Potential Impacts of Shade Treatments on Dormancy of Overwintering Redbud (*Cercis canadensis* L.) Trees at Southeastern Nurseries

C. T. Werle[1]* and A. L. Witcher[2]

Abstract

Dormancy accrual is an important process in mitigating the abiotic stressors of overwintering trees at ornamental nurseries, with frost-injured tree crops at heightened risk of ensuing biotic insect and disease attack. As mean global temperatures rise, overwintering nursery crops may lose dormancy earlier. Using potted eastern redbud (*Cercis canadensis* L.) trees placed under two types of shade cloth, under full sun, or in walk-in coolers, we measured stem, air and root zone temperatures, accrual of chill hours and mean time to bud break at two sites. While there was no significant difference between the two shade treatments, shade cloths did moderate both high and low temperatures to which trees were exposed. Differences in mean time to first bud break were observed from shaded trees versus those in full sun at each site. It may be useful to alter our shading design to continue protection from overnight lows while preventing excess warming from daytime highs, and thus promoting dormancy and preventing frost exposure in some regions, but further tests will be required.

Species used in this study: eastern redbud (*Cercis canadensis* L.).

Index words: abiotic stress, aluminet, bud break, climate change, frost injury.

Significance to the Horticulture Industry

Among the many challenges to profitable nursery production, global climate change may make an outsized impact in reduced tree quality due to damage from extreme climate conditions (Campoy et al. 2011). Tree phenology is highly sensitive to changing temperatures, with leaf bud break either advanced or delayed by warmer winter temperatures, depending on species and cultivar (Nanninga et al. 2017). One primary concern of higher winter temperatures includes the potential loss of dormancy in tree crops, with potential impacts on leaf and flower production and defense against frost injury and subsequent insect pest attacks (Augspurger 2013, Kim et al. 2014, Ranger et al. 2019). Nursery managers may be looking for ways to limit loss of dormancy in overwintering tree crops as a way of protecting against these abiotic and biotic stressors. For this reason, we looked for effects of shade treatments on overwintering container-grown redbud (*Cercis canadensis* L.) trees in Mississippi and Tennessee. While air and root zone temperatures were similar for our full sun and shade treatments in the TN experiment, shade moderated other environmental conditions (stem temperature) at both sites and led to increased MTB over the full season in MS. Overwintering trees under shade in certain regions could potentially promote greater dormancy, delaying bud break and preventing late-season frost injury.

Introduction

Ornamental nursery crops beautify landscapes and increase property values, but they also make a large contribution to local and regional southeastern economies, including Mississippi (15,000 jobs, $835 million) and Tennessee (13,000 jobs, $865 million) (Posadas et al. 2020, Jensen et al. 2020). When including the southeastern U. S. as a whole, those contributions increase to nearly 60,000 jobs and $6.5 billion in output (Hall et al. 2006). Challenges to this important industry are wide-ranging, including shifting consumer preferences, competition with low prices from big chain stores, and access to trained seasonal workers. Climate change presents another looming challenge to the ornamental industry, with impacts ranging from abiotic stress due to higher average temperatures, unseasonal weather patterns and shifting precipitation levels, and migrations of pest populations (Campoy et al. 2011, Francini and Sebastiani 2019).

Phenology of ornamental trees is highly sensitive to changes in winter temperatures, with leaf bud break either advanced or delayed by warmer winter temperatures, depending on individual species and cultivar requirements (Nanninga et al. 2017). Primary concerns from higher average temperatures, and specifically milder winter temperatures, include insufficient accrual of chill hours and earlier loss of dormancy in certain tree species. Dormant-season chilling is a requirement for many important horticultural crops to produce leaves and flowers in the following growing season.

Tree dormancy also serves as a defense mechanism against frost injury for many ornamental and fruit tree crops. Tree responses to shorter daylength and lower temperatures can include suspension of new growth, reduced metabolic activity, and desiccation of cell tissues (Howell and Weiser 1970, Li et al. 2002). For tree crops that are less-dormant due to mild winter temperatures, and especially those that experience premature bud break, risk

Received for publication February 8, 2022; in revised form April 27, 2022.

[1] Southern Horticultural Research Unit, USDA-ARS, Poplarville, MS 39475.

[2] Otis L. Floyd Nursery Research Center, College of Agriculture, Tennessee State University, McMinnville, TN 37110.

*Corresponding author email: chris.werle@usda.gov.

Table 1. Shade[z] and time duration[y] treatments used at two research sites[x], with number of days under treatment conditions before moving container-grown (1 gal) *Cercis canadensis* trees to greenhouse conditions, and mean time (days) to first bud break for each group, +/- standard error (SE) .

