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Rest Completion of Eastern Black Walnut

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Abstract

The time of rest completion of buds of eastern black walnut *(Juglans nigra* L.) cultivars was compared from 2004 to 2008 and various models for estimating chilling were evaluated. The chilling model that best accounted for the variation in days to budbreak among cultivars and temperatures during dormant periods had the following two components: 1) a chilling inception temperature of -2.2ºC and 2) weighted chilling hours that accumulated after the chilling inception temperature. Chilling hours in this model were weighted as follows: <0ºC = 0; 0 to 9.1ºC = 1; 9.2 to12.4 ºC = 0.5; 12.5 to 15.9ºC = 0; 16 to 18ºC = -0.5; >18ºC = -1. Based upon this chilling model, 'Schessler', 'Davidson', and 'South Fork' ranked among the cultivars with the shortest chilling requirements (< 1400 chill units). 'Jackson' also had a relatively short chilling requirement (≈ 1400 units). In contrast, 'Sparks 147' and 'Thomas Myers', did not complete rest during the experimental period (i.e., break bud within 14 days after exposure to 21ºC) and required > 1625 chill units. This study also elucidated that a black walnut model with a chilling inception temperature of -2.2ºC estimated chilling more accurately than one with chilling inception just after the maximum negative accumulation of chill units as used in the Utah chilling model. Also, temperatures between 0 and 2.4ºC must be weighted more heavily in a black walnut model than in the Utah peach model to accurately estimate chilling and rest completion.

Many temperate zone fruit and nut trees require a period of low temperatures during dormancy to grow vegetatively and bloom in the spring. The number of hours necessary to fulfill the chilling requirement varies among fruit and nut crops (26) and cultivars (3, 5, 24). Several models have been used to estimate the chilling requirements and to predict the time of rest completion. In 1932, Hutchins (25) proposed a model for peach that accumulated chilling hours at temperatures ≤ 7ºC. Chandler et al. (3) studied chilling of deciduous fruit and nut trees, small fruit crops, and ornamentals. This work indicated that temperatures from 0 to 7ºC were most effective in satisfying the cold requirement. For peach, temperatures as low as 1.5ºC have been used to accumulate units in the Utah chilling model (16), and temperatures as warm as 13ºC have been used to accumulate units in chilling models in Israel (11). As temperatures increase to 10ºC, about twice as many hours are required for rest completion of peach than at 6ºC (9, 12). Above a specific temperature, chilling is nullified. Thus, weighted values were assigned to temperature ranges (10, 12, 16). A chilling model developed for 'Starkrimson Delicious' apple trees in North Carolina accumulated units between 1.6 and 13ºC (19). For highbush blueberry, an Arkansas model accumulated chilling units at temperatures <12.5ºC (15). Dale et al. (5) published a raspberry chilling model in which temperatures below 5.6ºC = 1 chill unit and those above 13ºC = -1 chill unit. More recently, Warmund and Krumme (24) developed a blackberry chilling model that was modified from the Utah peach model that used a chilling inception at -2.2ºC and weighted values at different temperatures.

The reported chilling requirements of nut trees vary widely (1, 4, 17). Westwood (25) reported that rest was completed in pecan buds after 400 to 1500 h of temperatures below 7ºC. 'Desirable' and 'Mahan' pecan required 500 h of chilling below 7.2ºC, while 'Stuart' pecan required 600 h of chilling (13). Other researchers (2, 20) also studied the cold requirement of pecan at various temperatures, but did not develop a chilling model. The

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cold requirement of Persian walnut (*Juglans regia* L.) has been listed at 500 to 1500 h at temperatures below 7ºC (17). Chandler et al. (3) reported that eastern black walnut (*Juglans nigra* L.) had a chilling requirement less than that of 'Franquette' Persian walnut. Although these chilling requirements have been reported, little is known about the time of chilling inception or the effective range of temperatures for which chilling hours are accumulated in eastern black walnut. Therefore, the objectives of this study were: 1) to compare the time of rest completion for several black walnut cultivars, 2) to determine the time of chilling inception, and 3) to evaluate various chilling models for estimating rest completion in eastern black walnut.

