Analysis of the April 2007 Freeze Event in Oklahoma

Eric T. Stafne

Assistant Professor and Extension Fruit Specialist

Oklahoma State University

Recap of Events

A devastating spring freeze event occurred during the nights of April 7 and April 8 of 2007, which severely affected wine grapes throughout the state. The timing of the freeze was not unusual, as April is typically a time for frosts and occasional freezes (Table 1). However, what made this particular freeze event so significant was the much warmer than normal temperatures of March. According to the March 2007 Oklahoma monthly climate summary (OCS, 2007), for the entire state of Oklahoma March was the 2nd warmest on record about 8 degrees above normal. All areas of the state reported March 2007 as being in the top three warmest on record, with the Northeast, Central, and East Central regions of the state all reporting the month as the warmest on record. The Northeast part of the state was 9.0 °F above normal. These conditions coupled with extremely low temperatures that followed in April (as low as 17 °F in Jay, OK) resulted in early budbreak, thus predisposing vines to freeze injury. The April climatological outlook prepared by the OCS (2007) in March proved prescient, as they stated that even though freezes are uncommon, any sub-freezing temperatures would be injurious to many fruiting plants. Critical temperatures for grapes vary depending on duration of cold and affected tissues. Frost injury can begin at 31 °F after 30 minutes of exposure, but several hours at 26 to 28 °F can cause significant damage (Peacock, 1998).

Oklahoma was not the only state impacted by this freeze event. Missouri and Arkansas reported complete or nearly complete loss of primary shoots that will likely lead to an approximately 95% reduction in crop for 2007. *Vitis vinifera* and *V. labrusca* cultivars will have little to no crop and hybrids a much reduced crop (Striegler et al., 2007). Researchers in Missouri are also concerned about the potential for cordon and trunk damage. Indiana reported a 70% loss and states as far east as Virginia and North Carolina were also heavily impacted (Bordelon, 2007).

Grower Reports

Several grape growers in Oklahoma reported have some level of injury. A grower in the East Central portion of the state described severe shoot injury, especially on cultivars in more advanced phonological stages such as 'Chardonel' (86%) and 'Muscat Canelli' (94%). Other cultivars with later budbreak ['Cynthiana' (32%) and 'Vignoles' (29%)] had less damage (C. Lake, personal communication). This may be related to genetic background, as 'Chardonel' and 'Muscat Canelli' are either 100% *V. vinifera* or have a significant portion of their parentage as *V. vinifera*; whereas, 'Cynthiana' and 'Vignoles' are either entirely American or have a larger portion of American species in their background. The damage could also be related to other factors such as location within the vineyard, duration of the cold temperatures, wind, and previous crop load among other management practices. Another grower in the southern portion of the East Central region described the injury as a complete loss on 'Cabernet Sauvignon', 'Shiraz', and 'Cabernet Franc' (S. Devens, personal communication).

The situation in the Northeast region was described by one grape grower as "horrific", with at least 90% injury on vines, including 'Blanc du Bois' (D. Stowers, personal communication). Another reported injury on all cultivars in the vineyard, but somewhat less on 'Cynthiana' than 'Chambourcin', 'Cabernet Franc', and 'Vignoles' (M. Butler, personal communication).

An account from the Southwest area believed that injury to vines was minimal, although too early to tell the full extent of damage (D. Pound, personal communication).

Another frost and freeze event April 13-16 could have impacted vines in some areas that may not have been impacted by the first event (R. Miller, personal communication), although temperatures never reached lower than 28 °F in most grape growing areas.

Growers in Central Oklahoma had varying levels of damage. One grower said there was a lot of variation in damage on ‘Viognier’, from complete loss to almost no injury (G. and J. Ingels, personal communication). Another vineyard owner observed some damage on the tips of new growth (R. King, personal communication). John Coleman (personal communication) surveyed ‘Syrah’ (85-100%), spur-pruned ‘Syrah’ (100%), ‘Roussanne’ (80-100%), ‘Marsanne’ (95-100%), ‘Vermintino’ (60-95%), and ‘Tempranillo’ (100%). The first injury number is for the top of the slope in his vineyard and the second number is for the bottom of the slope. These results stress the importance of proper site selection for proper air drainage. Even though in some cases 5% difference may not be a lot, other cultivars showed large differences in injury levels (i.e. ‘Vermintino’). This difference could mean the difference between no crop and a moderate harvest. Vines in Stillwater had substantial injury, especially in low areas where the temperature reached as low as 20 °F, and were below 25 °F for 7 hours (I. Hane, personal communication).