Research Site	Time Treatment	Shade Treatment	No. Plants	Treatment Duration (days)	Mean Time to Bud Break (days), +/- SE
Mississippi	Early Winter	Cooler	8	34	43.7 (+/- 7.5)
		Full Sun	8	34	49.8 (+/- 2.6)
		Black Shade	8	34	43.5 (+/- 6.2)
		Aluminet Shade	8	34	47.9 (+/- 4.1)
	Late Winter	Cooler	8	63	19.0 (+/- 2.2)
		Full Sun	8	63	27.5 (+/- 0.5)
		Black Shade	8	63	22.6 (+/- 3.8)
		Aluminet Shade	8	63	30.0 (+/- 1.9)
	Full Season	Cooler	8	89	12.5 (+/- 1.9)
		Full Sun	8	124	10.1 (+/- 2.2)
		Black Shade	8	124	20.4 (+/- 1.5)
		Aluminet Shade	8	124	19.7 (+/- 0.8)
Tennessee	Early Winter	Cooler	8	23	45.8 (+/- 1.0)
		Full Sun	8	23	52.1 (+/- 1.6)
		Black Shade	8	23	46.3 (+/- 1.2)
		Aluminet Shade	8	23	47.1 (+/- 1.3)
	Late Winter	Cooler	8	71	12.1 (+/- 0.9)
		Full Sun	8	71	17.3 (+/- 0.7)
		Black Shade	8	71	19.7 (+/- 2.0)
		Aluminet Shade	8	71	19.6 (+/- 0.9)
	Full Season	Cooler	8	105	6.0 (+/- 0.5)
		Full Sun	8	128	0.9 (+/- 0.9)
		Black Shade	8	128	0.0 (+/- 0.0)
		Aluminet Shade	8	128	3.0 (+/- 0.8)

[z] All plants were placed under 60% shade (Aluminet or black shade cloth), in full sun, or in a cooler at project initiation (15 December 2020 in Mississippi and 23 December in Tennessee).

[y] A subset of trees from each shade treatment was moved to a greenhouse at pre-determined dates at each site and subjected to bud-forcing conditions (13 C and 14 hr photoperiod).

[x] Research sites were located in Mississippi (USDA-ARS Southern Horticultural Research Unit farm in McNeill, MS) and Tennessee (Tennessee State University Nursery Research Center in McMinnville, TN).

of acute frost injury may be heightened. This type of damage has been particularly pronounced during the recent late-winter "polar vortex" events which have occurred in 2014 and 2021 (Augspurger 2013, Kim et al. 2014). Such abiotic frost injuries to leafless trees would not be immediately apparent to nursery managers, and also would facilitate the additive effects of biotic stressors such as insect attacks on frost-injured tree crops (La Spina et al. 2013, Ranger et al. 2019, Teshome et al. 2020).

Limiting exposure to solar radiation may be one way of preventing loss of dormancy in overwintering ornamental tree crops, which can be accomplished through the use of shade cloths (Stamps 2009). There are a variety of shade cloths in use at production nurseries, ranging from standard black to reflective/metallic white, with shade reducing capabilities of 30-80%. Shade cloths often are marketed as a way of preventing summer heat stress, but they also have been shown to improve tree stem strength through a reduction in excessive vertical growth (Fare 2012, Mohawesh et al. 2022). By reducing solar radiation of overwintering trees, we hypothesize that providing shade to container-grown ornamental trees also will promote accumulation of chill hours and prevent loss of dormancy, thus reducing risk of frost injury and subsequent biotic injuries.

Materials and Methods

Research plots were set up at two locations: The MS Agricultural and Forestry Experiment Station in McNeill, MS (30°65′96.84"N, 89°63′50.69"W), and at the Tennessee State University Nursery Research Center in McMinnville, TN (35°42′34.81"N, 85°44′27.94"W). Eastern redbud (*Cercis canadensis* L.) seedlings grown in pine bark in 4 L (1 gal) black containers (0.5" caliper, 5′ tall, no added fertilizer) were randomly assigned to one of four treatments: standard black shadecloth (60% shade), aluminet (white) shadecloth (60% shade) (Growers Supply, Dyersville, IA), full sun, and a control group placed in a walk-in cooler set to 8 C (46 F). Shadecloths measuring 6 × 6 m (20 × 20 ft) were draped over metal frames measuring 3 × 3 × 1.5 m (10 × 10 × 5 ft) and secured using bungee cords along the bottom frame of the East, South and West ends to block sunlight, while the North end was left open for access to trees.

Within each shade treatment, a subset of trees was randomly assigned to three time durations, designated as early winter, late winter and full season. Eight replicates (individual trees) for each shade/time duration treatment were placed under the designated shade treatment conditions on 15 December 2020 in MS, and 23 December in TN (Table 1). Each subset of trees was removed from the shade treatments at predetermined dates and placed in a greenhouse under bud-forcing conditions at 13 C (55 F) and 14:10 photoperiod, using supplemental lighting [LED (MS) or HID (TN)] from 4-7 pm. All plants were irrigated as needed to maintain adequate moisture.