Materials and Methods

Rest completion. Eastern black walnut tissue samples of 'Jackson', 'Football', 'Kwik Krop', 'Sparks 127', 'Surprise', and 'Tomboy' were obtained from seven year-old trees in a planting located at the Horticulture and Agroforestry Research Center (HARC), New Franklin, Missouri, on 1 and 17 Mar. and 1 Apr. 2005 and 2006. Cultivars were on Thomas seedling rootstock and trees had been trained to a palmette system described previously (21) on a trellis to induce early nut production. At each sampling date, 5 eight-node sections of wood from each cultivar were removed from the terminal portion of lateral branches at 1.5 to 2.5 m above the soil surface from each of three trees. Five single cutting replicates of each cultivar were then placed in oasis wedges (Smithers Oasis Company, Kent, Ohio) in a greenhouse maintained at 21ºC. Cuttings were misted with water for 30 sec twice daily at 0800 and 1700 hr. After samples were placed in the greenhouse, budbreak of the terminal bud of each cutting was recorded daily for a period of 30 days for each date of collection to determine dates of rest completion. Because the number of days to budbreak for the terminal bud decreased at successive collection dates and only a few axillary buds on the cuttings grew during 30 days in the greenhouse, the average days to budbreak for terminal buds were calculated.

In 2007, 5 eight-node cuttings were removed on 14 Mar., and 1 and 9Apr., as previously described from 11-year-old free-standing trees grafted onto Thomas walnut seedling rootstocks located in a clonal repository planting at HARC. Two trees (five cuttings per tree) of each of twenty cultivars were sampled at each date. The identity of each cultivar was confirmed by DNA fingerprinting, using a series of ten single sequence repeat microsatellite markers during the previous year (M.V. Coggeshall, unpublished data). In 2008, the same trees were sampled in a similar manner, but sampling dates were adjusted to 14 Mar., and 1 and 15 Apr. because of the cool temperatures. After cuttings were obtained, they were evaluated as previously described and the average days to budbreak for terminal buds were calculated for each cultivar. Rest was considered complete when the terminal bud exhibited growth at $\leq$ 14 days after samples were placed in the greenhouse (6).

Chilling models. Hourly temperature data were recorded by a MetData1 weather station (Campbell Scientific, Inc., Logan, Utah) located within 400 m of the walnut plantings in all years except for February 2007 due to equipment malfunction (Fig. 1). Thus, data presented in Fig 1B from 1 to 25 Feb. 2007 were acquired from another weather station located 3.4 km from the repository block of 20 cultivars. Chilling hours or units were calculated for all dormant seasons except for 2006-2007 using models that varied in the time when chilling hours began accumulating (chilling inception) and in the range of temperatures that induced chilling. Because previous researchers (7, 27) considered inception of chilling after the first killing frost (-2.2ºC), this method of determining chilling accumulation was included in the study for comparative purposes with one chill unit accumulating for each hour between 0 and 7ºC (3). The Utah chilling model (16, 18) was also tested, as well as the blackberry model reported by Warmund and Krumme (24). The

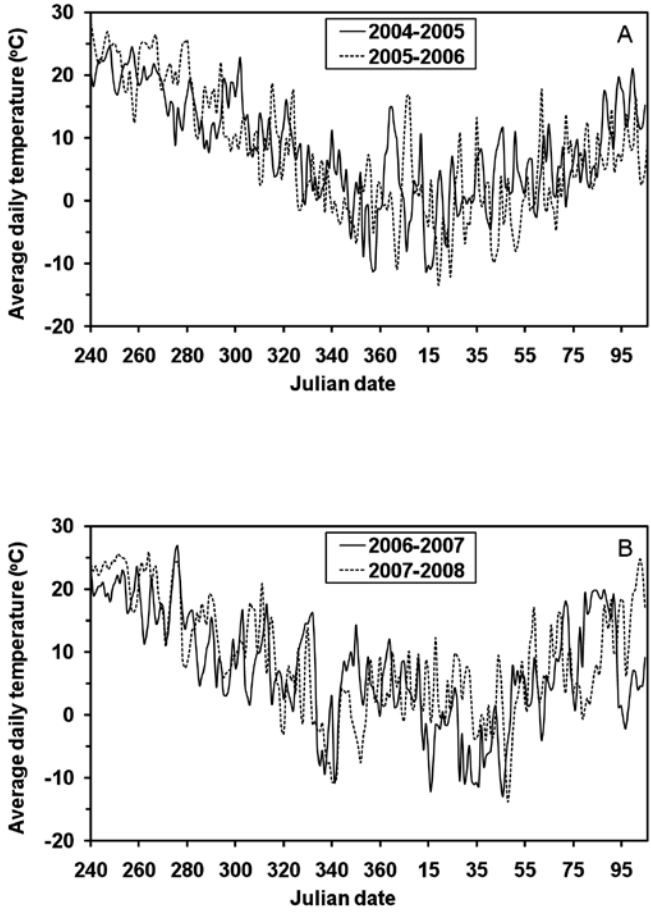

Figure 1. Average daily temperature at New Franklin, Missouri during four dormant seasons.

chilling hours in this model were weighted as follows: <0ºC = 0; 0 to 9.1ºC =1; 9.2 to12.4 ºC = 0.5; 12.5 to 15.9ºC = 0; 16 to 18ºC = -0.5; >18ºC = -1.

