Chilling Requirement of Pecan

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Abstract. 'Dodd' pecan seedlings [*Carya illinoensis* (Wangenh.) K. Koch] were chilled at 6C for 0 to 1800 hours in 300-hour intervals and percent budbreak and days to budbreak recorded. Chilling duration required for $\geq 50\%$ budbreak was 900 hours. Chilling > 900 hours increased budbreak percentage and reduced time to budbreak. 'Dodd' seedlings chilled at 1, 5, or 9C for 0 to 2500 hours in 500-hour intervals had more lateral budbreak after 1000 hours of chilling at 5C than at 1 or 9C. When chilling hours ranged from 1500 to 2500, 1C increased budbreak of the first lateral bud compared with 5 or 9C. As chilling was increased from 1000 to 2500 hours, the days to budbreak declined, and the uniformity of budbreak increased.

The existence of a cold requirement for pecan buds to break rest and grow normally was first suggested by Waite (1925). Lack of chilling apparently delays foliation, increases fruit drop, and reduces yield when pecans are grown in climates without sufficient chilling hours (Nasr and Hassan, 1975; Van Horn, 1941). Lack of knowledge to predict the completion of rest prevents development of growth models for pecan that would be useful in such applications as pest management, plant propagation, and evaluation of climatic adaptation of cultivars.

A chilling requirement of pecan has been confirmed, and in one study, the chilling hours to break rest were reported to be 500 for 'Desirable' and 'Mahan' and 600 for 'Stuart' (McEachern et al., 1978). In another study, the chilling hours to break rest were 300 to 400 for 'Mahan', 'Success', 'Desirable', and 'Schley', and 700 to 1000+ for 'Stuart' (Amling and Amling, 1980). In both studies, 'Stuart' had a higher chilling requirement than the other cultivars evaluated. Van Horn (1941) reported that 'Burkett' trees grown at low elevations in Arizona were seriously affected by delayed foliation; whereas 'Humble' foliated normally during the spring. Differences among the two cultivars were attributed to a higher chilling requirement for 'Burkett' than 'Humble'.

Chilling hours are calculated as the number of hours $< 7C$. However, studies with other crops have shown that low temperatures vary in their effectiveness in breaking rest (Couvillon and Erez, 1985a; Norvell and Moore, 1982; Richardson et al., 1974; Scalabrelli and Couvillon, 1985; Young, 1992). Richardson et al. (1974) presented a mathematical model relating temperature to rest completion of peach [*Prunus persica* (L.) Batsch]. This model assigns values (chill units) to the various temperatures based on their effectiveness in satisfying the chilling requirement, then the chilling requirement is calculated based on chilling units (the weighted hourly temperatures). No such model has been developed for pecan, nor has the effectiveness of different temperatures to break rest of pecan been evaluated. Therefore, this study was initiated to determine the number of chilling hours necessary to break rest and to evaluate the effectiveness of selected temperatures in breaking rest.

Materials and Methods

Influence of chilling duration at 6C. Stratified 'Dodd' pecan nuts were planted in 11-liter containers filled with a fire-hardened calcite clay (Turface, Wyandotte Chem. Corp., Wyandotte, Mich.), amended with essential elements (Smith and Bourne, 1989). Trees were grown in the greenhouse until no new shoot growth was observed (≈ 6 months). Our prior observations indicated that no new growth would occur until trees received a chilling treatment.

Trees were blocked according to size, manually defoliated and transferred to a cooler (8-h photoperiod, $100 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF) with the thermostat set at 6C. Bud temperature, measured hourly with thermocouples, was $6.2 \pm 0.9C$. Seven trees were transferred from the cooler to the greenhouse every 300 h, from 0 to 1800 h. Bud temperature in the greenhouse was $23 \pm 2C$, and the photoperiod was extended to 15 h with incandescent lights.

The number of days to budbreak of the terminal and first two lateral buds from the apex was recorded. Days to budbreak were analyzed by fitting selected nonlinear models, with the best model chosen based on the smallest SE of the regression, the sequential analysis of variance of the equation components, and the analysis of variance (ANOVA) of the model (Draper and Smith, 1966). Confidence limits (95%) were calculated for the model. Chilling treatments ≤ 600 h were not included in the analysis for the number of days to budbreak, since no trees initiated growth. The percentage of trees with the terminal or first two lateral buds initiating growth was calculated.

Influence of chilling temperature and chilling duration. 'Dodd' pecan nuts were planted and grown as described above. Treatments were chilling at 1, 5, or 9C for 0 to 2500 h in 500-h intervals. Transfer of trees to the cooler was staggered such that all trees completed their chilling treatment at the same time and were transferred to the greenhouse at the same time. Trees were manually defoliated immediately before being transferred to the cooler. Bud temperatures, monitored with thermocouples, were $0.6 \pm 2.0C$, $5.3 \pm 1.7C$, and $9.2 \pm 2.1C$ for the 1, 5, and 9C treatments, respectively. Photoperiods were adjusted to 8 h ($100 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PPF) in the coolers and 15 h in the greenhouse using incandescent lights.

