

Chilling Duration Affects Foliar Budbreak Of Linden Cultivars

Barrett C. Wilson,¹

Jeff L. Sibley,² and

James E. Altland³

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SUMMARY. A study evaluating the effects of varying levels of chilling on foliar budbreak of linden (*Tilia* spp.) cultivars was initiated in 1999 in Auburn, Ala. [lat. 32°36'N, long. 85°29'W, elevation 709 ft (216m), USDA Hardiness Zone 8a]. Littleleaf linden (*T. cordata*) 'Greenspire' and 'Fairview' required the most chilling to produce measurable budbreak and exhibited the lowest budbreak percentages. Silver linden (*T. tomentosa*) 'Sterling' and american linden (*T. americana*) 'Redmond' needed the fewest hours of chilling to produce budbreak and exhibited the highest budbreak percentages. 'Sterling' was the top performer in foliar budbreak percentage and in subsequent growth. Although 'Redmond' attained high budbreak numbers, its overall growth during the following growing season was inferior to that of 'Sterling', 'Greenspire' and 'Fairview'. This information can contribute to the development of regional planting recommendations, which can aid in the selection of lindens suitable for the area in which they will be grown. Calculated r^2 values indicated the models used provided a good fit to the data for all cultivars.

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¹Graduate research assistant, Department of Horticulture, Auburn University, 101 Funchess Hall, Auburn University, AL 36849.

²Associate professor, Department of Horticulture, Auburn University, 101 Funchess Hall, Auburn University, AL 36849.

³Assistant professor, North Willamette Research and Extension Center, Oregon State University, 15210 NE Miley Road, Aurora, OR 97002-9543.

Lindens are large, deciduous shade trees [50 to 80 ft (15.2 to 24.4 m) tall and 25 to 50 ft (7.6 to 15.2 m) wide] found in much of the northern hemisphere, with species native to North America, Europe, and Asia. They produce exceptional shade with dark green leaves and a stately, beautiful form. There are about 10 cultivars of american linden (USDA Zones 3b to 8), 23 cultivars of littleleaf linden (USDA Zones 3b to 7), and 5 cultivars of silver linden (USDA Zones 4 to 7) (Dirr, 1998). Of the readily available cultivars, few have gained popularity in the southern U.S., probably a result of the prevailing belief that lindens are northern trees with poor performance in the southern states.

Research suggests that performance of cultivars and selections of woody ornamentals can vary greatly depending upon their provenance or area of origin, as was the case with sugar maple (*Acer saccharum*) and red maple (*Acer rubrum*) as well as other species (Kriebel and Wang, 1962; Perry and Hellmers, 1973; Sibley et al., 1995, 1999; Townsend et al., 1982). Trees in previous studies exhibited differences in date of budbreak, budbreak numbers, stem diameter and elongation, root growth, leaf retention, fall color, flowering and fruiting, and winter injury.

One of the determining factors causing variations in growth and performance of woody plants is release of bud endodormancy through chilling responses. The influence of chilling temperatures during the dormant season is widely known for fruit trees, but not ornamental trees. Chilling affects timing and amount of vegetative and floral budbreak of woody plants, as well as subsequent growth, development, and hardiness (Couvillon and Erez, 1985; Dokoozlian, 1999; Mahmood et al., 2000; Murray et al., 1989; Roberts and Zwiazek, 1999). Ashby's (1962) work with american linden showed that increased chilling led to a significantly faster rate of budbreak. The least chilled plants, which broke bud and began growth later, also stopped growth and began losing leaves at a later date. As a result, the growth periods between chilling treatments did not vary greatly. In other research, some lindens lifted from the field in the fall and stored at 38 °F (3.3 °C) through spring had partial

budbreak while still in cold storage. Trees receiving minimal chilling did not break bud at all.

The objectives of this study were to determine if selected linden species and cultivars respond differently to chilling and to estimate the chilling requirement for the selections. From this information and future research, regional planting recommendations can be determined to assist in the selection of lindens suitable for southern landscapes.

Materials and methods

Tissue cultured plants of littleleaf linden 'Greenspire' (Greenspire®) and 'Fairview' (Fairview™), silver linden 'Sterling', and american linden 'Redmond' were obtained as 4 to 5-ft (1.2 to 1.5-m) tall bare-root, whips in February 1999. The trees were planted into 7-gal (22.0-L) containers in a 6 pinebark : 1 sand (by volume) substrate amended with 5 lb/yard³ (3.0 kg·m⁻³) dolomitic limestone, 1.5 lb/yard³ (0.9 kg·m⁻³) Micromax (O.M. Scott Co., Marysville, Ohio), and 11.1 lb/yard³ (6.3 kg·m⁻³) of 18-6-12 (18N-2.6P-10K) Osmocote (O.M. Scott Co.). Trees were grown in full sun under overhead irrigation for 10 months in Auburn, Ala. [lat. 32°36'N, long. 85° 29'W, USDA Hardiness Zone 8a, elevation 709 ft (216m)] until December 1999.

