# Impact of Delayed Planting on Heat Unit Requirements for Seed Maturation in Maize

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## Abstract

Delayed planting shortens the effective growing season for corn (*Zea mays* L.), increasing the risk of exposure to late season lethal cold temperatures prior to grain maturation. Consequently, growers often must decide whether to switch to early maturity hybrids to minimize this risk. Heat unit or growing degree day (GDD) ratings of hybrids are potentially more accurate descriptors of hybrid maturity than the traditional 'days to maturity' system. The objective of this study was to determine whether delayed planting influenced the GDD ratings of silking and kernel black layer development of corn. The effects of delayed planting on the phenological responses of three corn hybrid maturities common to the eastern USA Corn Belt were investigated at four locations in Indiana and Ohio over four years. Delayed planting decreased the number of calendar days after planting to grain maturation by 9 d for early June versus early May plantings. Thermal time from planting to silk emergence decreased an average of 34 GDDs for June versus early May plantings, while the grain fill period decreased an additional 110 GDDs with late plantings. The total decrease in GDDs from planting to kernel black layer was 144 GDDs for corn planted in early June compared to early May, equal to a linear response to delayed planting of 3.8 fewer GDDs per day of delayed planting. The three hybrids responded differently to delayed planting, with greater GDD decreases occurring with late maturity hybrid. Linear rates of GDD decrease with delayed planting ranged from 4.5 to 3.2 GDDs per day of delayed planting for late and early maturity hybrids, respectively. Delayed planting decreases the GDD requirements of corn hybrids, resulting in less risk to grain maturation for adapted hybrid maturities from late season killing freezes than previously thought.

**Abbreviations:** AP, after planting; GDD, growing degree day (Celsius); BL, kernel black layer; VE, emergence; R1, silking; R6, physiological maturity; DAP, days after planting; DAE, days after emergence; DAS, days after silking; DOY, day of year; GDDAP, Growing degree days (Celsius) after planting;

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GDDAE, Growing degree days (Celsius) after emergence; GDDAS, Growing degree days (Celsius) after silking.

## Introduction

Planting field corn in the eastern U.S. Corn Belt can be delayed beyond the optimum late April to early May time frame when excessive rainfall occurs prior to or during the planting season. Occasionally, fields planted during the optimum time frame require replanting at later dates after weather stresses or pests cause excessive plant mortality. Because delayed planting and replanting shorten the effective growing season, producers often must decide whether to switch to earlier maturity hybrids to ensure that physiological grain maturity occurs before a killing fall frost.

Making such a decision about appropriate hybrid maturity requires accurate characterization of the growing season requirements of corn hybrids. However, the 'days to maturity' hybrid maturity system most commonly used by the seed industry, also called 'relative maturity', does not refer to finite calendar time (Nielsen *et al.*, 1994). Consequently, a relative hybrid maturity rating is not suitable for predicting whether a given hybrid maturity can be safely grown in a late planting situation.

A second hybrid maturity system often used by the seed industry involves heat units or Growing Degree Day (GDD) units and is based on the close relationship between corn phenology and thermal time (Nielsen *et al.*, 1994). Hybrid maturities vary for cumulative GDDs from planting to silking and/or kernel black layer (BL) formation. Early relative maturity hybrids typically require fewer GDDs to reach silking and BL than do late relative maturity hybrids.

Growing degree day hybrid maturity ratings are potentially more useful when making late planting decisions than the relative maturity method. In late planting situations, the goal is to allow the corn crop to utilize as much of the remaining growing season as possible, yet still reach BL prior to the first occurrence of a killing frost. Deciding when to switch to earlier maturing hybrids can theoretically be based on (1) hybrid GDD ratings, and (2) the estimated GDDs remaining until the average date of a killing fall freeze.

