

A STUDY OF CHILLING FACTORS ON TAXA OF RED MAPLE

(*ACER RUBRUM* L. AND *ACER X FREEMANII* E. MURRAY)

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THESIS ABSTRACT

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The objectives of this research were to (1) determine the response on budbreak of red maples to natural (ambient) chilling versus constant (forced) chilling; (2) determine the response on budbreak of red maples of forced chilling of red maple at various refrigeration unit settings; and (3) determine the response on budbreak of red maples of incremental chilling totals at various refrigeration unit settings. In the first study, the rate of percent budbreak in container-grown red maple (*Acer rubrum* L.) trees that were chilled in a 7E C (45° F) cooler was compared to red maple trees that were chilled naturally outdoors. The experiment was carried out during the fall of 2002 and the winter and spring of 2003. The red maple trees were placed in a 22E C (72E F) greenhouse after accumulating 600, 800 and 1000 total chilling hours. In January of 2003 percent

budbreak was visually determined and recorded every four days until all trees reached 100 percent budbreak. The trees were moved out of the greenhouse and placed outdoors under irrigation as they reached 100 percent budbreak. Statistical analysis of these data showed no difference between the rate of budbreak in the red maples receiving 600 hours of chilling in a 7E C (45E F) cooler and those that received 600 chilling hours outdoors. The same results held true at the 800 chill hour level and the 1000 chill hour level. Comparison between the three levels of cooler chilling (600, 800, 1000 hours) showed no difference in percent budbreak over time. Comparison between the three levels of natural chilling (600, 800, 1000 hours) showed no difference in percent budbreak over time. In the second study the rate of percent budbreak in container-grown red maple (*Acer rubrum* L.) trees chilled in three coolers with temperature set points of 1.7° C, 4.4° C and 7° C (35, 40 and 45° F) respectively was calculated. The experiment was carried out during the fall of 2002 and the winter, and spring of 2003. Trees were placed in a 22E C (72E F) greenhouse after accumulating 500 to 1000 chilling hours in 100 hour increments. In January of 2003 percent budbreak was visually determined and recorded every four days until all trees reached 100 percent budbreak. The trees were moved out of the greenhouse and placed outdoors under irrigation as they reached 100 percent budbreak. Statistical analysis of these data showed no significant difference between the 3 levels of forced chilling 1.7° C, 4.4° C and 7° C (35, 40 and 45° F) for percent budbreak over time.

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CHAPTER 1

LITERATURE REVIEW

Red maple (*Acer rubrum* L.) ,a popular ornamental, tree is found naturally in the forests of eastern North America, ranging from southeastern Manitoba across southern Canada to Quebec and south through Florida, with a western limit of Minnesota and south through Illinois and Indiana (Sternberg and Wilson, 1995). Kielbaso (1990) and Townsend and Douglass (1998) indicated that red maple is one of the most frequently planted landscape trees in the United States. This trend continues today, as evidenced by the availability of more than 60 red and Freeman maple (*Acer x freemanii* E. Murray) cultivars (Dirr 1998; J. Sibley, pers. comm.). The list of cultivars grows every year, as red maple is prized for shade provided and exceptional fall coloration.

Research suggests that performance of red maple taxa can vary greatly depending upon provenance or area of origin. Sibley et al. (1995) demonstrated this difference in cultivars from different provenances grown at Camp Hill, Alabama. In this study, growth and fall color of the cultivars were observed. Considerable variation was shown in fall color, color duration, and time of peak fall color. Sibley et al. (1999b) indicated that red maple is a good candidate for regional selection. In studies in the southeast United States, cultivars exhibited substantial differences in regional adaptability based on height, stem diameter, canopy width, leaf retention, fall color, and root growth (Ruter et al., 1998; Ruter and Sibley, 2000; Sibley et al., 1997, 1998, 1999a, 1999b).

Results from the research of Townsend et al. (1982) also showed the wide genetic variability among red maples. Seedlings grown from seed collected throughout the species= natural range and planted in five upper midwestern states exhibited differences in flowering, fruiting, winter injury, and stem elongation. Townsend and Douglass (1998) found wide variation in the relative quality, timing and duration of autumn leaf color, growth rate, and other traits in 40 selections and cultivars of red and Freeman maple grown in Maryland. A major factor in determining a plant's performance in a given climate or hardiness zone is dormancy. Dormancy is a phase in plant development that allows survival in winter weather conditions (Saure, 1985). Samish (1954) and Romberger (1963) defined dormancy as a state in which visible growth is temporarily suspended. Amen (1968) stated that dormancy is an endogenously controlled but environmentally imposed temporary suspension of growth. Dormancy continues to be a poorly understood concept with scientists offering many distinct definitions. Some believe that lack of growth is due to the blockage of cell division by interactions between the signaling pathways controlling dormancy and those controlling the cell cycle (Anderson et al., 2001).

Metabolic activity and tissue development do not cease in dormant plants but occur normally, allowing a slow and steady increase in bud weight (Lang et al., 1987; Young et al., 1974). In addition, because dormancy is not a uniform, static state in plant development, but covers a range of physiological conditions, several phases of dormancy can be differentiated (Saure 1985). Previous research terminology used to describe the various phases of dormancy has become quite cumbersome and complex. Some of the more confusing terms associated with the stages of dormancy include quiescence,

inhibition, rest, main rest, deep rest, winter rest, post rest, summer dormancy, true dormancy, winter dormancy, true winter dormancy, primary and secondary dormancy, internal and external dormancy, and post dormancy.

Nomenclature has been proposed that encompasses and eliminates the need for the multitude of previously used terms (Lang et al., 1987). The terms ecodormancy, paradormancy, and endodormancy are becoming more widely accepted among researchers of dormancy. Ecodormancy is regulated by external factors such as nutrient deficiencies and water stress. Paradormancy is regulated by physiological factors outside the affected plant part such as apical dominance and photoperiodic responses. Finally, endodormancy is regulated by physiological factors inside the affected plant part such as chilling responses.

Most research has focused on breaking dormancy, with little attention to the conditions that induce dormancy (Dennis, 1994). Dormancy release is of particular interest to the nursery industry, for early budbreak can lead to a longer growing season and accelerated production (Lechowicz, 1984). Dennis (1994) stated that dormancy ends when further chilling no longer increases the rate of budbreak. Once a critical number of chill units have been reached, the accumulation of heat units stimulates budbreak. It has been known for centuries that low temperatures are necessary for dormancy transition (Seeley, 1994). Temperate plant species must be exposed to a certain period of chilling temperatures for dormancy release to occur, with the obligate period known as the chilling requirement (Saure, 1985).

Temperatures effective in releasing endodormant buds from dormancy in woody plants are variable. In Olmsted's (1951) work with sugar maple (*Acer saccharum* Marsh.),

temperature values below 5-8°C (41-46°F) were effective in dormancy release. Murray et al. (1989) made the assumption that all species detect days cooler than 5°C (41°F) as chill days and those warmer than 5°C (41°F) as promoting growth. Curtis and Clark (1950) mentioned an effective range from 0-6°C (32-43°F). Crocker (1948) stated that 0-10°C (32-50°F) was effective but higher temperatures and temperatures below freezing were not, while Rowland et al. (1999) maintained that chill units accumulate in the 0-7°C (32-45°F) range. Ashby et al. (1991), using silver maple (*Acer saccharinum* L.), and Sorenson et al. (1984) using canyon maple (*Acer grandidentatum* Nutt.), used 5°C (41°F) as the standard in their research. Erez and Couvillon (1982) and Gilbreath and Buchanan (1981) identified 8°C (46°F) as the most effective temperature for vegetative peach (*Prunus persica* L.) buds. Weaver and Iwasaki (1977) showed that budbreak is more rapid on 'Zinfandel' (*Vitis vinifera* L.) grapevine cuttings when stored at 0-3.9°C (32-39°F) as compared to 10°C (50°F).

Several methods have been utilized over the years to calculate chilling hours and units, most of which entail counting the number of hours below a certain temperature. Avery et al. (1947) and Erez and Lavee (1971) concluded that simply adding all hours at or below a certain temperature would not be sufficiently accurate. Richardson et al. (1974) shared this concept and began using a method delineating chill units instead of chilling hours. In calculating chill units, the smaller effect a temperature has in breaking dormancy, the lower its chill unit value is. Consequently, more hours are needed at less effective temperatures in order to produce the same response as more effective temperatures. Richardson et al.'s (1974) model is known as the Utah Chill Unit Model.

Hall and McPherson (1997) found the accumulation of chill units followed by the accumulation of heat units unsuccessful in predicting budbreak in kiwifruit (*Actinidia deliciosa*). They developed models that were successful for that fruit, based on daily mean temperatures modified by changing weighted averages dependent on the progression of budbreak. McPherson, et al. (1997) found a rapid increase in respiration rate 3 to 6 weeks prior to budbreak in kiwifruit buds. This coincided with developmental changes within the buds. This gas exchange rate could provide a useful index tool to help indicate when the chilling requirement of a plant is met.

Chilling hour calculations are still commonly used in many parts of the country. In Alabama, Powell et al. (1999) proposed using a Modified-45 chilling hour model. The Modified-45 model uses a complex method for determining when dormancy begins in the fall and counts hours below 7.2E C (45E F) as chilling hours. Although this model does not take into account the negative effect of high temperatures on chilling accumulation and also counts hours below 0E C (32E F), it has proven superior to the Utah and other models in measuring chilling for fruit crops under Alabama conditions. The Old-45 model is still widely used and is similar to the Modified-45 model (Powell et al., 1999). However, the Old-45 measures hours below 7.2E C (45E F) after October 1; therefore, a difference in the number of chilling hours calculated will exist based on which model is employed. In Auburn, Alabama for example, by December 15, 1999, 215 hours of chilling had accumulated using the Old-45 model, but only 100 hours using the Modified-45 model (Alabama Weather Information Service, www.awis.com, 2006).

Duration of chilling is important and varies from region to region across the United States. Generally, the greater the number of chilling hours received by a plant, the

more rapidly budbreak will occur (Dokoozlian, 1999; Murray et al., 1989; Webb, 1977; Wilson et al., 2002a; 2002b; 2003; 2004). Often the amount of chilling required by a plant species to break endodormancy is affected by its provenance. Perry and Hellmers (1973) demonstrated the influence of provenance in a study of two races of red maple, one from Florida and the other from Massachusetts. When exposed to dormancy inducing conditions (8 hour photoperiod, 20EC day, 4EC night), the Massachusetts race began to develop red foliage after 10-15 days. The Florida race continued to grow and form new leaves regardless of photoperiod and temperature. Older leaves of the Florida trees did senesce and abscise in response to the low night temperatures, but the axillary buds of the abscised leaves began to elongate and break within 10 days of abscission. Buds of the Massachusetts race did not renew growth until exposed to 2 months or more of a continuous 4E C (39.2E F) chilling treatment. Grafted trees having both races showed the same results. This information suggests that taxa of plants that originate from different geographic areas will demonstrate different chilling requirements to break endodormancy. “The differential behavior of buds of the two races and the independent behavior of the stock and scion on interracial grafts indicate that the development of internal rest and cold resistance is mediated by local biochemical processes within the tissues.”

A plant that is grown in an area where it will not receive a sufficient amount of chilling will exhibit some predictable effects. Some of these effects are delayed foliation (prolonged period of opening of buds within and among shoots) and poor shoot growth (Cook and Jacobs, 1999; Skinner, 1964). Cook and Jacobs (1999) noted that opening of the terminal bud in apple (*Malus x domestica* Borkh.) trees with insufficient chilling is

slow, giving trees an increased tendency toward basal dominance. Slow breaking of the terminal bud and dominance of lateral buds has been demonstrated with basswood (*Tilia americana* L.) (Ashby, 1962) and silver maple (*Acer saccharinum* L.), (Ashby et al., 1991) as well as other tree species, signifying that terminal buds may have a higher chilling requirement than lateral buds. It should be noted that this might not hold true for some tree species. Scalabrelli and Couvillion (1986) found that lateral vegetative buds of >Redhaven= peach (*Prunus persica* L. 'Redhaven') exposed to 600 chilling hours at 2, 3 and 7.2E C (35.6, 37.4 and 45E F) had a much lower percentage budbreak than terminal vegetative buds subjected to the same treatments.

Prolonged exposure to chilling temperatures after the chilling requirement has been satisfied will also generate noticeable effects. A common result is that budbreak will occur at a rapid rate when plants are exposed to favorable conditions. Couvillon and Erez (1985) suggested that prolonged chilling exposure reduces the heat requirement for budbreak. This suggestion is further supported by Scalabrelli and Couvillion (1986).

There are also observable differences in natural chilling versus artificial chilling or cold storage. Ritchie (1987) noted that trees placed in cold storage are no longer exposed to natural environmental factors, like fluctuating temperatures and photoperiod, that provide energy for growth and drive biochemical reactions. Trees in cold storage are typically exposed to low, constant temperatures, no light, and high relative humidity. Dormancy release has been shown to occur at a much slower rate in cold stored trees compared to naturally chilled trees. Walser et al. (1981) observed that under normal environmental conditions, 'Gleason Elberta' peach (*Prunus persica* L. 'Gleason Elberta') peach leaf buds required 790 chill units to break endodormancy. Trees receiving artificial

cold treatments required between 1345 and 1395 chill units. They concluded that the difference resulted from using constant (cold storage) rather than fluctuating (natural) temperatures. Kriebel and Wang (1962) made note of a similar response in sugar maple. Maples were first grown from seed collected from different geographical locations. Representative trees from the different provenances were grown at Florida and Ohio sites. The trees grown in Florida required fewer chilling hours than their counterparts in Ohio. Temperatures in Florida fluctuated widely during the winter months while those in Ohio remained consistently cold.

It is widely accepted that chilling is an integral part of endodormancy release in plants. However, while the mechanisms are not fully understood, some budbreak can occur in the absence of chilling (Gianfanga and Mehlenbacher, 1985; Herter et al., 1993; Mauget and Rageau, 1988). Consequently, chilling could be considered a facultative and not an absolute requirement for budbreak (Dokoozlian, 1999) for some species.

Other factors play a part in endodormancy release in some trees. Garber (1983) and Ruter et al. (1994) noted that photoperiod affected endodormancy release in loblolly pine (*Pinus taeda* L.) and dogwood (*Cornus florida* L.), respectively, although the effect decreased with increased chilling hours. The major role of photoperiod, however, is believed to be induction of dormancy by combining with low, above freezing temperatures (Howe et al., 1999).

Wood and Hanover (1981) observed that complete defoliation induced summer budbreak in sugar maples. The presence of a single leaf at any location on the stem was enough to maintain bud dormancy, providing evidence of correlative inhibition in sugar maple predormancy, suggesting that leaves produce a budbreak inhibitor. Spiers and

Draper (1974) also noticed a defoliation effect in rabbiteye blueberry (*Vaccinium ashei* Reade), where fall defoliation before chilling treatments was able to hasten vegetative budbreak. Plants not defoliated prior to treatment had a longer rest period. In other species, drought and high temperatures can stimulate vegetative and floral budbreak in late summer (Kaya et al., 1994). However, while other factors may play a role in budbreak, temperature is considered the major environmental factor controlling endodormancy release through chilling (Howe et al., 1999).

While many studies have documented variability in growth and performance (Sibley et al., 1995; Ruter and Sibley 2000; Witte et al., 1996; 1997), and differences in chilling requirement among races of red maple (Perry and Wu, 1960; Townsend et al., 1982), there have been few reports on the chilling requirements of individual red maple cultivars (Wilson et al., 2002a).

The objectives of this research were to (1) determine the response on budbreak of red maples to natural (ambient) chilling versus constant (forced) chilling; (2) determine the influence of forced chilling on budbreak of red maple at various refrigeration unit settings; and (3) determine the impact of incremental chilling totals on budbreak of red maples at various refrigeration unit settings. This research is needed to continue development of a model for regional planting recommendations of red maple, as has been done for many deciduous fruit trees (Childers et al., 1995; Westwood, 1993). Additionally, this research will provide growers with information that can be used to modify lifting, storage, and transplanting schedules.

Literature Cited

- Amen, R. D. 1968. A model of seed dormancy. *Bot. Rev.* 34:1-31.
- Anderson, J. V., W. S. Chao, and D.P. Horvath. 2001. A current review on the regulation of dormancy in vegetative buds. *Weed Science* 49:581-589.
- Ashby, W. C. 1962. Bud break and growth of basswood as influenced by daylength, chilling, and gibberellic acid. *Bot. Gaz.* 123:162-170.
- Ashby, W. C., D. F. Bresnan, C. A. Huetteman, J. E. Preece, and P. L. Roth. 1991. Chilling and budbreak in silver maple. *J. Environ. Hort.* 9:1-4.
- Avery, G. S., Jr. and E. B. Johnson. 1947. *Hormones and Horticulture*. McGraw-Hill Book Co., New York, NY.
- Childers, N. F., J. R. Morris, and G. S. Sibbett. 1995. *Modern Fruit Science: Orchard and Small Fruit Culture*. Horticultural Pub., Gainesville, FL.
- Cook, N. C. and G. Jacobs, 1999. Suboptimal winter chilling impedes development of acrotony in apple shoots. *HortScience* 34:1213-1216.
- Couvillon, G. A. and A. Erez. 1985. Influence of prolonged exposure to chilling temperatures on budbreak and heat requirement for bloom of several fruit tree species. *J. Amer. Soc. Hort. Sci.* 110:47-50.
- Crocker, W. 1948. *Growth of Plants*. Reinhold Publishing, New York, NY.
- Curtis, O. F. and D. G. Clark. 1950. *An Introduction to Plant Physiology*. McGraw-Hill Book Co., New York, NY.
- Dennis, F. G. 1994. Dormancy- what we know (and don't know). *HortScience* 29:1249-1255.
- Dirr, M. A. 1998. *Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses*. Stipes Publishing, Champaign, IL.
- Dokoozlian, N. K. 1999. Chilling temperature and duration interact on budbreak of >Perlette= grapevine cuttings. *HortScience* 34:1054-1056.
- Erez, A. and G. A. Couvillon. 1982. The effect of climatic conditions on breaking the rest in peach buds: a reassessment of chilling requirement. In: *Abstr. 21st Intern. Hort. Congr.*, Vol. 1, Hamburg, p. 1142.