In MS, a subset of trees was moved to the greenhouse on 19 January 2021 (early winter), 17 February (late winter)

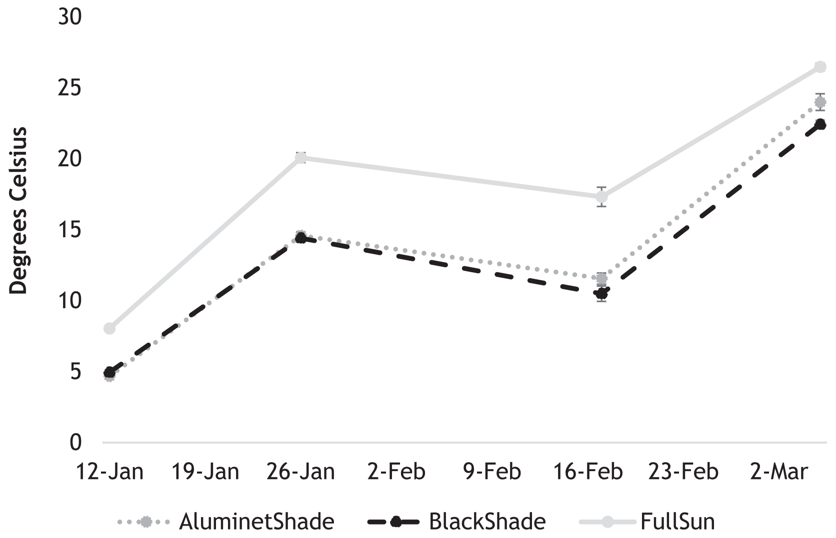

Fig. 1. Mean stem temperatures (+/- SE) of container-grown (1-gal) *Cercis canadensis* trees randomly selected from three shade treatments in Mississippi.

and 15 March (full season; only trees from the cooler). All full season, non-cooler trees remained in the field for observation until 21 April, when the study was concluded, in order to determine if the shade treatments had any effect on timing of bud break when exposed to the ambient conditions encountered at a commercial nursery. In TN, a subset of trees was moved to the greenhouse on 15 January 2021 (early winter), 4 March (late winter) and 7 April (full season; only trees from the cooler) while all other full season trees remained in the field for observation until 30 April when the study was concluded.

Measurements of the accumulation of chill hours, as well as temperatures of air (MS and TN, near ground level) and root zone (TN), were monitored (at 60-min intervals) in each treatment group throughout the study using WatchDog 1000 Series Micro Stations equipped with 4 soil temperature sensors (Spectrum Technologies, Inc., Aurora IL). At the beginning of the trial, 4 trees were randomly selected within each shade treatment and the soil temp sensors were inserted approximately 2.5 cm (1 in) into the container substrate halfway between the container sidewall and the tree stem. Periodic stem temperature measurements were made using a handheld infrared thermometer (OEM Tools, Easton, MA) on 8 trees randomly selected each time from each shade treatment (MS and TN).

The date of first bud break was recorded for each greenhouse tree by rating all trees 3 times weekly (Monday, Wednesday and Friday, MS and TN) as per Alvarez et al. 2018. Following guidelines from Denny et al. (2014), bud break was considered to occur when the first green tissues became visible. Mean time to first bud break (MTB) was calculated by using the number of days between the date greenhouse forcing conditions or bud-break for trees kept outside were initiated and the date for appearance of the first leaf bud. The experimental design was a randomized complete block, with each treatment replicated 8 times.

Statistical analysis. All analyses were conducted using SAS 9.4 (SAS Institute, Cary, NC) and based on $\alpha = 0.05$. Stem temperature measurements were compared using Repeated Measures Analysis of Variance (ANOVA), with Tukey's Studentized Range test for mean separation (Proc GLM). Analysis of the mean high/low root zone temperatures, accumulated chill hours, and MTB were tested using ANOVA with Tukey's test (Proc GLM).

Results and Discussion

Shade treatment had a significant effect on stem temperature measurements from both sites [(MS: $F = 171.34$; $df = 2$; $P < 0.0001$; Fig. 1) (TN: $F = 2231.24$; $df = 3$; $P < 0.0001$; Fig. 2)]. While there were coolant problems in the MS experiment, preventing inclusion of cooler trees for repeated measures analysis, MS and TN stem temperature measurements remained consistent with significant time effects [(MS: $F = 1282.02$; $df = 3$; $P < 0.0001$) (TN: $F = 729.72$; $df = 6$; $P < 0.0001$)] and time by shade interactions [(MS: $F = 7.43$; $df = 6$; $P < 0.0001$) (TN: $F = 87.62$; $df = 18$; $P < 0.0001$)]. In each experiment, mean stem temperatures of shaded trees were significantly lower than those in full sun, with the exceptions of two March measurements in TN during cloudy and lower wind-chill conditions (Fig. 2).

When comparing mean high air temperatures from MS, the full sun treatment plants were exposed to significantly higher temperatures (24.6 C) than plants in the other treatments, while there was no difference between the aluminet (22.1 C) and black (21.8 C) shade treatments ($F = 12.8$; $df = 139$; $P < 0.0001$; Fig. 3). Mean low temperatures also were significantly lower in the full sun treatment (10.2 C), as compared with the aluminet (11.1 C) and black (11.2 C) shade cloths ($F = 31.05$; $df = 139$; $P < 0.0001$; Fig. 3). The MS walk-in cooler malfunctioned at times during the course of the experiment, once from a loss of coolant and again from a bad compressor. While the cooler trees still averaged a significantly lower high-temperature (18.4 C) than other treatments, the malfunctions also caused significantly higher low temperatures (12.8 C).

