# CORN

## Delayed Planting Effects on Flowering and Grain Maturation of Dent Corn

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### ABSTRACT

**Delayed planting shortens the effective growing season for corn (*Zea mays* L.), increasing the risk of exposure to lethal cold temperatures late in the season before grain maturation. Consequently, growers often must decide whether to switch to early maturity hybrids to minimize this risk. The objective of this study was to determine whether delayed planting influenced the growing degree day (GDD) ratings of silking and kernel black-layer (BL) development of corn. The effects of delayed planting on the phenological responses of three corn hybrid maturities common to the eastern U.S. Corn Belt were investigated at four locations in Indiana and Ohio over 4 yr. Thermal time from planting to silk emergence decreased an average of 34 GDDs for June vs. early May plantings while the grain-fill period decreased an additional 110 GDDs with late plantings. The total decrease in GDDs from planting to BL was 144 GDDs for corn planted in early June compared with 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.**

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 before 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. Unfortunately, the *days-to-maturity* hybrid maturity descriptor 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 descriptor often used by the seed industry involves 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.

Hybrid maturity ratings based on GDDs 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 before the first occurrence of a killing frost. Deciding when to switch to earlier maturing hybrids can theoretically be based on (i) hybrid GDD ratings and (ii) 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 on the thermal interval between planting and midsilk in Texas. Daynard (1972) observed that delayed planting in Ontario increased the thermal interval from planting to midsilk but decreased the thermal interval between midsilk and BL formation. Sutton and Stucker (1974) reported that thermal intervals between planting and BL decreased as planting was de-

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Published in Agron. J. 94:549–558 (2002).

**Abbreviations:** BL, black layer; DAP, days after planting; GDD, growing degree day (°C); GDDAP, growing degree days (°C) after planting.

layed 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 in the following year under less stressful conditions.

Finally, genotype × planting date interactions may exist for the relationship between GDD accumulation and corn phenology. In a study conducted in Nebraska (Stevens et al., 1986), the thermal interval between planting and BL of one popcorn hybrid decreased as planting was delayed while that of a second hybrid remained the same and that of a third increased. The thermal interval between planting and BL for a dent corn hybrid (B73 × Mo17) decreased with initial planting delays and then increased as planting was further delayed.

According to recent Canadian studies (Stewart et al., 1998; Dwyer et al., 1999a, 1999b), the GDD system provides a reliable estimate of thermal time required for vegetative (the interval between planting and silking) development. Estimates of thermal time required for grain filling (the period between silking and maturity) vary considerably, however, with the GDD system frequently overestimating thermal time required for grain filling. Dwyer et al. (1999a) developed the general thermal index, based on a combination of two temperature response curves for the vegetative and grain-filling periods of corn, which may predict and describe development rate more accurately than the GDD method. While the general thermal index may offer a more accurate estimate of crop development, it requires a priori knowledge of the silking date, which becomes the transition date from the vegetative function to the grain-filling function (Dwyer et al., 1999a, 1999b). This complication, plus the need to understand separate thermal response functions for vegetative and grain fill, may limit practical use of the general thermal index by crop production agronomists and consultants.

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 in the eastern U.S. Corn Belt. Because most production agronomists, consultants, and farmers in the U.S. Corn Belt are familiar with the GDD system (Barger, 1969), some general guidelines for using the system when confronted with late-planting decisions are required 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 BL 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, IN (≈40° 29′ N, 87° 02′ W), on a Drummer silty clay loam (fine-silty, mixed, mesic Typic Haplaquoll) and at the Western Branch Research Farm of the Ohio State University Ohio Agricultural Research and Development Center, near South Charleston, OH (≈39° 51′ N, 83° 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 Agricultural Center, near Butlerville, IN (≈39° 3′ N, 85° 29′ W), on a Clermont silt loam (Typic Ochraqualf) and at the Northwest Branch Research Farm of the Ohio State University Ohio Agricultural Research and Development Center, near Hoytville, OH (≈41° 12′ N, 83° 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 2 km from the field study at each location. Maximum and minimum air temperatures were reported daily at 0800 h 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 3 wk 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.

At the first indication of seedling emergence, the number of visible coleoptile tips in a 7.6-m length of each of four rows per subplot was recorded daily until emergence was complete. The date of emergence for a subplot (developmental stage VE) was defined as that date by which 50% or more of the seedlings had emerged (Ritchie et al., 1986).

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

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

† West Lafayette, IN (Purdue Univ. Agron. Res. Cent.); Hoytville, OH (Ohio State Univ. Northwest Branch Res. Farm); Butlerville, IN (Southeast Purdue Agric. Cent); South Charleston, OH (Ohio State Univ. Western Branch Res. Farm).

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

| Hybrid | CRM† | Silk GDDs‡ | Black layer GDDs§ |
|---|---|---|---|
| 3527 | 106 | 803 | 1497 |
| 3394 | 111 | 801 | 1533 |
| 3245 | 115 | 839 | 1576 |

† Comparative relative maturity ratings (Pioneer Hi-Bred Int., 1991).
‡ Growing degree days from planting to midsilk (Pioneer Hi-Bred Int., 1991). GDDs calculated using the Modified 30/10 Cutoff Method (Barger, 1969).
§ GDDs from planting to black layer (Pioneer Hi-Bred Int., 1991).

Before anthesis, 10 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, semiweekly 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.