- Erez, A. and S. Lavee. 1971. The effect of climatic conditions on dormancy development of peach buds. 1. Temperature. *J. Amer. Soc. Hort. Sci.* 96:711-714.
- Garber, M. P. 1983. Effects of chilling and photoperiod on dormancy-release of container-grown loblolly pine seedlings. *Can. J. For. Res.* 13:1265-1270.
- Gianfanga, T. J. and S. A. Mehlenbacher. 1985. Importance of heat requirement for budbreak and time of flowering in apple. *HortScience* 20:909-911.
- Gilbreath, P. R. and D. W. Buchanan. 1981. Rest prediction model for low-chilling >Sungold= nectarine. *J. Amer. Soc. Hort. Sci.* 106:426-429.
- Hall, A. J. and H. G. McPherson. 1997. Modelling the influence of temperature on the timing of bud break in kiwifruit. *Acta Hort.* 444:401-406.
- Herter, F. G., J. C. Mauget, R. Rageau, and M. Bonhomme. 1993. Effect of a short treatment at high temperature (45E C) on the release from dormancy in cold-deprived apple trees. *C. R. Acad. Sci. Paris, t. 316, Serie III*:315-321.
- Howe, G. T., J. Davis, Z. Jeknic, T. H. H. Chen, B. Frewen, H.D. Bradshaw, Jr., and P. Saruul. 1999. Physiological and genetic approaches to studying endodormancy-related traits in *Populus*. *HortScience* 34:1174-1184.
- Kaya, Z., W. T. Adams, and R. K. Campbell. 1994. Adaptive significance of intermittent shoot growth in Douglas-fir seedlings. *Tree Physiology* 14:1277-1289.
- Kielbaso, J. J. 1990. Trends and issues in city forests. *J. Arboric.* 16:69-76.
- Kriebel, H. B. and C. W. Wang. 1962. The interaction of provenance and degree of chilling in bud-break of sugar maple. *Silv. Gen.* 11:125-130.
- Lang, G. A., J. D. Early, G. C. Martin, and R. L. Darnell. 1987. Endo-, para-, and ecodormancy: Physiological terminology and classification for dormancy research. *HortScience* 22:371-377.
- Lechowicz, M. J. 1984. Why do temperate deciduous trees leaf out at different times? Adaptation and ecology of forest communities. *Amer. Naturalist* 124:821-842.
- Mauget, J. C. and R. Rageau. 1988. Bud dormancy and adaptation of apple trees to mild winter climates. *Acta Hort.* 232:101-108.
- McPherson, H. G., W.P. Snelgar, P. J. Manson, and A.M. Snowball. 1997. Bud respiration and dormancy of kiwifruit (*Actinidia deliciosa*). *Annals Bot.* 80:411-418.
- Murray, M. B., M.G.R. Cannell, and R.I. Smith. 1989. Date of budburst of fifteen tree

- species in Britain following climatic warming. *J. Applied Ecology* 26:693-700.
- Olmsted, C. E. 1951. Experiments on photoperiodism, dormancy, and leafage and abscission in sugar maple. *Bot. Gaz.* 112:365-393.
- Perry, T. O. and H. Hellmers. 1973. Effects of abscisic acid on growth and dormancy of two races of red maple. *Bot. Gaz.* 134:283-289.
- Perry, T. O. and W. L. Wu. 1960. Genetic variation in the winter chilling requirement for date of dormancy break for *Acer rubrum*. *Ecology* 41:790-794.
- Powell, A., D. Himelrick, W. Dozier, and D. Williams. 1999. Fruit culture in Alabama-winter chilling requirements. *Ala. Coop. Ext. Sys. Bull.* ANR-53-D.
- Richardson, E. A., S. D. Seeley, and D. R. Walker. 1974. A model for the completion of rest for >Redhaven= and >Elberta= peach trees. *HortScience* 9:331-332.
- Ritchie, G. A. 1987. Some effects of cold storage on seedling physiology. *Tree Planters= Notes* 38:11-15.
- Romberger, J. A. 1963. Meristems, growth, and development in woody plants. U.S. Dept. Agric. Forest Serv. Tech. Bull. 1293.
- Rowland, L. J., E. L. Logan, R. Arora, C. C. Lira, J. S. Lehman, A. Levi, and G.R. Panta. 1999. Use of blueberry to study genetic control of chilling requirement and cold hardiness in woody perennials. *HortScience* 34:1185-1191.
- Ruter, J. M., M. P. Garber, and D. J. Moorhead. 1994. Early lifting and transplanting of flowering dogwood seedlings increases survival in the southern United States. *J. Environ. Hort.* 12:164-166.
- Ruter, J. M. and J. L. Sibley. 2000. Performance of red maple selections in southern Georgia. *HortTechnology* 10:621-625.
- Ruter, J.M., J.L. Sibley, and M.A. Dirr. 1998. Red maple selections for the Southeastern United States. *Georgia Green Ind. Assoc. Journal* 9(2):16-20.
- Samish, R. M. 1954. Dormancy in woody plants. *Ann. Rev. Plant Physiol.* 5:183-204.
- Saure, M. C. 1985. Dormancy release in deciduous fruit trees. *Hort. Rev.*, Vol.7:239-300.
- Scalabrelli, G., and G. A. Couvillon. 1986. The effect of temperature and bud type on rest completion and the GDHEC requirement for budbreak in >Redhaven= peach. *J. Amer. Soc. Hort. Sci.* 111:537-540.

- Seeley, S. D. 1994. Dormancy-the black box. *HortScience* 29:1248.
- Sibley, J. L., D. J. Eakes, C. H. Gilliam, G. J. Keever, and W. A. Dozier, Jr. 1995. Growth and fall color of red maple selections in the southeastern United States. *J. Environ. Hort.* 13:51-53.
- Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1999a. Bark anthocyanin levels differ with location in cultivars of red maple. *HortScience* 34:137-139.
- Sibley, J. L., J. M. Ruter, and D. J. Eakes. 1999b. Growth periodicity for container-grown red and Freeman maple cultivars in AHS heat-zone 8. *J. Environ. Hort.* 17:141-146.
- Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1998. Differences in growth of container-grown red maple cultivars in different hardiness zones. *J. Environ. Hort.* 16:130-134.
- Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1997. Multiple location differences in growth of red maple 'October Glory'. *HortTechnology* 7:258-260.
- Skinner, E. J. 1964. Delayed foliation. *Decid. Fruit Grower* 14:195-197.
- Sorenson, E., C. F. Williams, R. H. Walser, J. D. Davis, and P. Barker. 1984. Growth response of *Acer grandidentatum* Nutt. to chilling treatments. *J. Environ. Hort.* 2:128-130.
- Spiers, J. M. and A. D. Draper. 1974. Effect of chilling on bud break of rabbiteye blueberry. *J. Amer. Soc. Hort. Sci.* 99:398-399.
- Sternberg, G. and J. Wilson. 1995. *Landscaping With Native Trees*. Chapters Publishing, Shelburne, VT.
- Townsend, A. M. and L. W. Douglass. 1998. Evaluation of various traits of 40 selections and cultivars of red maple and Freeman maple growing in Maryland. *J. Environ. Hort.* 16:189-194.
- Townsend, A. M., J. W. Wright, W. F. Beineke, R. P. Guries, and C. A. Mohn. 1982. Early patterns of flowering, winter injury, and flushing of red maple progenies grown in five locations. *Can. J. For. Res.* 12:814-821.
- Walser, R. H., D. R. Walker, and S. D. Seeley, 1981. Effect of temperature, fall defoliation, and gibberellic acid on the rest period of peach leaf buds. *J. Amer. Soc. Hort. Sci.* 106:91-94.
- Weaver, R. J. and K. Iwasaki. 1977. Effect of temperature and length of storage, root growth, and termination of bud rest in 'Zinfandel' grapes. *Amer. J. Enol. Viticult.*

28:149-151.

Webb, D. P. 1977. Root regeneration and bud dormancy of sugar maple, silver maple, and white ash seedlings: effects of chilling. *Forest Sci.* 23:474-483.

Westwood, M. N. 1993. *Temperate Zone Pomology: Physiology and Culture*. Umber Press, Portland, OR.

Wilson, B. C., J. L. Sibley, J. E. Altland, E. H. Simonne, and D. J. Eakes. 2002a. Chilling and heat unit levels affect foliar budbreak of selected red and Freeman maple cultivars. *J. Arboric.* 28:148-152.

Wilson, B. C., J. L. Sibley, and J. E. Altland. 2002b. Chilling duration affects foliar budbreak of Linden cultivars. *HortTechnology* 12:660-662.

Wilson, J. C., J. E. Altland, J. L. Sibley, K. M. Tilt, and W. G. Foshee, III. 2003. Chilling affects budbreak of *Ginkgo biloba* L. *J. Environ. Hort.* 21:153-158.

Wilson, J. C., J. E. Altland, J. L. Sibley, K. M. Tilt, and W. G. Foshee, III. 2004. Effects of chilling and heat on growth of *Ginkgo biloba* L. *J. Arboric.* 30:45-51.

Wilson, J. C., J. L. Sibley, J. E. Altland, K. M. Tilt, and W. G. Foshee, III. 2002c. Impact of chilling on *Ginkgo biloba* L. *Comb. Proc. Intl. Plant Prop. Soc.* 52:571-575.

Witte, W. T., R. Sauve, M. T. Mmbaga, and P. C. Flanagan. 1996. Maple evaluations at TSU-NCRS. *Proc. South. Nurs. Assoc. Res. Conf.* 41:385-392.

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Wood, B. W. and J. W. Hanover. 1981. Environmental control of sugar maple seedling growth. *Research Report- Michigan State University Agr. Exp. Sta., Jan.* 1981:1-10.

Young, L. C. T., J. T. Winneberger, and J. P. Bennett. 1974. Growth in resting buds. *J. Amer. Soc. Hort. Sci.* 99:146-149.

CHAPTER II
AMBIENT VERSUS FORCED
CHILLING OF RED MAPLE

Abstract

The percent of budbreak in container-grown red maple (*Acer rubrum* L.) trees that were chilled in a 7E C (45° F) refrigerated structure was compared to red maple trees that were chilled naturally outdoors. The experiment was carried out during the fall of 2002 and the winter and spring of 2003. After receiving 400 ambient chilling hours outdoors (to ensure dormancy and complete defoliation), starting December 10th 2002, the red maple trees received an additional 200, 400, or 600 chilling hours in either outdoors (ambient) or in a refrigeration unit (forced) set at 7 C (45 F). After receiving the assigned hours of chilling, trees were moved to a greenhouse at 22 C (72 F) beginning December 19th 2002. In January of 2003, percent budbreak was visually determined by judging the total number of buds per tree likely to break bud and of those buds, in a 5 percent increment, what percent had broken bud. These data were recorded every four days until all buds likely to break bud had actually broken. June 9th 2003, after all trees had completed budbreak, the trees were moved out of the greenhouse and placed outdoors under irrigation.

Additional Index Words. dormancy, endodormancy, cold storage

Introduction

Red maple (*Acer rubrum* L.), a popular ornamental tree, is found naturally in the forests of eastern North America, ranging from southeastern Manitoba across southern Canada to Quebec and south through Florida, with a western limit of Minnesota and south through Illinois and Indiana (Sternberg and Wilson, 1995). Kielbaso (1990) and Townsend and Douglass (1998) indicated that red maple is one of the most frequently planted landscape trees in the United States. This trend continues today, as evidenced by the availability of more than 60 red and Freeman maple (*Acer x freemanii* E. Murray) cultivars (Dirr 1998; J. Sibley, pers. comm.). The list of taxa grows every year, as red maple is prized for shade provided and exceptional fall coloration.

Research suggests that performance of red maple cultivars can vary greatly depending upon provenance or area of origin. Sibley et al. (1995) demonstrated this difference in red maple cultivars from different provenances grown at Camp Hill, Alabama. In this study, growth and fall color of the cultivars were observed. Considerable variation was shown in fall color, color duration, and time of peak fall color. Sibley et al. (1999b) indicated that red maple is a good candidate for regional selection. In studies in the southeast United States, cultivars exhibited substantial differences in regional adaptability based on height, stem diameter, canopy width, leaf retention, fall color, and root growth (Ruter et al., 1998; Ruter and Sibley, 2000; Sibley et al., 1997, 1998, 1999a, 1999b).

Because dormancy is not a uniform, static state in plant development, but covers a range of physiological conditions, several phases of dormancy can be differentiated (Saure 1985). Temperatures effective in releasing endodormant buds from dormancy in woody plants are variable. In Olmsted's (1951) work with sugar maple, temperature

values below 5-8EC (41-46EF) were effective in dormancy release. Murray et al. (1989) made the assumption that all species detect days cooler than 5EC (41EF) as chill days and those warmer than 5EC (41EF) as promoting growth. Curtis and Clark (1950) mentioned an effective range from 0-6EC (32-43EF). Crocker (1948) stated that 0-10EC (32-50EF) was effective but higher temperatures and temperatures below freezing were not, while Rowland et al. (1999) maintained that chill units accumulate in the 0-7EC (32-45EF) range.

While many studies have documented variability in growth and performance (Sibley et al., 1995; Ruter and Sibley 2000; Witte et al., 1996; 1997), and differences in chilling requirement among races of red maple (Perry and Wu, 1960; Townsend et al., 1982), there have been few reports on the chilling requirements of individual red maple cultivars (Wilson et al., 2002a). The objective of this research is to determine the response on budbreak of red maples to natural (ambient) chilling versus constant (forced) chilling. This research will contribute to the development of a model for regional planting recommendations for red maple taxa as has been done for many deciduous fruit trees (Childers et al., 1995; Westwood, 1993). Additionally, this research will provide growers with information that can be used to modify lifting, storage, and transplanting schedules. In the studies reported on here, one hour at 22EC (72EF) in the greenhouse was considered one heat unit to be consistent with prior research published on chilling of fruit trees. Chilling hours were determined with a Modified-45 Model (Powell et al., 1999) for consistency with prior chilling studies of woody ornamentals at Auburn Alabama.

The Modified -45 model has proven to be superior to the Utah model in predicting budbreak in fruit crops in Alabama. This model uses a complicated method to determine when chilling hours begin to accumulate in the fall, unlike the Old-45 Model (Powell et al., 1999), which measures all hours below 7° C (45° F) after the first day of October. The Modified-45 Model counts chilling hours below 0° C (32° F) and does not take offsetting negative effects of high temperatures on chilling hour accumulation into account.

Materials and Methods

Red maple trees were received as 0.91 m to 1.2 m (3 to 4 ft.) bare root whips from J. Frank Schmidt and Son Nurseries, Boring, Oregon in January 2001 and potted to 3.8 L (1 gal) containers, in a 6:1 pinebark:sand substrate amended with 3 kg/m³ (5 lb/yd³) dolomitic limestone, 0.9 kg/m³ (1.5 lb/yd³) Micromax (The Scotts Co., Marysville, Ohio) and 6.3 kg/m³ (11.1 lb/yd³) 18N-6P-12K Osmocote (The Scotts Co.). In the fall of 2002, the year trees were potted into 11.4 L (3 gal) containers using the same substrate components. Initially all trees were grown outdoors with overhead irrigation using standard nursery practices at the Paterson Greenhouse Complex at Auburn, Alabama.

After receiving 400 ambient chilling hours outdoors (to ensure dormancy and complete defoliation), red maple trees received additional 200, 400, or 600 chilling hours in either outdoors (ambient) or in a refrigeration unit (forced) set at 7 C (45 F). The refrigeration unit is 5 m x 5 m x 2.5 m (16 ft. x 16 ft. x 8 ft.) and was custom made with no supplemental lighting.

After receiving the assigned hours of chilling, trees were moved to a greenhouse at 22° C (72° F) beginning December 19th 2002. Starting January 24th of 2003, percent budbreak was visually determined by judging the total number of buds per tree likely to break bud and of those buds, in a 5 percent increment, what percent had broken bud. These data were recorded every four days until all buds likely to break bud had actually broken bud. June 9th 2003, after all trees had completed budbreak, the trees were moved out of the greenhouse and placed outdoors under irrigation. Budbreak was considered to be the point where overlapping bud scales began to separate, revealing leaf tips.

All trees were hand watered and weeded as needed. All chilling hours were determined with the Modified-45-Model (Powell et al., 1999). In the greenhouse, one hour at 22°C (72° F) was considered to be one heat unit.

This study was conducted using a Randomized Complete Block Design (RCBD) with 6 blocks. Treatments were composed of two experimental factors, chilling type (ambient temperature and forced temperature) and chilling hours (600, 800, and 1000 hours), in a 2 × 3 factorial arrangement.

Effects of the qualitative variable, chilling type, and the quantitative variable, chilling hours, on the percent of budbreak were analyzed using a linear model. Statistical analysis was conducted with the GLM procedure of SAS (SAS Version 9.1, SAS Institute, Cary, NC) with data from each tree included as repeated measures. The interaction between chilling type and chilling hours was found to be nonsignificant ($p > 0.1500$), and so it was excluded from the final model. The final multivariate model included the terms block, chilling type, and chilling hours, with repeated measures by day for the response variable of percent budbreak.

Results and Discussion

Results for the within-tree effects indicate that the effect on percent budbreak by day was significant, with the effect of day being notably different depending on block, but not chilling type or chilling hours (Table 1). Results for the between-tree effects indicate that percent budbreak was not affected by chilling type or chilling hours.

Generally speaking, trees from both treatments, forced chilling and ambient chilling, exhibited a normal budbreak after being placed into the greenhouse. Foliage emerged from the broken buds and appeared healthy and one could not visually distinguish a difference between the set of forced chilled trees and the set of ambient chilled trees. (Figures 1, 2, 3).

Looking at a comparison of the 3 forced chilling treatments of 600, 800, and 1000 hours respectively, no differences are indicated in the percent budbreak over time for any of the treatments (Figure 4).

As in the 600, 800 and 1000 hour forced chilling treatments, no differences in the percent budbreak over time is indicated for any of the 600, 800, and 1000 hour ambient chilled treatments (Figure 5).

Our study indicates that forced chilling produced similar percent budbreak response compared to ambient chilling, which suggests that southern tree growers can produce northern red maple taxa in southern climates, dig and chill, then sell to northern growers. Our study also indicates a cost savings to southern tree growers who are force chilling red maple trees in refrigerated structures. By reducing the time the trees remain in the refrigerated structure and chilling at higher temperatures less expensive

refrigeration equipment can be used and energy cost can be reduced.

Results for the within-tree effects indicate that the effect of day on percent budbreak was significant as heat units accumulated after chilling requirement in the red maple trees had been met (Table 1). There was no indicated correlation within-trees on chilling type or chilling hours suggesting that for the red maple trees studied 600 forced or ambient chilling hours at 7EC (45EF) or below was sufficient to meet the trees chilling requirement given a sufficient number of heat units for budbreak. Results for the between-tree effects indicate that percent budbreak was not influenced by chilling type (ambient chilling versus forced chilling at a temperature of 7EC (45EF) or chilling hours of (600, 800 1000 hours forced and ambient).

Literature Cited

- Childers, N. F., J. R. Morris, and G. S. Sibbett. 1995. Modern Fruit Science: Orchard and Small Fruit Culture. Horticultural Pub., Gainesville, FL.
- Crocker, W. 1948. Growth of Plants. Reinhold Publishing, New York, NY.
- Curtis, O. F. and D. G. Clark. 1950. An Introduction to Plant Physiology. McGraw-Hill Book Co., New York, NY.
- Dirr, M. A. 1998. Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses. Stipes Publishing, Champaign, IL.
- Murray, M. B., M.G.R. Cannell, and R.I. Smith. 1989. Date of budburst of fifteen tree species in Britain following climatic warming. *J. Applied Ecology* 26:693-700.
- Olmsted, C. E. 1951. Experiments on photoperiodism, dormancy, and leafage and abscission in sugar maple. *Bot. Gaz.* 112:365-393.
- Perry, T. O. and W. L. Wu. 1960. Genetic variation in the winter chilling requirement for date of dormancy break for *Acer rubrum*. *Ecology* 41:790-794.
- Powell, A., D. Himelrick, W. Dozier, and D. Williams. 1999. Fruit culture in Alabama-winter chilling requirements. *Ala. Coop. Ext. Sys. Bull.* ANR-53-D.
- Rowland, L. J., E. L. Logan, R. Arora, C. C. Lira, J. S. Lehman, A. Levi, and G.R. Panta. 1999. Use of blueberry to study genetic control of chilling requirement and cold hardiness in woody perennials. *HortScience* 34:1185-1191.
- Ruter, J. M. and J. L. Sibley. 2000. Performance of red maple selections in southern Georgia. *HortTechnology* 10:621-625.
- Ruter, J.M., J.L. Sibley, and M.A. Dirr. 1998. Red maple selections for the Southeastern United States. *Georgia Green Ind. Assoc. Journal* 9(2):16-20.
- Saure, M. C. 1985. Dormancy release in deciduous fruit trees. *Hort. Rev.*, Vol.7:239-300.
- Sibley, J. L., D. J. Eakes, C. H. Gilliam, G. J. Keever, and W. A. Dozier, Jr. 1995. Growth and fall color of red maple selections in the southeastern United States. *J. Environ. Hort.* 13:51-53.
- Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1999a. Bark anthocyanin levels differ with location in cultivars of red maple. *HortScience* 34:137-139.