Statistical analysis. Data for the number of days to budbreak at each date of collection for the seven black walnut cultivars evaluated in 2004 to 2006 were subjected to ANOVA using the GLM procedure of SAS (Version 9.1; SAS Institute, 2004, Cary, N.C.) and means were separated by Fisher's protected LSD test, $P \leq 0.05$. Standard error of mean days to budbreak for each cultivar was calculated for data recorded in 2007 and 2008.

Results and Discussion

Rest completion. Average daily temperatures at New Franklin varied among the years of this study (Fig. 1). In early 2005, average temperatures were generally cooler than those on corresponding dates in 2006. In 2007, the third warmest 21 Mar. through 3 Apr. period since 1898 was followed by the coldest 4 Apr. to 9 Apr. period on record (23). On 7 Apr. 2007, the temperature at HARC, dropped to -7.3ºC. In contrast to 2007, temperatures in late February through the end of March 2008 were cooler (Fig. 1B).

The six walnut cultivars sampled in 2005

and 2006 exhibited relative differences in the number of days required to break bud after exposure to warm temperatures, indicating differences in their chilling requirement. In 2005 and 2006, all of the terminal buds on cuttings grew after exposure to warm temperatures when sampled on 1 Mar. (Table 1). However, 'Kwik Krop' averaged more days to budbreak than other cultivars on 1 Mar. 2005. On 1 Mar. 2006, 'Football' and 'Jackson' averaged fewer days to budbreak than other cultivars. By 17 Mar. 2005 and 2006, the number of days to budbreak was reduced considerably for all cultivars when compared to the days to budbreak from the earlier collection date. 'Jackson' was the only cultivar in which terminal buds averaged < 14 days to budbreak. 'Tomboy and 'Football' broke bud about 2 to 4 days later than those of 'Jackson' when samples were collected on 17 Mar. Also, terminal buds of 'Kwik Krop', 'Sparks 127' and 'Surprise' required ≥ 2.3 additional days to grow than those of 'Tomboy' and 'Football'. By the last collection date, 'Kwik Krop' and 'Sparks 127' were the only two cultivars that did not grow in < 14 days after exposure to warm temperatures in the greenhouse.

Terminal buds of 'Thomas Myers', 'Sparks 147', 'Sauber #1', and 'Thomas' sampled on 14 Mar. did not exhibit growth after exposure to 30 days at 21ºC in the greenhouse in 2007 or 2008 (Table 2). Additionally, 'Kwik Krop', 'Hare', 'Sparrow', 'Sparks 127', and 'Surprise' did not produce growth in the greenhouse when sampled on 14 Mar. 2008. Terminal buds of cuttings from 'Thomas Myers', 'Sparks 147, 'Thomas', 'Sparrow', 'Sparks 127', and 'Surprise' trees collected on 1 Apr. 2008 also did not produce visible growth following warm temperature exposure. In contrast, on 1 Apr. 2007, nine of the 20 cultivars evaluated broke bud in less than 14 days. Only four cultivars, 'Brown Nugget', 'Jackson', 'Davidson', and 'Schessler' produced growth from buds in less than 14 days at the same date in 2008. Because of the very warm temperatures in late March 2007, terminal buds of 'Football', 'South Fork', 'Davidson', and 'Schessler' produced leaves on trees in the field at HARC by 9 Apr. 2007. Seven additional cultivars broke bud in < 14 days after warm temperature exposure in the greenhouse at this date. In contrast, none of the trees had leafed out in the field by 14 Apr.

Table 1. Average number of days to budbreak for eastern black walnut cultivars at each sampling date after exposure to 21ºC.

