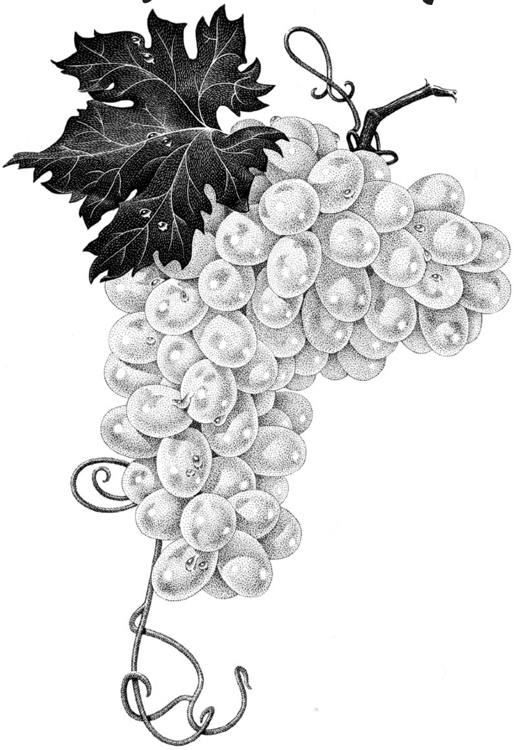
Profile and Challenges of the Emerging Oklahoma Grape Industry



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Division of Agricultural Sciences and Natural Resources
Oklahoma State University

Profile and Challenges of the Emerging Oklahoma Grape Industry

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This publication is a historical account of the Oklahoma Grape Industry up to 2007. Some items may have changed since this publication was written, such as the occurrence of Pierce's Disease in the state. Grape Berry Moth now can be a significant pest. Licensed winery numbers have grown to 64 as of May 2015. Oklahoma vineyard owners continue to experiment with new varieties, both vinifera and hybrid types and are working to find the best management strategies in this somewhat new industry.

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Profile and Challenges of the Emerging Oklahoma Grape Industry

Past and Present Overview of the Oklahoma Grape Industry

Oklahoma has had a long-standing relationship with grape cultivation. Oklahoma once had vast vineyards of domesticated table and wine grapes in the late 1800s and early decades of the 20th century. Cultivar constitution of those vineyards is mostly unknown, but probably involved 'Catawba,' 'Concord,' and 'Delaware' as major components (Fischer, 1977). The acreage of grapes grown in 1907 and 1908 was estimated to be 3,700 acres and 5,425 acres, respectively (Oklahoma Grape Growers' and Wine Makers' Association (OGGWMA), 2005). The climate and soils of Oklahoma are favorable for grapes, as several species are native to the state, including *Vitis aestivalis* Michx., *V. lincecumii* Buckl., *V. mustangensis* Buckley, *V. riparia* Michx., and *V. rupestris* Scheele (Munson, 1909), many of which have been instrumental in creating high quality French-American hybrids. Munson (1909) indicated that some *V. vinifera* L. could be grown as far north as southern Oklahoma.

Prohibition laws have played a prominent role in the shaping of the Oklahoma grape and wine industry. In the 1890s, the Anti-Saloon League and the Woman's Christian Temperance Union focused on creating local anti-alcohol laws and by 1917, the "Bone Dry Law" banned all importation of alcoholic beverages into Oklahoma. This law was overturned the following year, but the 18th Amendment enacting prohibition soon followed in 1919 (McCraw, 2005). From 1919 to 1932, overall grape-related activity declined, although Oklahoma still produced more than 1800 tons of grapes on average – more than any state in the south central U.S., aside from Arkansas, for the period of 1925 through 1928 (USDA, 1929).

The dust bowl and depression era followed; yet Oklahoma State University (then Oklahoma A&M College) re-initiated grape research in 1933 with 75 American and other hybrid cultivars, adding 43 French-American hybrids in 1950 (Hinrichs, 1955). Because prohibition continued for Oklahoma until 1959, these trials were essentially done to identify locally appropriate juice and table grapes (Einset and Pratt, 1975). Interest in wine grapes increased in Oklahoma throughout the 1960s and 1970s (McCraw, 2005), but waned during the 1980s. A steady increase in grape production has occurred since the mid-1990s and continues to today. Recently, a resurgence of the grape growing and wine making industries in Oklahoma has led to an increase of vineyards, especially along the Route 66 corridor that runs through the state (Stafne, 2006). Recent developments in Oklahoma, such as the passage of State Question 688 in November 2000 that allowed Oklahoma wineries to sell wine they produce directly to liquor stores and restaurants, initiated the expansion of the grape growing and wine making industries, However, in 2006 that legislation was ruled to be unconstitutional, and Oklahoma wineries must currently use wholesalers to distribute their products. The grape and wine industry is working toward modification of current laws to help expand the industry.

The winegrape industry in Oklahoma is primarily dependent upon *V. vinifera* cultivars, although some areas of the state have found hybrids and American cultivars more appropriate. *V. vinifera*, or European, grapes are generally considered the premium grapes for winemaking. French-American hybrids arose from the phylloxera outbreak in France in the late 19th Century and combine *V. vinifera* with American species, such as *V. labrusca*, *V. riparia*, and *V. rupestris*. Originally they were bred as rootstocks, but good wine quality later became important as well. There are many American species of grapes, but few of them are acceptable for wine-making without combining with another species. They do possess better cold hardiness and disease resistance than *V. vinifera* and therefore are important in breeding, especially for use in difficult climates.

As recently as 1997, approximately 170 acres of grapes were grown in the state of Oklahoma; that number grew to 375 acres in 2002 and 525 acres in 2005 (OGGWMA, 2005). The number of licensed wineries has increased from four in 2001 to 50 in 2007 and continues to grow. While much of the growing industry is supported by *V. vinifera* cultivars, opportunities remain for high-quality hybrids. Hybrids offer better cold tolerance and disease resistance than *V. vinifera* cultivars, which is important in the Oklahoma climate where temperatures can change drastically in a short period of time. Winter temperatures can fluctuate significantly, and humidity in the summer can foster high disease pressure. Despite the difficult environmental conditions, many growers have not embraced hybrids as a viable alternative to European grapes.

Current Industry Profile

In 2006, a survey was conducted through the Oklahoma Grape Growers' and Wine Makers' Association (OGGWMA) with direction from the author to help ascertain the present state of the grape growing industry in Oklahoma. The survey was distributed to all members of the OGGWMA, as well as being posted on their organization website. It was also sent to all Oklahoma county Cooperative Extension educators who might have contact with grape growers. The survey consisted of 33 questions: two preliminary, three introductory, six on cultivar information, 13 on yield and use, eight general, and one optional comment. A total of 90 surveys were returned. Questions concerning all aspects of viticulture were addressed, especially those that brought problem areas to the forefront.

