	19.1	12.9	24.6	446	0.5
	251	13.6	7.9	16.2	216	0.0
	252	12.7	3.6	20.2	262	0.0
	253	15.8	5.0	23.3	533	0.0
	254	16.5	10.7	22.1	360	0.0
	255	15.8	8.3	22.6	475	0.0
	256	18.9	15.3	22.5	288	1.0
	257	19.6	12.6	24.3	115	9.4
	258	12.8	6.9	18.6	389	0.0
	259	13.9	4.5	21.3	518	0.0
	260	15.1	5.7	22.0	504	0.2
	261	15.8	7.2	22.9	403	1.2
	262	13.9	3.5	17.3	440	0.0
	263	13.0	0.0	18.0	504	0.2
	264	14.6	13.8	15.8	58	30.7
	265	13.8	10.8	14.9	115	1.5
	266	11.9	4.3	16.9	518	0.0
	267	12.2	2.3	17.5	504	4.3
	268	13.2	2.9	19.7	418	0.0

Table 45 (Continued).

Calendar day	Julian day	Shelter Adj. Average T* °C	min T °C	max T °C	Radiation Ly/day	Rain mm/day
	269	14.6	8.5	23.7	389	0.0
	270	15.2	10.0	22.0	446	0.0
	271	14.8	13.7	15.7	180	30.2
	272	17.3	15.1	20.7	158	0.7
Oct. 1	273	18.1	15.3	21.6	173	0.0
	274	16.7	14.3	18.6	101	0.0
	275	17.0	14.0	23.5	187	10.6
	276	14.2	12.4	15.6	101	31.7
	277	15.6	11.5	19.4	374	0.0
	278	11.5	7.2	16.8	29	43.0
	279	10.9	4.7	13.3	274	0.5
	280	10.0	5.6	9.4	101	2.6
	281	10.4	5.2	13.4	245	1.2
	282	10.9	2.9	13.4	72	3.1
	283	10.0	1.9	6.8	173	0.7
	284	10.1	0.0	11.1	374	4.8
	285	10.2	5.1	11.2	173	5.0
	286	10.0	1.5	8.8	230	2.6
Oct. 15	287	10.0	0.0	7.7	144	0.0

*Adj. Average T is the adjusted average temperature (base 10°, 30°C) calculated with the adjusted average heat system.

Table 46. Soil temperature at 5 cm depth recorded at 8 locations in the experiment field at the nearby weather station from 6 June to 6 July 1979.

Calendar day	Locations									
	1	2	3	4	5	6	7	8	Average	Weather Station
06 June	16.0	17.0	19.0	20.0	17.0	17.0	17.0	17.0	17.5	17.7
08	30.0	23.0	31.0	31.0	31.0	31.0	26.0	31.0	25.5	22.9
13	18.0	18.0	17.0	19.0	21.0	20.0	19.0	19.0	18.9	19.5
18	22.0	22.0	22.0	23.0	24.0	23.0	22.0	22.0	22.5	23.3
20	23.0	24.0	25.0	22.0	27.0	26.0	23.0	23.0	24.0	18.3
22	24.0	22.5	27.0	29.0	29.0	28.0	24.0	22.0	25.7	23.4
25	23.5	22.0	20.5	24.0	27.8	24.5	22.5	22.5	23.4	24.1
27	19.2	25.5	22.4	26.5	28.5	25.2	23.5	23.5	24.3	23.9
29	21.5	21.0	20.0	23.0	24.0	22.0	20.0	20.5	21.5	21.6
05 July	21.0	20.0	19.0	19.0	21.0	20.0	19.0	19.0	19.8	17.9
06	22.0	21.5	20.5	22.5	25.0	23.5	20.0	20.0	21.9	23.0