Unfortunately, the use of hybrid GDD ratings for selecting hybrid maturities in late planting situations is not without problems. First of all, there is no standardized system within the seed industry for assigning hybrid GDD maturity ratings (Nielsen *et al.*, 1994). Discrepancies result when companies use different GDD calculation methods, initiate GDD accumulation from the date of seedling emergence rather than from the planting date, or differ in defining the date of actual BL. Secondly, the relationship between GDD accumulation and corn phenology may itself be influenced by planting date. Gilmore and Rogers (1958) included delayed plantings in their evaluation of GDD calculation methods but observed no effects in Texas on the thermal interval between planting and mid-silk. Daynard (1972) observed that delayed planting in Ontario increased the thermal interval from planting to mid-silk but decreased the thermal interval between mid-silk and BL formation. Sutton and Stucker (1974) reported that thermal intervals between planting and BL decreased as planting was delayed from early to late May in Minnesota. Roth and Yocum (1997) reported that delayed planting increased GDDs to BL for three hybrids in a drought year, but decreased GDDs to BL for the same three hybrids the following year under less stressful conditions.

A better understanding of the phenological response of corn to thermal time as planting is delayed is necessary to improve the accuracy of hybrid maturity selection for late planting situations. Since most production agronomists, consultants, and farmers are familiar with the GDD system (Barger, 1969), some general guidelines for using the system when confronted with late planting decisions are required in order to better determine whether to switch to earlier maturing hybrids. The specific objective of this study was to determine whether delayed planting influenced the GDD ratings of silking and kernel black layer development of corn across a range of environmental conditions.

## Materials and Methods

Field studies were conducted from 1991 to 1994 at the Purdue University Agronomy Research Center, near West Lafayette, Indiana (~ $40^0$ 29' N, ~$87^0$ 02' W) on a Drummer silty clay loam (fine-silty, mixed, mesic Typic Haplaquoll), and at the Ohio State University (OSU) - Ohio Agricultural Research and Development Center (OARDC) Western Branch Research Farm near South Charleston, Ohio (~ $39^0$ 51' N, ~$83^0$ 40' W) on a Kokomo silty clay loam (fine, mixed, mesic, Typic Argiaquoll). In 1993 and 1994, additional locations were established at the Southeast Purdue Ag. Center, near Butlerville, Indiana (~ $39^0$ 3' N, ~$85^0$ 29' W) on a Clermont silt loam (Typic Ochraqualf) and at the OSU-OARDC Northwest Branch Research Farm near Hoytville, Ohio (~ $41^0$ 12' N, ~$83^0$ 45' W) on a Hoytville silty clay loam (fine, illitic, mesic Mollic Ochraqualf). The four locations represent a north-south range of approximately 241 km and an east-west extent of approximately 282 km. For the purpose of data analyses, locations and years were combined and defined as 'environments'.

Official National Weather Service temperature recording stations were located within two km from the field study at each location. Maximum and minimum air temperatures were reported daily at 8 a.m. for the preceding 24 h. The number of GDDs for each day was calculated using the Modified 30/10 Cutoff Method (Barger, 1969).

The treatment design at each location was a 3 × 3 treatment factorial replicated three times in a randomized complete block experimental design arranged in a split plot layout. The first factor (whole plot) was planting date, targeted once every three weeks from late April through early June, for a total of three plantings. Actual planting dates for each environment (location-year combination) are listed in Table 1. The second factor (subplot) in the study was corn hybrid, represented by three hybrids that varied for GDD requirements to reach silking and BL (Table 2). These hybrids represented the range of hybrid maturities commonly grown throughout Indiana and Ohio.

The previous crop at each location was soybean (*Glycine max* (L.) Merr.). Plots at each location were established using commercial planting equipment. Seeding rates were 67 000 and 74 000 seeds ha$^{-1}$ at the Indiana and Ohio locations, respectively. Subplot size at each location for an individual planting date and hybrid combination was 9.1 m wide (twelve 76 cm rows) by about 21 m long. Whole plots (planting date) were bordered by four additional rows as a buffer between planting dates. Nutrient, insect and weed management strategies appropriate for minimizing crop stress were implemented at each location.