Sibley, J. L., J. M. Ruter, and D. J. Eakes. 1999b. Growth periodicity for container-grown red and Freeman maple cultivars in AHS heat-zone 8. *J. Environ. Hort.* 17:141-146.

Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1998. Differences in growth of container-grown red maple cultivars in different hardiness zones. *J. Environ. Hort.* 16:130-134.

Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1997. Multiple location differences in growth of red maple 'October Glory'. *HortTechnology* 7:258-260.

Sternberg, G. and J. Wilson. 1995. *Landscaping With Native Trees*. Chapters Publishing, Shelburne, VT.

Townsend, A. M., J. W. Wright, W. F. Beineke, R. P. Guries, and C. A. Mohn. 1982. Early patterns of flowering, winter injury, and flushing of red maple progenies grown in five locations. *Can. J. For. Res.* 12:814-821.

Westwood, M. N. 1993. *Temperate Zone Pomology: Physiology and Culture*. Umber Press, Portland, OR.

Wilson, B. C., J. L. Sibley, J. E. Altland, E. H. Simonne, and D. J. Eakes. 2002a. Chilling and heat unit levels affect foliar budbreak of selected red and Freeman maple cultivars. *J. Arboric.* 28:148-152.

Witte, W. T., R. Sauve, M. T. Mmbaga, and P. C. Flanagan. 1996. Maple evaluations at TSU-NCRS. *Proc. South. Nurs. Assoc. Res. Conf.* 41:385-392.

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Table 1. Influence of chilling type (Type) and chilling hours (Hours) on the percent budbreak of (*Acer rubrum* L.) over time, utilizing a Randomized Complete Block Design and repeated measures (Day) collected every four days over a 132-day period.

| Effect | <i>p</i> -value ^z |
|----------------|------------------------------|
| Within-trees: | |
| Day | <0.0001 |
| Day × Block | <0.0001 |
| Day × Hours | 0.7648 |
| Day × Type | 0.0968 |
| Between-trees: | |
| Block | 0.0099 |
| Hours | 0.7780 |
| Type | 0.2028 |

^z*P*-values for within-trees effects were obtained using Wilk's Lambda Test. *P*-values for between-trees effects were obtained using *F* tests.

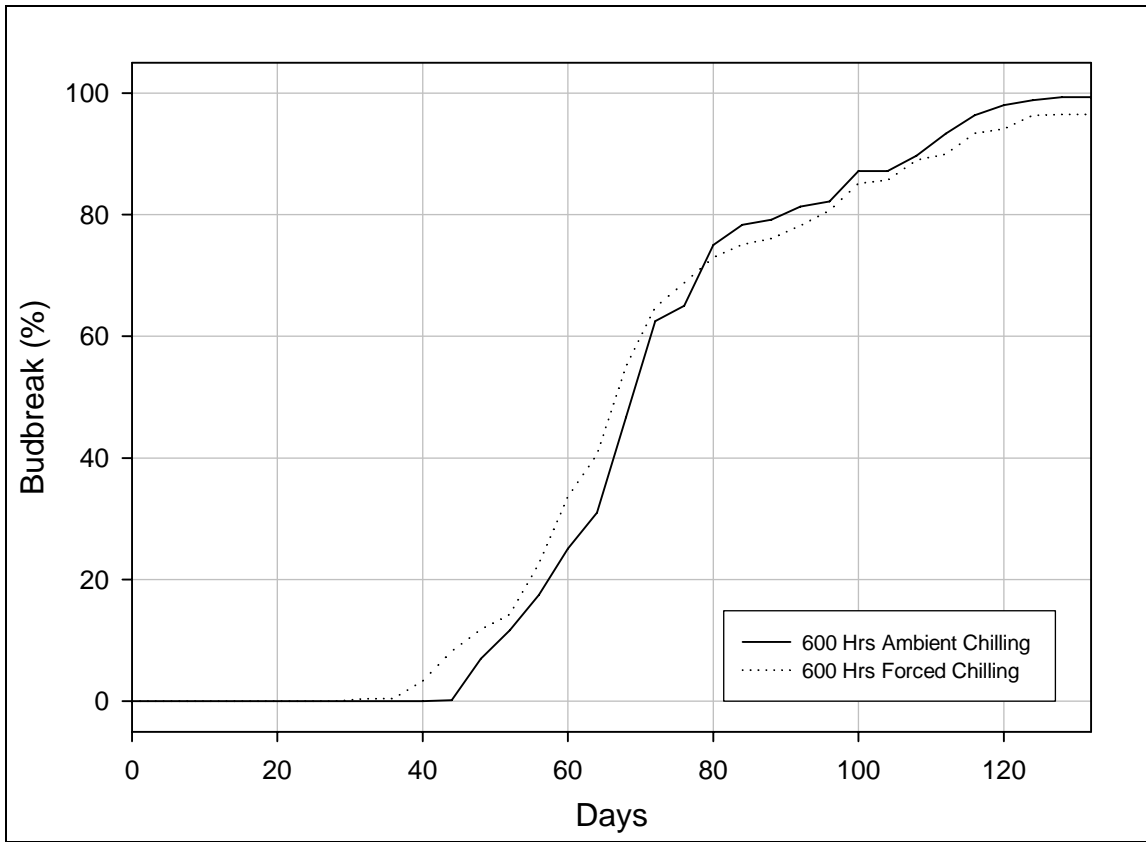


Figure 1. Percent budbreak over time of red maple (*Acer rubrum* L.) in a 22EC (72°F) greenhouse. Graph compares a block of red maples receiving 600 hours of ambient chilling to a block of red maples receiving 600 hours of forced chilling.

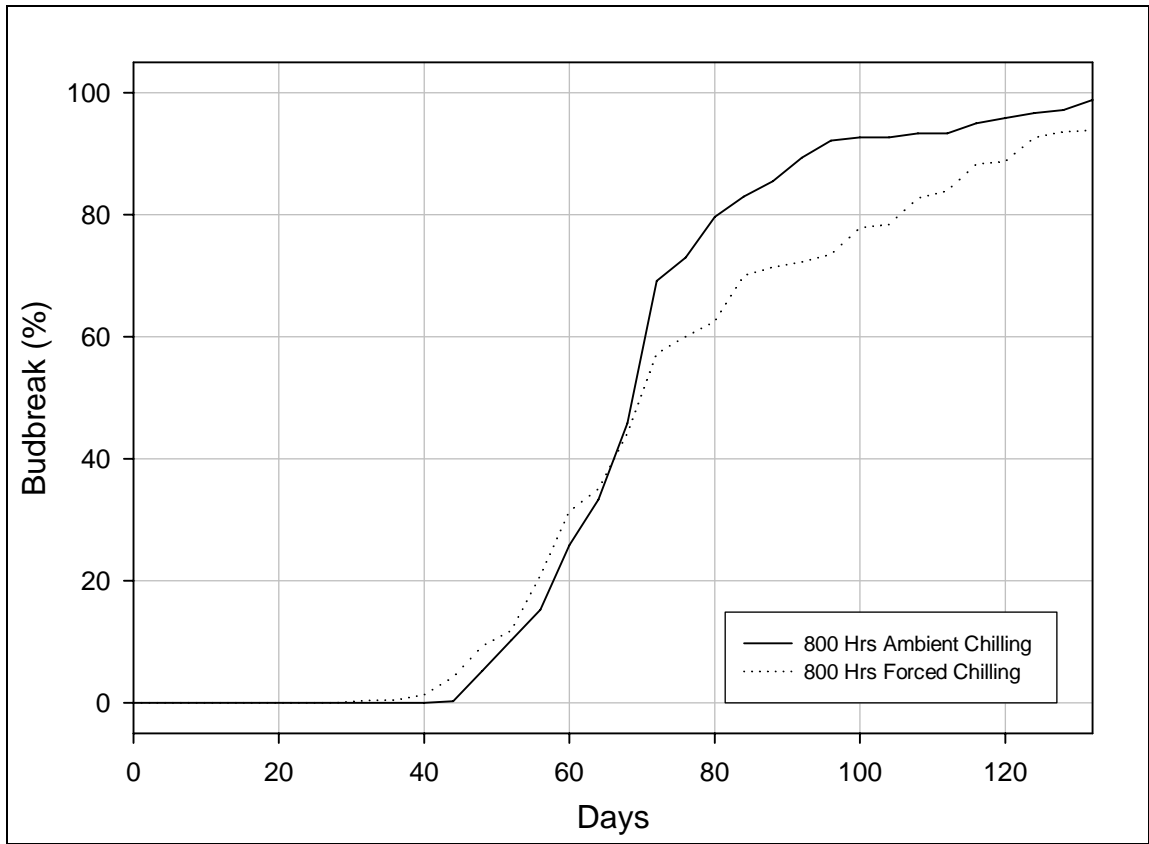


Figure 2. Percent budbreak over time of red maple (*Acer rubrum* L.) in a 22EC (72°F) greenhouse. Graph compares a block of red maples receiving 800 hours of ambient chilling to a block of red maples receiving 800 hours of forced chilling.

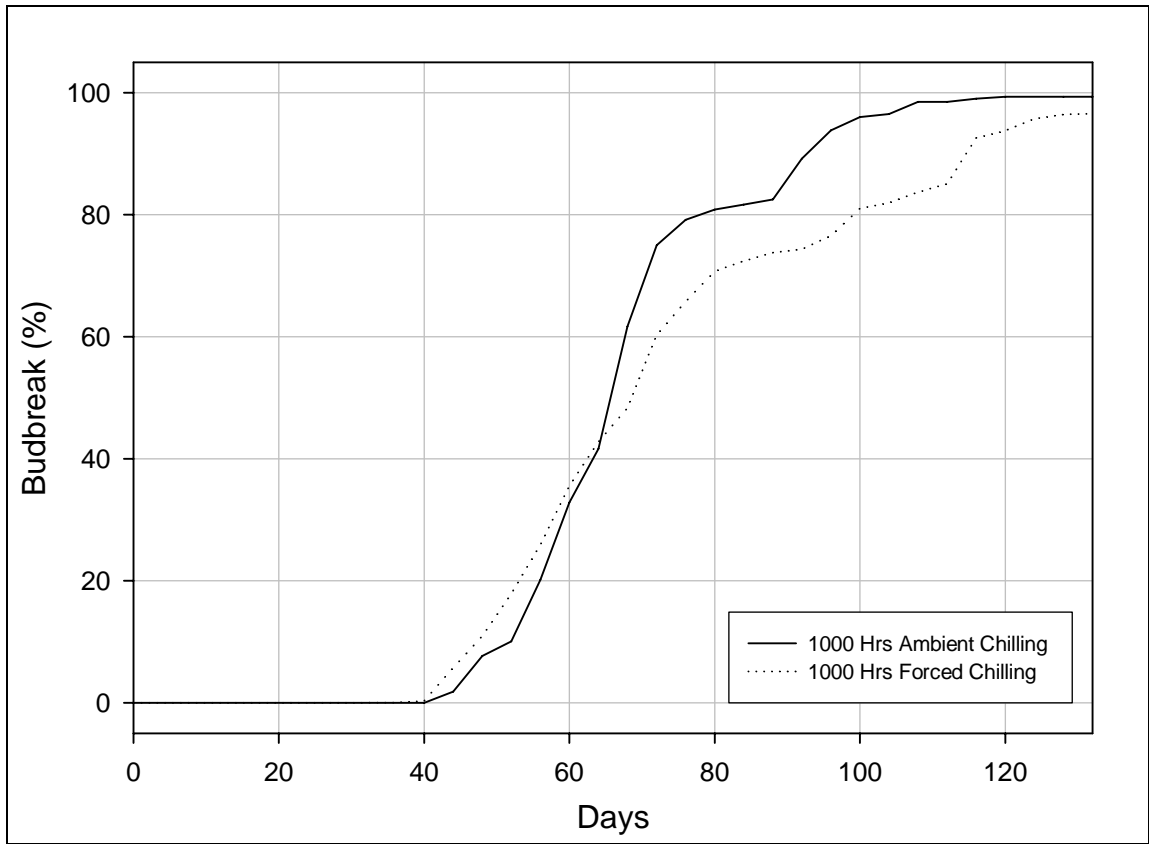


Figure 3. Percent budbreak over time of red maple (*Acer rubrum* L.) in a 22EC (72°F) greenhouse. Graph compares a block of red maples receiving 1000 hours of ambient chilling to a block of red maples receiving 1000 hours of forced chilling.

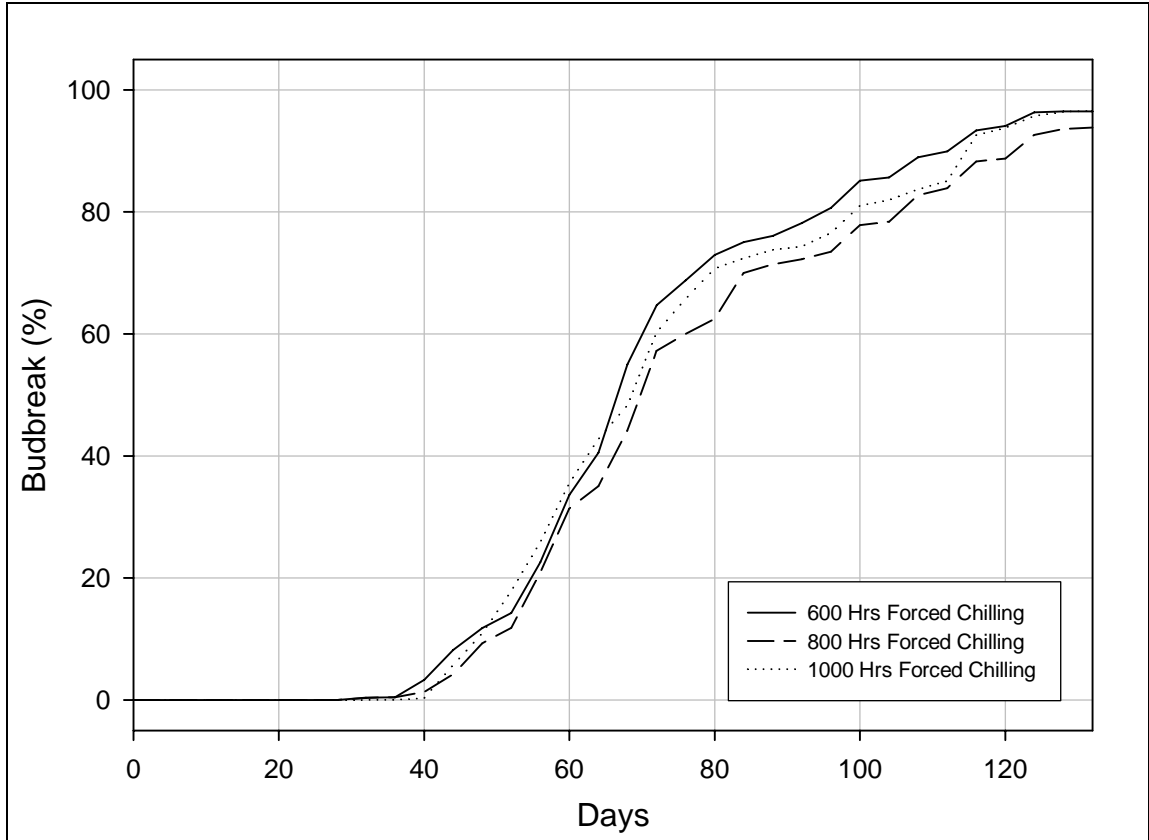


Figure 4. Percent budbreak over time of red maple (*Acer rubrum* L.) in a 22EC (72°F) greenhouse. Graph compares a block of red maples receiving 600 hours of forced chilling to a block of red maples receiving 800 hours of forced chilling and a block of red maples receiving 1000 hours of forced chilling.

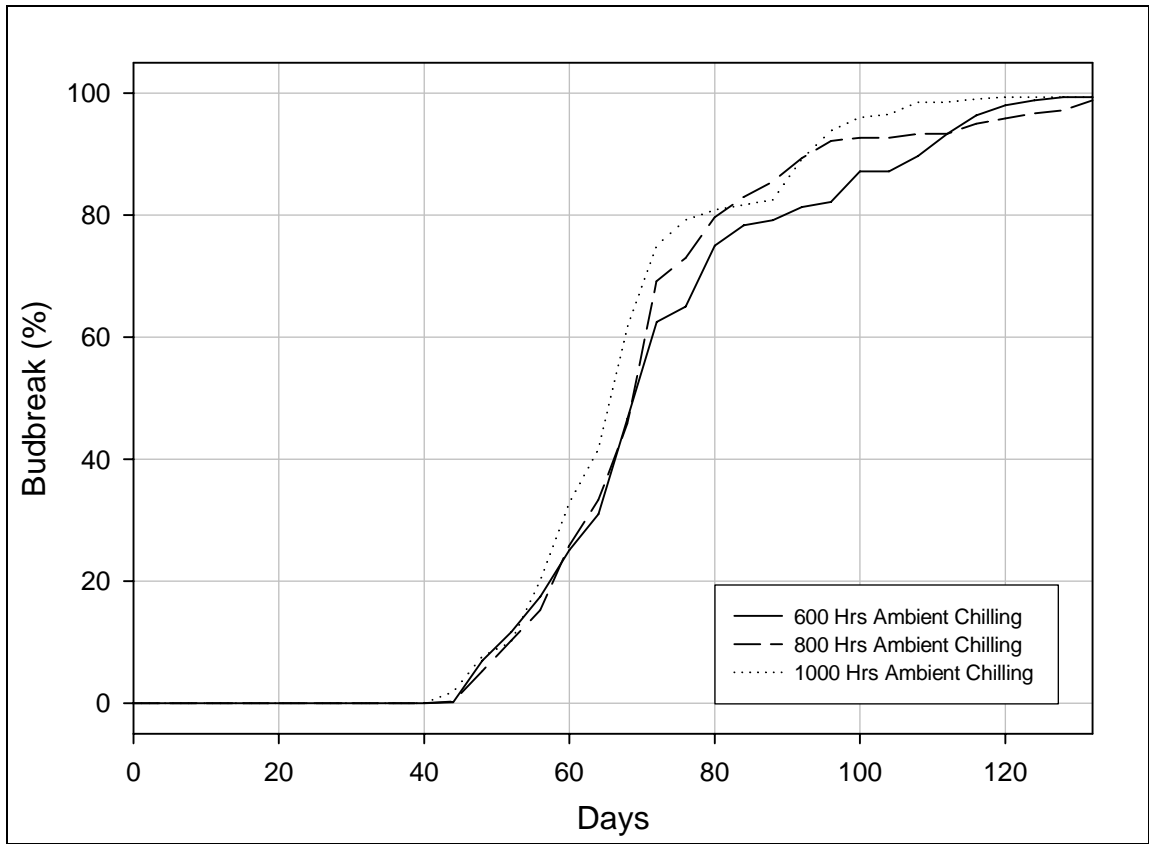


Figure 5. Percent budbreak over time of red maple (*Acer rubrum* L.) in a 22EC (72°F) greenhouse. Graph compares a block of red maples receiving 600 hours of ambient chilling to a block of red maples receiving 800 hours of ambient chilling and a block of red maples receiving 1000 hours of ambient chilling.