Cultivar	1 Mar.	17 Mar.	1 Apr.
2005			
Kwik Krop	27.5 a [z]	19.4 a	14.6 ab
Football	23.6 b	16.2 b	10.2 c
Sparks 127	23.2 b	20.6 a	15.4 a
Tomboy	22.8 b	16.2 b	8.8 cd
Surprise	22.4 b	18.8 a	13.0 b
Jackson	20.6 b	13.6 c	7.8 d
2006			
Kwik Krop	27.2 a	19.8 a	16.2 a
Football	23.5 b	16.4 c	9.4 c
Sparks 127	28.4 a	19.0 ab	17.2 a
Tomboy	26.4 a	16.7 c	9.2 c
Surprise	26.5 a	19.7 a	12.6 b
Jackson	22.8 b	13.2 d	8.8 c

[z] Mean separation within columns by years by Fisher's protected LSD test, P ≤ 0.05.

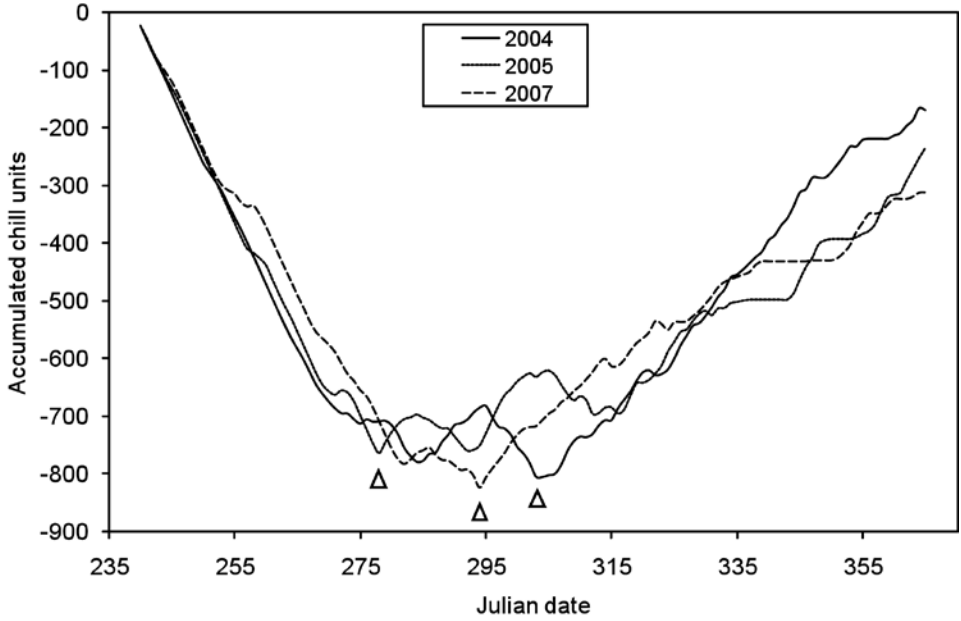

Figure 2. The maximum negative accumulation of chill units at New Franklin, Missouri calculated by the Utah peach model (16, 18). Triangles indicate the maximum negative accumulation of chill units (i.e., chilling inception dates) on Julian date 305, 278, and 293 in 2004, 2005, and 2007, respectively.

2008 and ten of the cultivars collected at this date exhibited budbreak in the greenhouse in < 14 days.

Chilling models. Differences among the dormant seasons in field temperatures provided an opportunity to compare and evaluate various chilling models (Fig. 1). In 2008, 1 Mar. to 1 Apr. was considerably cooler than the same period in 2005 and 2006. There were 52 more hours of average hourly temperatures below 0ºC for this period of time in 2008 than for 2006. Thus, fewer chilling hours were accumulated by 1 Apr. 2008, than at the same date in 2005 and 2006.

Models 1 and 3 used the same time of chilling inception (-2.2ºC), which occurred on 21 Nov. 2004, 13 Dec. 2005, and 16 Nov. 2007. In contrast, chilling inception for Model 2 (Utah peach model) occurred at earlier dates when the maximum negative chill units were accumulated (31, 5, and 22 Oct. in 2004, 2005, and 2007, respectively) (Fig. 2). In spite of the later dates of chilling inception, Model 3 accumulated more chill units than the other models by the last collection date in all years because of the weighted values (Table 3).