Prior to anthesis, ten consecutive plants were selected and marked in each of the four center rows per plot. At the first indication of silk emergence, the number of marked plants with visible silks was recorded daily until silking was complete. The date of silk emergence (developmental stage R1) was defined as that date by which 50 % or more of the marked plants exhibited silks (Ritchie *et al.*, 1986).

For any particular subplot, semi-weekly sampling for kernel BL determination began when the subplot's ear development had reached developmental stage R5 (Ritchie *et al.*, 1986). Five ears per subplot were selected, avoiding obviously stunted or damaged plants. Each ear was broken in half and 20 kernels were removed from the center of each ear. With a razor blade or sharp utility knife, each kernel was cut in half from tip to dent and scored for kernel BL development following the method described by Hunter *et al.* (1991). The date of physiological maturity for a subplot (developmental stage R6) was defined as that date by which kernel BL development had occurred in at least 50 % of the kernels from ears within the sample area (Ritchie *et al.*, 1986). The calendar and thermal timings of the VE, R1, and R6 developmental stages were measured beginning from planting (to VE, R1, and R6), emergence (to R1 and R6), or silking (to R6). The acronyms and definitions for the calculated variables are listed in Table 3.

Planting date and hybrid were considered fixed effect variables for the statistical analyses. Environments were also considered fixed effect variables: north to south and east to west in the eastern Corn Belt. The three targeted planting date periods at each environment were labeled as Early, Mid and Late. Analyses of variance (ANOVA) were performed for each of the variables listed in Table 3 according to the model for such split plot experiments described by McIntosh (1983). Mean separations were performed on the main treatment effects (planting date and hybrid) using the least significant difference test ($\alpha = 0.05$) if the F test for treatment effects was significant ($P \leq 0.05$) (Steel and Torrie, 1980). Upon visual inspection of the data, simple linear or quadratic regressions were performed for the effects of delayed planting on thermal times to R1 and R6.

## Results and Discussion

Flowering and grain maturation timing of three dent corn hybrids were altered when planted at increasingly later dates. Calendar time from planting to R1 decreased about 14 d when corn was planted in early June compared to early May (Table 4). Calendar time from R1 to kernel black layer development increased, however, by about 5 d for June planting versus early May plantings. The net effect of delayed planting on the calendar timing of grain maturation was a reduction of about 9 DAP for late versus early plantings or about 0.25 d per day of delayed planting.

Thermal time from planting to R1 decreased an average of 34 GDDs for June versus early May plantings, while the grain fill period (R1 to R6) decreased an additional 110 GDDs with late plantings (Table 4). Total accumulated GDDs from planting to R6 decreased 10 % or about 144 GDDs for corn planted in early June compared to early May. When considering early May versus early June plantings, the average linear response to delayed planting was 3.8 fewer GDDs per day of delayed planting.

The three hybrids responded differently to delayed planting, with greater decreases in GDDs occurring with later relative hybrid maturity (Figures 1 and 2). Linear rates of GDD decrease with delayed planting varied among the three hybrids from 4.5 (hybrid 3245) to 3.2 (hybrid 3527) GDDs per day of delayed planting.

This study demonstrated that reductions in GDDs to R6 are consistent and predictable. Coupled with the fact that the measured GDDs from planting to R6 for the three hybrids used in this study were five percent less than company GDD ratings, these results can help growers and their consultants determine the suitability of a given hybrid maturity when faced with delayed planting situations in the eastern U.S. Corn Belt. For example, a hybrid whose listed maturity rating is 1500 GDDs may only require about 1382 GDDs from planting to R6 if planted on June 2 (31 d of delay multiplied by 3.8 fewer GDDs per day equals about 112 total fewer GDDs). Historical GDD accumulation normals for west central Indiana suggest that 1417 GDDs would be expected from June 2 to October 13 (the historical average first date of 0° C for west central Indiana). Therefore, one could predict that a hybrid whose listed maturity rating is 1500 GDDs would safely mature prior to a normally occurring killing fall frost. For a more detailed discussion of the results of this study, consult Nielsen *et al.* (2002).