CHAPTER III
EFFECTS OF CHILLING TEMPERATURES AND CHILLING
HOURS ON PERCENT BUDBREAK OF RED MAPLE

Abstract

The rate of percent budbreak in container-grown red maple (*Acer rubrum* L.) trees chilled in three refrigeration units with temperature set to 1.7° C, 4.4° C, or 7° C (35, 40, or 45° F) respectively was calculated. The experiment was carried out during the fall of 2002 and the winter and spring of 2003. After receiving 400 ambient chilling hours outdoors (to ensure dormancy and complete defoliation), starting December 10th 2002, the red maple trees received an additional 100, 200, 300, 500, or 600 chilling hours in one of three refrigeration units with temperatures of 1.7° C, 4.4° C, or 7° C (35, 40, or 45° F). After receiving the assigned hours of chilling, trees were moved to a greenhouse at 22 C (72 F) beginning December 19th 2002. In January of 2003, percent budbreak was visually determined by judging the total number of buds per tree likely to break bud and of those buds, in a 5 percent increment, what percent had broken bud. These data were recorded every four days until all buds likely to break bud had actually broken. June 9th 2003, after all trees had completed budbreak, the trees were moved out of the greenhouse and placed outdoors under irrigation.

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lifting, storage, and transplanting schedules. In the studies reported on here, one hour at 22EC (72EF) in the greenhouse was considered one heat unit to be consistent with prior research published on chilling of fruit trees. Chilling hours were determined with a Modified-45 Model (Powell et al., 1999) for consistency with prior chilling studies of woody ornamentals at Auburn Alabama. The Modified -45 model has proven to be superior to the Utah model in predicting budbreak in fruit crops in Alabama. This model uses a complicated method to determine when chilling hours begin to accumulate in the fall, unlike the Old-45 Model (Powell et al., 1999), which measures all hours below 7° C (45° F) after the first day of October. The Modified-45 Model counts chilling hours below 0° C (32° F) and does not take offsetting negative effects of high temperatures on chilling hour accumulation into account.

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Starting January 24th of 2003, percent budbreak was visually determined by judging the total number of buds per tree likely to break bud and of those buds, in a 5 percent increment, what percent had broken bud. These data were recorded every four days until all buds likely to break bud had actually broken bud. June 9th 2003, after all trees had completed budbreak, the trees were moved out of the greenhouse and placed outdoors under irrigation. Budbreak was considered to be the point where overlapping bud scales began to separate, revealing leaf tips.

All trees were hand watered and weeded as needed. All chilling hours were determined with the Modified-45-Model (Powell et al., 1999). In the greenhouse, one hour at 22°C (72° F) was considered to be one heat unit.

The study was conducted as a Randomized Complete Block Design (RCBD) with 18 blocks. Treatments were composed of two experimental factors, chilling temperature (three levels) and chilling hours (eight levels), in a 3 × 8 factorial arrangement. These data were also used to determine the number of days until 50 percent budbreak for each tree.

Effects of the two quantitative variables, chilling temperature and chilling hours, on the percent of budbreak were analyzed using a linear model. Statistical analysis was conducted with the GLM procedure of SAS (SAS Version 9.1, SAS Institute, Cary, NC)

with data from each tree included as repeated measures. Preliminary analyses indicated that transformation of the response variable (percent budbreak) was unnecessary.

Preliminary evaluation of variables in the statistical model examined main effects, interaction, and quadratic terms in order to select a final model. Interaction between chilling temperature and chilling hours was found to be nonsignificant ($p > 0.1000$), and so was excluded from the final model. A quadratic term for chilling hours was found to be significant. The final multivariate model included the terms Block, Temp, Hours, and Hours \times Hours, with repeated measures by day for the response variable of percent budbreak.

Effects of chilling temperature and chilling hours on number of days to 50 percent budbreak were analyzed using a generalized linear model with a negative binomial distribution and a log link. Statistical analysis was conducted with the GENMOD procedure of SAS. Preliminary evaluation determined that neither the interaction term nor quadratic terms were of significant benefit in the statistical model. The selected model included the terms block, temperature, and chilling hours.

Results and Discussion

Results for the within-tree effects (Table 1) indicate that the effect on percent budbreak by day was significant, with the effect of day being notably different depending on block and number of chilling hours, but not refrigeration unit temperature. Results for the between-tree effects indicate that percent budbreak was notably influenced by Block and hours of chilling (Hours, and Hours \times Hours,), but not refrigeration unit temperature (Temp). Individual univariate analyses of budbreak by day (results not shown) tended to

show positive coefficients for the Hours term, and negative coefficients for the Hours \times Hours term, with the signs and magnitude of the coefficients indicating that percent budbreak tended to increase with increasing number of chilling hours, but the increase becoming less as the number of chilling hours increased.

Results indicate that number of days to 50 percent budbreak were notably influenced by hours of chilling, but not refrigeration unit temperature. The coefficient for the Hours term was negative in sign, indicating that days to 50 percent (minimum) budbreak tended to decrease with increasing hours of chilling (Table 2).

Results suggest a positive correlation of increasing forced chilling hours and an increasing percent budbreak in red maple trees. Results also indicate no difference in percent budbreak at any forced chilling hour point relative to the different chilling temperatures. This seems to indicate that the number of forced chilling hours is a major factor in breaking endodormancy in red maple trees and refrigeration unit temperature, within the range evaluated, is a minor factor (Figure 1).

Results indicate that the refrigeration unit setting has a diminishing influence on days to 50 percent budbreak in red maple trees as the number of forced chilling hours increases (Figure 2). Our results indicate 7° C (45° F) to be as effective as 1.7° C (35° F) for forced chilling.

Literature Cited

- Childers, N. F., J. R. Morris, and G. S. Sibbett. 1995. *Modern Fruit Science: Orchard and Small Fruit Culture*. Horticultural Pub., Gainesville, FL.
- Crocker, W. 1948. *Growth of Plants*. Reinhold Publishing, New York, NY.
- Curtis, O. F. and D. G. Clark. 1950. *An Introduction to Plant Physiology*. McGraw-Hill Book Co., New York, NY.
- Dirr, M. A. 1998. *Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses*. Stipes Publishing, Champaign, IL.
- Murray, M. B., M.G.R. Cannell, and R.I. Smith. 1989. Date of budburst of fifteen tree species in Britain following climatic warming. *J. Applied Ecology* 26:693-700.
- Olmsted, C. E. 1951. Experiments on photoperiodism, dormancy, and leafage and abscission in sugar maple. *Bot. Gaz.* 112:365-393.
- Perry, T. O. and W. L. Wu. 1960. Genetic variation in the winter chilling requirement for date of dormancy break for *Acer rubrum*. *Ecology* 41:790-794.
- Powell, A., D. Himelrick, W. Dozier, and D. Williams. 1999. Fruit culture in Alabama-winter chilling requirements. *Ala. Coop. Ext. Sys. Bull. ANR-53-D*.
- Rowland, L. J., E. L. Logan, R. Arora, C. C. Lira, J. S. Lehman, A. Levi, and G.R. Panta. 1999. Use of blueberry to study genetic control of chilling requirement and cold hardiness in woody perennials. *HortScience* 34:1185-1191.
- Ruter, J. M. and J. L. Sibley. 2000. Performance of red maple selections in southern Georgia. *HortTechnology* 10:621-625.
- Ruter, J.M., J.L. Sibley, and M.A. Dirr. 1998. Red maple selections for the Southeastern United States. *Georgia Green Ind. Assoc. Journal* 9(2):16-20.
- Saure, M. C. 1985. Dormancy release in deciduous fruit trees. *Hort. Rev.*, Vol.7:239-300.
- Sibley, J. L., D. J. Eakes, C. H. Gilliam, G. J. Keever, and W. A. Dozier, Jr. 1995. Growth and fall color of red maple selections in the southeastern United States. *J. Environ. Hort.* 13:51-53.
- Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1999a. Bark anthocyanin levels differ with location in cultivars of red maple. *HortScience* 34:137-139.

Sibley, J. L., J. M. Ruter, and D. J. Eakes. 1999b. Growth periodicity for container-grown red and Freeman maple cultivars in AHS heat-zone 8. *J. Environ. Hort.* 17:141-146.

Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1998. Differences in growth of container-grown red maple cultivars in different hardiness zones. *J. Environ. Hort.* 16:130-134.

Sibley, J.L., J.M. Ruter, and D.J. Eakes. 1997. Multiple location differences in growth of red maple 'October Glory'. *HortTechnology* 7:258-260.

Sternberg, G. and J. Wilson. 1995. *Landscaping With Native Trees*. Chapters Publishing, Shelburne, VT.

Townsend, A. M., J. W. Wright, W. F. Beineke, R. P. Guries, and C. A. Mohn. 1982. Early patterns of flowering, winter injury, and flushing of red maple progenies grown in five locations. *Can. J. For. Res.* 12:814-821.

Westwood, M. N. 1993. *Temperate Zone Pomology: Physiology and Culture*. Umber Press, Portland, OR.

Wilson, B. C., J. L. Sibley, J. E. Altland, E. H. Simonne, and D. J. Eakes. 2002a. Chilling and heat unit levels affect foliar budbreak of selected red and Freeman maple cultivars. *J. Arboric.* 28:148-152.

Witte, W. T., R. Sauve, M. T. Mmbaga, and P. C. Flanagan. 1996. Maple evaluations at TSU-NCRS. *Proc. South. Nurs. Assoc. Res. Conf.* 41:385-392.

Witte, W. T., R. Sauve, and P. C. Flanagan. 1997. Update on maple evaluations at TSU-NCRS. *Proc. South. Nurs. Assoc. Res. Conf.* 42:446-452.

Table 1. Influence of refrigeration unit temperature (Temp) and chilling hours (Hours) on the percent budbreak of (*Acer rubrum* L.) over time, utilizing a Randomized Complete Block Design and repeated measures (Day) collected every four days over a 132-day period.

| Effect | <i>p</i> -value ^z |
|---------------------|------------------------------|
| Within-trees: | |
| Day | <0.0001 |
| Day × Block | <0.0001 |
| Day × Hours | 0.0013 |
| Day × Temp | 0.1799 |
| Day × Hours × Hours | 0.0050 |
| Between-trees: | |
| Block | <.0001 |
| Hours | 0.0033 |
| Temp | 0.1772 |
| Hours × Hours | 0.0121 |

^z*P*-values for within-trees effects were obtained using Wilk's Lambda Test.

P-values for between-trees effects were obtained using *F* tests.

Table 2. Influence of refrigeration unit temperature and chilling duration on number of days to 50 percent budbreak for (*Acer rubrum* L.)

| Effect | <i>p</i> -value ^z |
|--------|------------------------------|
| Block | <0.0001 |
| Hours | <0.0001 |
| Temp | 0.1402 |

^z*P*-values were obtained using Wald χ^2 test statistics in a generalized linear model using a negative binomial distribution and a log link for examination of the influence of refrigeration unit temperature (Temp) and chilling hours (Hours) on number of days to 50 percent budbreak for *Acer rubrum* L., utilizing a Randomized Complete Block Design.

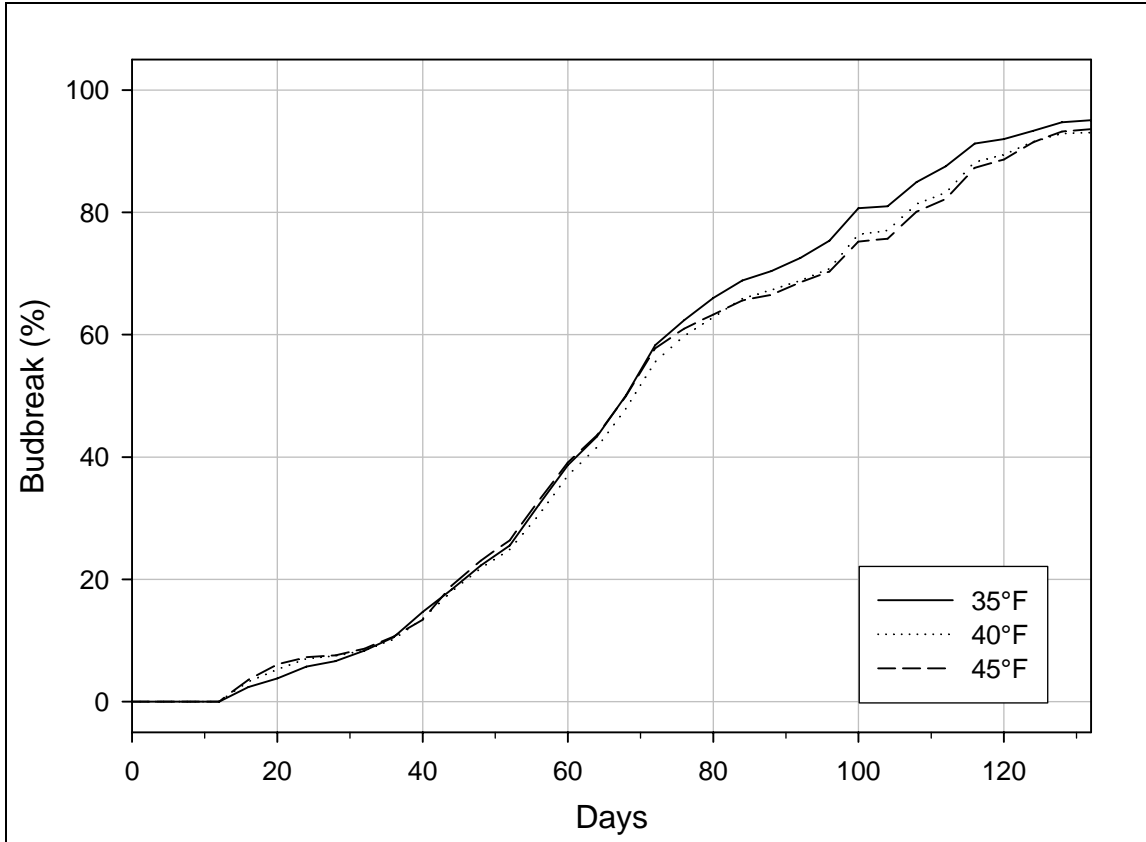


Figure 1. Budbreak Over Time of Red Maples Following Forced Chilling at Different Refrigeration unit Temperatures.

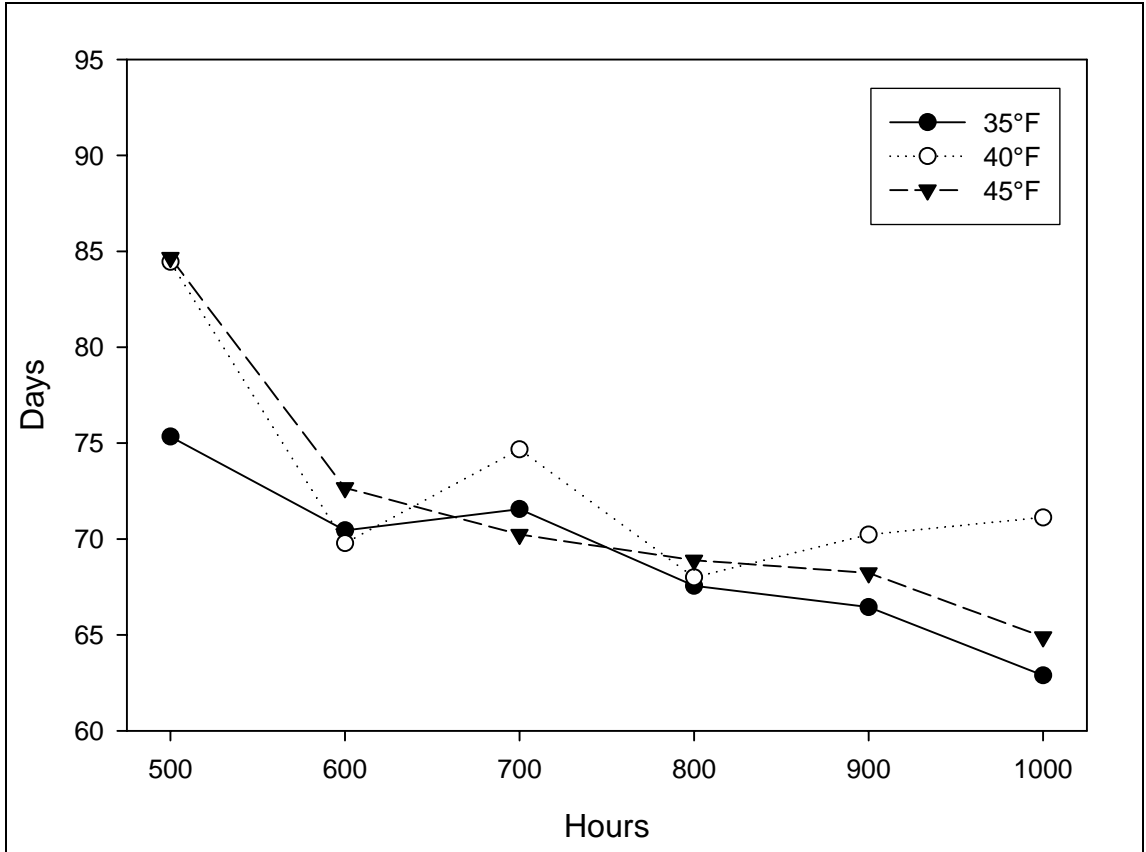


Figure 2. Days to 50 Percent Budbreak of Red Maple Based on Forced Chilling Hours at Different Refrigeration unit Temperatures.

CHAPTER IV

FINAL DISCUSSION

The objectives of this research were to (1) determine the influence of forced chilling on budbreak of red maple at various refrigeration unit settings; (2) determine the impact of incremental chilling totals on budbreak of red maples at various refrigeration unit settings; and (3) determine the impact of incremental chilling totals on budbreak of red maples at various refrigeration unit temperatures. From this and future studies, a model for regional planting recommendations of red maple taxa can be constructed, as has been done for many deciduous fruit trees. Additionally, this research will provide growers information that can be used to modify lifting, storage, and transplanting schedules.

Our results indicate that forced chilling is similar in budbreak response to ambient chilling, which suggests that southern tree growers can grow northern red maple cultivars in southern climates, dig and chill, then sell to northern growers.