Perkins Situation

The experimental vineyard at the OSU Cimarron Valley Experiment Station in Perkins was also significantly impacted by the freeze. The Mesonet recording for Perkins had the lowest temperature at 26 °F, but watchdog weather sensors in the vineyard recorded as low as 23.7 °F. Four separate areas within the vineyard were assessed for injury four days after the April 8 freeze. Three different trellis systems are in the vineyard as well: high cordon (HC), Geneva double curtain (GDC), and vertical shoot positioning system (VSP).

An area of observational cultivars, some on HC and some on VSP, were evaluated for injury on a rating scale of 1-10, with each number corresponding to percentage injury. Injury ratings ranged from complete (10 or 91-100%) for 'Noiret' and 'Valvin Muscat' to minimal (0-10%) for 'Cimarron' (Table 2). Most of these cultivars are on VSP. Trought et al. (1999) stated that buds on a high cordon system 6 ft off the ground would be 7 °F warmer than those on a VSP system and 13 °F warmer than ground level in some types of frost conditions. Genetic background did not seem to play heavily into the amount of injury observed. 'Noiret' and 'Valvin Muscat' are both hybrids, but have a significant amount of V. vinifera in their backgrounds, as do 'Traminette' and 'Chardonel'. Hybrids with more American species like 'Chambourcin', 'Rubaiyat', 'Sunbelt', 'Vignoles', 'Frontenac', 'Cynthiana', and 'Cimarron' fared somewhat better, but still had substantial average injury (>50%) except for 'Frontenac' (4.5), 'Cynthiana' (4.4), and 'Cimarron' (1.0).

Two rootstock trials on GDC, one of 'Cabernet Franc' and one of 'Chardonnay' were also rated. The 'Cabernet Franc' rootstock trial consisted of three rootstocks: 110R, St. George, and 3309C. There were no significant differences between rootstocks, although 3309C had slightly less injury than the other two (Table 3). The damage on the GDC for 'Cabernet Franc' was slightly less than those on VSP (9.06 vs. 9.39). The 'Chardonnay' rootstock trial consisted of six rootstocks (1103P, 140R, 3309C, 5BBK, Freedom, and St. George) and an own-rooted control. The rootstocks were not significantly different from the own-rooted control (Table 4); however, 3309C did provide a little better tolerance (or avoidance) to the freeze. Though in practical terms, a rating of 8.9 is not much different from 9.5. Ratings of 'Chardonnay' on VSP averaged 9.8 vs. 9.5 for GDC.

The replicated trial consisted of 13 cultivars, each on 1103P and own-rooted. All of these cultivars were on HC. There were no significant differences based on rootstock (1103P = 7.32 vs. Own = 7.37). Overall ratings for the HC was lower (meaning less damage) than those of VSP (7.34 vs. 7.94). 'Cabernet Franc', 'Chardonnay', 'Viognier', 'Merlot', and 'Sangiovese' had the most injury (Table 5). The level of injury is directly correlated to timing of budbreak (Fig. 1). The cultivars with the latest budbreak seemed to do best, although not universally. 'Cynthiana' had the latest budbreak of any cultivar and had the least amount of injury. When the cultivars were partitioned by date of budbreak, the mean injury rating increased as budbreak date decreased. Cultivars $\geq$ 90 had an average rating of 2.45. Cultivars $\geq$ 88 had an average rating of 6.4. Cultivars $\geq$ 84 had an average rating of 7.0. Cultivars < 84 had an average rating of 8.5.