Only 16 of the more than 40 wineries (at the time) participated in the survey. The survey results identified approximately 240 acres of vineyards in the state. If one were to estimate total acreage based on the percentage of wineries that responded (~40 percent), the total acreage would likely approach 600 acres statewide. Even though the reported acreage likely does not reflect the extent of the industry, the cultivars and other information are representative of the industry as a whole. Therefore, acreages in Table 1 are presented both as an absolute number and as a relative percentage of the total reported.

State Grape Production

Red grapes are preferred by growers with nearly 60 percent of the total acreage (Table 1). *Vitis vinifera* dominates the species breakdown at nearly 80 percent. Hybrid grapes account for less than 15 percent, American species grapes approximately 7 percent, and muscadine grapes make up less than 1 percent of the total. The majority of grapes grown in Oklahoma are for use in wine, but grapes for fresh market, juice, and jelly are also being grown. Room exists for expansion of muscadine grape production (Stafne and Carroll, 2007), as it is a much sought after commodity in surrounding states. Muscadine production in Oklahoma is primarily limited to the far southeast corner of the state.

The breakdown of grapes being grown by county in Oklahoma had Lincoln County reporting the largest acreage, followed by Pottawatomie, McClain, Washita, Okfuskee, Oklahoma, and Kiowa Counties

Table 1. Approximate acreage, percentage, and number of vines breakdown of winegrape types in Oklahoma.

	Grape Color		
Color	*Acres*	*%*	*# of vines*
Red	137.5	59.2	85,101
White	94.8	40.8	57,201
	Grape Types		
American	17.7	7.3	9,661
Hybrid	34.5	14.3	19,793
Vinifera	188.8	78.0	117,971
Muscadine	1	0.4	242

Table 2. Breakdown by county by approximate total acres of grapes, bearing acres of grapes, percent bearing acres grown, and number of vineyards of growers who responded to the 2006 grape grower's survey.

County	*Total acres*	*Bearing acres*	*% bearing*	*Vineyards reporting*
Beckham	4	1	25	1
Creek	3.1	1	32	2
Caddo	3	2	67	1
Canadian	9.3	5.6	60	2
Cleveland	6.1	3.7	61	4
Comanche	2.5	0	0	2
Craig	6.6	4.1	62	2
Custer	5	0	0	1
Delaware	5	0	0	1
Greer	2	0	0	1
Hughes	2.5	0.5	20	2
Kiowa	10.5	5	48	1
Lincoln	42.5	17	40	15
Logan	7	4	57	3
Major	5.5	4.8	87	2
Mayes	3	1	33	2
McClain	14.6	7	48	3
McIntosh	5	1	20	1
Murray	6	2	33	1
Okfuskee	11.3	9	80	3
Oklahoma	11.3	7	62	6
Osage	8.1	0.5	6	6
Payne	8.6	7	81	2
Pittsburg	5.5	0	0	1
Pottawatomie	16.1	2.2	14	7
Roger Mills	3.5	3.5	100	1
Rogers	1.5	1.5	100	1
Seminole	3.5	2	57	3
Sequoyah	2	2	100	1
Stephens	5	0	0	2
Tillman	2	1	50	1
Tulsa	0.9	0.3	33	1
Wagoner	5.8	5.3	91	2
Washita	12.8	10.8	84	3
Total	241.1	113.8	47	86

(Table 2). Four of the six counties are located in the mid-central portion of Oklahoma, and the other two (Washita and Kiowa) are in the southwest area of the state. Only Lincoln County reported more than 10 vineyards. Forty-seven percent of the reported acres were in production, indicating that the majority of vineyards were planted within the last three years.

Of the *V. vinifera* (European) grapes grown in Oklahoma, 'Cabernet Sauvignon' constitutes the most acres (Table 3). 'Cabernet Sauvignon' is considered to be a fairly cold tender European grape that is relatively easy to grow. It is also one of the most widely grown grapes in the world, hence it is not surprising that it is grown by many grape growers in Oklahoma. This cultivar also has very late budbreak in the spring, which is a beneficial trait for avoidance of spring frosts. Second behind 'Cabernet Sauvignon' is 'Merlot' followed by 'Shiraz' ('Syrah'). Both of these grapes make excellent red wines and are widely grown in grape growing areas throughout the world. However, neither of them is particularly cold hardy, thus they may be predisposed to injury from cold mid-winter temperatures as well as fluctuating fall, winter, and spring temperatures. 'Shiraz' is also extremely vigorous and its vegetative growth is difficult to control. These two cultivars are probably grown in Oklahoma more from name recognition rather than appropriateness for the climate. 'Merlot' and 'Shiraz' are followed by 'Riesling'. 'Riesling' is one of the most cold-hardy European grapes. It may have some difficulties with the oppressive summer heat in Oklahoma, but overall has been observed to have less winter injury when compared to other European grapes. 'Muscat Blanc' and 'Chardonnay' rank after 'Riesling.' 'Chardonnay' is somewhat cold hardy, but breaks bud early in the spring predisposing it to frost that can destroy succulent, green tissue and therefore result in crop reduction or loss. 'Zinfandel' is also in the top 10 grapes grown in Oklahoma, but often has difficulty accumulating sugars in the fruit, and is too fruitful as well, leading to overcropping of vines. It is also highly susceptible to winter injury.

The two hybrids in the top 10 are 'Chambourcin' and 'Chardonel.' Both of these are better options for certain parts of Oklahoma that experience considerable cold periods during the winter. 'Chambourcin' is a red wine grape that is grown in surrounding states and does quite well in Oklahoma. It is one of the less cold hardy hybrid grapes, but still has

Table 3. Top 10 grape cultivars grown in Oklahoma as reported in 2006 survey.

Cultivar	*Acres*	*%*	*# of vines*	*Color*	*Type*
Cabernet Sauvignon	32.4	14	20,524	red	Vinifera
Merlot	22.4	9	14,180	red	Vinifera
Shiraz	21.6	9	13,653	red	Vinifera
Riesling	17.9	7	10,458	white	Vinifera
Muscat Blanc	15.2	6	9,153	white	Vinifera
Chardonnay	12.6	5	7,243	white	Vinifera
Cynthiana	11.0	5	5,630	red	American
Chambourcin	8.2	3	4,513	red	Hybrid
Zinfandel	7.9	3	4,534	red	Vinifera
Chardonel	7.7	3	4,510	white	Hybrid

more tolerance than most, if not all, European grapes. 'Chardonel' is a white wine release from Cornell University that has 'Chardonnay' as a parent. It is more cold tolerant than 'Chardonnay' and produces a high quality wine, but also breaks bud early in the spring. The only strictly American grape (*V. aestivalis*) to make the list is 'Cynthiana' ('Norton'). This grape has been cultivated for more than 100 years and has become the primary grape of the Missouri wine industry (Ambers and Ambers, 2004). It is tolerant of diseases, insects, and inclement weather. The vine produces small clusters, but can be prolific under the right management and environmental conditions. 'Cynthiana' will likely see a strong surge in acreage in Oklahoma because of its natural adaptation to continental climate conditions.