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## References

Barger, G. L. 1969. Weekly Weather and Crop Bulletin. 56:10 (May 5). National Oceanic and Atmospheric Administration.

Daynard, T.B. 1972. Relationships among black layer formation, grain moisture percentage, and heat unit accumulation in corn. Agron. J. 64:716-719.

Gilmore, E.C., Jr., and J.S. Rogers. 1958. Heat units as a method of measuring maturity in corn. Agron. J. 50:611-615.

Hunter, J.L., D.M. TeKrony, D.F. Miles, and D.B. Egli. 1991. Corn seed maturity indicators and their relationship to uptake of Carbon-14 assimilate. Crop Sci. 31:1309-1313.

McIntosh, M.S. 1983. Analysis of combined experiments. Agron. J. 75:153-155.Nielsen, R.L., Peter R. Thomison, Greg A. Brown, and Anthony L. Halter. 1994. Hybrid Maturity Selection for Delayed Planting: Do GDD Maturity Ratings Help? Report of the 49th Ann. Corn and Sorghum Industry Res. Conf. 49:191-205. American Seed Trade Association, Washington, D.C.

Nielsen,R.L., and P.R.Thomison, G.A. Brown, A.L. Halter, J. Wells, and K. L. Wuethrich. 2002. Delayed planting effects on flowering and grain maturation of dent corn. Agron. J. 94:549-558.

Ritchie, S.W., J.J. Hanway, and G.O. Benson. 1986. How a corn plant develops. Iowa St. Univ. Sci. Technol., CES, Spec. Rpt. 48 (revised).

Roth, G.W. and J.O. Yocum. 1997. Use of hybrid growing degree days ratings for corn in the northeastern USA. J. Prod. Agric. 10:283-288.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and Procedures of Statistics, 2nd ed. McGraw-Hill Book Co.

Sutton, L.M. and R.E. Stucker. 1974. Growing degree days to black layer compared to Minnesota relative maturity rating of corn hybrids. Crop Sci.14: 408-412.

Table 1. Calendar dates for the Early, Mid and Late plantings at each environment.

| Environment | | Planting dates | | |
|---|---|---|---|---|
| Location[1] | Year | Early | Mid | Late |
| W. Lafayette | 1991 | May 8 | May 22 | June 10 |
| | 1992 | May 2 | May 22 | June 12 |
| | 1993 | May 12 | May 28 | June 16 |
| | 1994 | April 22 | May 13 | June 4 |
| S. Charleston | 1991 | May 3 | May 21 | June 13 |
| | 1992 | April 29 | May 21 | June 10 |
| | 1993 | May 3 | May 21 | June 11 |
| | 1994 | April 22 | May 19 | June 8 |
| Butlerville | 1993 | May 8 | May 25 | June 8 |
| | 1994 | May 23 | June 2 | June 13 |
| Hoytville | 1993 | May 10 | May 26 | June 17 |
| | 1994 | April 25 | May 20 | June 14 |

[1] W. Lafayette, IN (Purdue University Agron. Res. Center); Hoytville, OH (NW Branch Res. Farm); Butlerville, IN (SE Purdue Ag. Center); S. Charleston, OH (Ohio State University Western Branch Res. Farm)

Table 2. Corn hybrids (Pioneer® brand) and their maturity classifications.

| Hybrid | CRM[1] | Silk GDDs[2] | Black layer GDDs[3] |
|---|---|---|---|
| 3527 | 106 | 803 | 1497 |
| 3394 | 111 | 801 | 1533 |
| 3245 | 115 | 839 | 1576 |