Budbreak was monitored daily, and the number of days to budbreak of the terminal and first two lateral buds was recorded. The experiment was designed as a randomized complete block with seven single-tree replications. The number of days to budbreak was tested by ANOVA with single degree-of-freedom linear and nonlinear orthogonal contrasts for chilling temperature, linear, quadratic, and cubic orthogonal contrasts for chill-

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ing hours, and the interaction of chilling temperature with chilling hours. Means and confidence intervals of the mean ($P = 0.95$) were calculated for each treatment combination (Little and Hill, 1978). Additionally, the percentage of trees that initiated growth of the terminal or first two lateral buds was calculated.

Results

Influence of chilling duration at 6C. The percentage of trees with terminal budbreak was higher than the percentage of trees with lateral budbreak (Fig. 1). The days to budbreak of the terminal bud were similar to values for lateral buds (Fig. 2). Completion of rest is usually defined as 50% budbreak that occurs within a specified number of days at forcing temperature. In this study, no terminal buds broke when trees were exposed to ≤ 600 h at 6C, then transferred to 23C (data not shown), and 71% of the terminal buds broke after 900 h of chilling (Fig. 1). However, the average number of days to budbreak after transfer to 23C was 78 days when trees were chilled for 900 h (Fig. 2). Additional chilling up to 1800 h reduced the time to budbreak of the terminal bud from 78 to 26 days (Fig. 2) and increased terminal budbreak from 71% to 100% (Fig. 1).

The percentage of trees with the first lateral bud breaking was usually higher than those with the second lateral bud breaking (Fig. 1). No lateral buds broke within 100 days when trees were exposed to ≤ 600 chilling hours then transferred to 23C (data not shown). Lateral budbreak occurred after 900 h of chilling, but additional chilling did not consistently increase the percentage of trees with lateral budbreak (Fig. 1). The number of days to budbreak of the terminal and lateral buds when trees were transferred to 23C decreased curvilinearly between 900 and 1800 chilling hours (Fig. 2).

Influence of chilling temperature and chilling duration. All terminal buds broke after 1000 h of chilling at 1, 5, or 9C (Fig. 3). There were no trees with terminal or lateral budbreak when trees were not exposed to chilling temperatures (data not shown). The percentage of budbreak of the first lateral bud after 1000 h of chilling at 5C was higher than at 1 or 9C, and the only budbreak of the second lateral bud after 1000 h of chilling occurred when the chilling temperature was 5C (Fig. 3). The percentage of trees with first lateral budbreak following exposure to 1C was higher after 1500 than after 1000 h of chilling. Budbreak of the first lateral following 1500 or 2000 h of chilling at 1C was greater than following chilling at 5 or 9C. The percentage of trees with budbreak of the second lateral bud was higher after 1000, 1500, or 2000 h of chilling at 5C than after

Fig. 1. Influence of chilling hours at 6C followed by transfer to 23C on percent budbreak of the terminal bud, first lateral bud, and second lateral bud of seedling 'Dodd' pecan trees.

Fig. 2. Influence of chilling hours at 6C followed by transfer to 23C on days to budbreak of the terminal bud ($Y = 10.29 + 55222090/X$, $R^2 = 0.77$, $P \geq 0.001$, top graph), first lateral bud ($Y = 18.31 + 52343403/X^2$, $R^2 = 0.75$, $P \geq 0.001$, middle graph), and second lateral bud ($Y = 16.97 + 53772057/X^2$, $R^2 = 0.76$, $P \geq 0.001$, bottom graph) of seedling 'Dodd' pecan trees. Dotted lines indicate 95% confidence limits.

chilling at 1 or 9C. After 2500 h of chilling, budbreak of the second lateral was greater when the trees were exposed to 1C than to 5 or 9C.

There was a significant interaction between the chilling temperature and the number of chilling hours in respect to the num-

Fig. 3. Influence of chilling temperature and chilling hours followed by transfer to 23C on percent budbreak of the terminal bud (top graph), first lateral bud (middle graph), and second lateral bud (bottom graph) of seedling 'Dodd' pecan trees.

ber of days to budbreak of the terminal bud (Fig. 4). The interaction indicated a nonlinear response to chilling temperatures with a linear decrease in the days to budbreak as chilling hours increased ($P = 0.03$). Fewer days were required to budbreak when trees were exposed to 5C for 1000 h than when exposed to 1 or 9C for 1000 h. However, when the number of chilling hours were ≥ 1500 h, the three temperatures were equally effective in decreasing the number of days to budbreak. The number of chilling hours was negatively related to the number of days to budbreak.