Many different grape cultivars are grown in Oklahoma, aside from the 10 previously mentioned in Table 3, with *V. vinifera* cultivars making up a large portion of the list (Table 4). Many of the European grapes are not well-adapted to Oklahoma's climate. Other cultivars in addition to those in Table 4 are grown as well, but on a miniscule scale.

The majority of growers who indicated that they would be adding vines in 2007 were planning to plant *V. vinifera* grapes. Of the new grapes to be planted, 62.5 percent will be *V. vinifera* grapes, followed by 22.5 percent hybrids, and 15 percent American types. These numbers perhaps represent a departure from the near exclusive planting of European grapes, as 2006 results show. However, there were some troubling choices for cultivar selections indicated by some respondents. For example, 'Merlot' and 'Roussanne' in Osage County, 'Sauvignon Blanc' and 'Semillon' in Roger Mills County, and 'Pinot Noir' in Tulsa County were all identified. All of these cultivars are not cold hardy enough for the chosen planting location and chances for long-term survival are poor. Certainly, the selection of an appropriate cultivar for the planting site is critical in the pursuit of sustainable, long-term success for Oklahoma vineyards.

As expected, *V*. *vinifera* cultivars are the most widely grown in Oklahoma because of the burgeoning wine industry; however, observation and research has shown most European cultivars to be highly susceptible to cold damage. More research needs to be conducted to elicit where European cultivars will do best in Oklahoma. French-American hybrids are good alternatives due to their better cold tolerance, but have not been embraced by Oklahoma grape growers outside the northeast part of the state. Reasons for this bias likely include hybrid cultivars being perceived as lower quality than European cultivars, lack of knowledge of available hybrid cultivars, personal preference, and misinformation.

Yield and Potential Economic Return

The yields reported on a tons per acre basis ranged from 0.5 tons to 5 tons per acre, with an average of 2.4 tons per acre. Specific cultivar

Table 4. Breakdown of major cultivars grown in Oklahoma by approximate acreage, number of vine, number of counties represented, and type of grape.

Cultivar	*Acres*	*# of vines*	*# of counties*	*Type*
Baco Noir	0.3	247	2	Hybrid
Cabernet Franc	6.1	4,144	11	Vinifera
Cabernet Sauvignon	32.4	20,524	19	Vinifera
Catawba	0.4	254	2	American
Cayuga	0.8	488	3	Hybrid
Chambourcin	8.2	4,513	8	Hybrid
Chardonel	7.7	4,510	9	Hybrid
Chardonnay	12.6	7,243	15	Vinifera
Chenin Blanc	1.4	708	3	Vinifera
Concord	1.0	575	3	American
Cynthiana	11.0	5630	11	American
Fredonia	0.5	349	2	American
French Colombard	1.4	807	4	Vinifera
Gewurztraminer	3.1	2324	4	Vinifera
Grenache	1.2	813	2	Vinifera
Malbec	0.3	150	2	Vinifera
Marechal Foch	3.0	1627	3	Hybrid
Mars	0.9	592	2	Hybrid
Marsanne	0.6	360	2	Vinifera
Merlot	22.4	14,180	17	Vinifera
Mourvedre	0.6	410	2	Vinifera
Muscat Blanc	15.2	9,153	12	Vinifera
Niagara	2.6	1,628	5	American
Orange Muscat	3.2	2,376	5	Vinifera
Petite Sirah	0.3	178	3	Vinifera
Pinot Gris	3.2	2,072	5	Vinifera
Reliance	0.5	380	3	Hybrid
Riesling	17.9	10,458	15	Vinifera
Roussanne	0.4	278	2	Vinifera
Ruby Cabernet	1.3	659	2	Vinifera
Sangiovese	1.2	750	4	Vinifera
Sauvignon Blanc	5.6	3,755	9	Vinifera
Seyval Blanc	1.6	915	4	Hybrid
Shiraz	21.6	13,653	13	Vinifera
St. Vincent	0.5	310	2	Hybrid
Sunbelt	0.5	277	2	Hybrid
Tempranillo	3.7	2,500	3	Vinifera
Traminette	3.0	1,725	4	Hybrid
Vignoles	3.0	1,706	6	Hybrid
Viognier	6.4	3,724	6	Vinifera
Zinfandel	8.0	4,534	11	Vinifera

results varied; 'Chardonnay' yielded an average of approximately 2.7 tons per acre, 'Merlot' 2.6 tons per acre, and 'Cabernet Sauvignon' 2.3 tons per acre. These types of yields are typical of vineyards managed for high-quality wine, but also may indicate the relative youth of the industry. Most vineyards do not come into full production until the third year of harvest. Future yields may increase to 5 tons per acre or more on some cultivars when vines are healthy and well managed.

Prices paid for grapes were similar whether one had a contract with a winery or not, based on the few responses that were given in the survey. Those growers with a contract received an average of $1,100 per ton. The growers who had no contract were paid an average of $1,000 per ton. However, this average included American grapes (cultivars unreported), which had low prices per ton ($300 to $400). If the American grapes were excluded and only *V. vinifera* and hybrid grapes were used to calculate the average, then the price per ton increased to $1,300. From this very small sample, it appears that growers who do not have a contract receive slightly better prices for their grapes, perhaps due to free-market demand, but is inconclusive. One grower reported receiving up to $1,600 per ton for 'Cabernet Sauvignon.'

Grape acreage in Oklahoma has increased most years since 1998. Presently, there appears to be no ceiling for grapes in Oklahoma. The industry is vibrant and public interest is high. The main obstacles for development of a sizable and sustainable industry are unfavorable liquor laws, lack of education, and most prominently, environment (particularly cold and frost damage).

Insect, Disease, and Other Problems

Insects

Numerous insect pests are present in Oklahoma with the most problematic being green June beetle (*Cotinis notida*), grasshoppers (many species), and Japanese beetle (*Popillia japonica*). Green June beetle is the most prevalent insect that growers in Oklahoma encounter. These beetles feed on the grapes just before harvest and can cause catastrophic damage if not controlled. The main problem in controlling this insect is having an effective insecticide with a pre-harvest interval (PHI) of short duration.

Japanese beetles were also reported although they are not known to be widespread throughout Oklahoma. They are usually an urban insect that is transported to new areas as grubs in sod or ornamental potted plants (Stewart et al., 2004). Although they are known to exist in areas around Tulsa, Oklahoma City, and Ponca City, it is possible that misidentification is leading to higher reports of their numbers than actually exists, or they exist in areas that were previously unreported. They are pests, mainly foliar feeders, thus disrupting photosynthetic activity in the grape vine that can lead to delayed harvest and a decrease in cold hardiness.

Grasshoppers, like Japanese beetles, are mainly foliar feeders that can defoliate a vine in a short period of time. Grasshoppers usually appear during hot, dry conditions and do not pose a significant threat every year. Vineyards near weedy fields and row crops may have greater problems with grasshopper damage.