A major consequence of delayed planting relative to crop development is the decrease in the length of available growing season. Several climatic factors in late summer and early fall contribute to the end of the defined growing season, including shorter daylengths, increasingly cooler temperatures, and ultimately the occurrence of lethal cold temperatures. Given that substantial damage to leaf, stalk, and husk tissue can occur when temperatures decline to −2.2°C or lower (Carter and Hesterman, 1990), we defined the end of the growing season to be the first date on which the recorded daily minimum temperature was −2.2°C or lower.

**Table 3. Acronyms used for growth stage intervals.†**

| 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 (°C) after planting to emergence |
| GDDAP-R1 | Growing degree days (°C) after planting to silking |
| GDDAE-R1 | Growing degree days (°C) after emergence to silking |
| GDDAP-R6 | Growing degree days (°C) after planting to physiological maturity |
| GDDAE-R6 | Growing degree days (°C) after emergence to physiological maturity |
| GDDAS-R6 | Growing degree days (°C) after silking to physiological maturity |

† Growth stages VE, R1, and R6 according to Ritchie et al. (1986).

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

## Climatic Data

Among the environments of the study, the May-through-September periods of 1991 at West Lafayette and South Charleston were the warmest (data not shown). The coolest environments occurred in 1992 at West Lafayette and South Charleston. Total rainfall among the 12 environments during this same time period ranged from 277.6 to 667.3 mm (Table 4).

Average growing season lengths for the Early, Mid, and Late planting dates were 166, 148, and 128 d, respectively (Table 5). The maximum growing season length was 188 d (South Charleston in 1994, Early planting date), and the minimum was 113 d (Butlerville in 1993, Late planting date).

**Table 4. Monthly rainfall totals from May to September at each of the 12 environments.**

| Environment | | | | | | | |
|---|---|---|---|---|---|---|---|
| Location | Year | May | June | July | Aug. | Sept. | Total |
| | | mm | | | | | |
| W. Lafayette | 1991 | 111.0 | 14.0 | 21.6 | 99.3 | 49.5 | 295.4 |
| | 1992 | 26.2 | 29.5 | 282.2 | 30.7 | 191.5 | 560.1 |
| | 1993 | 92.2 | 160.5 | 124.7 | 123.4 | 166.4 | 667.3 |
| | 1994 | 42.9 | 143.0 | 187.2 | 123.2 | 52.6 | 548.9 |
| S. Charleston | 1991 | 85.1 | 36.6 | 34.8 | 64.8 | 73.7 | 295.0 |
| | 1992 | 55.9 | 55.4 | 180.8 | 45.5 | 44.2 | 381.8 |
| | 1993 | 20.1 | 89.9 | 196.6 | 22.1 | 84.3 | 413.0 |
| | 1994 | 42.2 | 60.5 | 96.5 | 158.0 | 33.5 | 390.7 |
| Butlerville | 1993 | 89.2 | 100.1 | 41.4 | 153.2 | 92.7 | 476.6 |
| | 1994 | 79.5 | 78.7 | 47.5 | 126.0 | 47.0 | 378.7 |
| Hoytville | 1993 | 39.9 | 112.5 | 45.7 | 26.4 | 64.8 | 289.3 |
| | 1994 | 24.6 | 91.2 | 37.6 | 100.3 | 23.9 | 277.6 |

**Table 5. Number of days, mean daily air temperatures, mean daily growing degree day (GDD) accumulations, and total GDD accumulations for the interval from planting date (PD) to the first fall date of −2.2°C or less for each environment × planting date combination.**