Results for the within-tree effects indicate that the effect on percent budbreak by day was significant, with the effect of day being notably different depending on block (cultivar), but not chilling type or chilling hours. Results for the between-tree effects indicate that percent budbreak was notably influenced by block, but not chilling type or chilling hours. In personal correspondence with Keith Warren, Director of Product Development with J. Frank Schmidt and Son Nurseries, Boring, Oregon Keith stated “We really don't force

chilling of red maples, as we get so much natural chilling. Chilling models usually show our area as having about the highest hours of natural chilling in the US. From November to April, our temperatures are between -1°C (30°F) and 10°C (50°F) almost continually. We are aware of the chilling needs of red maples, but it is only a factor in the rare situation when we want to force a crop in the greenhouse in January or February. Our cold storage is for holding dormancy, not for breaking a chilling requirement. Therefore, we store at 0.6°C (33°F) to 1°C (34°F). The colder it is the longer the dormancy holds and less fungal problems develop in storage.”

In another communication Carlton Davidson, production manager of Carlton Plants, Dayton, Oregon wrote “ The nursery, including propagation, has approximately 2.2 hectares ($5\frac{1}{2}$) acres of cold storage. Cost of electricity runs about \$20,000 a month. Also, we start our coolers at 2°C (36°F) and once the cooler is at or near capacity, we lower it to 10°C (34°F). We find the colder temperatures reduce the occurrence of storage diseases.”

It is noteworthy that in both nurseries, trees are kept as cold as possible at great expense not to satisfy chilling requirement but for disease control and to maintain dormancy. Our results indicate 7°C (45°F) is as effective as 1.7°C (35°F) for forced chilling thus we can save growers money on the type of refrigeration storage units used (refrigerated storage units are cheaper than freezer storage units); and reduced energy cost for these refrigeration storage units would be helpful. Almost all cultivars broke bud earlier in refrigeration unit temperatures of 7°C (45°F) than when stored at 1.7°C (35°F) (Figures 2 through 18). Our results indicate noticeably later budbreak between northern origin cultivars like Autumn Spire, Northwood, and Sclesengeri and cultivars of

southern origins like Florida Flame and Summer Red (Figures 5, 11, 14 and 9, 17).

Results for the within-tree effects indicate that the effect on percent budbreak by day was significant, with the effect of day being notably different depending on block (cultivar) and number of chilling hours, but not refrigeration unit temperature. Results for the between-tree effects indicate that percent budbreak was notably influenced by block and hours of chilling (Hours and Hours \times Hours), but not refrigeration unit temperature.

Results indicate that number of days to 50 percent budbreak were notably influenced by hours of chilling, but not refrigeration unit temperature. The coefficient for the Hours term was negative in sign, indicating that days to 50 percent budbreak tended to decrease with increasing hours of chilling.

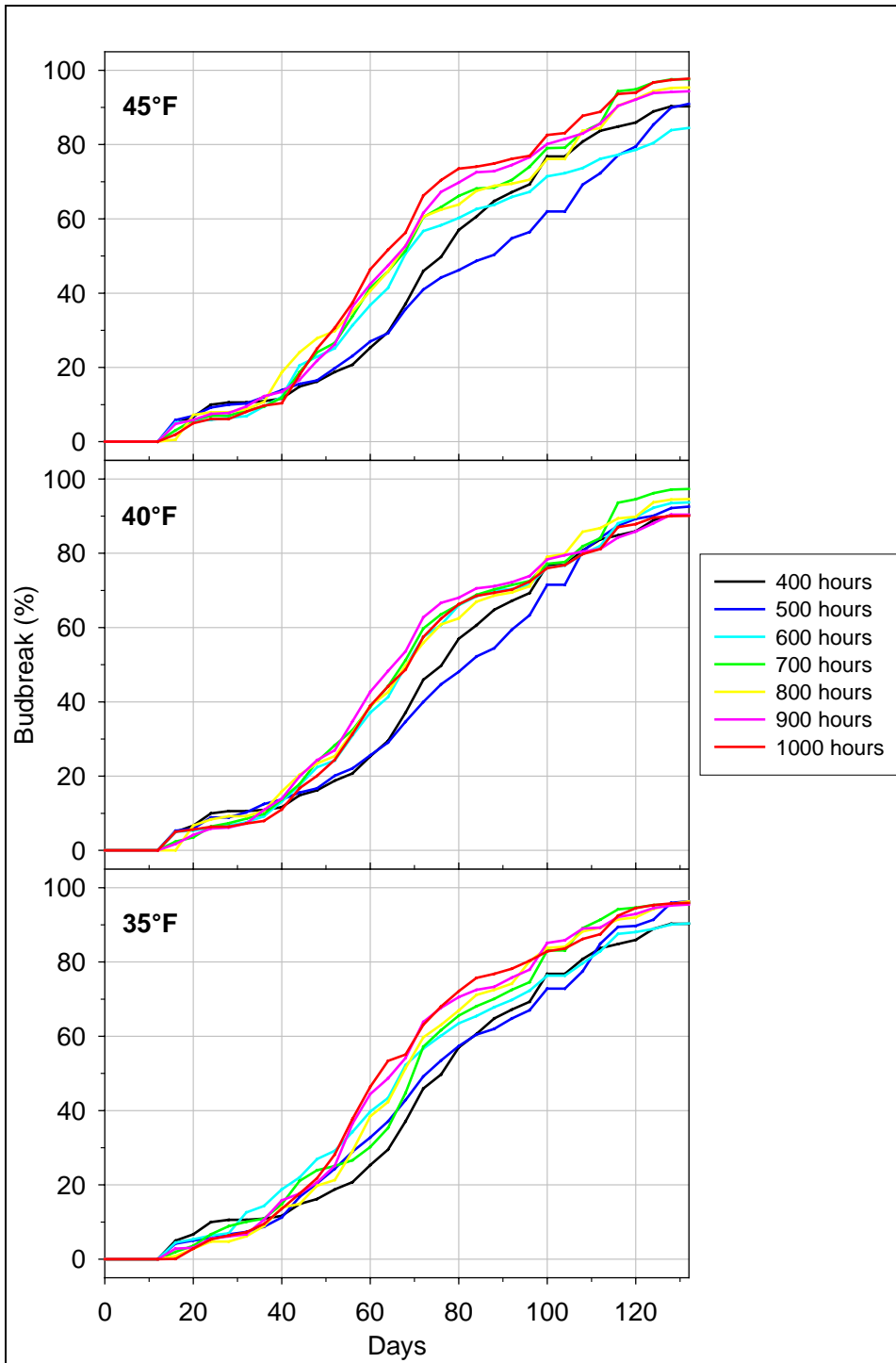


Figure 1. Temperature influence on average budbreak of 18 cultivars of red maple in response to incremental (100 hours), forced chilling at different refrigeration temperatures.

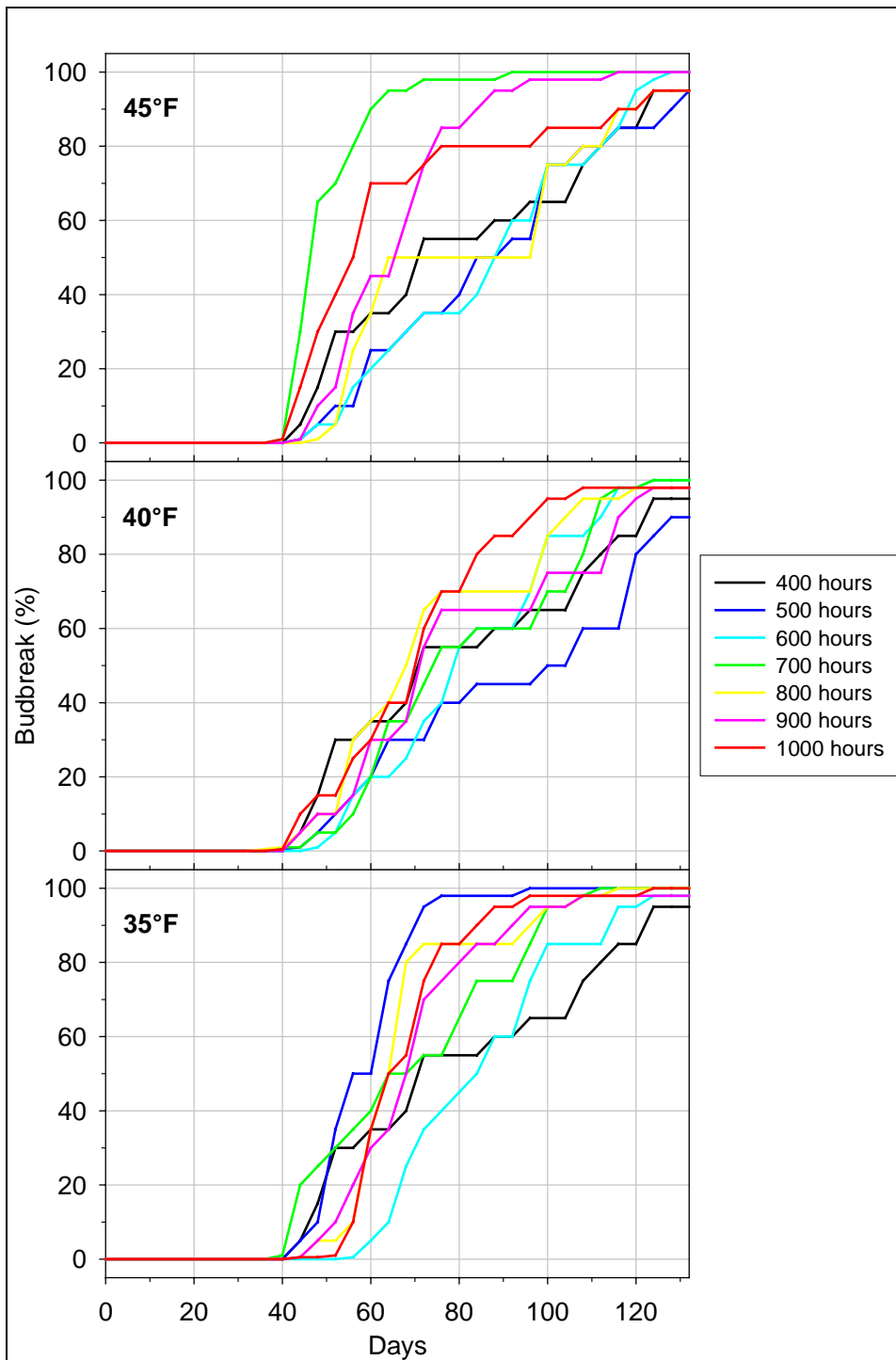


Figure 2. Temperature influence on chilling response (budbreak) of red maple 'Autumn Blaze'.

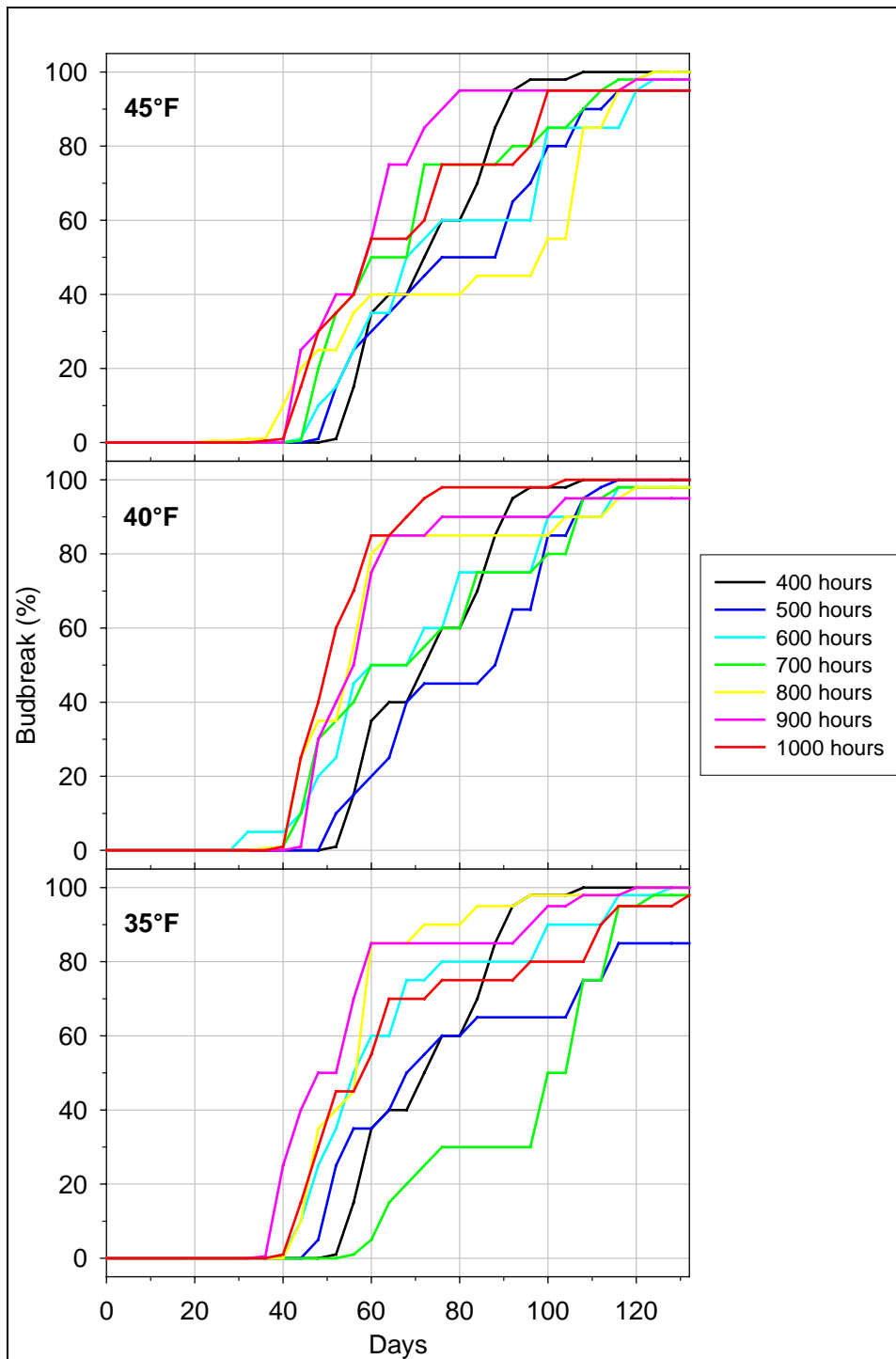


Figure 3. Temperature influence on chilling response (budbreak) of red maple 'Autumn Flame'.

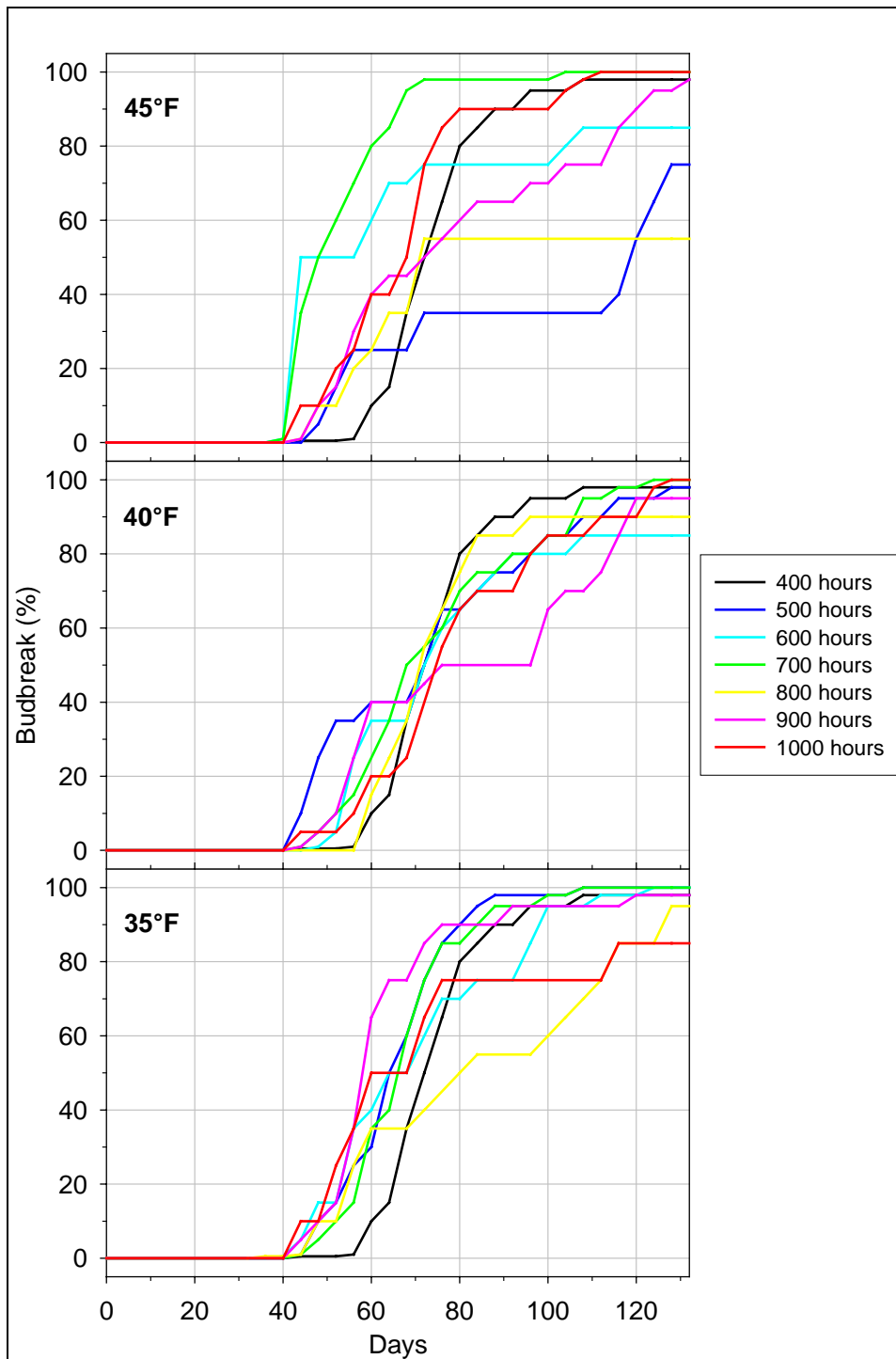


Figure 4. Temperature influence on chilling response (budbreak) of red maple 'Armstrong'.

