Special Report 901
June 1992

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Table of Contents

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INTRODUCTION

Oregon's wine grape industry has grown rapidly (450 percent) in the last 10 years (Figure 1). In 1991, Oregon had 6,050 acres of wine grapes with 3,700 acres harvested. The farm gate value of 9,600 tons harvested in 1991 was $8.3 million. The processed value of this industry is estimated to be from $25 to $30 million.

Oregon is a cool climate viticultural region recognized internationally for the production of high quality, premium varietal wines, especially those made from Pinot noir, Pinot gris, and Chardonnay. Other varieties grown in Oregon include White Riesling, Cabernet Sauvignon, Gewurztraminer, Muller Thurgau, Sauvignon blanc, Merlot, Semillon, Chenin blanc, and Zinfandel.

The 1991 wine grape crop was the highest on record, despite that harvested acres were down 5 percent from 1990. The higher statewide production was due to high yields, with an average yield per acre 0.8 tons higher than 1990, at 2.59 tons/acre. Higher yields are attributable to good, dry weather during bloom, delayed two to three weeks by a cool, wet spring. Fruit set was excellent. Also, there was little inflorescence necrosis, a disorder that reduced crop levels in 1990.

Winter injury became an issue once again during the winter of 1990-91. Many vineyards had just begun to recover from the effects of the 1989 freeze. Although many vineyards suffered cold damage in 1972, winter freeze events of the magnitude experienced in 1989 and 1990-91 are predicted to occur, on average, every 10 to 25 years in areas west of the Cascade Mountains.

Two storms hit the Pacific Northwest during the December 20 to 24, 1990 period. The first did the most damage in the western valleys of Oregon. However, the second caused considerable damage in the region of Prosser in Washington State, where temperatures dropped as low as -9°F. In the Willamette Valley, mild conditions prevailed during the first half of December. The temperature dropped precipitously to extreme lows during the middle of the month (Table 1), followed by unusual warming in January. In December 1990, temperatures dropped to -5 to 8°F in the Willamette Valley, depending on vineyard site, -4 to 0°F in the Umpqua region, -9 to 0°F in southern Oregon, and as low as -15°F in eastern Oregon (Table 1).

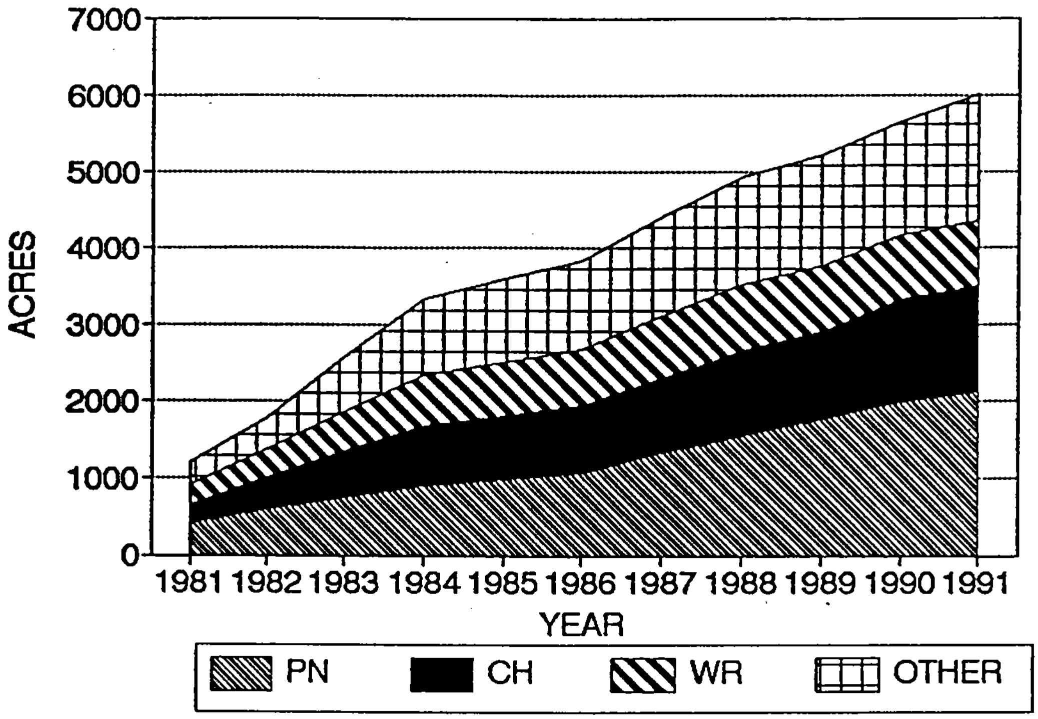

Figure 1. Oregon wine grape acreage (1981-1990) for Pinot noir (PN), Chardonnay (CH), White Riesling (WR), and other cultivars.