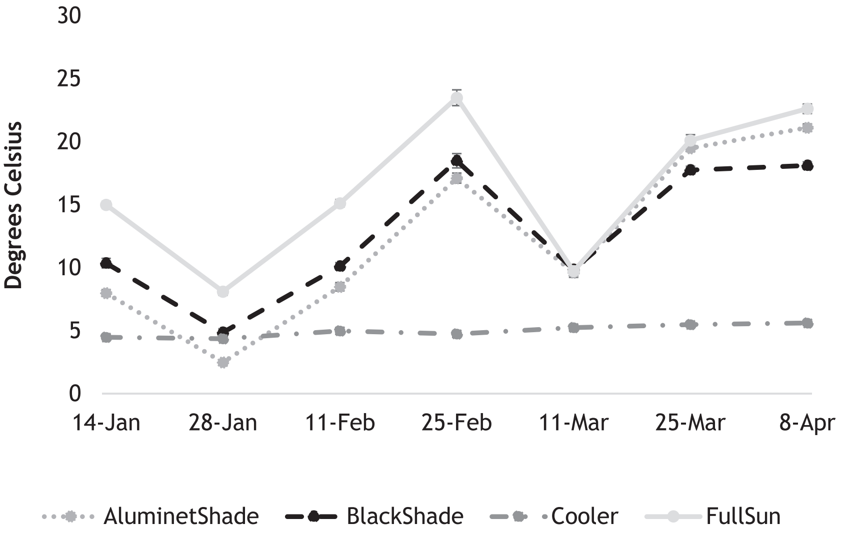

Fig. 2. **Mean stem temperatures (+/- SE) of container-grown (1-gal) *Cercis canadensis* trees randomly selected from four shade treatments in Tennessee.**

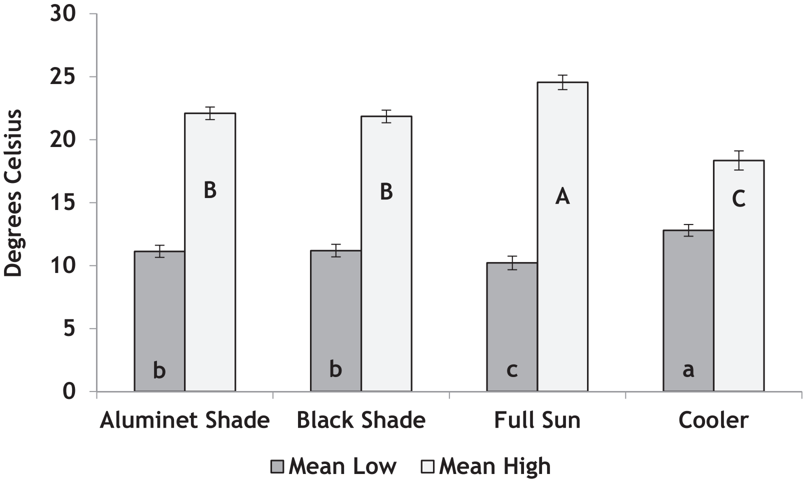

Fig. 3. **Mean low and high air temperatures (+/- SE) of container-grown (1 gal) *Cercis canadensis* trees under four shade treatments in Mississippi. Bars sharing the same letter, upper case for the mean highs and lower case for mean lows, are not statistically different.**

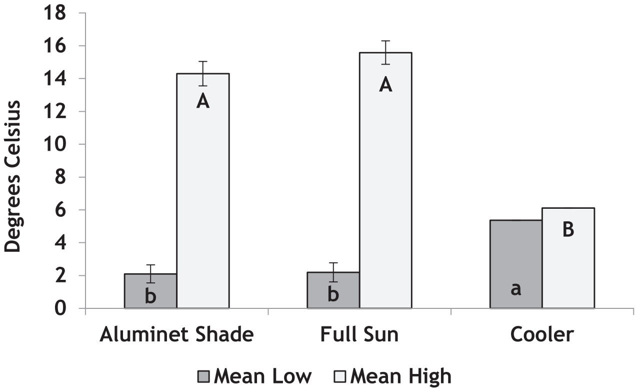

Fig. 4. **Mean low and high air temperatures (+/- SE) of container-grown (1 gal) *Cercis canadensis* trees under three shade treatments in Tennessee. Bars sharing the same letter, upper case for the mean highs and lower case for mean lows, are not statistically different.**

The TN trial had a sensor failure in the black shaded group, but due to more moderate temperatures from this region as compared with MS, the air high temperatures from the full sun treatment (15.6 C) were not significantly different from that seen in the trees under the aluminet shade (14.3 C) ($F = 7.09$; $df = 130$; $P < 0.0001$; Fig. 4). The TN cooler operated correctly, with a higher mean low temperature (5.4 C) and a lower mean high temperature (6.1 C) as compared with the full sun (2.2, 15.6 C) and aluminet shade (2.1, 14.3 C) trees ($F = 6.09$; $df = 130$; $P < 0.0001$).