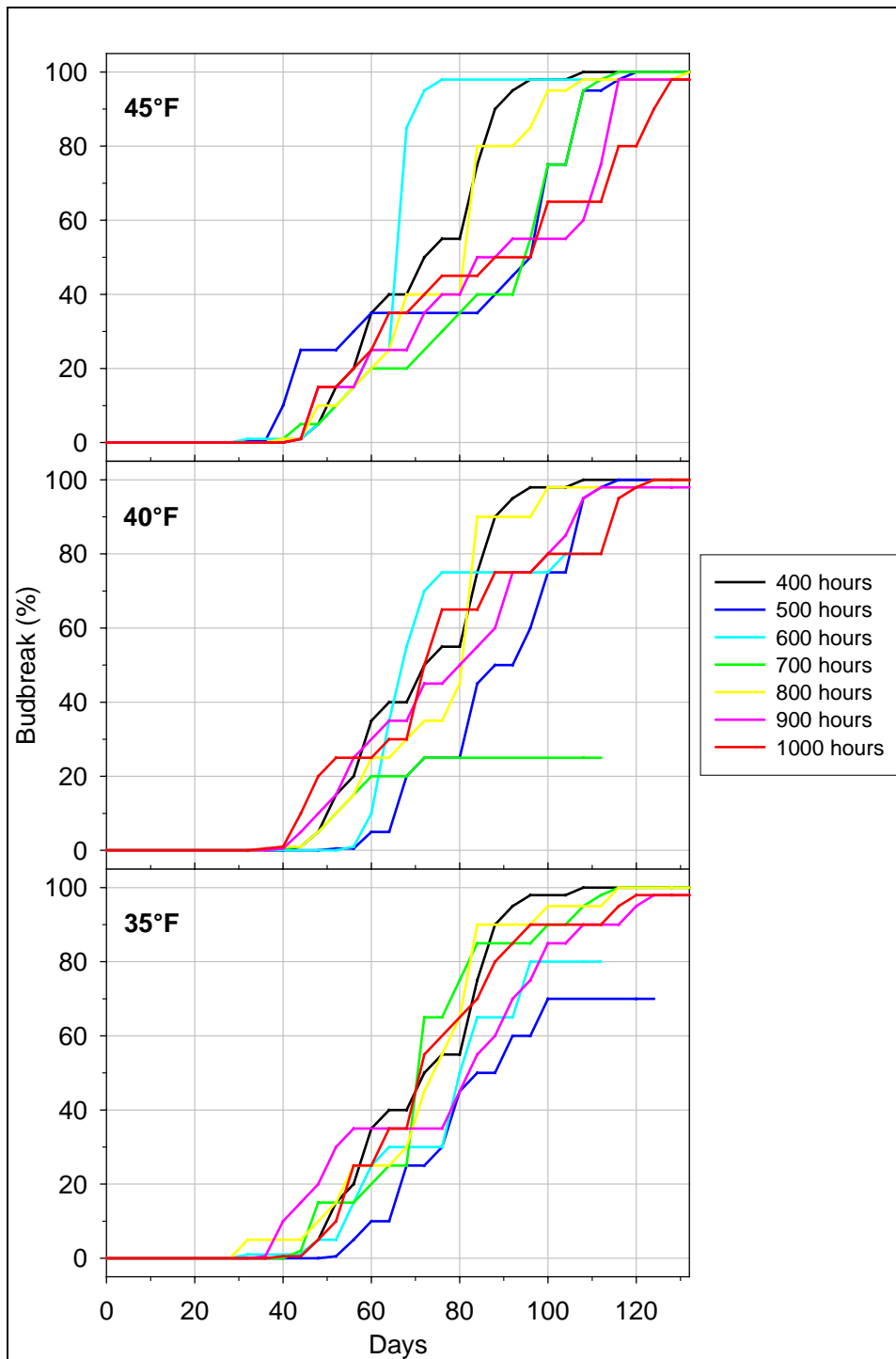


Figure 5. Temperature influence on chilling response (budbreak) of red maple 'Autumn Spire'.

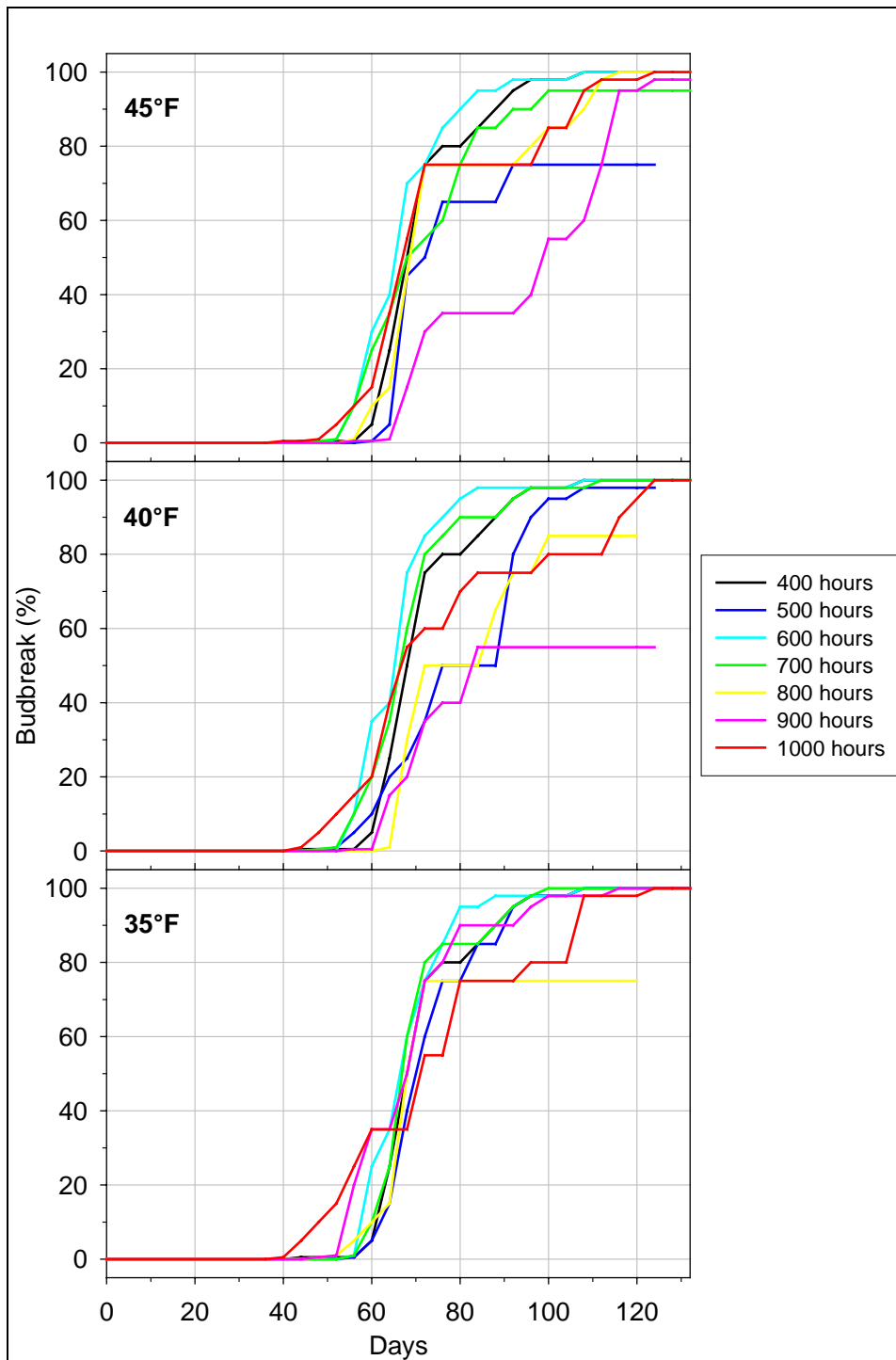


Figure 6. Temperature influence on chilling response (budbreak) of red maple 'Bowhall'.

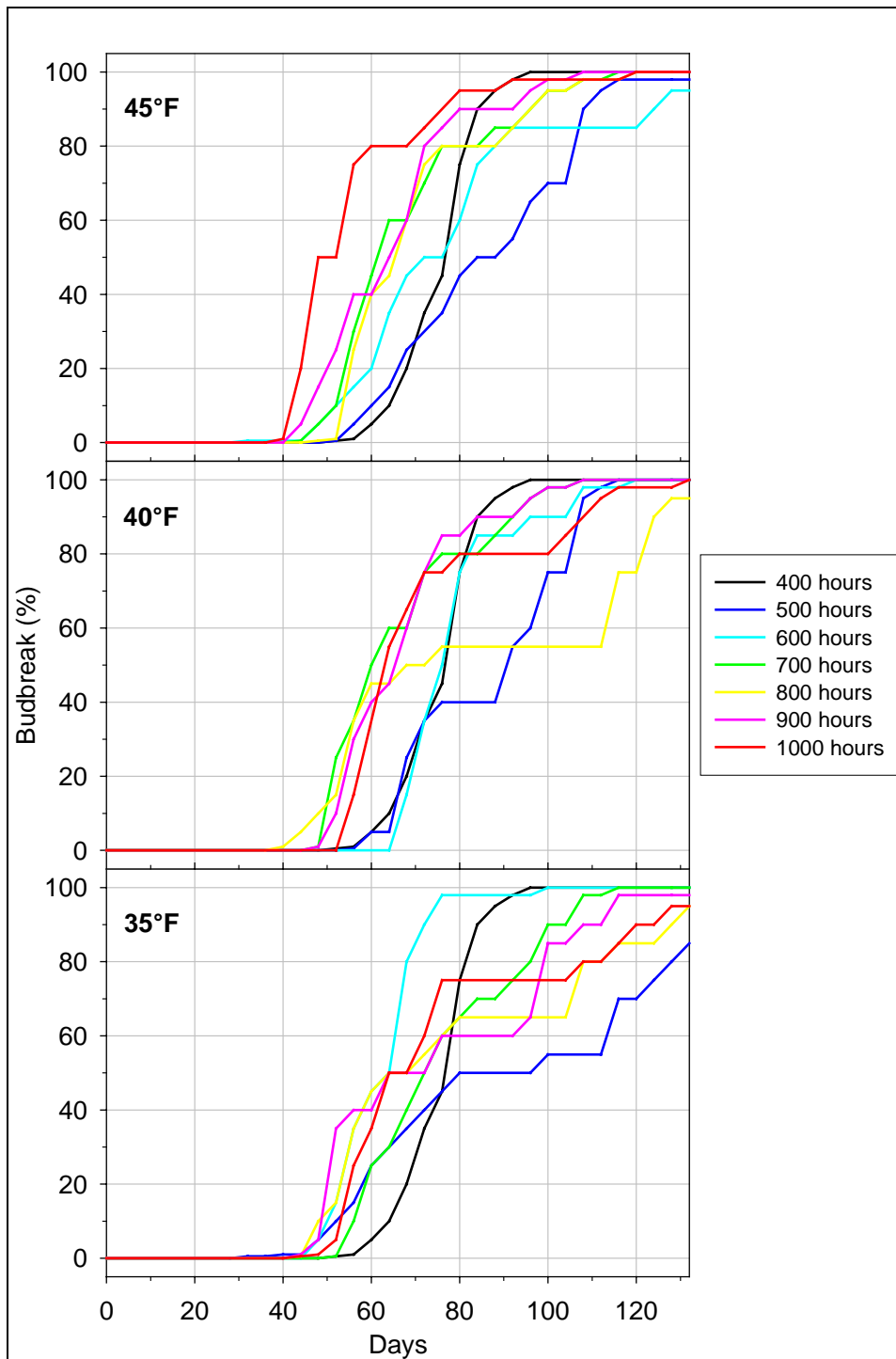


Figure 7. Temperature influence on chilling response (budbreak) of red maple 'Brandywine'.

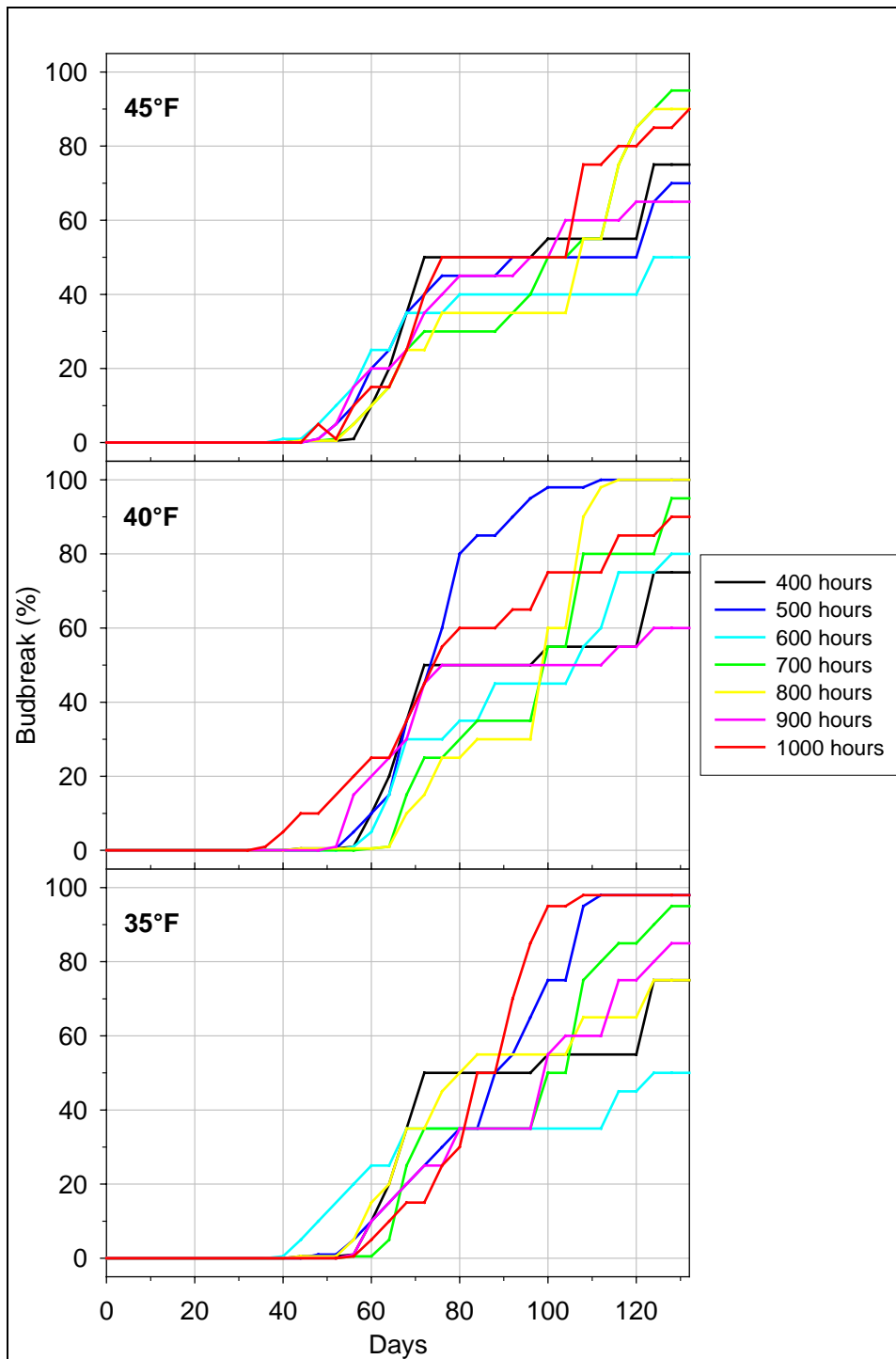


Figure 8. Temperature influence on chilling response (budbreak) of red maple 'Autumn Fantasy'.

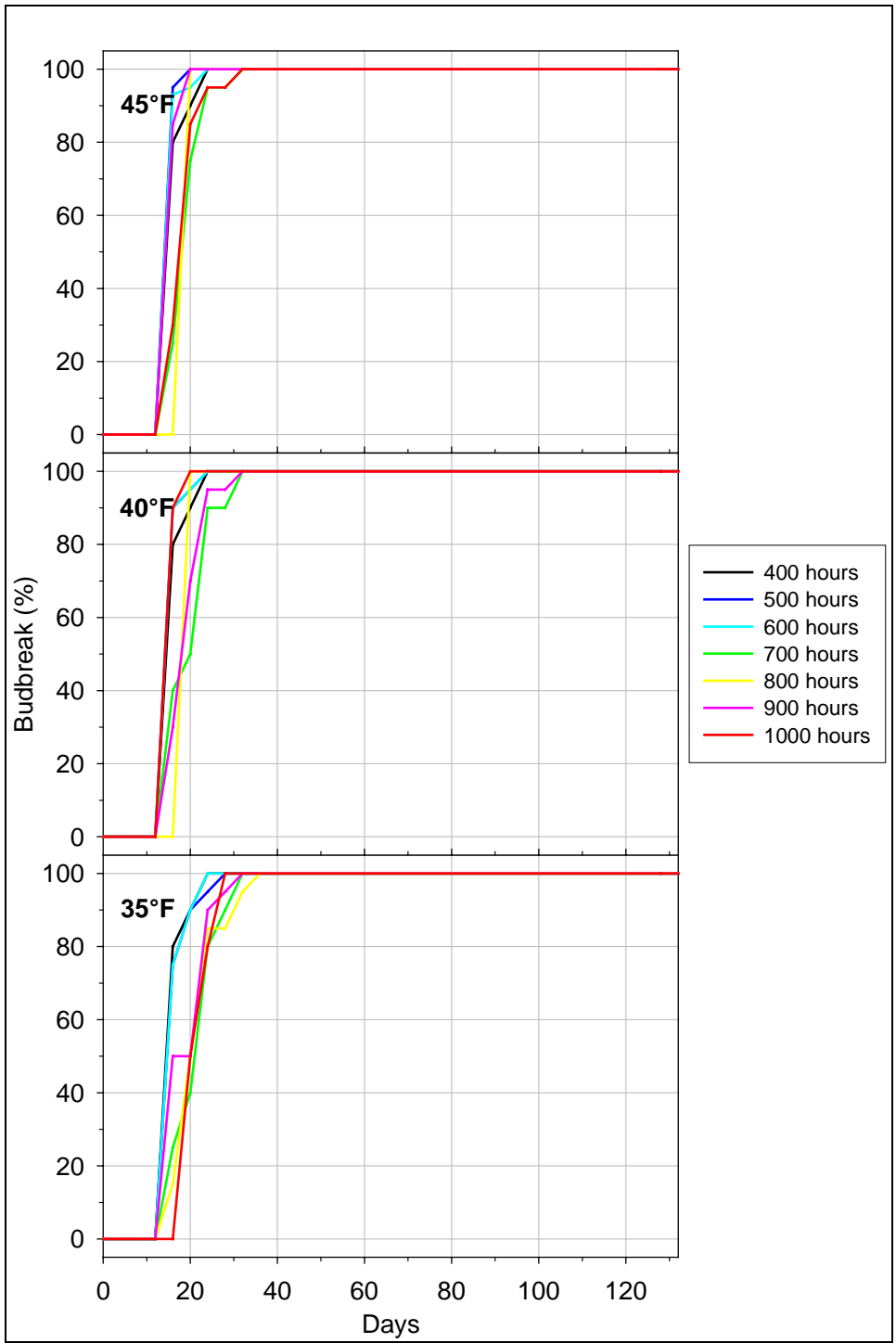


Figure 9. Temperature influence on chilling response (budbreak) of red maple 'Florida Flame'.