Other insects prevalent in bordering states, such as phylloxera (aerial and root) (*Daktulosphaira vitifoliae*), grape berry moth (*Endopiza viteana*), and apple twig borer (*Amphicerus bicaudatus*) were not reported as being significant problems in Oklahoma although they do exist.

Diseases

Even though insects are a serious problem in Oklahoma, they do not approach the potential damage of grape diseases. The most serious disease encountered in Oklahoma is black rot (*Guignardia bidwellii*). Black rot is widespread throughout Oklahoma and prevention with fungicides and/or genetic resistance is the only method to control it. Black rot is an endemic disease and must be prevented to ensure healthy vines and fruit. It requires humidity to proliferate, so eastern parts of Oklahoma will have more serious problems than western sections of the state, but all areas are susceptible. Both leaf temperature and duration of leaf wetness play important roles in infection rates. According to Spotts (1977), when temperatures average 50° F leaves need to remain wet for 24 hours for infection to occur; however, at 80° F leaves only need to be wet for six hours. Temperatures above and below 80° F appear to inhibit infection slightly. Most cultivars are susceptible, especially European grapes and some hybrids, although many hybrid cultivars with American species background carry some level of genetic resistance to the disease.

Other reported diseases are crown gall (*Agrobacterium* spp.), downy mildew (*Plasmopara viticola*), powdery mildew (*Uncinula necator*), bunch rot (*Botrytis cinerea*), eutypa (*Eutypa lata*), and phomopsis (*Phomopsis viticola*). Of these diseases, crown gall is most serious. It is most likely brought in through infected plants from nurseries outside of the state. The bacterium lives in the soil on vine tissues once established. Only one strain of Agrobacterium, *A. vitis*, appears to cause the tumor-like galls typically associated with the disease. Grapes may also host other Agrobacterium species, such as *A. tumefaciens* or *A. rhizogenes*, but these cause other symptoms. Crown gall on grapes is often manifested through winter injury in Oklahoma.

Pierce's disease (*Xyllela fastidiosa*) is not known to exist in Oklahoma. A survey for the disease was carried out in 2003 and 2004 by Dr. Sharon von Broembsen and Dr. Phil Mulder (unpublished data), but no evidence of the pathogen or main vector (glassy-winged sharpshooter, *Homalodisca coagulata*) was discovered. It has been found in across the Red River from Oklahoma in Cooke County, Texas (Kamas et al., 2000), so it is likely only a matter of time before the disease occurs in southern Oklahoma.

Other Problems

Several other problems were identified in the survey. The most cited problem was winter injury on *V. vinifera* grapes (namely, 'Cabernet Sauvignon,' 'Shiraz,' 'Merlot,' 'Cabernet Franc,' and 'Muscat Blanc'). These results show that *V. vinifera* grapes are being grown in areas where they may not be best adapted. Many other problems were mentioned, including bird, deer, and raccoon damage. As more grapes are grown in Oklahoma depredation will likely increase, especially from birds. In the future, many growers may need to net their vineyards to ensure harvestable fruit. Environmental factors such as drought and spring frosts were also mentioned. Some of the problems resulted from poor management (cattle damage, lack of irrigation water, poor nutrition, and overproduced vines).

Abiotic issues like harsh environment and herbicide drift vary in their importance depending on location and cultivar and it is incumbent upon the grower to manage and/or avoid these problems. Injury from phenoxy herbicides, like 2,4-D, were also reported. Grapes are highly sensitive to phenoxy herbicides and damage can range from minor to severe. Slight damage may not affect the final crop, but more serious damage can hinder vine growth for years or even be a factor in vine death. A sensitive crop viewer that vineyard owners can register for with the Oklahoma Department of Agriculture, Food, and Forestry (www.ok.gov/~okag/) is a good initial step to curb potential herbicide drift; however, grape growers must also be vigilant in educating neighbors of the potential ramifications of phenoxy (and other) herbicide drift on grapes.

Phenoxy injury can occur anywhere and often the source may be miles from where intended spraying was done. In 2006 and 2007, an unknown source of phenoxy herbicide drift was detected at the OSU Cimarron Valley Experiment Station. The overall damage was greater in 2006 than 2007. The dates of occurrence were unknown. This drift resulted in visual symptoms of injury. The severity rating was dictated by finding at least one leaf of the most severe rating. Injury ratings were based on those described in Ogg et al. (1991) (Table 5).

There seemed to be no relationship between severity rating and species in relation to the European and hybrid cultivars (Table 6). The average of *V. vinifera* was essentially the same as for the hybrid cultivars, especially in 2006. The 2007 injury was slightly higher in the hybrid vines. The American species, *V. aestivalis* had high injury over 10 total vines for both years.

Table 5. Rating scale based on the severity index proposed by Ogg et al. (1991).

Scale	*Interpretation*
0	No visible symptoms of phenoxy-like herbicide exposure. Margins and lobes are well defined. No apparent rugose (bumpy) texture.
1	Possible rugose features on leaf surface. Possible slight shortening of lobes and sinus. The leaf will grow to normal or near normal size.
2	Rugose features as well as disfigured margins. The leaf will be noticeably, but not significantly smaller than leaves with a lesser rating.
3	Deformation of leaf margins. Has diminished or possible lack of sinus. Lobes may be blunt. Lighter leaf color. Leaf will be significantly smaller than those with a lesser rating.
4	A definite deformation of leaf margins and sinus. Noticeable vein clearing. The leaf will be very stunted in size.
5	The leaf will be severely dwarfed. Veination will be parallel. The margins may resemble the end of a straw broom. Grossly deformed leaf.

Table 6. Ratings of phenoxy injury on grapevines at Perkins by cultivar, year, and number of vines with comparison of V. vinifera, hybrid, and American winegrapes.

Cultivar	*2006*	*2007*	*Total vines*
Sunbelt	5.00	5.00	4
Cimarron	4.67	5.00	6
Riesling	4.25	3.50	4
Cynthiana	4.00	5.00	10
Rubaiyat	4.00	1.67	3
Traminette	4.00	4.33	3
Sauvignon Blanc	3.50	0.00	4
Villard Blanc	3.33	3.75	4
Corot Noir	3.00	2.50	4
Frontenac	3.00	0.00	4
Valvin Muscat	2.75	0.00	4
Chardonel	2.71	0.36	14
Vignoles	2.00	0.36	14
Zinfandel	2.00	0.00	13
Noiret	1.25	0.25	4
Montepulciano	1.00	1.67	3
Chambourcin	0.00	0.00	10
Grape type	*2006*	*2007*	*Genotypes rated*
V. vinifera	2.69	1.29	4
Hybrid	2.70	1.70	20
American	4.00	5.00	1

It is difficult to ascertain whether or not the highest rated (most injury) is related to cultivar or placement within the field since the drift was not a controlled event. 'Cynthiana' had very high severity (Table 6) both years which concurs with Saenz and Hellman (2002) who stated that 'Cynthiana' was among the most susceptible cultivars, with 'Vignoles' and 'Chambourcin' being intermediate in terms of injury, and 'Villard Blanc' less susceptible. A study done at Iowa State University (2002) found that 'Cynthiana' and 'Traminette' were most susceptible, followed by 'Vignoles,' 'Chambourcin,' and 'Frontenac.' 'Chambourcin' showed no visible injury in either year at Perkins, possibly suggesting that it is somewhat resistant to small doses of phenoxy herbicides, even though Kadir et al. (2003) reported that 'Vignoles' and 'Villard Blanc' were less susceptible to phenoxy exposure, whereas 'Chambourcin,' 'Frontenac,' 'Cynthiana,' 'Traminette,' and 'New York Muscat' were more susceptible.