Table 1. Low temperatures and snow cover for the winter freezes of 1989 and 1990.

Location	Low Temperature (°F) Feb. 2-10, 1989	Low Temperature (°F) Dec. 20-24, 1990	Snow Cover (inches) 1989	Snow Cover (inches) 1990
Milton-Freewater	-8	-14	3	6
Boardman	-13	-12	T	--
The Dalles	-1	-5	4	--
Hood River	-5	-3	4	8
McMinnville	8	--	4	--
Forest Grove	--	3	--	3
Salem	-1	7	9	1
Dallas	7	5	12	0.5
Corvallis	7	7	10	2
Eugene	4	4	4	3
Roseburg	3	3	6	--
Cave Junction	4	6	13	13
Grants Pass	3	--	1	--
Ruch	2	- 6	3	--
Medford	9	-4	1	2

T = trace; -- no data.

These extreme low temperatures during mid-December could, in themselves, cause injury in European wine grapes. The extent of injury may also have been increased both by the mild conditions earlier in the month and the temperature fluctuations later. Examination of grape buds after the freeze indicated that plants suffered some damage. Growers needed information on how to accurately assess the extent of the damage to adjust pruning and crop levels. Information on assessing winter injury and pruning accordingly was included in a "Winter Injury to Grapevines" report mailed to growers in January 1991 (Strik, 1991).

Early and accurate assessment of the extent of injury is important in wine grapes. Growers need to adjust pruning levels to compensate for both injury and crop load. Both may have a significant effect on wine quality. This report includes a review of literature regarding hardiness and winter injury of grapes and a summary of our 1991 winter injury survey.

REVIEW OF LITERATURE

Winter injury of grapevines occurs when the vine is exposed to temperatures below a critical level. Cold tolerance of a grapevine is affected by: 1) its genetic potential for hardiness--species and cultivars differ in hardiness; 2) the environment during the growing season which affects acclimation or hardiness development; 3) cultural practices such as pruning, crop control, fertilization, irrigation, canopy management, and pest management; 4) the temperature regime prior to the freeze event; and 5) the time, duration, and extent of the freeze.

Grapevines and other perennial plants go through three phases during the period of fall through later winter: 1) growth cessation and the onset of hardiness (acclimation), 2) development of maximum winter hardiness, 3) and deacclimation (loss of hardiness).

Grapevine Dormancy and Cold Hardiness

Acclimation. In the fall, in response to short days and warm temperatures (Fennell and Hoover, 1991; Schnabel and Wample, 1987), the grapevine begins to cease growth (enter dormancy) and enter the first phase of cold hardiness. After growth cessation, temperatures slightly below 32°F favor acclimation (Damborska, 1978).

Although terminal buds are not formed in grapevines, shoot growth stops as the canes mature. With cane maturation comes lignification (hardening) and periderm (bark) formation. The bark becomes brown when the canes are fully mature. Maturation begins at the basal nodes and progresses outward towards the shoot apex. In general, wood maturity is related to hardiness--basal nodes are hardier than nodes toward the apex of the cane (Howell and Shaulis, 1980; Wolpert and Howell, 1985). Factors that delay acclimation (gain in hardiness) or wood maturation include overcropping (Howell, 1988; Howell and Shaulis, 1980; Stergios and Howell, 1977); defoliation in August due to stress or pests, for example (Stergios and Howell, 1977); over-fertilization (Wolf and Pool, 1988); and drought stress (Andersen and Odneal, 1985). These conditions may delay the entire hardiness process and increase the chance of winter injury during a cold spell. Also, canes well-exposed to light during the growing season (promoted by good canopy management) are hardier than canes that developed in shaded canopies (Howell and Shaulis, 1980; Wolpert and Howell, 1985). Large diameter canes, indicating excess vigor, are less hardy (Howell and Shaulis, 1980).

Maximum cold hardiness. In general, maximum cold hardiness occurs sometime during early January to February. During this period of maximum hardiness, the grapevine may withstand low temperatures up to -20°F, depending on the cultivar (Howell, 1988). The actual time of winter that the vine is in maximum hardiness can vary, depending on the environment and cultural factors mentioned previously. In general, maximum hardiness occurs after the chilling requirement for rest has been satisfied (400-1000 hours).