APPENDIX B

Leaf Area and Leaf Area Index Data

Table 47. Leaf area (cm^2) per plant measured at various dates for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Harvest date	LA/Plant/Planting date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	cm^2							
169		98 (10.5)				88 (9.7)		
184	1638 (19.2)	535 (18.1)			1455 (15.0)	511 (14.8)		
186	2106 (8.6)	650 (13.6)			1670 (7.6)	554 (17.4)		
190			341 (9.6)				222 (8.4)	
191	2630 (15.0)	1068 (18.4)			2390 (14.4)	1000 (19.1)		
194	3107 (13.8)	1290 (25.8)			2844 (13.7)	1274 (12.9)		
200	4295 (14.0)	2629 (19.6)	1177 (12.5)	160 (12.6)	4183 (9.5)	2356 (14.8)	1127 (9.3)	256 (10.7)
206			2569 (13.1)					
207	4944 (10.4)	3620 (19.7)			5189 (8.7)	3765 (18.9)		
214	4655 (13.9)	4319 (19.4)	4245 (10.4)	1887 (10.5)	5107 (11.2)	4625 (14.7)	4156 (7.8)	1628 (12.4)
222	4544 (9.2)	4178 (1.3)	5316 (9.9)	3721 (14.2)	4886 (7.2)	5412 (9.2)	5570 (5.9)	3121 (9.6)
227				3879 (11.3)				4123 (17.1)
228	4533 (10.4)	4452 (10.9)	4467 (11.5)		5297 (8.6)	5472 (9.5)	5994 (8.1)	
234			4349 (9.5)	4182 (16.4)			5880 (9.7)	4780 (11.0)
235		4220 (7.2)				5681 (7.6)		
241				4108 (15.0)				5109 (10.4)
243			4185 (10.1)				5297 (11.7)	
249				4046 (9.2)				4755 (14.3)

The coefficient of variation (c.v.) of the leaf area is in parentheses.
There were 16 plants in each mean.

Table 48. Leaf Area Index calculated for various periods of growth for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Harvest date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
169		0.1				0.1		
184	1.4	0.4			0.9	0.3		
186	1.8	0.5			1.1	0.4		
190			0.3				0.1	
191	2.3	0.4			1.6	0.6		
194	2.7	1.1			1.8	0.8		
200	3.7	2.2	0.9	0.1	2.7	1.5	0.7	0.2
206			1.9				1.2	
207	4.3 }	3.0			3.4	2.4		
214	4.0	3.6 }	3.1	1.6	3.3	2.9 }		1.0
222	3.9	3.5	3.9	2.9	3.2	3.4	3.2	1.9
227				3.0				2.5
228	3.9	3.7	3.3 }		3.4	3.4	3.5 }	
234			3.2	3.2			3.4	2.8
235		3.5				3.6		
241				3.2				3.0
243			3.1				3.0	
249				3.1				2.8

The underlined LAI values indicate the leaf area index at midsilk.
The single bracket indicates that the actual LAI at midsilk falls between the two values shown in the table.

APPENDIX C

Plant Part Dry Weight Data and Correction Factor from 69°C to 104°C Dry Weight

Table 49. Stalk dry (69°C or 157°F) weight per 4 plants sampled at various periods of growth for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Harvest date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	grams							
173	0.1				0.1			
187	3.3	0.2			2.5	0.1		
190	9.2	0.4			6.4	0.4		
194	21.0	2.4			15.7	2.1		
197	45.6	6.1	0.4		29.6	4.4	0.2	
200	69.9	17.0	1.9		50.3	11.9	1.0	
204	107.4	28.1	6.2		93.8	18.6	3.2	
207		48.8	12.4	0.5	113.1	32.5	5.7	0.4
212	133.2	84.3	24.7	2.1	124.6	57.4	22.1	1.5
217	142.1	106.4	37.1	5.4	136.8	76.7	37.6	3.7
219	183.7		97.8	13.4	193.1		71.8	9.2
225	184.7	158.9	160.4	36.3	184.4	165.7	137.4	28.1
228		169.1		52.1		178.2		42.3
232		176.4	167.8	74.2		179.6	164.1	47.3
235				87.7				71.9
239			191.5	125.6			182.4	122.5
242			196.1	137.9			197.2	155.3
249				147.8				156.0