The study consisted of six durations of chilling, applied in increments of 200 h, to each cultivar (200 to 1200 h), with each treatment consisting of three single-tree replications per cultivar. Chilling was considered as total h below 45 °F (7.2 °C) beginning 1 Oct. using the "Old 45 Chilling Model" (Powell et al., 1999). Upon natural accumulation of 200 h of chilling in December 1999, the first treatment was placed in a glass greenhouse maintained at a minimum temperature of 72 °F (22.2 °C). Subsequent treatments were placed in the greenhouse at intervals of 200 h and were weeded and watered by hand as needed. Trees were arranged in a completely randomized design. Auburn normally receives 900 to 1000 h of natural chilling, therefore plants in treatments 1 to 4 (200 to 800 h) were allowed to accumulate natural chilling. Plants in treatments 5 to 6 (1000 to 1200 h) accumulated 925 h of natural chilling through March 2000, with the remainder added while stored at 38 °F

(3.3 °C) in a thermostatically controlled cooling unit because of warming temperatures outdoors. When the study was terminated in April 2000, heat units [total h at a minimum of 72 °F (22.2 °C)] accumulated in the greenhouse ranged from 2856 h for treatment 1 to 504 h for treatment 6.

After placement in the greenhouse, the trees were monitored twice weekly for foliar budbreak. The total number of buds was counted for each tree. Budbreak was considered to be the point where overlapping bud scales began to separate, revealing leaf tips. The highest budbreak count recorded for each cultivar by the end of the study was recorded. Heat units required to reach a given budbreak percentage were estimated from the observed budbreak percentages and accumulated heat units for each treatment and cultivar using regression analysis. The SAS stepwise procedure

was used to determine the best model for each cultivar (SAS, Chicago), using the R^2 and Mallows's C_p criteria (Neter et al., 1996) in the selection process.

Results and discussion

Predicted heat units required for initial, 10%, 25%, and 50% budbreak were estimated based on observations. Regression analysis indicated a similar polynomial model (though different coefficients for each cultivar) as the most accurate for predicting heat units in each cultivar: $Y = \beta_1 x_1 + \beta_2 x_1^2 + \beta_3 x_2 + \beta_4 x_2^2$, where Y = heat units, x_1 = chilling hours, and x_2 = percent budbreak.

For all cultivars, increasing the duration of chilling accelerated the rate of foliar budbreak. Increased chilling reduced the number of heat units required to initiate foliar budbreak (Table 1) and generally led to an increase in budbreak percentage. All

cultivars required over 1900 heat units to initiate budbreak after 200 h of chilling, but only 739 to 922 heat units after 600 h and between 2 to 227 heat units following 1000 h of chilling for initiation of budbreak. Calculated r^2 values indicate the model selected provided a good fit to the data for all cultivars.

Heat units required for initial budbreak were similar for 'Sterling' and 'Redmond'. Although the model predicted heat units required for budbreak to occur for 'Greenspire' and 'Fairview', actual budbreak was never observed for these cultivars in trees receiving only 200 h of chilling. 'Greenspire' and 'Fairview' trees receiving 200 h of chilling eventually declined to a point of death. Silver linden 'Sterling' performed well in this study and was the only cultivar receiving 200 h of chilling that reached 50% budbreak by the time the trees were moved from the greenhouse and transplanted to larger containers (Table 1).

The optimal chilling range for 'Greenspire' began at 800 to 1000 h, with 25% to 50% budbreak occurring after accumulation of 1134 to 1750 heat units. 'Fairview' produced minimal budbreak after 400 h, with an optimal range of 800 to 1000 h and 25% to 50% budbreak with 965 to 1634 heat units. An optimal chilling range for 'Sterling' was 600 to 800 h with 25% to 50% budbreak occurring after accumulation of 801 to 1515 heat units. 'Redmond', an american linden, exhibited sparse budbreak after only 200 h of chilling, with a wide optimal chilling range of 600 to 1000 h producing 25% to 50% budbreak after accumulation of 861 to 1861 heat units.