Deacclimation. Deacclimation, or the loss of hardiness, can occur during the late stages of rest and after rest has been completed. The rate of deacclimation varies by cultivar (Andrews et al., 1984; Damborska, 1978), on the length of time the vine has been exposed to warm temperatures, and the time of year or physiological state of the vine; deacclimation occurs more readily towards the end of winter (Damborska, 1978).

Reacclimation, to some extent, may occur during the quiescent period (after rest has been satisfied) if vines are once again subjected to non-lethal cold temperatures (Howell, 1988). However, hardiness can be lost quite rapidly during a period of "unseasonable" warm days. If this warm period is followed by a sudden drop to severe freezing temperatures, the vines may not be able to reacclimate in time, and vine injury may occur. Cultivars differ in their ability to deacclimate and reacclimate, and thus differ in their susceptibility to spring freeze events (Damborska, 1978).

Winter Injury

Grapevine tissues vary in cold hardiness. Cane tissues are hardier than the primary (1°) bud (Schnabel and Wample, 1987). Secondary (2°) and tertiary (3°) buds, about equal in hardiness, are hardier than the 1° bud (Stergios and Howell, 1977).

After a severe cold spell, damage is often not limited to a single location on the vine but is a combination of bud, cane, cordon, and trunk injury. Depending on the severity of the injury, the damage could range from stunting of shoots in spring to total collapse of the vine, either in early spring or during the summer (Ahmedullah, 1985).

The extent of crop loss due to winter injury is dependent on the percent of 1° and 2° buds killed (3° buds are usually infertile) and the amount of cane and trunk damage.

The reduction in crop on 2° shoots compared to 1° shoots depends on the cultivar. Howell (1989) found that, from experience, 1° bud mortalities of 10 percent or less did not reduce vine yield because losses were compensated for by either an increase in fruit set per cluster, berry size, or a combination of both.

Winter injury assessment. Accurately assessing the extent of winter injury is important to determine whether pruning methods and bud levels need to be adjusted. A detailed description of the grape compound bud and methods for assessing bud injury is given by Strik (1991, 1992b).

Winter injury to the 1°, 2°, and 3° growing points of compound buds can be observed by slicing buds longitudinally. As many as 100 buds per acre need to be randomly sampled and assessed for damage before pruning. Cultivars and different topographical areas should be sampled separately (Strik, 1991; 1992b). A formula to adjust pruning level based on bud injury is: number of nodes usually left per vine/(1--percent bud damage).

Cold injury to vascular tissues of the cane, cordon, and trunk of the vine can be more serious to the long-term health of the vine. Trunk splitting, which has been observed after winter injury, may be attributed to dehydration stress (Ahmedullah, 1985). This not only weakens the vine directly, but may lead to other problems such as crown gall (Strik, 1991b). Ahmedullah (1985) reported that trunk damage was observed in *V. vinifera*, especially Grenache and Cabernet Sauvignon, after temperatures of -8°F in January and February 1979. This type of damage was also observed in Oregon when temperatures dropped as low as -1°F in February 1989 in some western production regions (Strik, 1992b).

Damage to the cambium or xylem (woody tissue) of the canes or trunk can be assessed by scraping off the bark and observing the color of the underlying cambium and xylem--healthy cambium and xylem is bright green and moist whereas injured tissue is dark brown. However, judging the extent or seriousness of the injury is difficult. The sudden collapse of shoots following high temperatures in late spring is often a delayed manifestation of cambium or xylem injury.

Winter injury to the grapevine's trunk is more common on young vines and on the southwest side of the trunk when there is snow on the ground during the cold spell (Strik, 1992b).

Cultivar Effects

Vitis species and cultivars differ in rate of acclimation, maximum hardiness, and rate of deacclimation. *Vitis labrusca* (Concord, for example) and *V. vinifera* are hardy to -20°F and -4°F, respectively (Howell, 1988). Cultivars of European wine grapes differ in hardiness. Among the commercial wine grape cultivars grown in Washington and

Oregon, White Riesling is the most winter hardy (Ahmedullah, 1985; Strik, 1991). After a cold spell of -17°F in December 1983 at Prosser, Washington, Cabernet Sauvignon, Chenin blanc, Sauvignon Blanc, Semillon, Zinfandel, and Grenache suffered more 1° bud mortality than White Riesling, Chardonnay, and Pinot noir (Ahmedullah, 1985).