| Environment | | Interval | | | Mean daily temperatures | | | Daily GDDs | Total GDDs† |
|---|---|---|---|---|---|---|---|---|---|
| Location | Year | PD | ≤−2.2°C | Days | Max. | Min. | Mean | | |
| | | | | | | °C | | | |
| W. Lafayette | 1991 | 8 May | 15 Oct. | 160 | 27.4 | 14.9 | 21.1 | 11.2 | 1801 |
| | | 22 May | 15 Oct. | 146 | 27.4 | 14.8 | 21.1 | 11.2 | 1647 |
| | | 10 June | 15 Oct. | 127 | 27.1 | 14.4 | 20.7 | 10.9 | 1394 |
| | 1992 | 2 May | 18 Oct. | 169 | 23.9 | 11.6 | 17.7 | 8.5 | 1451 |
| | | 22 May | 18 Oct. | 149 | 23.9 | 11.9 | 17.9 | 8.6 | 1297 |
| | | 12 June | 18 Oct. | 128 | 24.1 | 12.2 | 18.2 | 8.8 | 1140 |
| | 1993 | 12 May | 12 Oct. | 153 | 24.9 | 13.5 | 19.2 | 9.7 | 1491 |
| | | 28 May | 12 Oct. | 137 | 25.3 | 14.1 | 19.7 | 10.1 | 1388 |
| | | 16 June | 12 Oct. | 118 | 25.6 | 14.3 | 19.9 | 10.3 | 1227 |
| | 1994 | 22 Apr. | 26 Oct. | 187 | 24.4 | 11.5 | 18.0 | 8.7 | 1634 |
| | | 13 May | 26 Oct. | 166 | 25.1 | 12.2 | 18.7 | 9.2 | 1534 |
| | | 4 June | 26 Oct. | 144 | 25.2 | 12.7 | 18.9 | 9.4 | 1363 |
| S. Charleston | 1991 | 3 May | 15 Oct. | 165 | 27.8 | 14.3 | 21.1 | 11.1 | 1835 |
| | | 21 May | 15 Oct. | 147 | 28.1 | 14.4 | 21.3 | 11.3 | 1666 |
| | | 13 June | 15 Oct. | 124 | 27.8 | 13.9 | 20.9 | 11.0 | 1370 |
| | 1992 | 29 Apr. | 18 Oct. | 172 | 24.3 | 11.6 | 18.0 | 8.7 | 1505 |
| | | 21 May | 18 Oct. | 150 | 24.6 | 12.0 | 18.3 | 8.9 | 1351 |
| | | 10 June | 18 Oct. | 130 | 25.2 | 12.2 | 18.6 | 9.3 | 1212 |
| | 1993 | 3 May | 22 Oct. | 172 | 26.2 | 13.2 | 19.7 | 9.9 | 1717 |
| | | 21 May | 22 Oct. | 154 | 26.5 | 13.5 | 20.0 | 10.2 | 1582 |
| | | 11 June | 22 Oct. | 133 | 27.0 | 14.0 | 20.5 | 10.6 | 1424 |
| | 1994 | 22 Apr. | 27 Oct. | 188 | 25.8 | 12.0 | 18.9 | 9.4 | 1771 |
| | | 19 May | 27 Oct. | 161 | 26.8 | 12.9 | 19.9 | 10.1 | 1635 |
| | | 8 June | 27 Oct. | 141 | 26.8 | 13.1 | 19.9 | 10.1 | 1440 |
| Butlerville | 1993 | 8 May | 29 Sept. | 144 | 26.7 | 14.3 | 20.5 | 10.6 | 1538 |
| | | 25 May | 29 Sept. | 127 | 27.3 | 14.9 | 21.1 | 11.1 | 1419 |
| | | 8 June | 29 Sept. | 113 | 27.9 | 15.6 | 21.8 | 11.6 | 1328 |
| | 1994 | 23 May | 26 Oct. | 156 | 26.5 | 12.8 | 19.6 | 10.0 | 1575 |
| | | 2 June | 26 Oct. | 146 | 26.5 | 12.8 | 19.7 | 10.1 | 1480 |
| | | 13 June | 26 Oct. | 135 | 26.4 | 12.7 | 19.6 | 10.0 | 1361 |
| Hoytville | 1993 | 10 May | 23 Oct. | 166 | 25.4 | 12.2 | 18.8 | 9.3 | 1561 |
| | | 26 May | 23 Oct. | 150 | 25.8 | 12.7 | 19.2 | 9.7 | 1459 |
| | | 17 June | 23 Oct. | 128 | 26.1 | 12.9 | 19.5 | 9.9 | 1281 |
| | 1994 | 25 Apr. | 11 Oct. | 169 | 25.9 | 12.0 | 18.9 | 9.4 | 1605 |
| | | 20 May | 11 Oct. | 144 | 27.1 | 13.1 | 20.1 | 10.2 | 1485 |
| | | 14 June | 11 Oct. | 119 | 27.2 | 13.6 | 20.4 | 10.4 | 1246 |

† Total GDDs equal cumulative GDDs from planting to the first date of −2.2°C or lower temperature in the fall; GDDs calculated using the Modified 30/10 Cutoff Method (Barger, 1969).

Mean daily average temperatures during the growing season intervals for the Early, Mid, and Late planting date treatments were 19.3, 19.8, and 19.9°C, respectively (Table 5). Mean GDD accumulations for these same intervals were 1623, 1494, and 1315, respectively. The greatest GDD accumulation occurred with the Early

**Table 6. Measured hybrid growing degree day (GDD) values for the intervals planting to R1 and planting to R6 (Early planting date treatments only).**

| Environment | | GDDs from planting to R1† | | | GDDs from planting to R6† | | |
|---|---|---|---|---|---|---|---|
| Location | Year | 3527 | 3394 | 3245 | 3527 | 3394 | 3245 |
| W. Lafayette | 1991 | 792 | 801 | 828 | 1478 | 1495 | 1591 |
| | 1992 | 703 | 703 | 739 | 1298 | 1319 | 1362 |
| | 1993 | 748 | 757 | 796 | 1412 | 1426 | 1425 |
| | 1994 | 723 | 728 | 755 | 1405 | 1406 | 1499 |
| S. Charleston | 1991 | 763 | 778 | 806 | 1449 | 1517 | 1511 |
| | 1992 | 762 | 758 | 801 | 1378 | 1393 | 1419 |
| | 1993 | 764 | 764 | 801 | 1434 | 1441 | 1463 |
| | 1994 | 794 | 785 | 824 | 1466 | 1499 | 1494 |
| Butlerville | 1993 | 786 | 786 | 841 | 1483 | 1389 | 1542 |
| | 1994 | 763 | 788 | 807 | 1402 | 1409 | 1448 |
| Hoytville | 1993 | 828 | 833 | 863 | 1417 | 1446 | 1454 |
| | 1994 | 840 | 835 | 877 | 1476 | 1513 | 1556 |
| Max. | | 840 | 835 | 877 | 1483 | 1517 | 1591 |
| Min. | | 703 | 703 | 739 | 1298 | 1319 | 1362 |
| SD | | 39 | 38 | 40 | 53 | 59 | 71 |
| Mean | | 772 | 776 | 811 | 1425 | 1446 | 1488 |
| Company‡ | | 803 | 801 | 839 | 1497 | 1533 | 1576 |
| M/C§ | | 96.2% | 96.9% | 96.7% | 95.2% | 94.3% | 94.4% |

† GDDs for the Early planting date treatments of each hybrid at each environment (*n* = 3).