Essentially there seem to be differences among cultivars with respect to how they respond to phenoxy herbicides. Unfortunately, we do not know how much drift each vine was exposed to; however, these observations can be useful to growers who plant in areas where phenoxy herbicide applications are common.

Environmental Challenges to Viticulture in Oklahoma

The 2006 survey identified harsh environmental factors as a significant issue for grape growers. Grapes must have adequate heat to ripen, but too much heat results in poor fruit quality. Grapes are also extremely susceptible to freeze damage due to their wide geographic distribution, especially when they are grown outside of their traditional production areas (Fennell, 2004). Oklahoma is subject to a continental climate that has wildly fluctuating temperatures throughout the fall, winter, and spring, thus cold injury regularly occurs. The unstable climate in Oklahoma poses many difficulties for grape growers trying to decide which cultivars to plant. Several of these environmental challenges are addressed in Table 7.

Continentality

Continentality is a measure of range between high and low temperatures (Gladstones, 1992) and in its traditional and intended use this means the range of temperature between winter and summer, which is usually defined as the difference between the hottest and coldest months of the year. In Oklahoma, these two months are July (hottest) and January (coldest). This is typical of continental climates, but may vary in maritime areas (Gladstones, 1992). Continentality is more severe in areas where the environment is not strongly influenced by large bodies of water. The continentality in Oklahoma varies from 35.7 in Mc-

Curtain and Pushmataha Counties to 42.8 in Alfalfa and Grant Counties (Table 7). These continentality values are comparable to other wine-growing regions of the world, including Vienna, Austria; Turin, Italy; Zagreb, Croatia; Eger, Hungary; Plovdiv, Bulgaria; Fresno, California; and Walla Walla, Washington (Gladstones, 1992); however, similarity in continentality does not imply that the locations are similar in other aspects. Continentality is important for wine quality and vine growth, and this measure can aid in determining the kind of vines that will grow in certain areas, although other environmental factors also are important as well.

Heating Degree Days

The concept of heat summation or heating degree days (HDD) was brought to prominence in viticulture by Amerine and Winkler (1944). This index assumes a vine growing season of April through October and is a summation of mean temperatures that exceed 50° F. Since this index was initially intended for California, the state was divided into five regions based on their HDD. Region I was designated as having less than 2,500 HDD and Region II was between 2,500 and 3,000 HDD. These two regions are said to produce the best table wines. Region III has 3,000 to 3,500 HDD, and produces full-bodied dry and sweet table wines. Region IV has 3,500 to 4,000 HDD, and is said to produce dessert wines and relatively inferior table wines. Region V has greater than 4,000 HDD and produces mainly table grapes and raisins with some poorer quality bulk table wines and fortified wines (Gladstones, 1992). Unfortunately, in Oklahoma, only Cimarron County fits below the Region V designation (Table 7), where growing grapes is rather unsuitable for other reasons. Some counties (Carter, Grady, Jefferson, Love, Okfuskee, and Tillman) have more than 5,000 HDD, drawing into question whether or not wine of any acceptable quality can be produced. This is a somewhat simplistic view of available heat for vine growth and fruit development and has been criticized by some researchers (Gladstones, 1992). Gladstones (1965) indicated that the Amerine and Winkler system did not work best for Australia, as Regions II and III were better for wine production.

Spring Frost Risk

Early bud break followed by rapid growth predisposes vines to injury from late spring frost during March and April in Oklahoma. This tendency is most prominent in vineyards located in low-lying sites or sites surrounded by tall trees or other structures that block air drainage. Timing of deacclimation is very worrisome for Oklahoma grape growers. This is particularly true for cultivars with early budbreak. Even southern parts of the state may experience a handful of freeze events during spring. At best, minimal bud and/or green shoot damage is ex-

Table 7. Important climatic measurements to assess grape growing potential in Oklahoma.

County	Continentality[z]	HDD[y]	FI[x]	PELI[w]
Adair	35.9	4,136	19.9	22
Alfalfa	42.8	4,485	8.1	22
Atoka	37.2	4,894	25.8	0
Beaver	41.3	4,060	5.0	44
Beckham	39.2	4,298	14.3	17
Blaine	40.6	4,573	19.3	28
Bryan	36.5	4,812	29.1	0
Caddo	39.8	4,527	21.0	17
Canadian	40.2	4,534	14.0	14
Carter	37.4	5,044	28.0	0
Cherokee	37.6	4,534	15.5	20
Choctaw	36.0	4,827	29.2	0
Cimarron	36.4	3,632	0.3	91
Cleveland	39.1	4,705	25.8	0
Coal	37.4	4,855	20.3	0
Comanche	39.5	4,870	26.9	12
Cotton	38.9	4,943	25.7	0
Craig	39.3	4,414	14.6	43
Creek	37.4	4,607	15.9	17
Custer	41.1	4,748	16.1	29
Delaware	37.0	4,356	14.8	33
Dewey	40.9	4,320	9.0	28
Ellis	40.3	4,023	13.6	32
Garfield	42.2	4,546	13.5	14
Garvin	38.8	4,741	27.0	8
Grady	38.1	5,142	15.5	13
Grant	42.8	4,549	13.0	27
Greer	38.7	4,702	18.8	11
Harmon	38.1	4,940	19.7	11
Harper	40.6	4,735	5.4	62
Haskell	37.2	4,726	24.7	0
Hughes	38.3	4,582	19.3	9
Jackson	39.1	4,980	22.6	9
Jefferson	36.7	5,472	28.0	9
Johnston	37.0	4,858	23.5	0
Kay	42.4	4,442	16.2	37
Kingfisher	41.8	4,475	14.0	17
Kiowa	39.9	4,940	19.6	13
Latimer	36.4	4,748	25.6	0
Leflore	36.9	4,793	21.5	14
Lincoln	39.4	4,402	24.1	18
Logan	40.3	4,524	22.4	22
Love	36.8	5,007	22.5	0
Major	41.4	4,751	16.3	50
Marshall	37.4	4,949	26.7	0