In Oregon, after the 1972 and 1989 freezes, White Riesling, Cabernet Sauvignon, and Pinot gris had less damage than Merlot, Muller Thurgau, Sauvignon Blanc, and Gewurztraminer; damage to Chardonnay and Pinot noir differed between years (Strik and Lombard, 1992). Proebsting et al. (1980) found that a temperature of -9°F killed 50 percent of 1° buds in White Riesling and Cabernet Sauvignon. In Oregon, Pinot noir buds at the enlarged stage in early spring have an LT_{50} (temperature that kills 50 percent of 1° buds) of 7°F (Sugar et al., 1992).

The relative hardiness of European wine grape cultivars may differ throughout the winter because of differences in acclimation, time of maximum hardiness, and rate of deacclimation.

The maximum hardiness of French-American hybrids (i.e. Seyval, Marechal Foch) depends upon their parentage; hardiness of hybrids decreases with an increasing amount of *V. vinifera* parentage (Bourne et al., 1991).

Rootstock Effects

Rootstocks can affect vine hardiness indirectly by affecting nutrition, water status, vigor, length of growing season, and time of bud break in the spring (Howell, 1988; Strik, 1992a). Rootstocks could possibly have a direct effect on scion hardiness by affecting acclimation in the fall or spring deacclimation. However, Wolf and Pool (1988) found no consistent effect of 3309C or Elvira rootstocks on hardiness of Chardonnay. To explore possible direct rootstock effects, one would need a uniform vine size and crop level among stocks.

Site Effects

Vineyard location affects the likelihood of an injurious cold spell. Within a particular region, site topography can have a large effect on winter injury. Sites with poor air drainage or "frost pockets" (depressions) are cooler and thus more susceptible to winter injury. Sites that face south or southwest and have a slope are warmer. Vineyard sites exposed to wind can suffer more cold desiccation injury. Also, high elevation sites are often cooler than lower elevation sites. These are just a few of the important factors that must be considered when selecting a site (Price, 1992; Strik, 1992b).

Cultural Effects

Pruning. Edgerton and Shaulis (1953) found that there was no difference in 1° bud hardiness in March of pruned (December) and unpruned Concord vines. Although Wolpert and Howell (1984) reported that pruning decreased hardiness of Concord during early to mid-dormancy, Hamman et al. (1990) found no effect of pruning on hardiness of Merlot during the deacclimation period.

Delayed pruning may be an advantage when considering winter hardiness or injury. Early pruning (in December, for example) may stimulate dehardening and thus increase susceptibility to cold injury (Howell, 1988; Wolpert and Howell, 1984). Also, late pruning allows for adjustment of bud number if injury has occurred (Howell, 1988; Strik, 1992b).

Pruning method can affect winter injury. Cold damage to cordons is less common than cane damage (Ahmedullah, 1985). Also, because basal buds are hardier than distal buds (Wolpert and Howell, 1985), spur-pruned vines have less winter injury than cane-pruned vines.

Crop load. Overcropping reduces the amount of carbohydrates available for shoot maturation, which can reduce hardiness (Howell and Shaulis, 1980; Stergios and Howell, 1977; Wolpert and Howell, 1985).

Date of harvest had no effect on bud cold hardiness of Cabernet Sauvignon (Wample and Barry, 1992).

Canopy management. Canopy management can affect vine hardiness through exposure of leaves and canes. Wolpert and Howell (1985) found that the 1° bud and cane tissues of exposed Concord shoots were 4-11°F hardier than those of shaded shoots. Vines with dense, shaded canopies have less carbohydrate and thus are more susceptible to cold injury (Strik, 1992b).

Trellis. Trellis type, single canopy or divided canopy, can have an effect on exposure. Bourne et al. (1991), when comparing a bilateral cordon and a 4-arm Kniffen training system, found no effect of trellis type on bud hardiness. Head height, however, may have an effect on hardiness, as vines with a head height close to the ground may be in a warmer microclimate (Stergios and Howell, 1977).

Irrigation. Excessive soil moisture in the fall has been shown to delay vine acclimation (Andersen and Odneal, 1985; Howell, 1988). Summer drought, especially in shallow soils, may increase susceptibility to winter injury by excessively stressing vines and by delaying senescence once water becomes available in early fall (Andersen and Odneal, 1985).