Timing of budbreak played heavily into the injury results observed at Perkins and likely throughout the entire state. Budbreak is an important phonological trait to consider when deciding what cultivar to plant. Table 6 shows the average budbreak date for several cultivars as observed at the OSU Cimarron Valley Experiment Station in Perkins. Even though specific dates will vary by location in the state, they can be used as a relative measure of when a particular cultivar will break bud in the spring. From this table one can also see the percentage of years that budbreak has occurred before frost and freeze events. Budbreak before the last frost is fairly common and often the duration of the cold is not enough to cause significant damage. However, more worrisome are the freeze events, though not always injurious can be a cause of long, sleepless nights. 'Chardonnay' is clearly the worst because in the last 5 years the last freeze date ($\leq$ 28 °F) has occurred after budbreak at Perkins. Yields were not noticeably reduced in any of the years 2003-2005, but were in 2006 and will be in 2007.

Forecasting of Spring Frosts

Methods of determining if a particular location is suitable for production of grapes based on spring weather have been developed (Gladstones, 2000; Trought et al., 1999). The method proposed by Gladstones is termed the Spring Frost Index (SFI). It is essentially a measure of continentality (the tendency to have large fluctuations in temperature over a short period of time). The index is based on the average mean temperature for a given month (in our case, April) and the average minimum temperatures for that month. The greater the range between those values indicates a greater chance of frost. There is no defined value that will indicate whether or not a site is appropriate or not; however, usually a site with a value < 11 is considered to have a relatively low risk, whereas a site > 13 is considered high risk (Wolf and Boyer, 2003). The Oklahoma climatological survey has broken the state into 9 divisions: Panhandle, North Central, Northeast, West Central, Central, East Central, Southwest, South Central, and Southeast (map available at www.agweather.mesonet.org). An average SFI by region reveals that the East Central area is the least susceptible to frost (Table 7), but is still in the moderate risk category, as are the Northeast, Central, and South Central regions. The Panhandle, North Central, West Central, Southwest, and Southeast regions all fall into the high risk category. These indices are based on historical weather data and offer broad, macroclimatic generalizations. A potentially more useful application of the SFI would be on a local basis.

Weather data for eleven cities within Oklahoma from 2003 through 2006 were analyzed for SFI (Table 8). Surprisingly enough, Skiatook had the lowest average SFI. Presumably, this is due to temperatures remaining cooler longer in the spring, thus resulting in delayed budbreak. With delayed budbreak, the vine is at less risk than areas farther south in Oklahoma. El Reno had the highest average SFI at 13.7, a high risk area. This is likely due to its location which borders the Central and West Central regions. It may have the attribute of high average monthly temperatures of the Central region coupled with the considerably lower average minimum temperature of the West Central region. Other cities falling into the high risk category are Fairview, Stillwater, and Woodward. The other cities on the list all fall into the moderate risk category, except Eufaula and Skiatook which were lower risk.

A further use of the SFI that has not been utilized previously is the extension of the index for use in cultivar-specific situations. This would be termed a Cultivar Spring Frost Index (CSFI). Admittedly, the usefulness of the CSFI is based on known budbreak data as well as known historical weather data that corresponds with the budbreak data. Such an instance is presented in Table 9. In this example, 'Chardonnay' is the cultivar and Perkins is the location. One would calculate the SFI as normal, only starting with the budbreak date instead of the arbitrary April 1-April 30 timeframe for Oklahoma. For 2003 and 2005, the budbreak date for 'Chardonnay' was April 1, so that coincides with the SFI. However, in 2004 the budbreak date was March 27 and in 2006 the date was March 17. In the four years that were observed in this example, years where the last frost date occurred after budbreak resulted in higher CSFI than the year where no frosts happened after budbreak (2004). This may serve as a general device for assessing appropriateness of a cultivar for a particular location in a mesoclimatic sense. Certainly microclimates differ and a cultivar may not be appropriate at the location where the weather data is recorded, but be suitable at another nearby site with a different meso- and microclimate. In the case of 'Chardonnay' at Perkins, it has a CSFI of 11.7, which fits in with the overall SFI of 12.0, a moderately risky location. This type of calculation can be done for any cultivar as long as budbreak date is known and daily weather data is available.