Table 50. Leaf sheath dry (69°C or 157°F) weight for 4 plants sampled at various periods of growth for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Harvest date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	grams							
173	2.0	0.4			2.0	0.4	0.2	
187	9.2	2.6	0.4		8.5	2.0	0.6	
190	14.4	4.0	0.9		13.0	3.6	2.5	
194	24.1	11.1	3.5	0.3	19.5	11.0	4.0	0.2
197	30.6	13.7	5.0	0.8	30.0	13.4	7.8	0.6
200	36.2	21.7	8.4	1.8	35.1	20.9	10.2	1.4
204	43.9	24.2	12.2	2.9	43.9	24.8	11.0	2.2
207		29.7	13.7	4.7		30.4	20.6	4.3
212	51.0	40.1	18.6	6.6	48.9	34.5	25.5	5.5
217	52.7	42.5	36.9	10.8	52.7	37.1	34.6	9.6
219			39.6	13.4				12.4
225	55.1	50.2	48.0	22.1	61.8	54.1	45.0	22.7
228				26.8				28.7
232		52.5	53.2			60.9	55.3	
235			53.9	36.2			62.8	32.5
239			58.3	44.2			62.5	42.4
242			53.5	41.4			63.0	45.8
249				45.5				48.4

Table 51. Leaf blade dry (69°C or 157°F) weight per 4 plants sampled at various periods of growth for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

	Planting Date							
	C281				P3780			
Julian Harvest date	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	grams							
173	7.8	2.5			7.8	2.0		
187	30.5	10.6	2.4		28.0	8.2	1.4	
190	44.8	13.7	4.5		41.2	12.9	3.1	
194	54.3	20.1	6.2	0.9	50.5	20.3	4.7	0.6
197	73.4	28.1	8.9	1.6	68.2	27.7	7.6	1.1
200	79.7	43.7	13.8	2.8	81.6	42.1	12.5	2.4
204	82.9	52.7	25.5	5.4	92.5	50.6	20.6	4.9
207	93.6	61.4	34.2	8.6	97.2	65.2	80.7	8.3
212		74.7	44.2	15.8		74.8	48.0	13.4
217	87.9	75.4	55.2	21.4	103.6	85.5	61.2	19.5
219	95.0		75.1	34.0	113.6		83.2	32.2
225	89.1	76.9	81.4	53.8	113.1	101.2	98.0	57.2
228		80.6	88.9	59.1		107.2	102.2	70.6
232		87.3		67.9		108.3		69.6
235				66.9				81.1
239			89.8	73.5			111.1	91.9
242			88.8	70.7			112.7	90.6
249				76.2				96.1

Table 52. Determination of the coefficient of dry weight correction for vegetative plant parts from 69°C to 104°C.

	Temperature			
Sample #	104°C	69°C	Excess H_2O	% H_2O
	----grams----			
1	94.44	96.50	2.06	2.14
2	115.66	118.51	2.85	2.41
3	90.35	92.48	2.13	2.30
4	107.00	110.16	3.16	2.87
Average	101.86	104.41	2.55	2.43

Dry Wt (104°C) = 0.9757 (DWt 69°C)

Table 53. Total dry (104°C) weight per plant sampled at various periods of growth for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Harvest date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	grams							
173	2.4	0.7			2.4	0.6		
187	10.5	3.3	0.7		9.5	2.5	0.4	
190	16.7	4.4	1.3		14.8	4.1	0.9	
194	24.2	8.2	2.3	0.3	20.9	8.1	1.7	0.2
197	36.5	11.7	3.5	0.6	31.2	11.1	2.9	0.4
200	45.3	20.1	5.8	1.1	40.7	18.2	5.2	0.9
204	57.1	25.6	10.7	2.0	56.1	22.9	8.3	1.7
207		34.1	14.7	3.4		31.2	11.5	3.2
212		48.6	21.3	6.0		40.5	22.1	4.9
217	75.2	54.7		9.1	76.1	48.6		8.0
219			51.8	14.8			46.3	13.1
225	124.0	82.6	70.7	27.4	132.7	87.0	68.4	26.3
228				33.6				34.5
232		106.1				103.7		
235				46.6				45.2
239			111.2	59.3			102.0	62.6
242			128.6	61.0			131.7	71.1
249				80.8				86.6