Model 1, which accumulated chilling hours between 0 and 7ºC, accumulated relatively few hours as compared to Model 3. Model 1 likely underestimates the chilling requirement of black walnut cultivars. Shaltout and Unrath (19) reported that 1200 chill units were required for 'Starkrimson Delicious' rest completion. At HARC, buds of 'Starkrimson Delicious' apple trees initiate growth in the field about 21 days before 'Sparks 127' black walnut and 'Darrow' blackberry canes break bud 31 days before 'Sparks 127'(M.R.Warmund, unpublished data). Average dates of black walnut budbreak in the field during the study period were 11, 16, 18, 18, 25, 26, 27 Apr., and 5 May for 'Schessler, 'Jackson', 'Tomboy', 'Football', 'Surprise', 'Kwik Krop', 'Sparks 127', and 'Thomas Myers', respectively.

Table 2. Average number of days to budbreak for eastern black walnut cultivars at each sampling date after exposure to 21ºC. [z]

	2007			2008		
Cultivar	14 Mar.	1 Apr.	9 Apr.	14 Mar.	1 Apr.	14 Apr.
Sauber#1	-- [y]	21.9 ± 1.1	17.1 ± 0.8	-- [y]	26.6 ± 0.8	20.4 ± 0.5
Sparks 147	-- [y]	23.5 ± 0.7	18.6 ± 0.7	-- [y]	-- [y]	22.4 ± 0.8
Thomas	-- [y]	21.4 ± 0.4	15.9 ± 0.3	-- [y]	-- [y]	19.7 ± 0.6
Thomas Myers	-- [y]	25.8 ± 0.9	23.3 ± 0.6	-- [y]	-- [y]	24.4 ± 0.8
Kwik Krop	29.0 ± 0.0	17.9 ± 0.2	15.5 ± 1.0	-- [y]	23.5 ± 0.7	16.8 ± 0.4
Sparrow	28.7 ± 0.2	19.0 ± 0.5	15.2 ± 0.8	-- [y]	-- [y]	16.2 ± 0.5
Surprise	28.3 ± 1.2	15.6 ± 0.9	12.7 ± 0.6	-- [y]	-- [y]	14.0 ± 0.9
Sparks 127	28.0 ± 1.0	16.2 ± 0.6	13.5 ± 0.3	-- [y]	-- [y]	14.9 ± 0.4
Tomboy	27.0 ± 0.3	12.0 ± 0.4	9.6 ± 0.5	30.0 ± 0.0	24.1 ± 1.0	9.0 ± 0.3
Football	26.8 ± 1.5	13.8 ± 1.6	-- [x]	28.3 ± 0.3	21.0 ± 0.9	9.7 ± 0.9
Emma K	26.2 ± 1.3	12.9 ± 0.7	8.3 ± 0.7	28.6 ± 0.4	24.3 ± 0.3	8.3 ± 0.4
Bowser	26.0 ± 3.0	21.9 ± 0.6	15.4 ± 0.4	30.0 ± 0.9	24.6 ± 0.7	18.2 ± 0.7
Crosby	25.3 ± 0.3	18.0 ± 0.9	17.0 ± 0.9	28.8 ± 0.9	23.9 ± 1.3	19.2 ± 0.3
Hare	24.1 ± 0.4	20.0 ± 0.4	15.6 ± 0.6	-- [y]	22.8 ± 0.5	16.6 ± 0.6
Mystry	23.9 ± 0.8	12.1 ± 0.4	9.1 ± 0.3	28.8 ± 0.6	18.5 ± 0.5	8.8 ± 0.3
Davidson	21.7 ± 1.9	6.4 ± 0.4	-- [x]	27.7 ± 0.6	11.9 ± 0.4	5.6 ± 0.4
Jackson	21.4 ± 0.9	8.8 ± 0.4	7.0 ± 0.6	28.9 ± 0.5	13.9 ± 0.1	8.0 ± 0.2
South Fork	21.2 ± 1.3	6.6 ± 0.7	--[x]	27.4 ± 0.7	16.8 ± 1.2	7.8 ± 0.7
Brown Nugget	19.2 ± 0.7	5.8 ± 0.7	7.6 ± 0.52	26.9 ± 0.5	5.7 ± 0.6	8.1 ± 0.3
Schessler	14.7 ± 0.6	3.9 ± 0.5	-- [x]	21.8 ± 0.3	9.2 ± 0.3	4.0 ± 0.2

[z] Standard error value is presented for each mean.
[y] Terminal buds did not exhibit growth after 30 days exposure to 21ºC in the greenhouse.
[x] Terminal buds of walnut trees already exhibited growth in the field.