Potential Frost/Freeze Ramifications

The April freeze could have several outcomes, none of which are wholly positive. These outcomes include:

-No injury (= normal crop),

-Some primary shoot injury (= minimal loss or severely reduced crop, depending on cultivar),

-Entire primary shoot injury (= severely reduced crop or no crop, depending on cultivar),

-Secondary bud injury (= no crop),

-Minimal damage to cordons (= weak growth, likely to recover),

-Moderate damage to cordons (= weak growth, cordon may collapse during growing season, or following winter),

-Severe cordon damage (= cordon dead, must be renewed from trunk),

-Minimal trunk damage (= weak growth, may split, may lose cordons during growing season or following winter, may recover),

-Moderate trunk damage (= loss of cordons and portion of trunk, may split, renewal from living portion of trunk, will be susceptible to winter injury),

-Severe trunk damage (= death of trunk to ground level, must retrain from root sprouts in case of own-rooted material, must remove and replant grafted plants), and

-Root damage (= permanent injury that will require removal and replanting of all plants).

The full extent of any injury will not be known until vines resume growth and move into the reproductive phases that require heavy reserves of stored carbohydrates that move through the xylem to the flowers and fruit. These stored reserves play an important role in the early production of flowers and fruit. Unfortunately, the vine has already put a great deal of energy into the production of primary shoots and flowers. The freeze has essentially "wasted" the reserves that have been used. Any damage to the cambium can also inhibit movement of stored carbohydrates, as well as photosynthates that can lead to cordon and trunk death. At this stage a lot in unknown. In cursory observations on a few cultivars at Perkins, 'Cynthiana' appeared to have no cambium injury, whereas 'Merlot' and 'Shiraz' were inconclusive, but potentially affected.

Post-Freeze Management

Management of vines post-freeze will depend on level of injury/damage and may vary from location to location, cultivar to cultivar, and vine to vine. Although unusual, certain portions of Oklahoma could still experience a frost that would further reduce crop load. The latest frost observed since 1994 was April 30, 1996 as observed in Fairview, Perkins, and Stillwater (Table 1).

Striegler et al. (2007) suggested several steps to consider for post-freeze management. First, is to determine whether any potential crop will be economical to harvest and intensively manage. They suggest performing cluster counts on newly emerging shoots. This should be done on 20 similar vines per acre by using this formula: (N x H) x B = Y, where N = average cluster number per vine, H = historical average cluster weights, B = number of bearing vines per acre, and Y = yield estimate. An adjustment may need to be done if new clusters are smaller than the historical average. Once a yield estimate is determined, then potential price should be discussed with the winery. A price estimate coupled with a yield estimate should allow a grower to make a revenue projection and determine whether or not the vineyard should be intensively managed for fruit production.

In the case of damage to permanent vine structures (i.e. cordons and trunk), renewal may be necessary. One should retain a few suckers and trunk shoots for replacement if trunks or cordons fail. Careful attention must be paid to weed control if shoots and suckers are retained. Systemic herbicides, such as Glyphosate, can seriously injury vines, so other options may be necessary (such as mulching, cultivation, and grass-specific herbicides).

Overly vigorous growth may become a problem on vines that do not produce a crop. Maintaining a balance between vegetative and reproductive growth is necessary for vine health and to maximize winter hardiness. Therefore, if vines do become excessively vigorous nitrogen fertilization should be minimized, irrigation should be limited, and any crop produced should be retained (even if not harvested). Weeds may also be allowed to compete with vines to slow down growth, but allowing this on sites with invasive and aggressive weed species would not be a viable option, as this may make the weeds difficult to control in future years. Sites with easily controlled annual weeds would be good candidates for this type of management. For more information on these suggestions, go to http://iccve.missouri.edu/alerts/.

Frost Avoidance

Much of the damage experienced in Oklahoma could not have been avoided because of the low temperatures and the duration of those cold temperatures. There are two main types of frost/freeze situations that occur during the spring: a radiation frost and an advective frost (Perry, 2001). A radiation frost has these traits normally associated with it: calm winds (< 5mph), clear skies, an inversion layer, and cold air drains to low spots. In this instance, frost protection often works to protect sensitive crops. An advective freeze has winds > 5 mph, may be cloudy, and a deep cold air mass. Advective freeze situations have no inversion layer to draw upon to change the temperature at the plant level.