‡ Company values are the hybrid GDD ratings provided by Pioneer Hi-Bred Int. in 1991.

§ Mean GDD values divided by company values equal M/C, expressed in terms of percent.

**Table 7. Effects of planting date treatment 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‡ | 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 June | 5.2 | 61.0 | 55.8 | 129.1 | 123.2 | 68.1 |
| | LSD(0.05) | 0.2 | 0.4 | 0.3 | 0.6 | 0.7 | 0.7 |
| | *F*-test | *** | *** | *** | *** | *** | *** |
| | | 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 June | 68.3 | 752.8 | 684.6 | 1309.1 | 1240.9 | 556.3 |
| | LSD(0.05) | 1.9 | 4.3 | 4.0 | 3.5 | 4.2 | 5.0 |
| | *F*-test | *** | *** | *** | *** | *** | *** |

*** Significant at $P \leq 0.001$.

† See Table 3 for acronym definitions.

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

planting date at South Charleston in 1991 (1835 GDD) and the least with the Late planting date at West Lafayette in 1992 (1140 GDD).

## Hybrid Growing Degree Day Means for Optimum Planting Dates

Most of the Early plantings in this study were within the planting time period generally considered *optimum* for the eastern U.S. Corn Belt. Consequently, most producers would expect that hybrid GDD values to R1 and R6 for such plantings would be similar to those assigned by the seed industry.

The average hybrid GDD values to R1 and R6 during the Early planting periods of this study were less than those provided by the seed company (Table 6). On average, the measured values for the GDD after planting (GDDAP)-R1 and GDDAP-R6 intervals were 3.4 and 5.4% less than the respective company values. Roth and Yocum (1997) also reported discrepancies between company and measured values for nine hybrids, including the three evaluated in our study.

Furthermore, the measured hybrid values for the GDDAP-R1 and GDDAP-R6 intervals fluctuated among the 12 environments of the study (Table 6). Averaged across hybrids, the ranges between minimum and maximum values for thermal times to R1 and R6 were 135 and 203 GDDs, respectively.

The relationship between corn phenology and GDD accumulation appears to be partly dependent on seasonal mean temperatures. Growing degree day accumulations for various developmental intervals for any given hybrid in our study were significantly correlated with seasonal mean air temperatures (data not shown). For example, the correlation coefficient between mean daily maximum temperatures (May through September) and the GDDAP-R6 intervals for the hybrid 3394 was equal to 0.82 (12 environments). Several previous researchers (Aspiazu and Shaw, 1972; Major et al., 1983; Sutton and Stucker, 1974) have reported similar relationships. Thus,

**Table 8. Analysis of variance (ANOVA) summary of *F*-test significance levels for calendar and thermal time phenological events.†**

| | Calendar time events | | | | | |
|---|---|---|---|---|---|---|
| | DAP-VE | DAP-R1 | DAE-R1 | DAP-R6 | DAE-R6 | DAS-R6 |
| Environment (Env) | *** | *** | *** | *** | *** | *** |
| Planting date (PD) | *** | *** | *** | *** | *** | *** |
| Env × PD | *** | *** | *** | *** | *** | *** |
| Hybrid (H) | *** | *** | *** | *** | *** | *** |
| H × Env | ns | *** | *** | *** | *** | *** |
| H × PD | ns | * | * | *** | *** | *** |
| H × PD × Env | ns | ns | ns | *** | *** | *** |
| | Thermal time events | | | | | |
| | GDDAP-VE | GDDAP-R1 | GDDAE-R1 | GDDAP-R6 | GDDAE-R6 | GDDAS-R6 |
| Env | *** | *** | *** | *** | *** | *** |
| PD | *** | *** | *** | *** | *** | *** |
| Env × PD | *** | *** | *** | *** | *** | *** |
| H | ** | *** | *** | *** | *** | *** |
| H × Env | ns | *** | *** | *** | *** | *** |
| H × PD | ns | ** | *** | *** | *** | *** |
| H × PD × Env | ns | ns | ns | *** | *** | *** |

* Significant at $P \leq 0.05$.

** Significant at $P \leq 0.01$.

*** Significant at $P \leq 0.001$.

† See Table 3 for acronym definitions.