APPENDIX D

Plant Height Data

Table 54. Plant height (cm) measured at various periods of growth for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Sampling Date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	cm							
171	23.4				21.5			
176	29.1				26.9			
184	38.8	21.7			37.9	20.7		
186	45.2	24.3			38.5	21.2		
191	57.0	32.2			50.2	31.1		
194	67.8	36.5			58.0	36.9		
200	116.4	63.3			87.5	54.1		
206								
207	204.6	102.6	67.7		153.0	83.7	52.1	
214	244.1	172.3	91.5	62.2	213.9	130.5	70.3	48.2
222	260.0	241.0	207.5	103.7	240.2	223.2	166.7	89.0
227				112.8				93.3
228	270.1	253.7	223.6		241.7	235.9	204.3	
234			250.0	165.7			236.1	139.9
235		241.0				237.0		
241				230.7				209.3
243			257.0				241.6	
249				253.9				230.9

APPENDIX E

Ear Shoot Development: Kernel site, Row Number, Kernel Filled and Ear Length Data

Table 55. Number of double rows on the topmost ear sampled at various dates for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Sampling Date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	# double rows/ear							
197	7.8*				7.9			
201	7.4	8.5			7.5	8.0		
204	7.3				7.8			
205		7.3				8.4		
208	7.5	7.6			7.4	7.5		
212	7.3				7.5			
213		7.5				7.6		
215		7.6				8.1		
218			7.6				7.0	
219	7.5	7.9			7.2	8.0		
222		7.3	7.5			8.0	7.5	
225	7.3				7.8			
226		7.9	7.1	7.1		7.8	7.4	7.3
229	7.3	7.6	7.4		7.4	8.0	7.4	
230				7.0				7.8
232		7.6				7.8		
233			7.0	7.1			7.5	7.6
235	7.2		7.2	7.5	7.4		7.5	7.5
239		7.3	7.6	7.0		7.9	7.4	7.1
242	7.4		7.4		7.4		7.5	
243				6.9				7.4
248		7.8	7.2			7.8	7.3	
249	7.6			7.3	7.5			7.2
253		7.5	7.3			7.7	7.4	
255	7.2			7.1	7.2			7.5

Table 55 (Continued).

Julian Sampling Date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	#double rows/ear							
260		7.5	7.8			7.8	7.6	
263	7.3			7.3	7.6			7.3
267		7.6	7.6			8.1	7.3	
270				7.1				7.5
277		7.2	7.3	7.3	7.1	7.4	7.3	7.3
283			7.4	7.0		7.4	7.3	7.3

* range 6-10 double rows/ear

Table 56. Kernel sites per double row on the topmost ear sampled at various dates for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Sampling Date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	# kernel sites/double row							
197	73.4				53.8			
201	84.9	39.0			76.5	28.0		
204	94.0				95.5			
205		72.6				49.4		
208	95.3	91.8			100.1	64.4		
212	99.8				104.5			
213		104.4				93.3		
215		104.0				97.8		
218			97.4				89.0	
219	92.2	97.6			100.9	105.3		
222		95.0	90.0			108.8	101.0	
225	91.5				100.8			
226		92.8	85.6	85.1		101.6	103.7	71.6
229	88.6	94.8	90.9		103.5	99.3	103.8	
230				95.4				80.6
232		92.4				98.6		
233			89.3	98.4			104.6	90.1
235			92.1	95.9			98.8	97.1
239			87.4	93.5			103.4	101.8
242			91.0				101.7	
243				92.1				100.5
249				90.8				95.5
255				87.1				98.4

Table 57. Number of kernels filled/double row on the topmost ear sampled at various dates for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Sampling Date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	# kernel sites/double row							
235	80.0				86.9			
239		82.8				66.8		
242	73.3		61.5				22.6	
248		70.3	61.5			69.9	19.0	
249	68.8				77.1			
253		61.4	60.5			59.9		
255	67.1			32.3	78.4			13.8
260		66.5	57.1			69.5	28.0	
263	63.1			39.4	76.6			19.6
267		61.5				56.5	26.2	
270				43.6				16.0
277		57.3	46.0	44.3	70.0	57.8	23.9	28.0
283			47.8	43.0		54.3	24.7	22.6