Analysis of mean daily root zone temperatures from the TN site revealed significantly higher temperatures from the full sun (8.33 C), aluminet (8.31 C) and black (7.74 C) shade treatments as compared with the cooler trees (5.3 C; $F = 7.23$; $df = 3$; $P < 0.0001$). Accumulation of chill hours was significantly higher for cooler trees as compared with other treatments in both MS (1424 chill hours; $F = 44.43$; $df = 139$; $P < 0.0001$; Fig. 5) and Tennessee (2543 chill

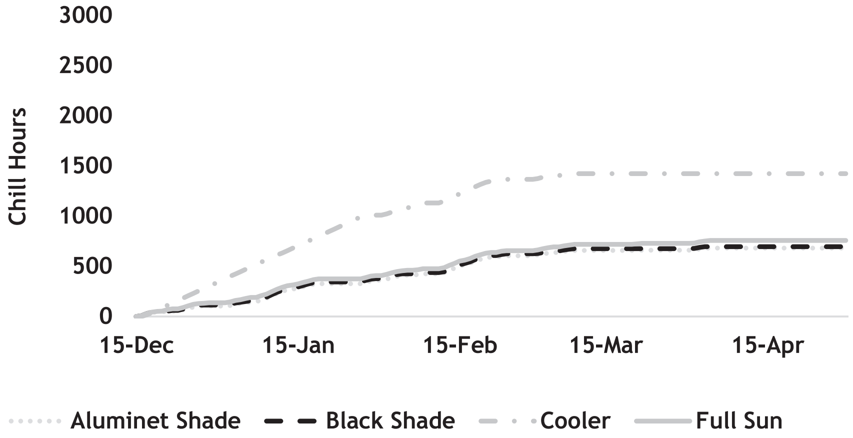

Fig. 5. Accumulated chill hours (December 2020 – April 2021) from four shade treatments for container-grown (1 gal) *Cercis canadensis* trees in Mississippi.

hours; $F = 15.78$; $df = 130$; $P < 0.0001$; Fig. 6). Trees in the MS full sun treatment group (758 hours) also had significantly higher chill accumulation than either the black (696 hours) or aluminet (682) shade groups, while there was no difference for the TN full sun (1194 hours) or aluminet (1230) shade trees.

When testing MTB for both the 4 shade and 3 time duration treatments, the ANOVA model revealed significant differences at both experiment sites [(MS: F = 14.86; df = 11; P < 0.0001) (TN: F = 333.07; df = 11; P < 0.0001)]. This overall model significance was largely due to the time treatments [(MS: F = 73.62; df = 2; P < 0.0001) (TN: F = 1792.64; df = 2; P < 0.0001)], where the Tukey's Studentized Range test revealed differences in MTB among all three time durations, at both sites. Trees removed from field conditions first (early winter) had the greatest MTB measurements, followed by late winter trees having increased MTB than the full season trees (Fig. 7–8).

When disregarding the time treatments and testing all MTB data among the shade treatments only, we found no statistical differences at either site [(MS: F = 2.05; df = 3; P = 0.11) (TN: F = 2.65; df = 3; P = 0.06)]. However, there was a significant time by shade interaction for the TN experiment, due to the full season cooler trees having the highest MTB from that time group, opposite of the two other treatment groups (F = 10.78; df = 6; P < 0.0001).

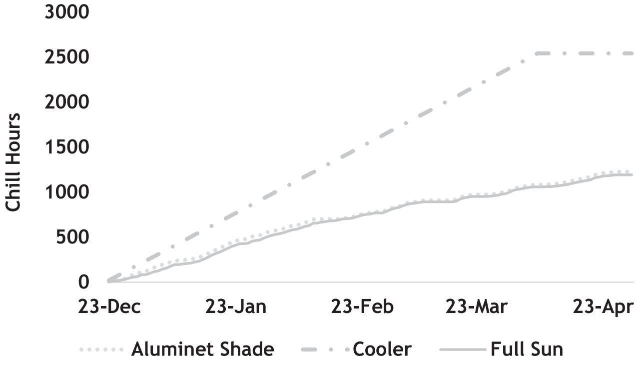

Fig. 6. Accumulated chill hours (December 2020 – April 2021) from three shade treatments for container-grown (1 gal) *Cercis canadensis* trees in Tennessee.

When conducting mean separation analysis of the MTB measurements from within each time grouping, there also were some interesting differences. In the MS experiment, when trees were left out for the full season, the full sun and cooler trees had significantly shorter MTB as compared with the two shade treatments. One potential explanation for this is that trees left in full sun made up for fewer chill hours with their more intense exposure to direct sunlight and higher daytime temperatures, a natural forcing condition, as compared with the two groups of shade treated trees that had neither the chill hours nor the direct sun exposure. While the TN winter was cold enough that shade did not affect MTB, in MS the shade treatments moderated the environment enough to delay bud break.

It was unsurprising to see the lowest stem temperature measurements from the cooler trees and the highest stem temperatures from trees in the full sun, especially during January-February, as these data were recorded during day hours. These trends corresponded to measurements of air temperatures, where full sun trees had the highest high and the lowest low temperatures, as these data were recorded both day and night. While differences in stem temperature for full sun and shaded trees were only significant at the MS site, this provides evidence that at some locations, a shade cloth can protect overwintering tree crops from exposure to low temperatures, as well as unseasonal warm weather that can reduce dormancy. Due to the insulating effects of the growing medium in our container-grown trees, it was not surprising to see less treatment effects in root zone temperatures in TN.