[1] Comparative relative maturity ratings: Pioneer Hi-Bred Int'l, 1991

[2] Growing degree days from planting to mid-silk: Pioneer Hi-Bred Int'l, 1991
GDDs calculated using the Modified 30/10 Cutoff Method (Barger, 1969)

[3] Growing degree days from planting to black layer: Pioneer Hi-Bred Int'l, 1991

Table 3. Acronyms used for growth stage intervals[1].

| Acronym | Definition |
|---|---|
| DAP-VE | Days after planting to emergence |
| DAP-R1 | Days after planting to silking |
| DAE-R1 | Days after emergence to silking |
| DAP-R6 | Days after planting to physiological maturity |
| DAE-R6 | Days after emergence to physiological maturity |
| DAS-R6 | Days after silking to physiological maturity |
| GDDAP-VE | Growing degree days (Celsius) after planting to emergence |
| GDDAP-R1 | Growing degree days (Celsius) after planting to silking |
| GDDAE-R1 | Growing degree days (Celsius) after emergence to silking |
| GDDAP-R6 | Growing degree days (Celsius) after planting to physiological maturity |
| GDDAE-R6 | Growing degree days (Celsius) after emergence to physiological maturity |
| GDDAS-R6 | Growing degree days (Celsius) after silking to physiological maturity |

[1] Growth stages VE, R1, and R6 according to Ritchie *et al.* (1986).

Table 4. Planting date treatment effects for calendar and thermal time phenological events. Values represent means across 12 environments and three hybrids.

| Planting date | | Calendar time events | | | | | |
|---|---|---|---|---|---|---|---|
| | | DAP-VE | DAP-R1 | DAE-R1 | DAP-R6 | DAE-R6 | DAS-R6 |
| | | Cumulative days | | | | | |
| Early | 3-May[1] | 10.5 | 75.2 | 64.7 | 138.4 | 127.9 | 63.2 |
| Mid | 22-May | 8.4 | 65.9 | 57.5 | 131.5 | 123.9 | 65.6 |
| Late | 11-Jun | 5.2 | 61.0 | 55.8 | 129.1 | 123.2 | 68.1 |
| | lsd (.05) | 0.2 | 0.4 | 0.3 | 0.6 | 0.7 | 0.7 |
| | F-test‡ | *** | *** | *** | *** | *** | *** |

| Planting date | | Thermal time events | | | | | |
|---|---|---|---|---|---|---|---|
| | | GDDAP-VE | GDDAP-R1 | GDDAE-R1 | GDDAP-R6 | GDDAE-R6 | GDDAS-R6 |
| | | Cumulative GDDs | | | | | |
| Early | 3-May | 68.1 | 786.6 | 718.6 | 1452.8 | 1384.7 | 666.2 |
| Mid | 22-May | 63.4 | 771.0 | 707.6 | 1401.9 | 1338.6 | 630.9 |
| Late | 11-Jun | 68.3 | 752.8 | 684.6 | 1309.1 | 1240.9 | 556.3 |
| | lsd (.05) | 1.9 | 4.3 | 4.0 | 3.5 | 4.2 | 5.0 |
| | F-test[2] | *** | *** | *** | *** | *** | *** |

[1] Calendar dates represent means for Early, Mid and Late planting date treatments among the 12 environments of the study.

[2] F-test significance levels *, **, *** refer to P ≤ 0.05, 0.01 and 0.001, respectively.