Also, black walnut trees have relatively later bloom dates than many other fruit and nut crops, including apricot, peach, plum, cherry, apple, pecan, blackberry, and raspberry in central Missouri. For example, average first bloom dates of most black walnuts at HARC range from 23 Apr. to 17 May (22), whereas the average bloom date for 'Starkrimson Delicious' trees is 18 Apr. (M.R. Warmund, unpublished data). Erect-growing blackberry cultivars, such as 'Kiowa' and 'Darrow' often bloom in late March or early April. In an earlier study with blackberry, 'Kiowa' generally had the shortest chilling requirement of those cultivars tested (≈ 500 units), whereas 'Darrow' had the longest chilling period (≈ 1000 units) using Model 3 (24). Because Model 1 predicted rest completion of 'Jackson' buds at 1106 and 1146 chill units in 2005 and 2006, while Model 3 estimated rest completion for this cultivar at 1370 and 1383, the latter model is more likely accurate based the relative times of rest completion (4, 17, 24), budbreak, and bloom of other fruit and nut species.

In 2005 and 2006, Model 1 also accumulated fewer chill units than Model 2, which did not accurately calculate chilling. For example, 'Football' samples broke bud after 1244 chill units were accumulated by 15 Apr. 2008 using Model 2 (Tables 2 and 3), but they failed to

Table 3. Chilling hours or units calculated by various models for eastern black walnut cultivars grown at New Franklin, Mo in 2005, 2006, 2008.

Sampling date	Model 1[z]	Model 2[y]	Model 3[x]
2005			
1 Mar.	972	1142	1200
17 Mar.	1106	1243	1370
1 Apr.	1299	1443	1607
2006			
1 Mar.	1028	1035	1252
17 Mar.	1146	1144	1383
1 Apr.	1318	1344	1625
2008			
14 Mar.	948	822	1089
1 Apr.	1156	1098	1400
14 Apr.	1301	1244	1574

[z] Model 1 is the number of hours between 0 and 7ºC, with chilling inception at the first incidence of - 2.2ºC in the fall.
[y] Model 2 is the Utah peach chilling model with chilling inception the day after the maximum number of negative chill units (above 15.9ºC) was recorded in the fall. In this model the chilling hours are weighted as follows: <1.4ºC = 0; 1.5 to 2.4ºC = 0.5; 2.5 to 9.1ºC =1; 9.2 to12.4ºC = 0.5; 12.5 to 15.9ºC = 0; 16 to 18ºC = -0.5; >18ºC = -1.
[x] Model 3 is a modified Utah chilling method with the chilling inception at the first incidence of -2.2ºC and the chilling hours weighted as follows: <0ºC = 0; 0 to 9.1ºC =1; 9.2 to12.4 ºC = 0.5; 12.5 to 15.9ºC = 0; 16 to 18ºC = -0.5; >18ºC = -1 (24). Due to a weather monitoring equipment failure, data are not presented for 2007.

grow when 1243 units were accumulated by 17 Mar. 2005 (Table 1). Additionally, Model 2 incorrectly calculated chill units for 'Tomboy' and 'Surprise' (Tables 1, 2, and 3).

Model 3 consistently predicted rest completion in all three years for 'Jackson', 'Football', 'Tomboy' and 'Surprise' (Table 3). Thus, 'Jackson' required about 1400 chill units for rest completion, whereas 'Football', 'Tomboy' and 'Surprise' required ≈ 1574 chill units to satisfy rest. Because 'Davidson' and 'Schessler' broke bud in the field by 9 Apr. 2007 and generally were the first cultivars to produce growth in the greenhouse at other sampling dates, these cultivars required fewer chill units than 'Jackson' (Table 2). Cultivars such as 'Thomas Myers', 'Sparks 147', 'Sauber #1', 'Thomas', and 'Crosby' required the most days of warm temperature exposure in the greenhouse for budbreak. Therefore, these cultivars had the longest chilling requirements of those tested in this study.

In conclusion, the chilling requirement for eastern black walnut cultivars ranged from ≈ 1400 units to more than 1600 units in this study. Because rest is considered complete when buds exhibit growth in ≤ 14 days after exposure to warm temperatures (6), the chilling requirement was not determined for several of the cultivars tested. In spite of this difficulty, the relative time of rest of completion was determined for 20 black walnut cultivars and chilling requirements of several cultivars were elucidated. Also, Model 3 accounted for the variation among cultivars in the time of rest completion most accurately among the models tested. Additionally, this study elucidated that a black walnut model with a chilling inception temperature of -2.2ºC estimated chilling more accurately than the Utah chilling model, which initiates chill unit accumulation immediately after the maximum negative accumulation of chill units in early fall.

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