Methods of protection are described by Perry (2001). She stated that site selection is the best method of protection against frosts and freezes. A site that allows for drainage of cold air is probably suitable for grapes in most situations. It is a preventative measure and is also the easiest to employ with a little forethought, as is cultivar selection (i.e. choosing cultivars with later budbreak). Other options suggested by Perry (2001) and Trought et al. (1999) include appropriate training systems (higher cordon systems have lower risk than low cordon systems), pruning techniques (double pruning, late pruning, long cane pruning), vineyard floor management (bare soil retains heat better than those with ground cover), heaters (may require many heater per acre with low winds to be effective), soil irrigation (moist soil will store more heat and release it at night), overhead irrigation (most reliable, expensive and requires significant amounts of water, must run when temperatures drop below freezing until temperatures rise above freezing, may produce enough ice weight to be destructive to vines and trellis), crop covers (labor intensive and only for light frost situations), wind machines (work only in radiation frost conditions and may do more harm than good in advective conditions), fog (seldom used and potentially hazardous), and chemical applications (not proven to be effective).

Conclusions

At this stage Oklahoma is in a "wait-and-see" situation. Any potential permanent damage should manifest itself in the next couple of weeks; however, some may not be apparent until summer or even next year. To avoid situations like this in the future (as much as possible), appropriate site and cultivar selection should be considered pre-plant. Good management of existing vines, along with steps to delay budbreak, will be important to vine response to future frost and freeze events. Post-freeze management should reduce vigor and maintain vine health. Continuous monitoring of vine response will be needed throughout the growing season into winter and next spring.

Researchers at Oklahoma State University recognize spring frosts and freezes as important environmental events that seriously impact grape growers throughout the state. This report is an attempt to address concerns and to provide information to prepare for future events. Feel free to contact me at any time to discuss this or other concerns at eric.t.stafne@okstate.edu or 405-744-5409.

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Table 1. Last recorded frost ($\leq$ 32 °F) and freeze ($\leq$ 28 °F) date for 11 locations within Oklahoma 1994-2007.

Frost Location	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Avg
Chandler	96	101	97	104	80	85	72	65	93	99	76	76	84	98	88
El Reno	97	102	97	104	107	107	99	108	105	100	105	92	99	105	102
Eufaula	97	68	86	104	72	85	80	84	86	100	58	76	83	98	84
Fairview	97	101	121	104	108	107	99	85	95	100	104	78	84	98	99
Medicine Park	96	101	86	103	80	74	77	85	93	99	57	76	83	97	86
Okemah	96	68	97	104	81	85	72	108	94	100	68	87	84	105	89
Perkins	97	101	121	104	80	85	95	84	95	99	76	114	84	98	95
Skiatook	96	68	97	103	80	74	80	85	94	99	91	78	83	98	88
Stillwater	97	101	121	104	81	108	95	108	95	100	105	114	99	105	102
Vinita	97	89	97	104	81	85	99	108	95	100	104	117	99	102	98
Woodward	96	102	97	103	94	107	107	85	94	99	104	86	84	104	97

Freeze Location	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	Avg
Chandler	69	68	86	103	80	74	72	59	85	99	57	76	83	98	79
El Reno	96	101	97	103	80	74	72	79	95	99	58	61	84	105	86
Eufaula	58	68	86	103	71	74	72	53	81	69	58	60	57	98	72
Fairview	97	101	97	103	72	73	64	64	94	99	62	78	83	98	85
Medicine Park	58	67	86	102	71	73	50	60	85	69	57	40	83	63	69
Okemah	69	68	86	103	80	74	72	59	81	100	58	76	84	98	79
Perkins	69	68	97	103	80	74	51	60	85	99	57	60	83	98	77
Skiatook	69	68	86	103	80	74	45	85	85	98	76	60	83	98	79
Stillwater	69	68	97	104	80	85	72	68	95	99	58	76	83	98	82
Vinita	87	89	97	104	80	85	80	91	94	100	82	87	84	98	90
Woodward	96	101	97	103	94	73	76	75	94	99	62	78	83	97	88

All numbers in above table are day of year, where Jan. 1 = 1 and Dec. 31 = 365.

Table 2. Spring freeze injury ratings on primary shoots for observational cultivars at the OSU Cimarron Valley Experiment Station, Perkins, OK, done in April, 2007.