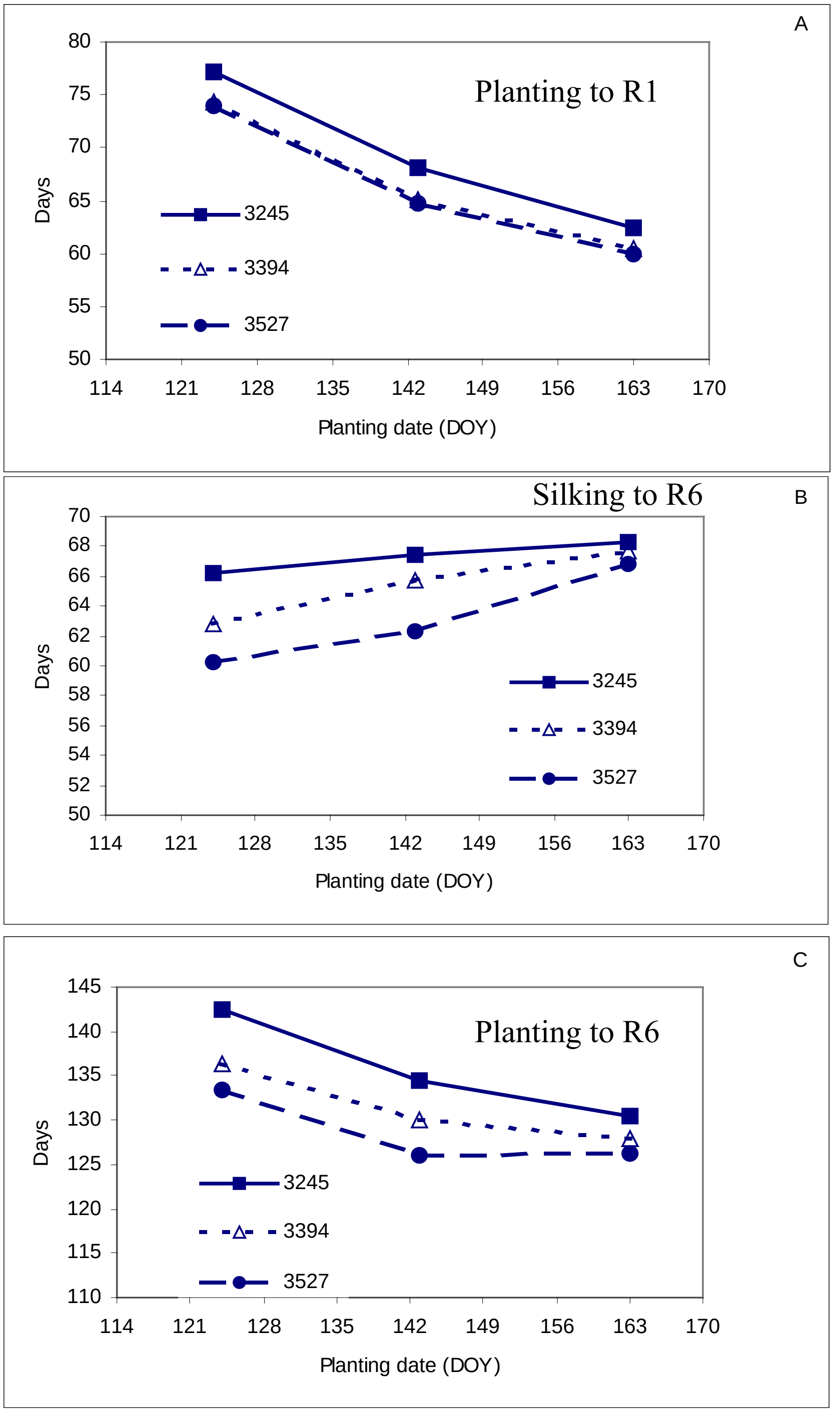

Fig. 1. Effects of delayed planting on calendar time to (A) silking from planting (DAP-R1), (B) kernel black layer formation from silking (DAS-R6) or (C) planting (DAP-R6) for three corn hybrids, 12 environments. The interaction Hybrid × Planting date was significant ($P \leq 0.05$) for each variable.