Accumulation of chill hours is just another way of looking at temperature data, with the more consistently low temperatures in our cooler treatments leading to a greater chill accumulation among those trees. Many temperate deciduous tree species, including high-value ornamental and fruit tree crops, require higher chill accumulation for normal development. Of five temperate deciduous tree species tested by Nanninga et al. (2017), all exhibited a significant negative correlation between MTB and exposure to chilling. The strongest such response was from the native *Acer rubrum* L., with a steep decline in days to bud burst with increasing chill hours, while a much weaker response was observed by the exotic *Rhamnus cathartica*

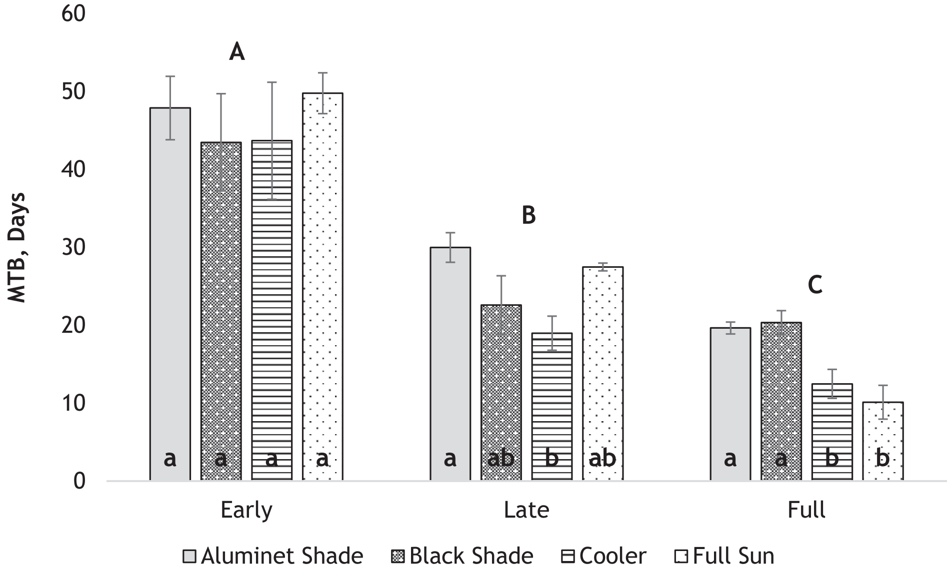

Fig. 7. **Mean time (days) to first bud break (+/- SE) for container-grown (1 gal) *Cercis canadensis* trees under four shade treatments and three time durations in Mississippi. Bar groups sharing the same letter, upper case for across the three time durations and lower case for within each time duration, are not statistically different.**

L. Leaf emergence of walnut (*Juglans nigra* L.) is strongly tied to accumulation of winter chilling hours, with delays in both flower and leaf emergence resulting from milder winters (Luedeling et al. 2013). As a native to our study areas, *C. canadensis* is similarly well-adapted to colder winter temperatures as exhibited by the negative correlation between MTB and chill accumulation (Kovaleski 2021).

Similarly, the more time our trees were left under experimental winter conditions, the shorter time it took them to break dormancy, with MTB measurements significantly higher from trees in the early winter vs. the late winter or full season groups. This data correlates well with the chill hour data, providing further evidence that *C. canadensis* is well-adapted to a higher chill climate. Implications of these data include a shorter MTB as mean winter temperatures rise, putting ornamental crops of *C. canadensis* at greater risk of late winter frost injury.

High variance in winter temperatures has been shown to negatively impact frost hardiness of overwintering oak (*Quercus* spp.) trees, leading to greater damage in bark and bud tissues (Thomas and Ahlers 1999). In addition to greater chill accumulation, trees from our cooler treatment groups were exposed to the least temperature variance, with both the lowest highs and the highest lows, and they also had lower MTB measurements at each site. High chill