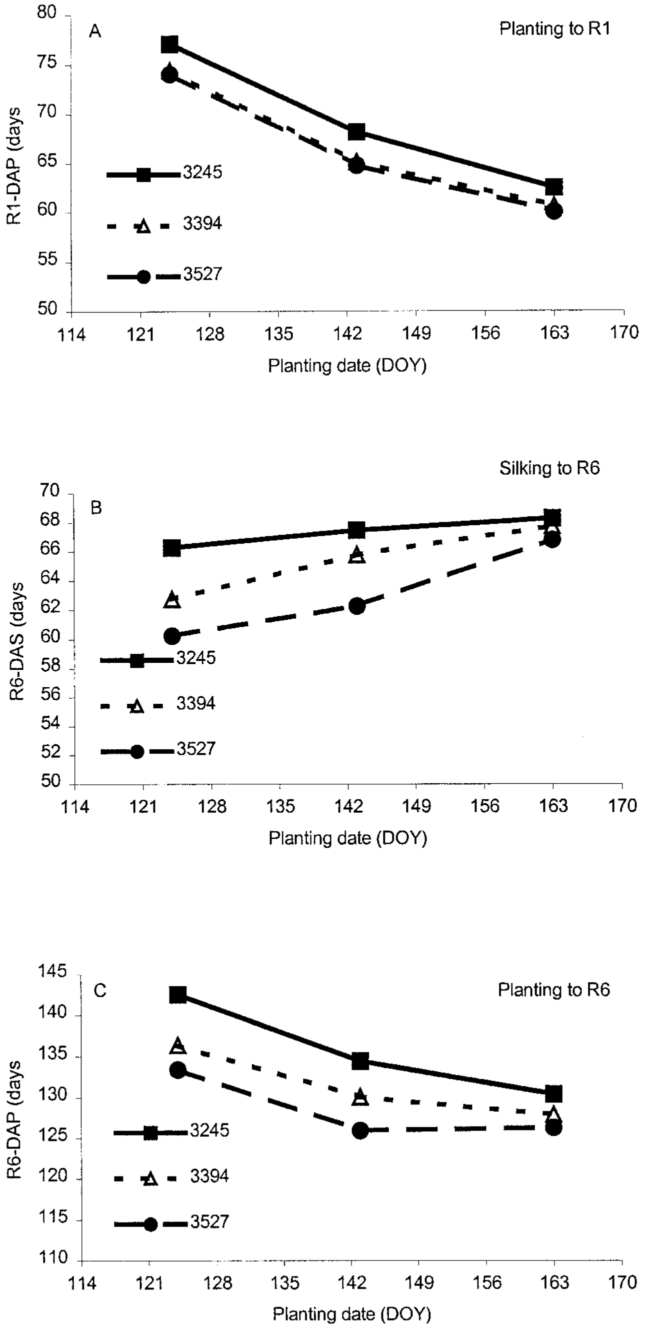

**Fig. 1. Effects of delayed planting on calendar time to (A) silking from planting (R1-DAP), (B) kernel black layer (BL) formation from silking (R1-DAS), or kernel black layer from (C) planting (R6-DAP) for three corn hybrids and 12 environments. The hybrid × planting date interaction was significant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

the hybrids appear to have the capacity to *adapt* to shorter-season environments.

## Effects on Phenology: Calendar Time

Seedling emergence (VE) occurred on average about 10.5 d after planting (DAP) for the Early plantings of the three hybrids (Table 7). Emergence occurred in fewer DAP as planting was delayed (Table 7). Quicker emergence times with delayed planting were not unexpected because soil temperatures at planting were greater with the Mid and Late plantings than with the Early plantings (data not shown).

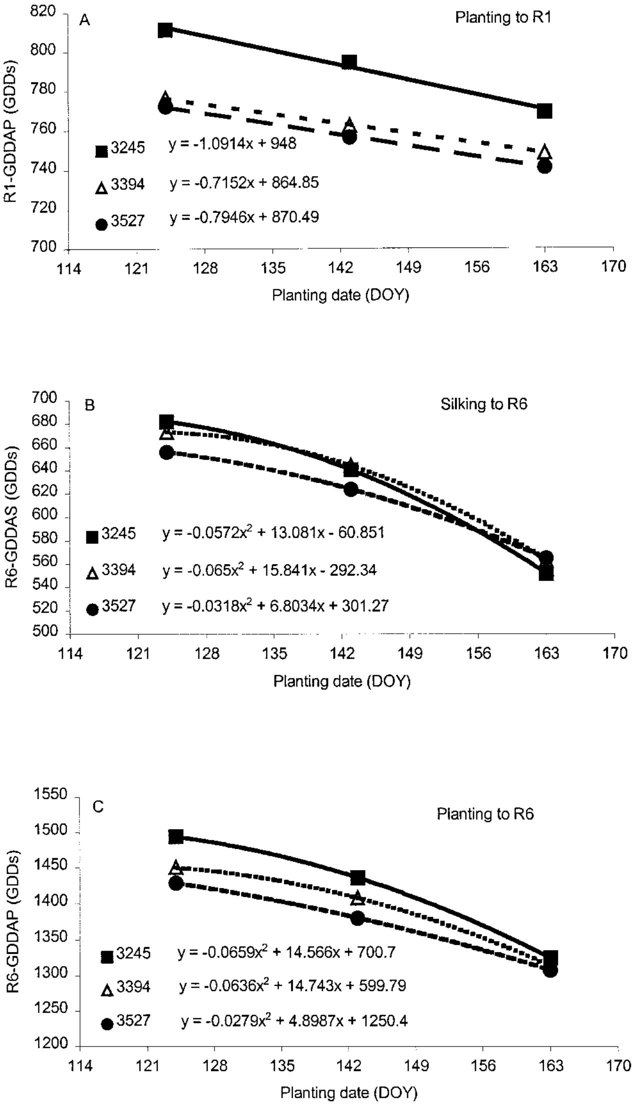

**Fig. 2. Effects of delayed planting on thermal time from (A) planting to silking (R1-GDDAP), (B) silking to kernel black layer (BL) formation (R6-GDDAS), or (C) planting to kernel BL formation (R6-GDDAP) for three corn hybrids and 12 environments. The hybrid × planting date interaction was significant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

Silk emergence (R1) and kernel BL formation (R6) also occurred in fewer DAP as planting was delayed (Table 7). Late plantings, on average, reached the R1 stage about 14 DAP sooner than Early plantings while the R6 stage occurred about 9 DAP sooner. Not all of this reduction in calendar timing to R1 and R6 was due to the faster emergence timing. Silking occurred about 10 d after emergence sooner with Late plantings than with Early plantings while R6 occurred 5 d after emergence sooner as planting was delayed to early June (Table 7).