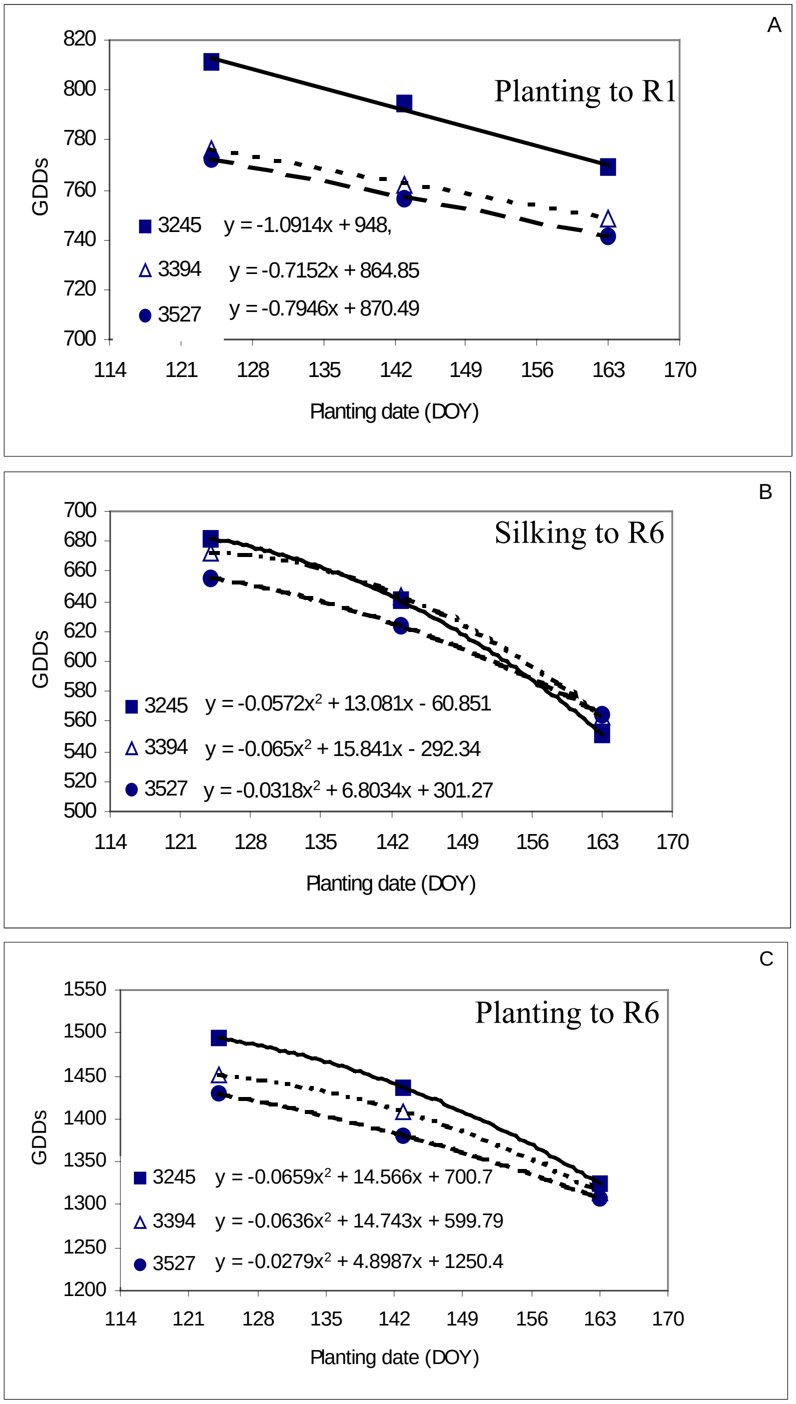

Fig. 2. Effects of delayed planting on thermal time from (A) planting to silking (GDDAP-R1), (B) silking to kernel black layer formation (GDDAS-R6) or (C) planting to kernel black layer formation (GDDAP-R6) for three corn hybrids, 12 environments. The interaction Hybrid × Planting date was significant ($P \leq 0.05$) for each variable. GDDs = Accumulated growing degree days during specified calendar period, DOY = Day of year.