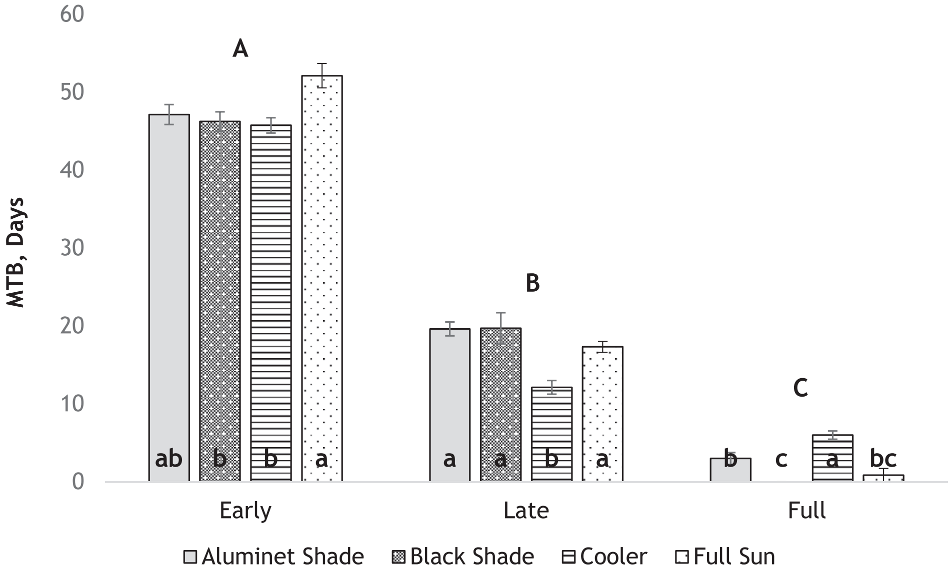

Fig. 8. **Mean time (days) to first bud break (+/- SE) for *Cercis canadensis* trees under four shade treatments and three time durations in Tennessee. Bar groups sharing the same letter, upper case for across the three time durations and lower case for within each time duration, are not statistically different.**

accumulation coupled with less temperature variance and less extreme cold exposure in our cooler trees may provide the best case scenario for overwintering *C. canadensis* crops, but of course this is not feasible in a production capacity.

There was no difference in MTB between the two shade treatments, and mostly not between shaded and full sun trees as well, indicating a lack of effect on tree dormancy using the current methodology. Yet a shade cloth may still provide some protection from the most damaging overnight low winter temperatures, as evidenced by our measurements of stem temperatures. While this level of protection would likely not justify the added expense in materials and labor for covering an ornamental crop, there may be some adjustments to our methodology that would offer protection from the lowest temperatures, while also yielding a lower MTB time. Future efforts to improve this research could include a larger overhead shade cloth that does not fully shield the sides of tree plots, allowing some protection from extreme cold while also providing daytime ventilation that could improve chill accumulation. Measurements of endogenous stress compounds such as abscisic acid or ethanol in tree tissues exposed to these various shade regimes could provide further evidence for differential responses to the treatments.

In recent years, increasing attention has been given to the impacts of exotic-invasive ambrosia beetles at ornamental tree nurseries (Curculionidae: Scolytinae: Xyleborina) (Fulcher et al. 2012). In their native habitats, ambrosia beetles preferentially attack stressed or injured trees, and have a known attractancy to the plant stress volatile ethanol (Ranger et al. 2013). However, non-native ambrosia beetles frequently will exploit "apparently healthy" trees that exhibit no outward signs of stress, but may or may not have been stressed during dormancy (Ranger et al. 2015). Due in part to the timing of ambrosia beetle flight activity in early spring, when vulnerable tree crops are just breaking dormancy and may not have achieved bud break, nursery managers often are unable to recognize which trees are stressed and are most likely to be attacked (Werle et al. 2015). Testing susceptibility of trees from our shading regimes to ambrosia beetle attacks, perhaps after frost exposure, might reveal some adaptive variability among the shade treatment groups. Testing these effects on a wider array of horticultural crops also would assist with mitigation of overwintering problems such as premature loss of dormancy at nurseries.

Potential consequences of a future scenario with milder, shorter winters include delayed budburst in high-chill species, potential temporal mismatches of fruit crops with pollinators, and a competitive disadvantage with low-chill invasive species (Caffarra and Donnelly 2011). With projections of increasing temperature variance and occurrence of extreme weather events, tree crops will continue to be exposed to the threat of late-season frost injury and ensuing biotic pest problems (Gregoire et al. 2001, Ranger et al. 2019). Gaining a greater understanding of the role of dormancy on health of overwintering tree crops, and our ability to manipulate dormancy to growers' advantage, will be valuable to the horticultural industry.

Literature Cited

Alvarez, H. C., M. Salazar-Gutierrez, D. Zapata, M. Keller and G. Hoogenboom. 2018. Time-to-event analysis to evaluate dormancy status of single-bud cuttings: an example for grapevines. Plant Methods 14:94. https://doi.org/10.1186/s13007-018-0361-0.

Augspurger, C. K. 2013. Reconstructing patterns of temperature, phenology, and frost damage over 124 years: Spring damage risk is increasing. Ecology 94:41–50.

Caffarra, A. and A. Donnelly. 2011. The ecological significance of phenology in four different tree species: effects of light and temperature on bud burst. Int. J. Biometeorol. 55:711–721.

Campoy, J. A., D. Ruiz and J. Egea. 2011. Dormancy in temperate fruit trees in a global warming context: A review. Sci. Hortic. 130:357–372.

Denny, E. G., K. L. Gerst, A. J. Miller-Rushing, G. L. Tierney, T. M. Crimmins, C. A. F. Enquist. 2014. Standardized phenology monitoring methods to track plant and animal activity for science and resource management applications. Int. J. Biometeorol. 58:591–601.

Fare, D. C. 2012. Evaluation of spectral light management on growth of container-grown willow oak, nuttall oak and summer red maple. J. Environ. Hort. 30:8–12.

Francini, A. and L. Sebastiani. 2019. Abiotic stress effects on performance of horticultural crops. Horticulturae 5:67. https://doi.org/10.3390/horticulturae5040067.