Mayes	39.5	4,598	18.0	19
McClain	38.6	4,818	24.4	8
McCurtain	35.7	4,592	27.0	0
McIntosh	37.5	4,949	26.4	10
Murray	38.1	4,806	21.6	0
Muskogee	39.2	4,674	23.6	13
Noble	41.9	4,598	17.3	14
Nowata	39.7	4,668	14.0	25
Okfuskee	37.1	5,075	22.8	0
Oklahoma	38.9	4,686	22.8	0
Okmulgee	38.2	4,454	20.3	10
Osage	39.9	4,616	23.2	33
Ottawa	39.6	4,118	16.7	27
Pawnee	39.2	4,595	20.4	38
Payne	40.7	4,641	22.9	20
Pittsburg	37.4	4,903	26.0	0
Pontotoc	36.7	4,757	27.0	0
Pottawatomie	39.0	4,555	24.6	8
Pushmataha	35.7	4,870	15.4	0
Rogers	40.4	4,381	21.3	15
Roger Mills	39.7	4,261	19.8	25
Seminole	38.9	4,891	19.4	0
Sequoyah	38.0	4,601	24.2	12
Stephens	37.6	4,839	N/A	0
Texas	39.2	4,026	8.6	59
Tillman	38.8	5,038	24.6	0
Tulsa	40.4	4,616	24.3	24
Wagoner	38.0	4,760	N/A	12
Washington	39.8	4,702	21.0	N/A
Washita	40.1	4,613	21.7	0
Woods	42.5	4,497	9.4	52
Woodward	41.4	4,054	17.4	45

[z] Mean temperature of hottest month (July) – mean temperature of coldest month (Jan.).

[y] Heating degree days from April through Oct., where HDD = total temperatures > 50 °F, based on Amerine and Winkler (1944).

[x] Frost index, where for April, FI = [(Avg temp – 32) – [(# days below 32 °F x 32) – (sum of temps below 32 °F] x [(1 – (# days from April 1 to last frost / # days in April (30))]; >27 = low risk, <13.5 = very high risk.

[w] Potential economic loss index, where PELI = √[(# of breakeven decades) + (# of economic loss decades)^2]/ (total # of decades) x 100; 0 = no loss, 100 = total loss.

perienced. At worst, trunk splitting and permanent trunk and cordon damage can occur.

A devastating spring freeze event occurred during the nights of April 7 and 8, 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 8). However, what made this particular freeze event so significant was the much warmer than normal temperatures of March. According to the March 2007

Table 8. Last recorded spring frost (< 32 °F) and freeze (< 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.

Oklahoma monthly climate summary (OCS, 2007), March 2007 was the 2nd warmest on record in Oklahoma, more than 7° F 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 reporting the month as the warmest on record. The Northeast part of the state was 9° F above normal. These conditions coupled with extremely low temperatures that followed in April (as low as 17° F in Jay) resulted in early budbreak, thus predisposing vines to freeze injury. The April 2007 climatological outlook prepared by the OCS (2007) in March 2007 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 28° F to 26° F can cause significant damage (Peacock, 1998).

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 weather sensors in the vineyard recorded as low as 23.7° F. Four separate areas within the vineyard (a replicated cultivar trial, two rootstock trials, and observational vines) 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).

The replicated trial consisted of 13 cultivars, each on 1103P and own-rooted (Table 9). 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 (less damage) than those of VSP (7.34 vs. 7.94) when compared over the entire vineyard (data not shown), but were not significantly different. 'Cabernet Franc,' 'Chardonnay,' 'Viognier,' 'Merlot,' and 'Sangiovese' had the most injury (Table 9). The level of injury is directly correlated to timing of budbreak. The cultivars with the latest budbreak did 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 with budbreak > March 31 had an average rating of 2.45. Cultivars > March 29 had an average rating of 6.4. Cultivars > March 25 had an average rating of 7.0. Cultivars < March 25 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 phenological trait to consider when deciding what cultivar to plant. Table 10 shows the average budbreak date for several cultivars as observed at the OSU Cimarron Valley Experiment Station at Perkins. Even though specific dates will vary by location in the state, they can be

Table 9. 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*[z, y]
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

[z]Means followed by the same letter are not significantly different ($P < 0.05$).

[y]Rating scale where 1 = little to no damage and 10 = severe damage to emerged primary shoots.

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 since 2003, the last freeze date (< 28° F) has occurred after budbreak at Perkins. Yields were not noticeably reduced in any of the years 2003 to 2005, but were reduced in 2006 and 2007.

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). These methods are essentially a measure of continentality (the tendency to have large fluctuations in temperature). A large continentality is indicative of a greater chance of frost. The Frost Index (FI) was developed to quantify the frost potential of a site. In the case presented in Table 7, each county in Oklahoma represents a site. The FI takes into account both maximum and minimum temperatures by using the average mean temperature. It also factors in the duration of frost, as well as the severity of the frost or

Table 10. 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
Cabernet Sauvignon	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
Cabernt 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 Cabernet	103	98	98	93	86	96	40	20
Cynthiana	104	96	98	100	90	98	40	20
Sauvignon 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
Montepulciano	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.

freeze events. Instances of very late frost (i.e. on the 30th of April or later) could result in an FI of 0. All indices were calculated for April (following the example of Wolf and Boyer, 2003), as April is typically the month where budbreak occurs and frost risk is highest. Frosts in May are rare for most of the locations analyzed. The base temperature of 0° C was used in calculating the FI because temperatures below that threshold can cause damage, especially to tender vegetation (Peacock, 1998; Vega et al., 1994).

Weather data for 75 counties within Oklahoma from 1994 through 2007 were analyzed for FI (Table 7). General guidelines for the FI are as follows: >27 is a low risk site, 22.5 to 27 is low to moderate risk, 18 to 22.5 is moderate to high risk, 13.5 to 18 is high risk, and < 13.5 is very high risk. Not surprisingly, the most at-risk counties are those in the Panhandle and northern parts of the state (Alfalfa, Beaver, Cimarron, Dewey, Grant, Harper, Texas, and Woods). On the other end of the spectrum, the counties least at risk for spring frosts are in the far southern sections of Oklahoma (Bryan, Carter, Choctaw, Garvin, Jefferson, McCurtain, and Pontotoc). By proportion, Oklahoma has more counties in the "high" categories (moderate to high, high, and very high) than in the "low" categories (low and low to moderate), 60 percent to 40 percent, respectively.

Of course an index is only as good as the data available. It is only intended for macroclimatic interpretations around sites where the climate data exists. Mesoclimates can differ from weather stations due to factors such as elevation, slope, and aspect and can vary widely in short distances (Smart and Dry, 1980). Caution should be taken when interpreting any index; however, the FI allows growers to make interpretations of risk based on a year-to-year basis and determine their risk threshold.