Cultivar	Average Damage Rating
Noiret	10.00
Valvin Muscat	10.00
Chardonnay	9.83
Traminette	9.67
Chardonel	9.67
Sauvignon Blanc	9.63
Cabernet Franc	9.39
Riesling	9.25
Gamay	9.25
Corot Noir	9.25
Zinfandel	9.20
Chambourcin	8.93
Montepulciano	8.67
Rubaiyat	7.75
Villard Blanc	7.75
Sunbelt	6.00
Vignoles	5.39
Frontenac	4.50
Cynthiana	4.40
Cimarron	1.00

Table 3. Cabernet Franc rootstock trial rating for freeze injury, April 2007.

Rootstock	Average Damage Rating
110R	9.17
St. George	9.10
3309C	8.90

Table 4. Chardonnay rootstock trial rating for freeze injury, April 2007.

Rootstock	Average Damage Rating
St. George	9.75 a
5BBK	9.70 a
1103P	9.67 a
Freedom	9.60 a
140R	9.50 a
Own	9.50 a
3309C	8.90 b

Numbers followed by the same letter are not significantly different ($P \leq 0.05$).

Table 5. Spring freeze injury ratings for cultivars and rootstock in a replicated trial at the Cimarron Valley Experiment Station, Perkins, OK, April, 2007.

Cultivar	Average Damage Rating
Cabernet Franc	9.69 a
Chardonnay	8.65 ab
Viognier	8.60 ab
Merlot	8.55 ab
Sangiovese	8.11 abc
Ruby Cabernet	7.83 bcd
Shiraz	7.65 bcd
Malbec	7.64 bcde
Pinot Gris	7.44 bcde
Cabernet Sauvignon	6.60 cde
Chambourcin	6.00 de
Petit Verdot	5.79 e
Cynthiana	2.45 f
Rootstock	**Average Damage Rating**
Own	7.37
1103P	7.32

Numbers followed by the same letter are not significantly different ($P \leq 0.05$).

Table 6. Budbreak date from 2003-2007 for grape cultivars grown at the OSU Cimarron Valley Experiment Station, Perkins, OK with average budbreak date, percentage of years coinciding with frost, and percentage of years coinciding with freeze.

Cultivar	2003	2004	2005	2006	2007	Avg.	%Frost	%Freeze
Pinot Gris	97	99	95	93	83	93	60	40
Malbec	99	96	96	97	86	95	40	20
Cab Sauv	102	103	101	97	89	98	40	20
Chambourcin	102	96	96	95	88	95	40	20
Sangiovese	97	90	93	90	81	90	60	40
Viognier	97	90	95	97	81	92	60	40
Shiraz	94	97	95	93	84	93	60	40
Cab Franc	97	93	95	93	81	92	60	40
Chardonnay	91	87	91	76	79	85	80	60
Merlot	99	91	95	93	83	92	40	20
Petit Verdot	101	96	96	97	86	95	40	20
Ruby Cab	103	98	98	93	86	96	40	20
Cynthiana	104	96	98	100	90	98	40	20
Sauv Blanc	102	94	100	95	88	96	40	20
Zinfandel	103	95	96	97	87	96	40	20
Vignoles	104	99	101	97	91	98	40	20
Chardonel	94	91	91	93	85	91	60	40
Montepulc.	102	103	105	100	90	100	40	20
Rubaiyat	106	108	100	97	80	98	40	20
Riesling	99	94	95	90	82	92	40	20
Frontenac	101	96	98	95	90	96	40	20
Sunbelt	97	95	95	93	82	92	60	40
Cimarron	97	91	98	97	91	95	60	40
Villard Blanc	94	96	98	93	87	94	60	40

All numbers in above table are day of year, where Jan. 1 = 1 and Dec. 31 = 365.

Table 7. Average Spring Frost Index (SFI) for Oklahoma climate divisions as defined by the Oklahoma Climatological Survey.

Region	April Avg Temp	April Min Temp	SFI	Risk level
Panhandle	55.6	40.5	15.1	High
North Central	56.9	43.6	13.3	High
Northeast	59.6	47.1	12.5	Moderate
West Central	57.7	44.3	13.4	High
Central	59.6	47.2	12.4	Moderate
East Central	60.3	48.3	12.0	Moderate
Southwest	60.0	46.4	13.6	High
South Central	61.2	48.9	12.3	Moderate
Southeast	60.8	47.8	13.0	High

Table 8. Spring Frost Index (SFI) at 11 locations within Oklahoma for 2003-2006, and the average SFI.