The season-long reduction in days to R6 development occurred exclusively preanthesis. Growth stage R6 actu-

**Table 9. Linear effects of delayed planting on thermal intervals [growing degree days (GDDs)] from planting to kernel black layer (BL), averaged across three corn hybrids, for 12 environments in Indiana and Ohio. (Environment × Planting Date = ***)**

| Environment | | | | |
|---|---|---|---|---|
| Location | Year | Linear regression† | $r^2$ | Model significance‡ |
| W. Lafayette | 1991 | GDD = 2162.09 − 5.02(DOY) | 0.97 | *** |
| | 1992 | GDD = 1827.09 − 4.00(DOY) | 0.96 | *** |
| | 1993 | GDD = 2123.82 − 5.28(DOY) | 0.98 | *** |
| | 1994 | GDD = 1740.21 − 2.65(DOY) | 0.94 | *** |
| S. Charleston | 1991 | GDD = 1948.04 − 3.71(DOY) | 0.99 | *** |
| | 1992 | GDD = 1857.18 − 3.79(DOY) | 0.98 | *** |
| | 1993 | GDD = 1681.02 − 1.84(DOY) | 0.80 | *** |
| | 1994 | GDD = 1800.89 − 2.45(DOY) | 0.85 | *** |
| Butlerville | 1993 | GDD = 2003.86 − 3.87(DOY) | 0.96 | *** |
| | 1994 | GDD = 1899.14 − 3.38(DOY) | 0.94 | *** |
| Hoytville | 1993 | GDD = 2102.13 − 5.04(DOY) | 0.97 | *** |
| | 1994 | GDD = 2028.34 − 4.31(DOY) | 0.91 | *** |

*** Significant at $P \leq 0.001$.
† GDD = GDD from planting to R6; DOY = day of year.
‡ Significance of the linear regression models.

ally took 5 d after silking longer to occur as planting was delayed from early May to early June (Table 7).

The effect of delayed planting on calendar timing of R1 and R6 occurrence was not similar among the three hybrids (i.e., significant hybrid × planting date interactions; Table 8). In particular, the increase in days after silking to R6 with delayed planting was greater for the hybrids 3394 and 3527 than for the later-maturity 3245 (Fig. 1B) and contributed to the season-long hybrid × planting date interaction for DAP-R6 (Fig. 1C).

## Effects on Phenology: Thermal Time

Even though days to VE were fewer with Late plantings, thermal time to VE was generally similar for all plantings (Table 7). Silking and kernel BL formation occurred in significantly (Table 7) fewer GDDs as planting was delayed from early May to early June. Silking occurred about 34 GDDs sooner in the Late plantings than in the Early plantings while growth stage R6 occurred about 144 GDDs sooner (Table 7). About 76% of the reduction in season-long GDDs to BL occurred postanthesis (Table 7).

The three hybrids did not respond similarly to delayed planting in terms of thermal timing of silk emergence and kernel BL formation (i.e., significant hybrid × planting date interactions; Table 8). Linear regression curves best described the change in GDDAP-R1 with delayed planting for each of the three hybrids, and their rates of GDD decrease varied from −0.72 to −1.09 GDD per day of delayed planting (Fig. 2A).

The effect of delayed planting on the hybrids' thermal timings for kernel BL formation was quadratic in nature. As planting was delayed, the number of GDDs to R6 decreased at ever-increasing rates from early May through early June (Fig. 2C). As previously suggested by the data in Table 7, the effect of delayed planting on thermal time was most pronounced during the postanthesis period but varied in magnitude among the three hybrids. The hybrid 3245, rated latest in maturity among the three, exhibited the greatest response to delayed planting, and the hybrid 3527, rated earliest in maturity, exhibited the least response (Fig. 2B).

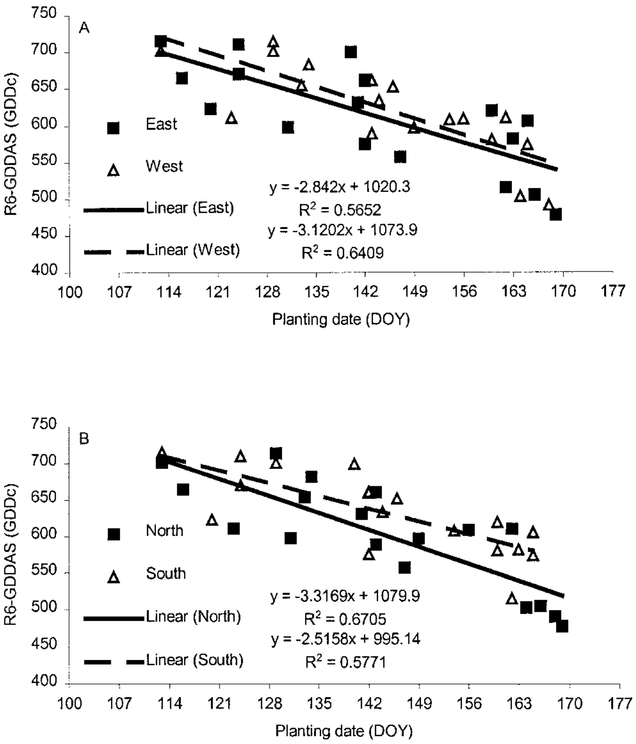

**Fig. 3. Effects of delayed planting on thermal time from silking to kernel black layer (BL) (R6-GDDAS) for (A) east vs. west environments and (B) north vs. south environments. Data points represent means of three hybrids and three replicates. Linear regression coefficients are not significantly different ($P \leq 0.05$) for either east vs. west or north vs. south. GDDs, accumulated growing degree days from silking to kernel BL; DOY, day of year.**

Interactions between the environment term and other terms in the ANOVA were often significant for both calendar and thermal variables (Table 8). The linear effects of delayed planting on GDDAP-R6 for each of the 12 environments are shown in Table 9 and illustrate the variability in planting date response. The 12 environments included in this study differed for seasonal rainfall and air temperature (Tables 4 and 5), but no correlations were identified between these variables and the environment × treatment responses (data not shown).