Impact of Winter Cold

Cold temperatures of -8° F or lower are generally recognized as a conservative estimate at which significant injury is sustained by European grapes (Wolf and Boyer, 2003). A site is generally determined to be profitable for *V. vinifera* grapes if -8° F is reached in one year out of 10. It is a break even situation if -8° F happens twice in 10 years. If -8° F is reached three times in 10 years, then the result is an economic loss. Temperatures were obtained from the Oklahoma Climatological Survey for all 77 counties in Oklahoma as far back as records were kept in an attempt to address the potential cold damage situation (Table 7) through use of the potential economic loss index (PELI). Washington County was not represented due to missing data, and Major County had little data to assess. The temperature data for some counties reaches back to the 1890s, but others only the mid-1900s. These temperatures may be from a single site or several sites, depending on the county; therefore, are only useful in a broad, macroclimatic sense. These interpretations, like the FI, do not take into account elevation, slope, aspect, or any other meso- or micro-climatic specifics. The formula for PELI = $\sqrt{[(\text{\# of breakeven decades}) + (\text{\# of economic loss decades})^2]}$ / (total # of decades) x 100. The scale for PELI is 0 to 100. Although there are no strict guidelines for what constitutes a high or low PELI, any number above 0 should be of concern. Since these values are based on *V. vinifera* grapes, a possible guideline would be: 0 = all grapes can be grown, but grow *V. vinifera* with caution, 0 to 20 = hardy *vinifera*, hybrids, and American grapes, 20 to 50 = hardy hybrid and American grapes only, and 50+ = commercially unsuitable for grape production.

Some counties have a greater likelihood of having three harvests in 10 years destroyed in the future than the other counties because it has already happened. The counties most likely to have decades where European grapes lose money due to freeze injury are Cimarron, Texas, Woods, Harper, Woodward, Beaver, and Craig. Some counties, like Pottawatomie County have only had one decade of economic loss of out

12, so that is fairly rare. Other counties have had only one economic loss decade, but when coupled with the breakeven decades the chances of success go down. An example is Adair County that has had only one decade of economic loss in nine, but also has had three decades of breakeven. So, four decades out of nine have been breakeven or economic loss for European grapes. There are counties that are likely safe for European grapes against mid-winter killing temperatures, even though a particular vineyard certainly could experience extensive damage. Canadian County has had three decades in 12 with that possibility. This data is only for mid-winter kill and does not include other factors that could also create crop loss (frost, disease, rain, herbicide drift, etc.).

Counties that only rarely get below -8° F may be the most suitable for *V. vinifera* grapes. These counties are represented by a value of 0 in the PELI column in Table 7. A caveat is that this list doesn't cover temperatures just warmer than -8° F that can also be damaging and as stated earlier, mid-winter killing temperatures are not the only cold-related problem in Oklahoma; fluctuating temperatures that occur in fall, winter, and spring without any acclimation period also occur frequently.

Winter Cold Damage

To understand freeze tolerances of grapes in Oklahoma, a late fall freeze on December 8-9, 2005 was monitored for damage. During these two days, low temperatures recorded at Woodland Park Vineyard and Winery, Stillwater and Oklahoma State University Cimarron Valley Experiment Station, Perkins reached as low as -4.4° F and -0.2° F, respectively. Cold damage ratings were taken on May 8, 2006 at Stillwater and May 18, 2006 at Perkins on a rating scale from one (plant dead) to five (no damage) (Table 11). The two locations are approximately 15 miles apart and both vineyards were intensely managed following the guidelines established by Oklahoma State University (McCraw, 2005).

At the Stillwater location, a trial of 14 cultivars within a larger vineyard was evaluated. The trial was established as a randomized complete

Table 11. Cold damage rating scale used to evaluate the winegrape cultivars at Stillwater and Perkins, OK.

Rating score	*Explanation*
1	Plant dead
2	Plant killed to ground, suckering from base or near base
3	Both cordons dead, trunk still alive
4	One cordon dead, some or minimal damage
5	No damage that will affect yield

block, with spacing of 8 feet between vines and 10 feet between rows. There were three vines per replication with four replications (blocks) per grafting type. The own-rooted vines in the trial were 4-years-old, and the grafted (rootstock) vines, on 3309 Couderc, were 3-years-old at the time of rating. 'Frontenac,' 'Cynthiana,' 'Sunbelt,' 'Traminette,' NY62.0122.01 ('Valvin Muscat'™), NY70.0809.10 ('Corot noir'™), and NY73.0136.17 ('Noiret'™) were only own-rooted. All vines were trained to a Geneva double curtain (GDC) system with a two-trunk system. Clone numbers are unknown.

At Perkins, a research trial consisting of 13 cultivars was rated for cold damage. The trial was established as a randomized complete block, with a spacing of 8 feet between vines and 12 feet between rows. There were two vines per replication with five replications (blocks) per grafting type. The vines grafted onto 1103 Paulsen were planted in 2001 and the own-rooted vines in 2002. Only 'Chambourcin' had no grafted vines in this trial. All vines were trained to a bilateral high cordon system using a two-trunk system. Clone numbers are only known for 'Chardonnay' (clone 4), 'Cabernet Sauvignon' (clone 7), and 'Cabernet Franc' (clone 1).

Perkins Winter Damage

The temperature conditions at Perkins were more moderate than those of Stillwater during December 8 to 9, thus leading to lower damage ratings. Temperatures of 1.0° F were recorded for only 30 minutes with a low of -0.2° F for 15 minutes. Rainfall for the period of October 1 to December 10, 2005 consisted of 1.7 inches, in contrast to the normal mean rainfall during that period of > 6 inches, thus potentially leading to vine stress. The crop loads were not managed at the Perkins location other than typical winter pruning, therefore crops have been excessive on certain cultivars due to the good site and lack of cluster thinning, which may have had some effect on freeze tolerance (Wample and Wolf, 1996). 'Cabernet Franc' in particular was overcropped, but other cultivars such as 'Cabernet Sauvignon' and 'Shiraz' had excessive vegetative growth and crop loads as well.

When averaged over cultivar and grafting type, the American cultivar Cynthiana had no damage, and hybrid and European cultivars had little (4.8 for both). There were no significant differences among the three types. The results indicate that no substantial injury was done to any of the genotypes at the Perkins location, regardless of grafting type.

There was no recorded injury on any winegrape that was grafted onto a rootstock (1103P). The cultivars included here are Chardonnay clone 4, Pinot Gris, Cabernet Franc clone 1, Cabernet Sauvignon clone 7, Malbec, Petit Verdot, Ruby Cabernet, Sangiovese, Cynthiana, Viognier, Merlot, and Shiraz. The reason for this probably is a direct result of the short duration of the freeze event and the overall good health of the vines that may have been conferred by the use of the rootstock.

The evaluation of the interaction effect of cultivar H grafting type revealed that most injury was not substantial. Most own-rooted cultivars had slight to moderate injury. ‘Cabernet Sauvignon,’ ‘Sangiovese,’ ‘Pinot Gris,’ ‘Chardonnay,’ and ‘Shiraz,’ all own-rooted, rated with some amount of injury, although not significantly different from those that had no injury. The exception was ‘Shiraz,’ a cultivar that originated in the Rhône Valley region of France and is not known for its cold hardiness, which had the greatest amount of cold damage (data not shown). This could be due to its extremely vigorous nature observed at Perkins. Other studies have reported that excessive crop loads can delay acclimation, therefore predisposing the vine to winter injury (Howell et al., 1978; Stergios and Howell, 1977).