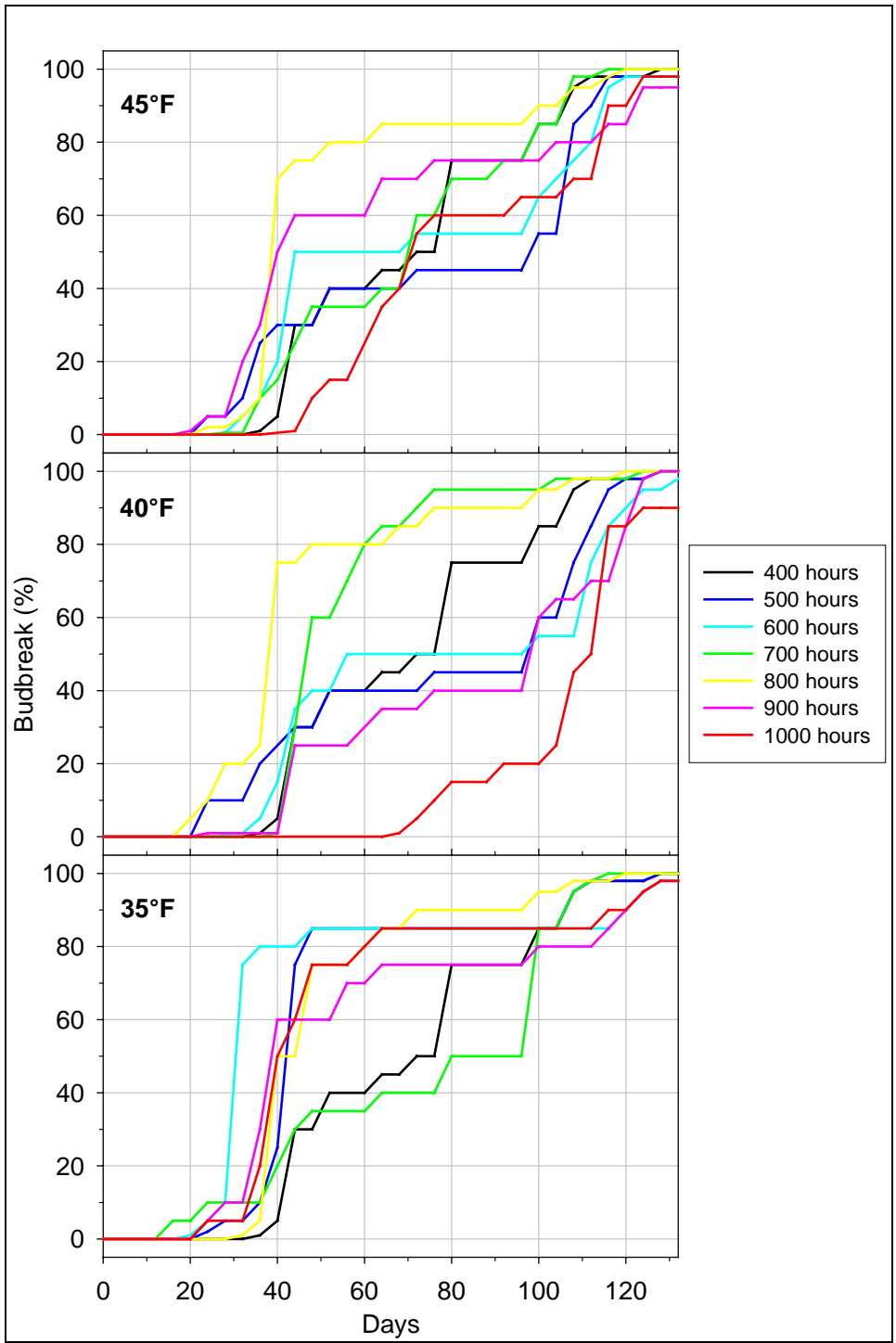


Figure 10. Temperature influence on chilling response (budbreak) of red maple 'Morgan'.

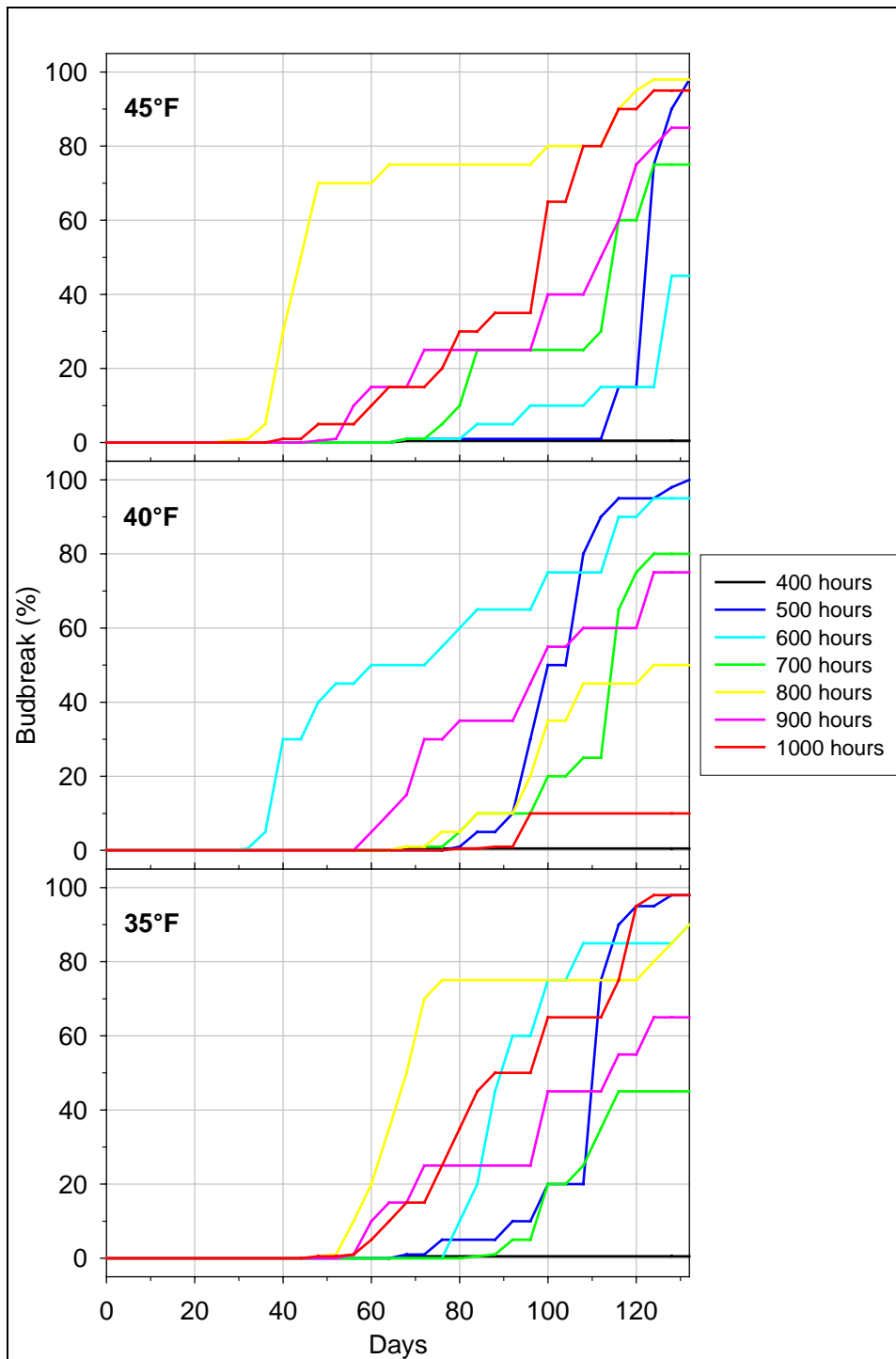


Figure 11. Temperature influence on chilling response (budbreak) of red maple 'Northwood'.

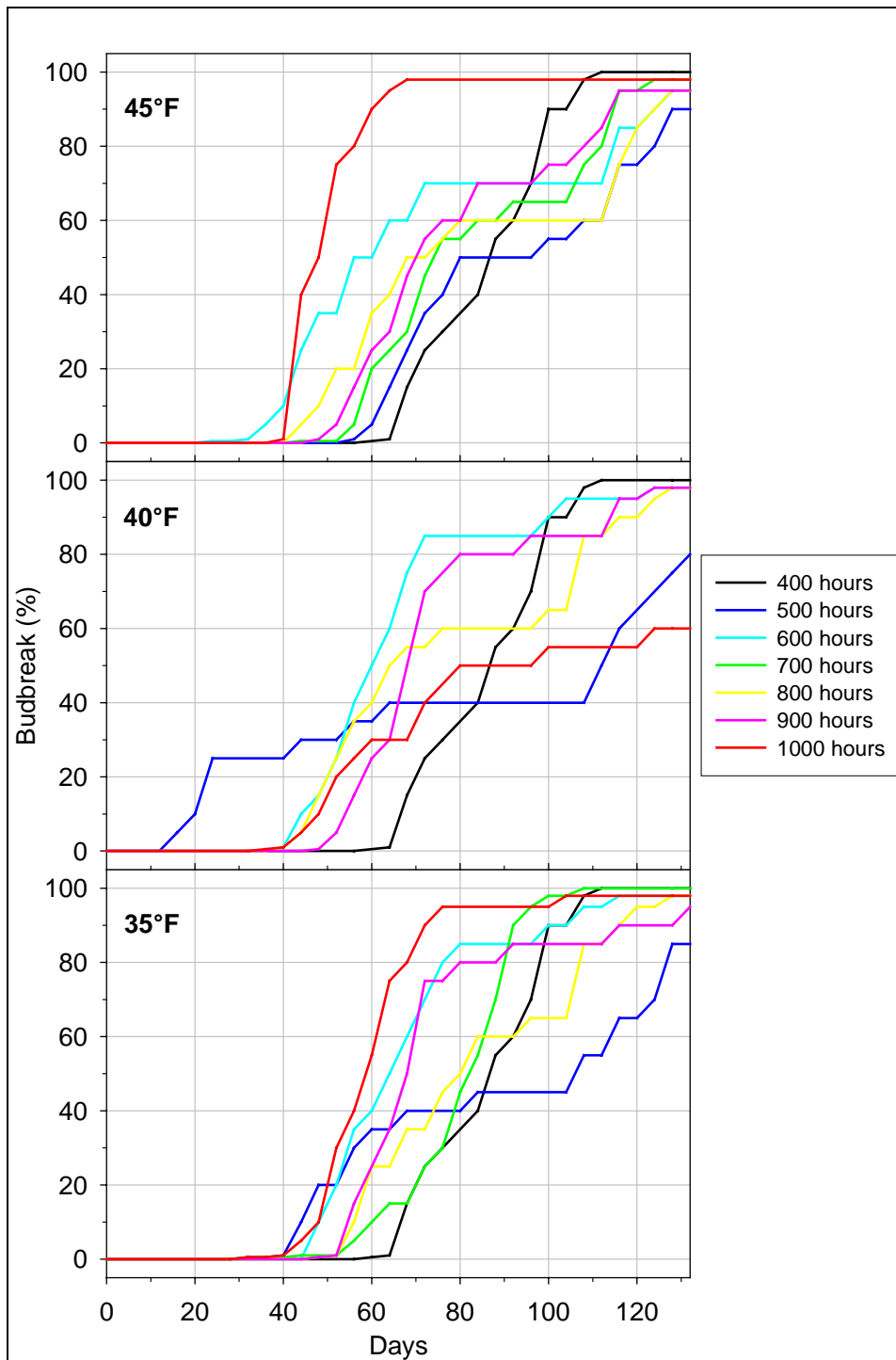


Figure 12. Temperature influence on chilling response (budbreak) of red maple 'October Glory'.

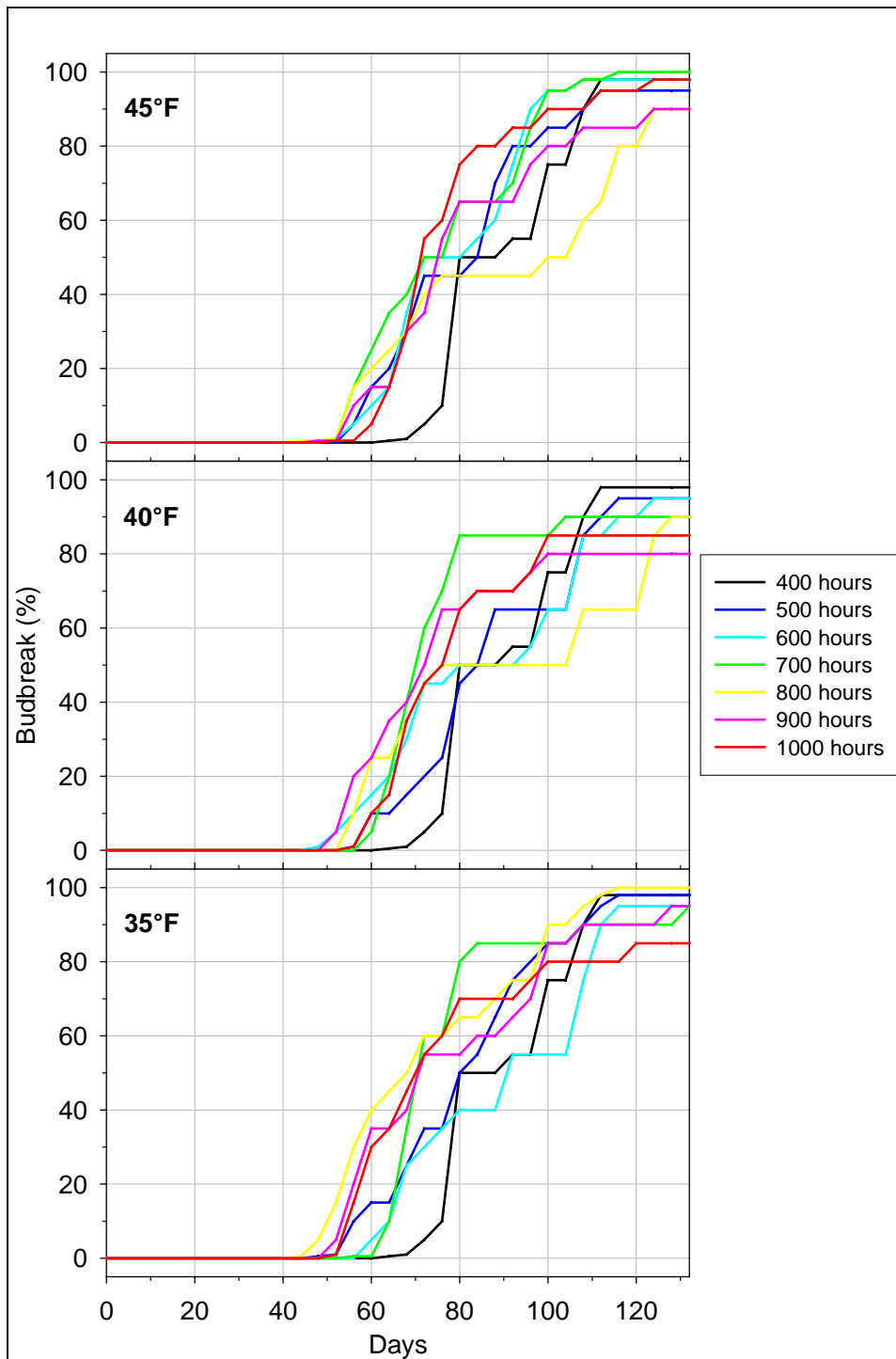


Figure 13. Temperature influence on chilling response (budbreak) of red maple 'Red Sunset'.

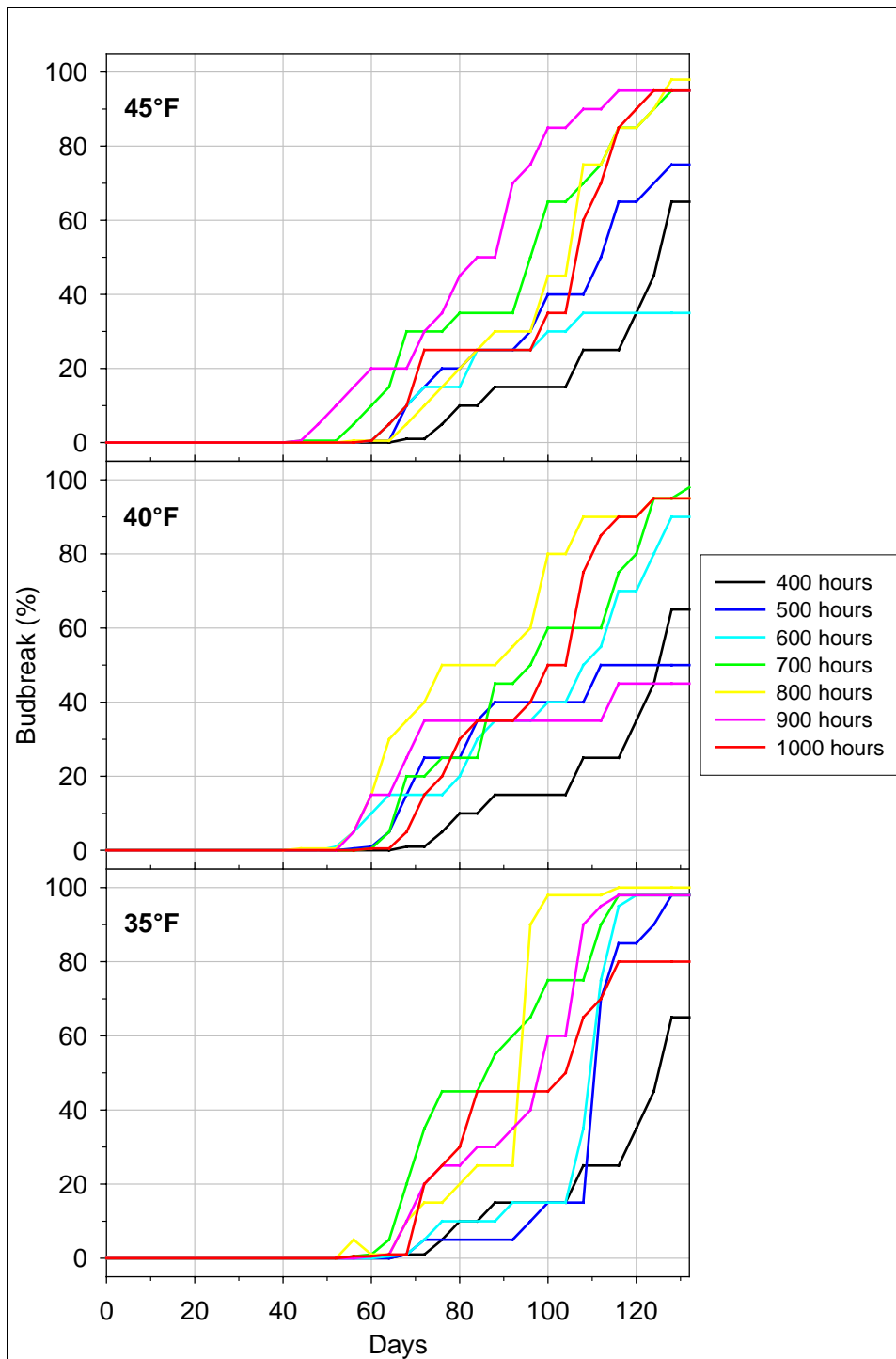


Figure 14. Temperature influence on chilling response (budbreak) of red maple 'Schlesingeri'.