The environments can be grouped into western (West Lafayette and Butlerville) and eastern (Hoytville and South Charleston) locations as well as northern (West Lafayette and Hoytville) and southern (Butlerville and South Charleston) geography. The effect of delayed planting on thermal time after silking to R6 was similar for the east and the west environments (Fig. 3A). The linear response of GDD after silking to R6 to delayed planting at the northern environments tended to be greater than at the southern environments (Fig. 3B); however, the two regression coefficients were not significantly different ($P \leq 0.05$).

Although previous field studies indicated decreased GDD requirements with delayed planting (Roth and Yocum, 1997; Sutton and Stucker, 1974; Daynard, 1972), no consistent satisfactory explanation for this response

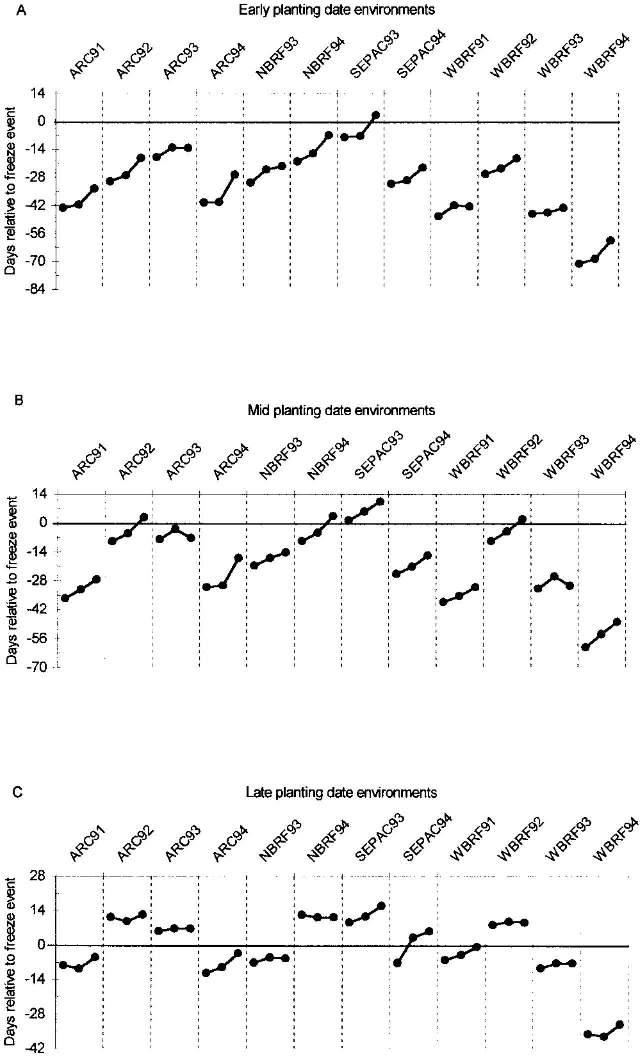

**Fig. 4. Timing of kernel black layer (BL) formation (R6) for three corn hybrids relative to dates of killing fall freezes (≤−2.2°C) for 12 environments (mean of three replicates). Negative *day* values represent days before the killing freeze for a given environment while positive day values represent days following a killing freeze. Connected data points represent the hybrids 3527, 3394, and 3245 from left to right, respectively, within an environment. ARC, Purdue Agronomy Research Center; NBRF, Northwest Branch Research Farm of the Ohio State University Ohio Agricultural Research and Development Center; SEPAC, Southeast Purdue Agricultural Center; WBRF, Western Branch Research Farm of the Ohio State University Ohio Agricultural Research and Development Center.**

has been presented (Nielsen et al., 1994). Lethal cold temperature (≤−2.2°C) kills plant tissue and causes premature kernel BL development (Carter and Hesterman, 1990). Therefore, one factor associated with delayed planting that may have contributed to the reduction in GDDs to R6 could be the occurrence of late-season frost or freeze events before kernel BL development for some of the later planted hybrid–environment combinations.

Of the 36 possible hybrid–environment combinations within the Early planting date treatment, only one did not mature (R6) before the first occurrence of −2.2°C or less (Fig. 4A). Within the Mid planting date treatment, six of the hybrid–environment combinations failed to mature before the first occurrence of −2.2°C or less (Fig. 4B). Seventeen hybrid–environment combinations failed to reach R6 before a lethal cold temperature event within the Late planting date treatment (Fig. 4C). Obviously, the greater incidence of freeze injury in the Late planting date treatments may have been a major determinant for the observed reduction in seasonal GDDs to kernel BL with delayed planting.

The 12 environments were therefore characterized as *frosted* or *nonfrosted* according to whether any of the three hybrids in the Late planting date treatment within an environment (Fig. 4C) failed to reach kernel BL before the first recorded lethal cold temperature event (≤−2.2°C). Interestingly, the hybrid–environment combinations that failed to mature before a killing freeze were not exclusively the late-maturity hybrid (3245) or the northern locations (West Lafayette and Hoytville) (Fig. 4).