Stillwater Winter Damage

At Stillwater, low temperatures of < 1.4° F for a duration of more than 11 hours existed on the night of December 8 and morning of December 9, 2005. The lowest temperature of -4.4° F lasted for nearly three hours. Winegrape cultivars at Stillwater averaged a 4.2 winter injury rating over all grafted cultivars and 3.9 for own-rooted vines. Hybrids performed best, having the least observable damage. When averaged over all grafted cultivars, the hybrids had a mean of 4.9 and the European cultivars had a mean of 3.6, a significant difference. When averaged over all own-rooted cultivars and when grafted and own-rooted vines were pooled, the American cultivar Cynthiana and the hybrids performed significantly better than European cultivars (5.0, 4.8, and 3.5, respectively), but not from each other (data not shown).

Own-rooted hybrid cultivars performed better than the own-rooted European cultivars. ‘Frontenac,’ ‘Cynthiana,’ ‘Corot noir,’™ ‘Traminette,’ ‘Valvin Muscat,’™ and ‘Noiret’™ had no discernible damage. The hybrids ‘Sunbelt,’ ‘Chardonel,’ ‘Vignoles,’ and ‘Chambourcin’ had minimal damage, as did the European cultivar Riesling. The other European cultivars Cabernet Franc, Cabernet Sauvignon, and especially Chardonnay were severely damaged (Table 12). Rootstock did not appear to have much effect, as none of the differences were statistically significant. Own-rooted European cultivars were not statistically different from those that were grafted with the exception of ‘Chardonnay’ which performed worse when own-rooted than when grafted, thus contributing to the interaction effect. The reason for this is unclear, but this trend was also observed at the Perkins location on a different rootstock.

‘Chardonnay’ and ‘Riesling’ were the best of the grafted European cultivars, not significantly different from the three hybrids ‘Chambourcin,’ ‘Vignoles,’ and ‘Chardonel.’ ‘Cabernet Franc’ and ‘Cabernet Sauvi-

Table 12. Results for cold damage evaluated at Stillwater, OK for own-rooted winegrape cultivars.

Cultivar	*Cold damage rating*[z]
Frontenac	5.0 a
Cynthiana	5.0 a
Corot noir™	5.0 a
Traminette	5.0 a
Valvin Muscat™	5.0 a
Noiret™	5.0 a
Sunbelt	4.8 a
Riesling	4.8 a
Chardonel	4.6 a
Vignoles	4.4 ab
Chambourcin	4.4 ab
Cabernet Franc	3.6 bc
Cabernet Sauvignon	3.0 cd
Chardonnay	2.3 d

[z]Means followed by the same letter are not significantly different ($P < 0.05$).

gnon' displayed significantly more damage than any of the hybrids on 3309 Couderc (Table 13). 'Riesling' was the only European cultivar that withstood the cold as well as the hybrid and American cultivars in both grafted and own-rooted states (Table 13). 'Riesling' was also reported to be the most freeze tolerant of European cultivars by Hamman (1993) in Colorado and Bordelon et al. (1997) in Indiana and Ohio.

The results detailed within this study indicate that hybrid cultivars show greater tolerance for fluctuating winter temperatures, regardless of grafting type, than the European cultivars. Of the European cultivars, 'Riesling' was the most cold tolerant. *V. vinifera* cultivars reacted differently to freezing temperatures depending on whether they were grafted onto a rootstock or not. 'Chardonnay' had less injury with a rootstock than when own-rooted at both locations, whereas for 'Cabernet Franc' and 'Cabernet Sauvignon' there was no significant difference between those vines grown on a rootstock and those that were own-rooted. Therefore, using a rootstock with some cultivars may be advantageous in the tolerance of cold temperature; however, vine death past the graft union still remains a potential risk. Oklahoma grape growers should consider the benefits of grafted vines against the risk from winter freeze injury. The climate of Oklahoma is precarious for the use of rootstocks, especially in the northern part of the state where fluctuating winter temperatures can kill grapes down below the graft union.

The freeze injury observed at Perkins, and especially Stillwater, indicate that cultivar selection is crucially important for tolerance of freeze events. Historical weather data suggest that Oklahoma has

Table 13. Interaction effects for cold damage of winegrape cultivars at Stillwater, OK that were both grafted onto rootstock and own-rooted.

Cultivar	*Grafted*	*Cold damage rating*[z]
Vignoles	Yes	4.9 a
Chambourcin	Yes	4.9 a
Chardonel	Yes	4.8 a
Riesling	No	4.8 a
Chardonel	No	4.6 ab
Chambourcin	No	4.4 ab
Vignoles	No	4.4 ab
Chardonnay	Yes	4.3 ab
Riesling	Yes	4.2 abc
Cabernet Franc	No	3.6 bcd
Cabernet Franc	Yes	3.1 cde
Cabernet Sauvignon	No	3.0 cde
Cabernet Sauvignon	Yes	2.9 de
Chardonnay	No	2.3 e

[z]Means followed by the same letter are not significantly different ($P < 0.05$).

weather extremes that could be challenging for grape growers. Freezes in early October and late April have occurred, as well as temperatures reaching as low as -18° F in mid-winter. *V. vinifera* grapes are mainly grown in regions where mid-winter temperatures reach no lower than -8° F (Fennell, 2004; Gustafsson and Mårtensson, 2005), and although infrequent in most areas of Oklahoma, temperatures below -8° F do occur. Periodic winter and spring cold damage is to be expected on grapes in Oklahoma. Hybrid and American grapes are less susceptible to cold injury than European grapes and should be considered for planting especially where risk of winter injury is high.

Conclusions

Grape growing in Oklahoma has been part of its history and recently has shown potential for substantial growth, as evidenced by the 2006 survey. Along with industry expansion come new areas of concern that must be faced, such as insect, disease, and abiotic problems. These are controllable for the most part with good management practices. Other issues pose greater barriers to successful vineyard establishment in Oklahoma.

The unpredictable continental climate of Oklahoma is one of the foremost obstacles for potential grape growers. It is essential that appropriate site selection be done prior to planting. Many locations in Oklahoma are unsuitable for most grapes, including hybrids and American grapes. European grapes are adapted to Mediterranean climates and do not tolerate cold winters or early spring frosts. There are areas where some European cultivars may succeed in Oklahoma because they do well on higher pH soils and are usually heat and drought tolerant. Southwestern Oklahoma counties provide the best environment for these types of grapes, but appropriate cultivar choice is essential. Many hybrid and American grapes are better suited for most areas of Oklahoma than European grapes. Growing grapes in Oklahoma is a risky endeavor and minimization of potential loss by consideration of cultivar and environmental interactions is paramount to ensure long-term success.

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