Nutrition. Pellet and Carter (1981), in a review of literature relating plant nutrition status to cold hardiness, concluded that maximum cold hardiness was achieved by a level of fertilization that promoted optimum plant growth and that "supra-optimal fertility levels can retard cold acclimation". Wolf and Pool (1988) found no effect of N fertilization on cold hardiness. The effect of K on hardiness, if any, has not been established in grapes (Howell, 1988).

Pest management. Any insect or plant pathogen that reduces leaf surface area can delay acclimation in fall by reducing carbohydrate production.

Cover crops. Cover crops compete with vines for water and nutrients. This type of competition after veraison can hasten vine maturation (Howell, 1988).

Reynolds (1987) gives a more detailed review of cultural practices affecting vine hardiness in British Columbia.

WINTER INJURY SURVEY, 1991

Methods

In late May 1991, we surveyed vineyards in the Willamette Valley, Umpqua, southern Oregon, Columbia River, and eastern Oregon wine grape growing regions to assess winter injury. We sampled a total of 45 vineyards--with 126 combinations of cultivar and pruning method. Information on site (elevation, aspect), cultivar, age of planting, pruning/training method, and rootstock (where applicable) were noted for each vineyard. As many of the above combinations ("treatments") were sampled as possible.

At each site, treatment combination, 25 vines were sampled in a block. To remain unbiased and to assess as large an area as possible, every tenth vine in every fifth row was assessed.

The following data were collected from 10 nodes on each vine; the same side of the vine was assessed each time (i.e. north side): percent bud break (number of nodes with at least one shoot ÷ 10 x 100), percent 1° bud break (number of nodes with a 1° shoot ÷ 10 x 100), total number of 1°, 2°, and 3° shoots/10 nodes, total number of clusters/10 nodes, average shoot fertility, and the number or clusters per node were calculated.

Vine spacing, number of nodes per vine, and an industry average for cluster weight were used, in addition to the above data, to estimate total yield.

Cambium or xylem damage to canes, or cordons, and the trunk of vines was rated on a scale of 0 to 5, with 0 being healthy (bright green cambium) and 5 dead (dark brown). Anything with a rating of 3 or greater was considered "severe damage" and was used to calculate percent cane/trunk damage. In this case, very little of the cambium or xylem was green, thus indicating that the cane or trunk may not survive the season.

Information on cultivar, clone, and rootstock (if applicable) and age of the planting was provided by the grower.

At the end of harvest, growers were asked for actual harvested yield data and percent fruit thinned for the blocks assessed for winter injury in the spring.

Results and Discussion

The winter injury survey data collected in spring 1991 for six wine grape growing regions are presented in Table 2. The extent of winter injury to grapevines differed with growing region, vineyard site, and cultivar (Table 2).

In general, winter injury was most evident as a reduction in percent 1° bud break (percent 1° shoots), because percent total bud break was quite high in many cultivars (Table 2).

Site. Site effects on winter injury were quite evident. Similarly aged cultivars within a region differed in extent of winter injury among sites. Also, at site #43, Pinot noir, planted in 1976, was planted in a cool location whereas Pinot noir, 1984, was in a relatively warm location; the effect of microclimate on winter injury was apparent when comparing percent 1° bud break, cambial damage to canes and trunk, and yield of these two plantings (Table 2). Many sites in the mid-Willamette Valley and some in southern Oregon showed little winter injury, whereas some sites in these regions suffered considerable damage (Table 2).

Planting age. Planting age had an effect on winter injury. Young vines, especially three years old or less, had more trunk injury. Trunk and cordon injury was also more evident in the Hood River and eastern Oregon regions where temperatures were lower (Tables 1 and 2).

Cultivar effects. A cultivar trial at site #1 allowed for easy comparison of cultivars. White Riesling was most hardy, while Malbec and Merlot were least hardy. Although Gewurztraminer, Pinot blanc, Pinot gris, and Muller Thurgau generally had 80 to 90 percent bud break, percent 1° bud break was from 35 to 60. Thus, these cultivars were affected by winter injury. Also, at site #1, Pinot noir was slightly more hardy than Chardonnay. Spur-pruned Cabernet Sauvignon had less damage than cane-pruned Cabernet Sauvignon (Table 2).

Table 3 shows hardiness rankings of cultivars grown in Oregon based on evaluations after freezes in 1972, 1989, and 1990. Table 4 shows injury ratings for cultivars grown at the Southern Oregon Experiment Station.