Location	2003	2004	2005	2006	Avg
Chandler	12.8	10.4	10.9	12.3	11.6
El Reno	14.7	11.4	13.5	15.1	13.7
Eufaula	11.1	9.5	10.6	11.2	10.6
Fairview	13.9	11.3	13.8	15.1	13.5
Medicine Park	12.2	9.9	11.2	12.6	11.5
Okemah	12.5	10.2	10.5	12.9	11.5
Perkins	12.4	10.8	11.6	13.3	12.0
Skiatook	10.8	9.6	9.9	10.7	10.3
Stillwater	14.1	12.0	12.5	14.2	13.2
Vinita	12.9	11.3	11.0	13.2	12.1
Woodward	13.2	10.7	12.7	15.8	13.1

Table 9. Cultivar Spring Frost Index (CSFI) for Chardonnay at Perkins, OK 2003-2006.

Event	2003	2004	2005	2006	Avg
Last Frost Date	99	76	114	84	84
Budbreak Date	91	87	91	76	86
CSFI	12.4	11.0	11.6	11.9	11.7
Days ≤ 32 °F[z]	2	0	1	5	2
Days ≤ 28 °F	1	0	0	1	0.5

[z]After budbreak.

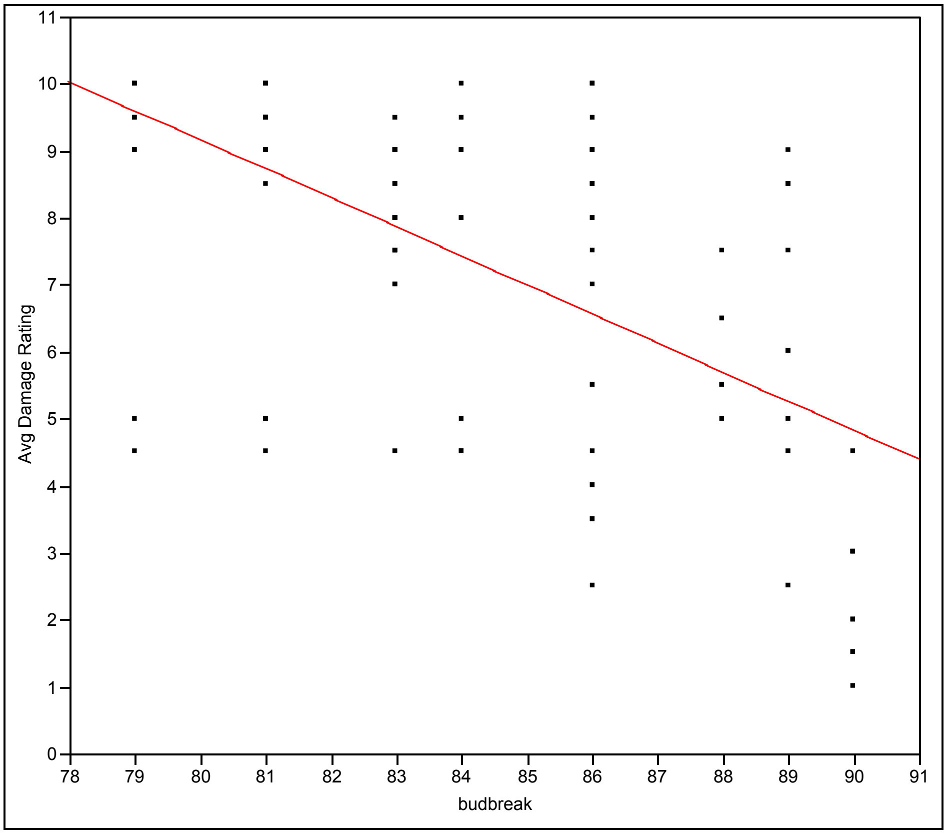

Fig. 1. Plot of average budbreak date vs. average injury rating averaged over all cultivars in the replicated trial at the OSU Cimarron Valley Experiment Station, Perkins, OK. All numbers in above figure for budbreak are day of year, where Jan. 1 = 1 and Dec. 31 = 365.