Separate analyses for these two groups of environments indicated that delayed planting resulted in fewer GDDs to kernel BL regardless of whether lethal cold temperature events occurred before kernel BL development although the percentage reduction tended to be greater in the frosted environments (Table 10). Consequently, the decrease in GDDs to kernel BL with delayed planting cannot be explained primarily by virtue of immature grain and lethal cold temperatures.

Daynard (1972) suggested that extended periods of cool temperatures, not frost, were a more probable cause of what he characterized as "premature" BL formation. He noted that BL formation occurred shortly after cold spells when mean daily maximum temperatures averaged 13°C or less. Other researchers have observed similar effects on corn maturation (Baker, 1971; Miles, 1943).

Moreover, there is evidence from controlled-environment studies that suboptimal nighttime temperatures during grain fill contribute to a reduction in GDDs to R6. Badu-Apraku et al. (1983) compared the effects of four day–night temperature regimes (25 and 25, 25 and 15, 35 and 15, and 35 and 25°C) on corn during the grain-fill interval 18 d postsilking to physiological maturity. Field-grown corn plants were transferred to controlled-environment growth cabinets where the varying temperature regimes were imposed. Lower night temperature increased the interval in calendar days by 3 to 8 d.

The authors did not refer to thermal time intervals, but GDDs calculated from their data indicate that the lower night temperatures decreased the grain-fill interval by 60 to 75 GDD. The low night temperature used in this controlled-environment study commonly occurs during the grain-fill periods of delayed plantings in commercial fields. Furthermore, late-planted corn experiences overall relatively cooler temperatures during late grain filling than does earlier-planted corn.

Photoperiod can also influence corn development and grain maturation (Bonhomme et al., 1994; Kiniry et al., 1983a, 1983b; Tollenaar and Hunter, 1983). However, the differences in photoperiod associated with the plant-

**Table 10. Planting date effects on several thermal time phenological events within frosted† and nonfrosted environments.**

| Planting date | | GDDAP-VE | GDDAP-R1 | GDDAE-R1 | GDDAP-R6 | GDDAE-R6 | GDDAS-R6 |
|---|---|---|---|---|---|---|---|
| | | **Frosted environments ($n = 6$)** | | | | | |
| | | **Cumulative GDDs** | | | | | |
| **Early** | **3 May‡** | **63.0** | **782.7** | **719.7** | **1430.4** | **1367.5** | **647.8** |
| **Mid** | **22 May** | **56.4** | **765.3** | **708.8** | **1373.8** | **1317.3** | **608.5** |
| **Late** | **11 June** | **74.7** | **749.6** | **674.8** | **1278.0** | **1203.3** | **528.4** |
| | **LSD (0.05)** | **1.7** | **6.7** | **6.6** | **3.9** | **4.4** | **7.8** |
| | ***F*-test** | ** | ** | ** | ** | ** | ** |
| | | **Nonfrosted environments ($n = 6$)** | | | | | |
| **Early** | **3 May** | **73.2** | **790.6** | **717.4** | **1475.2** | **1401.9** | **674.6** |
| **Mid** | **22 May** | **70.3** | **776.7** | **706.4** | **1430.1** | **1359.7** | **653.3** |
| **Late** | **11 June** | **61.8** | **756.1** | **694.3** | **1340.3** | **1278.4** | **584.2** |
| | **LSD (0.05)** | **3.7** | **5.8** | **4.9** | **5.9** | **7.5** | **6.6** |
| | ***F*-test** | ** | ** | ** | ** | ** | ** |

**** Significant at $P \leq 0.01$.**

**† The term *frosted* refers to whether any of the three hybrids in the Late planting date failed to reach kernel black layer prior to the recording of a lethal cold temperature event (−2.2°C).**

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

ing periods of this study were not sufficiently large at the critical photoperiod-sensitive interval (tassel initiation or about V5 to V7) to impact development and reduce GDD requirements from planting to R6 appreciably (Kiniry et al., 1983a). Differences in daylight length at the photoperiod-sensitive interval between the earliest and latest planting periods in our study were <2 h (U.S. Naval Observatory, 2001). Past studies have indicated that differences in photoperiod of 3 to 5 h are needed at the photoperiod-sensitive interval to generate differences in phenological response in Corn Belt germplasm (Tollenaar and Hunter, 1983). Ellis et al. (1992) concluded that corn cultivars adapted to higher latitudes show little sensitivity to photoperiod, whereas those adapted to tropical latitudes with natural photoperiods 13 h $d^{-1}$ show greater photoperiod sensitivity, up to three time greater than popular Corn Belt genetic backgrounds (e.g., B73 × Mo 17).

## SUMMARY

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 with early May. Calendar time from R1 to kernel BL development increased, however, by about 5 d for June planting vs. 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 vs. 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 vs. early May plantings while the grain-fill period (R1 to R6) decreased an additional 110 GDDs with late plantings. Total accumulated GDDs from planting to R6 decreased 10%, or about 144 GDDs for corn planted in early June compared with early May. When considering early May vs. 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. 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 5% 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 2 June (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 (Purdue Crop Diagnostic Training and Research Center, 1998) suggest that 1417 GDDs would be expected from 2 June to 13 October (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 before a normally occurring killing fall frost.

## ACKNOWLEDGMENTS

This research was partially supported by grants from the Crop Management Research Awards Program, Pioneer Hi-Bred International, Johnston, IA. Additional support was provided through the Purdue University Crop Diagnostic Training and Research Center.

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