Further study is needed to determine absolute chilling requirements for the various linden cultivars. Other topics that merit further study include the contrasting effects of cold storage chilling and natural outdoor chilling, and determination of optimal chilling temperatures. Also, greenhouse temperatures during budbreak and growth tend to remain constant while outdoor temperatures fluctuate. The work presented here indicates that littleleaf lindens 'Greenspire' and 'Fairview' have the highest chilling requirement of the selections evaluated. Silver linden 'Sterling' exhibited the highest budbreak percentage of all selections across all treatments evaluated. American lin-

Table 1. Predicted number of heat units required to reach a given budbreak percentage on selected linden (*Tilia* spp.) cultivars.

Cultivar	Hours chilled	Predicted number of heat units ^z			
		Initial budbreak	10% budbreak	25% budbreak	50% budbreak
Littleleaf linden 'Greenspire'	200	1935 ^y	2370	2843	---
	400	1389	1824	2297	2604
	600	922	1357	1830	2137
	800	535	970	1442	1750
	1000	227	662	1134	1442
	1200	---	433	906	1213
$r^2 = 0.58$					
Littleleaf linden 'Fairview'	200	1925	2320	2760	---
	400	1368	1763	2203	2532
	600	883	1278	1718	2047
	800	470	865	1306	1634
	1000	130	524	965	1293
	1200	---	256	696	1024
$r^2 = 0.65$					
Silver linden 'Sterling'	200	1952	2173	2442	2729
	400	1286	1506	1776	2062
	600	739	959	1229	1515
	800	311	531	801	1087
	1000	2	223	493	779
	1200	---	34	304	590
$r^2 = 0.66$					
American linden 'Redmond'	200	1900	2293	2723	---
	400	1268	1661	2091	2382
	600	747	1141	1571	1861
	800	337	730	1160	1451
	1000	38	431	861	1152
	1200	---	243	672	963
$r^2 = 0.71$					

^zCalculated with PROC REG, using the SAS stepwise procedure to determine the best model.

^yOne heat unit equals 1 h in the greenhouse at a temperature of at least 72 °F (22.2 °C).

^zPredicted heat unit level was less than or greater than that which was applied.

^wValues represent percent variation explained by the model.

den 'Redmond' and silver linden 'Sterling' required the fewest hours of chilling to produce measurable foliar budbreak.

Following termination of the greenhouse portion of this study, all trees were moved back to the growing area outdoors to allow observation of subsequent growth. By the end of the growing season in Fall 2000, differences observed in initial budbreak were magnified. Trees within each cultivar that had received greater amounts of chilling were larger than trees receiving less chilling. Furthermore, the overall growth was greater on 'Sterling' than the other cultivars, with the least overall growth occurring for 'Redmond'.

This study provides an indication of the need to carefully select lindens suitable for the region in which they will be grown, whether in field or container production or in the landscape. Based on the results of this study, considering the parameters evaluated for these four linden cultivars, 'Sterling' appears to be the most suitable linden for landscape use in similar climate regions to Auburn, Ala.

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Production of High-quality Tomato Transplants with a Novel Buffered Fertilizer

Kathleen M. Brown,¹
Charles S. Vavrina,²
Robert Snyder,¹
Mike Orzolek,¹ and
Jonathan P. Lynch¹

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SUMMARY. 'FTE 30' tomato (*Lycopersicon esculentum*) transplants were produced in Florida under standard commercial conditions and supplied with one of six treatments: zero, low (20% of the control rate), or high (control) super-phosphate (SP) fertilizer, or 0.5%, 1%, or 2% buffered-phosphorous fertilizer (Al-P). Growth characteristics were evaluated for four sets of transplants, produced in January, April, May, and August. Two sets of transplants were grown in the field in Florida (started in January and August) and one set was grown in Pennsylvania during the summer (started in May). Phosphorus concentration in leachate was measured weekly from one crop. Plants grown with Al-P showed a 72% to 88% reduction in P released in leachate compared with the high SP control. Transplants produced with 1% or 2% Al-P were of equal size and quality compared with transplants produced with conventional (high SP) fertilization, and had greater total root length and specific root length (length per unit root weight). Transplants grown with 0.5% Al-P were sometimes smaller than other fertilized treatments, while no-P plants were very small and grew slowly after transplanting. There were no significant differences in growth, yield, or fruit quality of plants from

¹Department of Horticulture, Pennsylvania State University, University Park, PA 16802.

²Southwest Florida Research and Education Center, 2686 State Road 29 North, Immokalee, FL 34142.