Table 58. Ear length (cm) measured at various periods of growth for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Harvest Date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	ear length (cm)							
197	1.3				0.6			
201	2.2	0.3			1.3	0.2		
204	4.5				2.8			
205		1.0				0.5		
208	7.6	2.2			4.1	0.8		
212	11.9				7.1			
213		4.7				2.8		
215		7.4				3.7		
218			4.9				2.8	
219	20.2	12.3			15.5	8.4		
222		13.1	9.2			11.2	5.4	
225	22.0				21.7			
226		17.3	10.8	2.1		12.2	6.6	1.1
229	22.0	20.5	12.9		21.9	17.3	8.6	
230				3.3				1.5
232		21.0				17.3		
233			14.2	4.6			10.4	2.3
235	22.4		17.3	6.5	22.0		13.6	3.9
239		22.4	20.7	10.1		22.8	17.8	7.3
242	22.4		21.7		22.3		21.1	
243				11.6				9.7
248		22.9	22.2			23.5	23.6	
249	22.6			20.0	22.4			16.6

Table 58 (Continued).

Julian Harvest Date	C281 12 May	C281 30 May	C281 08 June	C281 22 June	P3780 12 May	P3780 30 May	P3780 08 June	P3780 22 June
	ear length (cm)							
253		21.9	22.6			23.4	24.1	
255	22.4			21.1	22.8			21.3
260		22.1	22.3			24.0	24.0	
263				21.3				22.7
267					22.7		24.0	
270				20.8				22.2
277				22.0			24.2	22.8
283					22.8			

APPENDIX F

Kernel and Ear Dry Weight Data

Table 59. Dry (104°C) weight per kernel sampled at various periods during grain filling for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

	Planting Date							
	C281				P3780			
Julian Sampling Date	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	grams							
239		0.037						
242	0.155		0.026		0.105			
248		0.126	0.062			0.082	0.032	
249	0.206				0.165			
253		0.157	0.101			0.112	0.063	
255	0.240				0.215			
260		0.198	0.152			0.171	0.121	
263	0.279			0.052	0.240			0.029
267	0.274	0.228	0.187			0.201	0.152	
270				0.084				0.053
277		0.266	0.239	0.130	0.287	0.259	0.207	0.110
281					0.290			
283		0.268	0.251	0.151		0.278	0.223	0.145
288						0.261		
291			0.254	0.154			0.240	0.150

Table 60. Grain dry (104°C) weight per ear sampled at various dates during kernel filling for 2 corn hybrids (C281 and P3780) planted in the spring of 1979 at 4 dates.

Julian Sampling Date	Planting Date							
	C281				P3780			
	12 May	30 May	08 June	22 June	12 May	30 May	08 June	22 June
	grams							
235	23.8				14.1			
239		12.4						
242	59.9		7.0		44.4			
248		50.4	19.4			30.9	3.1	
249	83.5				75.5			
253		55.6	32.0			39.1	4.8	
255	92.5				93.3			
260		79.5	52.0			72.1	19.6	
263	100.7			7.9	113.4			2.4
267	105.0	86.4	53.3			74.4	21.7	
270				18.2				4.4
277		92.3	65.2	30.4	129.3	96.5	26.3	14.8
281					124.1			
283			68.6	33.3			32.4	17.0
288						107.1		
291			67.8	31.7			35.3	23.3

Table 61. Final grain dry (104°C) weight (g/6 foot row) of two corn hybrids (Cornell 281 and Pioneer 3780) planted in spring of 1979 at successive dates.

1979 Planting Date	Hybrid C281 Set I	Hybrid C281 Set II	Hybrid P3780 Set I	Hybrid P3780 Set II
	g/6 ft. of row			
12 May	940	835	1157	1226
30 May	957	848	995	900
08 June	670	597	244	110
22 June	272	307	155	177

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