Fulcher, A., W. E. Klingeman, J. H. Chong, A. LeBude, G. R. Armel, M. Chappell, S. Frank, F. Hale, J. Neal, S. White, J. Williams-Woodward, K. Ivors, C. Adkins, A. Senesac, and A. Windham. 2012. Stakeholder vision of future direction and strategies for southeastern U. S. nursery pest research and extension programming. J. Integr. Pest Manage. 3:1–8.

Gregoire, J.-C., F. Piel, M. De Proft and M. Gilbert. 2001. Spatial distribution of ambrosia-beetle trap catches: A possibly useful knowledge to improve mass-trapping. Integr. Pest Manage. Rev. 6:237–242.

Hall, C. R., A. W. Hodges and J. J. Haydu. 2006. The Economic Impact of the Green Industry in the United States. HortTechnol. 16:345–353.

Howell, G. S. and C. J. Weiser. 1970. The environmental control of cold acclimation in apple. Plant Physiol. 45:390–394.

Jensen, K. L., B. C. English, J. Menard, S. Schexnayder, J. Bruhin and A. Fulcher. 2020. Estimated economic contributions from the Nursery/Greenhouse industry in Tennessee. AREC Research Report 20-001, p. 1–26. https://ag.tennessee.edu/arec/Documents/publications/RR_20_001__003.pdf. Accessed December 2021.

Kim, B-M., S-W. Son, S-K. Min, J-H. Jeong, S-J. Kim, X. Zhang, T. Shim and J-H. Yoon. 2014. Weakening of the stratospheric polar vortex by Arctic sea-ice loss. Nat. Commun. 5:4646 DOI: 10.1038/ncomms5646

Kovaleski, A. 2021. Woody species do not differ in dormancy progression: differences in time to budbreak due to forcing and cold hardiness. bioRxiv, 1-20. DOI: 10.1101/2021.04.26.441354.

La Spina, S., C. De Canniere, A. Dekri and J.-C. Gregoire. 2013. Frost increases beech susceptibility to scolytine ambrosia beetles. Agric. For. Entomol. 15:157–167.

Li, C., T. Puhakainen, A. Welling, A. Vihera-Aarnio, A. Ernstsen, O. Junttila, P. Heino and E. Tapio Palva. 2002. Cold acclimation in silver birch (*Betula pendula*). Development of freezing tolerance in different tissues and climatic ecotypes. Physiol. Plant. 116:478–488.

Luedeling, E., L. Guo, J. Dai, C. Leslie and M. M. Blanke. 2013. Differential responses of trees to temperature variation during the chilling and forcing phases. Agric. For. Meteorol. 181:33–42.

Mohawesh, O., A. Albalasmeh, S. Deb, S. Singh, C. Simpson, N. AlKafaween and A. Mahadeen. 2022. Effect of colored shading nets on the growth and water use efficiency of sweet pepper grown under semi-arid conditions. HortTechnol. 32:21–27.

Nanninga, C., C. R. Buyarski, A. M. Pretorius and R. A. Montgomery. 2017. Increased exposure to chilling advances the time to budburst in North American tree species. Tree Physiol. 37:1727–1738.

Posadas, B., P. Knight, E. Stafne, C. Coker, E. Blythe, G. Bachman, J. DelPrince and S. Langlois. 2020. Qualitative Assessment of the Economic Impacts of Horticulture Research and Extension at MSU Coastal Research and Extension Center. Horticulturae 6:106. https://doi.org/10.3390/horticulturae6040106.

Ranger, C. M., M. E. Reding, P. B. Schultz and J. B. Oliver. 2013. Influence of flood stress on ambrosia beetle (Coleoptera: Curculionidae: Scolytinae) host selection and implications for their management in a changing climate. Agric. For. Entomol. 15:56–64.

Ranger, C. M., P. B. Schultz, S. D. Frank, J. H. Chong and M. E. Reding. 2015. Non-native ambrosia beetles as opportunistic exploiters of living but weakened trees. PLoS ONE 10. e0131496. https://doi.org/10.1371/journal.pone.0131496.

Ranger, C. M., P. B. Schultz, S. D. Frank and M. E. Reding. 2019. Freeze stress of deciduous trees induces attacks by opportunistic ambrosia beetles. Agric. For. Entomol. 21:168–179.

Stamps, R. H. 2009. Use of colored shade netting in horticulture. HortSci. 44:239–241.

Teshome, D. T., G. E. Zharare and S. Naidoo. 2020. The threat of the combined effect of biotic and abiotic stress factors in forestry under a changing climate. Front. Plant Sci. 11:601009. doi: 10.3389/fpls.2020.601009.

Thomas, F. M. and U. Ahlers. 1999. Effects of excess nitrogen on frost hardiness and freezing injury of above-ground tissue in young oaks (*Quercus petraea* and *Q. robur*). New. Phytol. 144:73–83.

Werle, C. T., J. H. Chong, B. J. Sampson, M. E. Reding and J. A. Adamczyk. 2015. Seasonal and spatial dispersal patterns of select ambrosia beetles (Coleoptera: Curculionidae) from forest habitats into production nurseries. Fla. Entomol. 98:884–891.