There was a significant linear ($P = 0.0001$) decrease in the number of days to budbreak of the first and second lateral bud as the number of chilling hours increased from 1000 to 2500 h

Fig. 4. Influence of chilling temperature and chilling hours followed by transfer to 23C on the days to budbreak of the terminal bud (top graph), first lateral bud (middle graph), and second lateral bud (bottom graph) of seedling 'Dodd' pecan trees. Vertical bars indicate 95% confidence intervals of the mean.

(Fig. 4). The three chilling temperatures tested were not significantly different in the number of days to budbreak of the first or second lateral bud. The most striking difference from additional chilling was the increased uniformity in budbreak of the terminal and lateral buds (note the smaller confidence limits as chilling hours increased).

Discussion

The chilling requirement of 'Dodd' pecan seedlings was ≈ 900 h at 6C to achieve 150% budbreak within 80 days after trees were transferred to 23C; however, the time to budbreak was reduced and uniformity in budbreak improved with additional chilling hours. Earlier reports have suggested shorter chilling requirements for pecan. McEachern et al. (1978), using non-terminal stem cuttings, reported that 'Desirable' and 'Mahan' required 500 chilling hours and 'Stuart' required 600 chilling hours. These chilling hours were determined as the first increase in the percent budbreak above no chilling. If $\geq 50\%$ budbreak

is used as the criterion for the end of rest, then 600 chilling hours is necessary for 'Desirable' and 'Mahan' and 700 chilling hours for 'Stuart', based on data of McEachern et al. (1978). Amling and Amling (1980) used terminal stem cuttings to determine the chilling requirement. They estimated the completion of rest as the time when the days to budbreak could not be reduced further by additional chilling. Using this criterion, they estimated 300 to 400 chilling hours for 'Mahan', 'Success', 'Desirable', and 'Schley', and 700 to 1000 chilling hours for 'Stuart'. If the same criterion is used in our study, the chilling requirement for 'Dodd' seedlings is 2500 chilling hours. The chilling requirement for 'Dodd' seedlings (900 h) is among the longest chilling requirements that have been reported. Different chilling requirements among cultivars have been documented (Amling and Amling, 1980; McEachern et al., 1978; Van Horn, 1941). The longer chilling requirement of 'Dodd' compared with those reported previously may relate to the cultivar origin. 'Dodd' is a selection from a native population in Oklahoma. The average chilling hours in Oklahoma are 1400, which is more than the chilling hours in the regions from which the cultivars used in the other studies originated.

Terminal buds of pecan had a lower chilling requirement than lateral buds. Similarly, Scalabrelli and Couvillon (1985) reported that terminal buds of peach had a shorter chilling requirement than lateral buds.

Chilling above that required for 50% budbreak increased uniformity in budbreak and reduced the time required for budbreak. Couvillon and Erez (1985b), working with peach, cherry (*Prunus avium* L.), apple (*Malus domestica* Borkh.) and pear (*Pyrus communis* L.), reported that the growing degree hours required for budbreak could be reduced with chilling hours above that required for 50% budbreak, and the uniformity in budbreak could be improved.

The three temperatures tested were not equally effective in satisfying the chilling requirement of pecan. At 1000 chilling hours, 5C was more effective than 1 or 9C in satisfying the chilling requirement of lateral buds. With more chilling, 1C was generally the most effective temperature for lateral buds. This response suggests that a model similar to that proposed by Richardson et al. (1974) for peach would be applicable to pecan. However, temperature optima and temperature ranges probably differ from those proposed for peach. For example, 1C was generally more effective in satisfying the rest requirement of lateral buds than other temperatures tested when chilling hours were ≥ 2000 h. However, the peach model does not consider temperatures < 1.4 C as effective in chilling. In highbush blueberry (*Vaccinium corymbosum* L.), 1C was an effective chilling temperature, as in pecan, and 1 h at 1C was estimated to contribute 0.5 chill unit toward the chilling requirement (Norvell and Moore, 1982).

The effectiveness of various temperatures in meeting the chilling

requirement of pecan apparently changes during the rest period of pecan. For example, when pecans were chilled for 1000 h, 5C was the most effective temperature in satisfying rest of the lateral buds, but when chilled for 1500 or 2000 h, 1C was the most effective. Amling and Amling (1980) suggested that the intensity of rest (number of chilling hours necessary for budbreak) was affected by the environment. Pecans grown in areas with mild falls and winters had a lower chilling requirement than the same cultivars in colder climates. However, Van Horn (1941) reported 'Burkett' trees grown in a mild Arizona climate expressed symptoms typical of lack of chilling. Young (1992), working with apple, reported that the effectiveness of various temperatures for breaking rest changed as chilling progressed. Pecan may be similar to apple in that the effective temperature ranges and optimum temperature for breaking rest change as the chilling process proceeds.

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