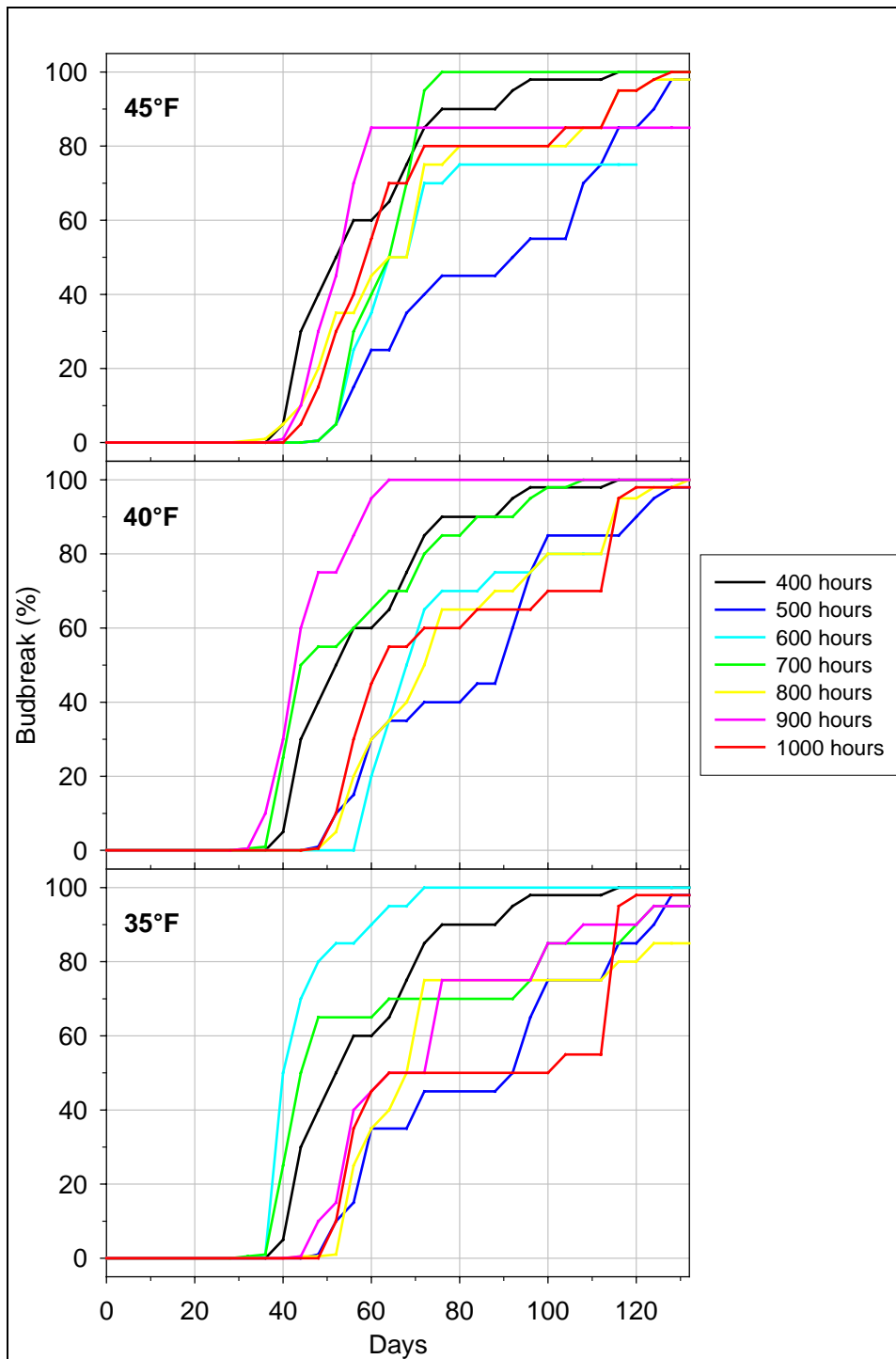


Figure 15. Temperature influence on chilling response (budbreak) of red maple 'Scarlet Sentinel'.

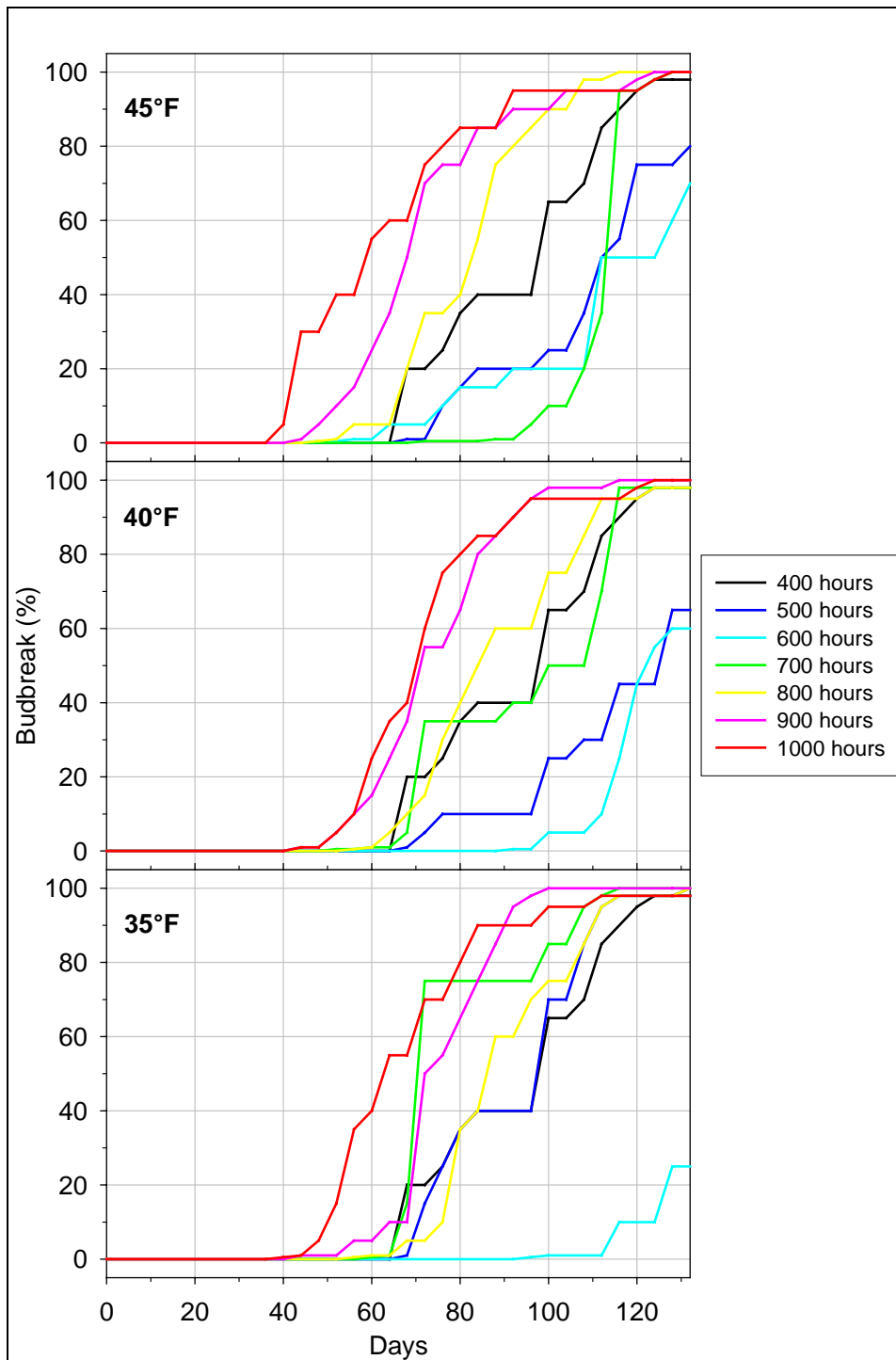


Figure 16. Temperature influence on chilling response (budbreak) of red maple 'Somerset'.

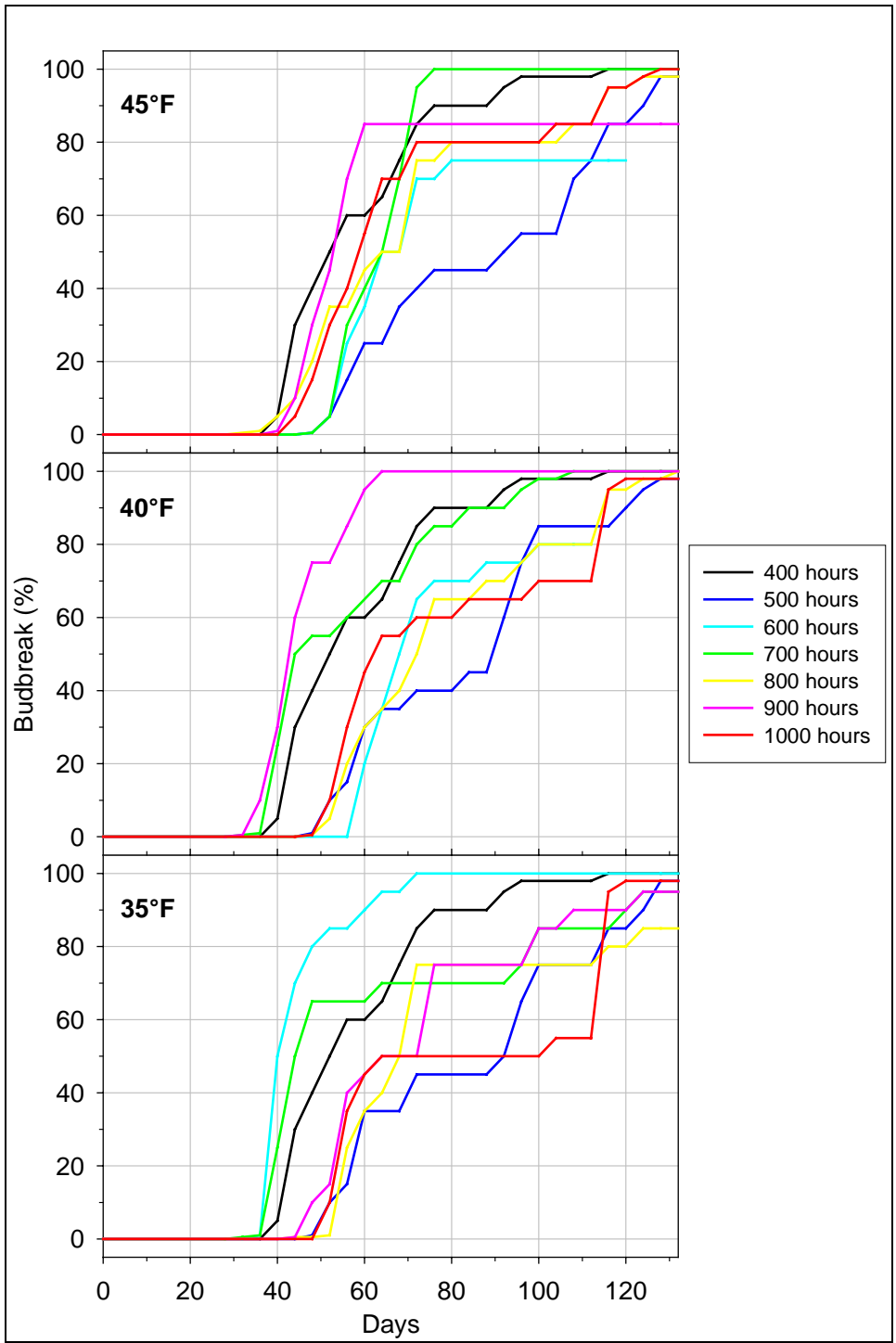


Figure 17. Temperature influence on chilling response (budbreak) of red maple 'Summer Red'.

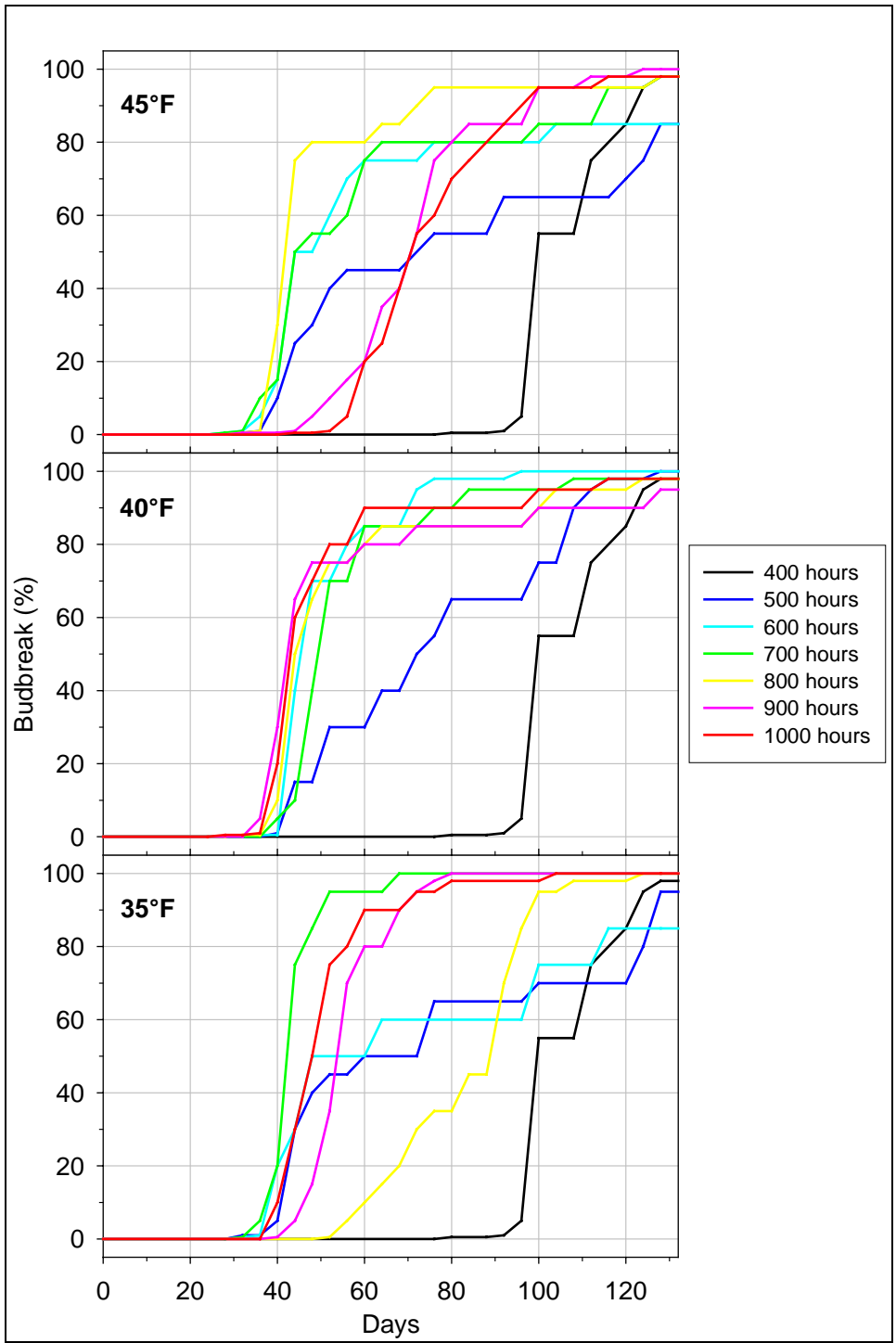


Figure 18. Temperature influence on chilling response (budbreak) of red maple 'Sun Valley'.

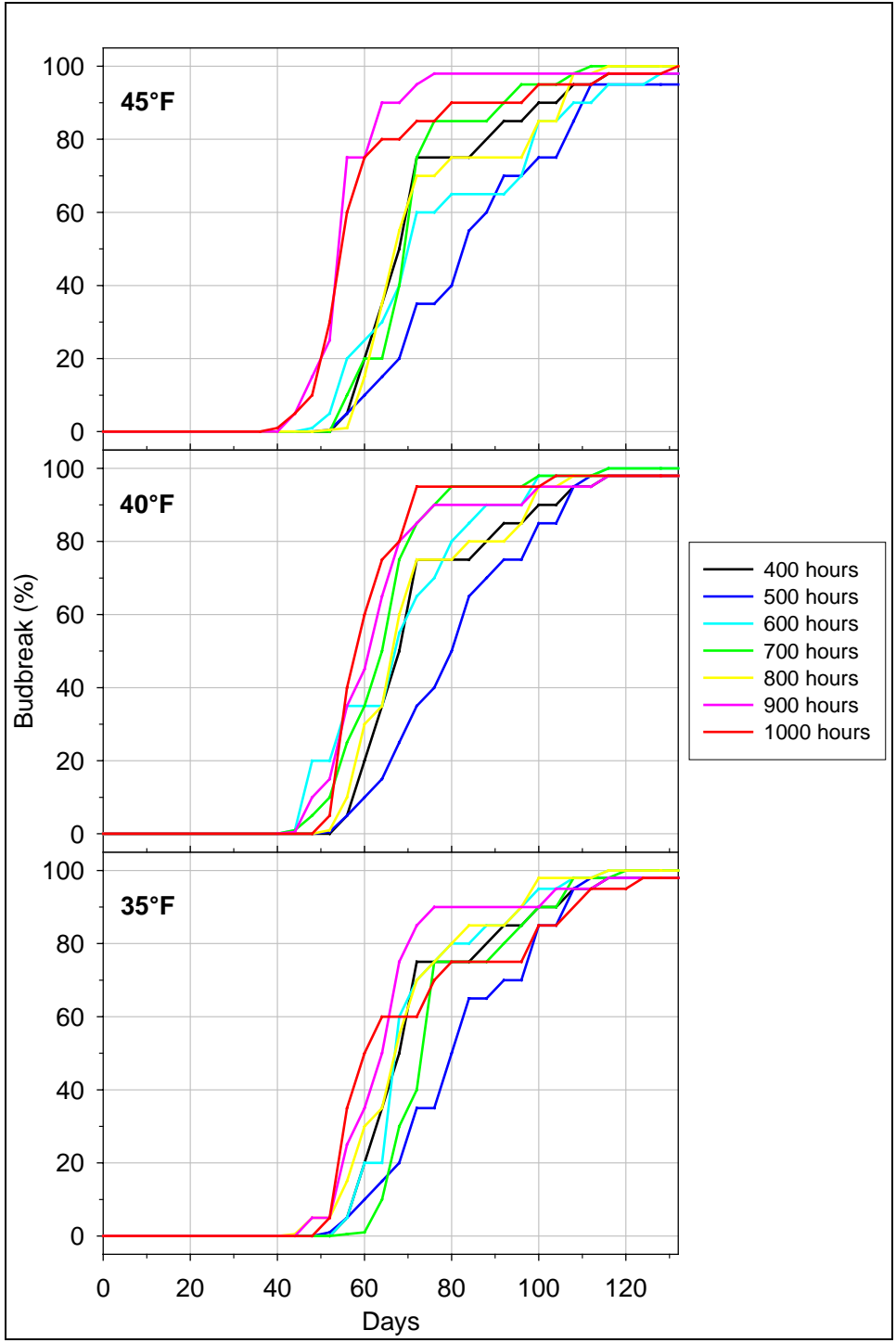


Figure 19. Temperature influence on chilling response (budbreak) of red maple 'V. J. Drake'.