Key for Table 2

Region

NWV	-	North Willamette Valley
MWV	-	Mid-Willamette Valley
U	-	Umpqua
SO	-	Southern Oregon
HRD	-	Hood River
EO	-	Eastern Oregon

Cultivar/Age/Training Method

CH	-	Chardonnay
CS	-	Cabernet Sauvignon
GW	-	Gewurztraminer
Ml	-	Merlot
MT	-	Muller Thurgau
Pb	-	Pinot blanc
Pg	-	Pinot gris
PN	-	Pinot noir
SB	-	Sauvignon Blanc
Sm	-	Semillon
WR	-	White Riesling
no dmg	-	no winter injury observed
UC	-	upright cane pruned (2)
UC4	-	upright cane pruned - 4 canes
UPd	-	upright pendelbogen, cane pruned
SW	-	single wire
GDC	-	Geneva Double Curtain
SH	-	Scott Henry, cane pruned
Cd	-	cordon, spur pruned
Ir	-	irrigated
lh	-	low head height
gd	-	growth diversion canes present
bf	-	pruned before freeze
af	-	pruned after freeze

Low, December, 1990

Estimated low temperature on actual site

<u>% Budbreak</u>

Total bud break on 10 nodes/vine
Bud break of 1° shoots only

<u>Cane/Trunk Damage</u>

Percent vines with a cane injury rating of 3 or greater (see Methods)
* Indicates cordon damage rating
A trunk damage rating is given if any was observed

<u>Average Shoot Fertility</u>

Average number of clusters per 1° and 2° shoots

<u>Estimated Yield</u>

Estimated yield (T/A) = no. plants/A x no. buds/plant x # clusters/node x avg. cluster wt. (g) ÷ 454 g/lb. ÷ 2000 lb./ton

The average cluster weight used is indicated in brackets: PN (100g); CH (200g); CH Wente (100g); MT (200g); GW (100g); CS (100g); Ml (100g); SB (100g): Sm (100g): WR (200g)

<u>Yield at Harvest</u>

Grower's actual harvested yield (not including thinned fruit)

<u>% Thinned</u>

Estimated percent fruit thinned by grower

<u>Total Potential Yield</u>

Actual yield + percent thinned

Table 2. **Winter injury assessment of cultivars grown in the grape production regions of Oregon, 1990-1991.**

Region	Cultivar/Age/Training	Vineyard #	Low Dec '90 (°F)	% Budbreak Total	% Budbreak 1°	Cane/Trunk Dmg (% ≥ 3)	Avg. Shoot Fertility (clusters/1°+2°)	Estimated Yield (T/A)	Yield at Harvest (T/A)	% Fruit Thinned	Potential Yield at Harv. + Fruit Thinned
NWV	PN '89 - UC	1	5-6	92	66	100/100	1.6	1.7	0.46	12.5	0.53
	PN '87 - UC			84	53	8	1.1	2.9	2.96	25	3.95
	PN '72 - UC4			88	69	36	1.8	3.8	3.04	40	5.07
	PN '73 - GDC			93	81	16	1.7	6.9	5.30	50	10.60
	CH '80 - SW			88	48	40	1.4	8.6	3.27	0	3.27
	MT '80 - SW			83	61	40	2.1	13.3	6.87		6.87
NWV	<u>Variety Block/'76-UC:</u>										
	Auxerrois			88	48	0	1.8	---			
	Muscat Ottonel			86	66	0	2.0	---			
	Gw			88	36	60	1.1	---			
	Pb			80	36	100	1.3	---			
	Pg			84	52	80	1.8	---			
	Malbec			0	0	100	0	---			
	MT			82	58	80	1.4	---			
	Cab. franc			90	72	0	1.6	---			
	WR			92	68	0	2.0	---			
	CH			68	40	80	1.4	---			
	Ml			44	32	0	1.0	---			
	PN			84	62	60	1.4	---			
	CS			67	40	0	0.9	---			
	CS-Cd			95	60	0	1.0	---			
NWV	PN '72 - UC	2	8	89	74	44	1.9	5.7	2.50	50	5.00
	PN '72 - UC, Ir			94	74	32	1.7	7.1	2.75	35	4.23
	CH '72 - UC			84	52	12	1.7	6.9	2.50	50	5.00
	MT '86 - UC			86	60	0	1.9	6.2	3.00	0	3.00
	WR - no dmg										
NWV	PN '88 - UC, lh, Ir	3		96	80	0/72	1.4	3.3	1.50	35	2.31
	PN/3309 '89 - Ir			93	59	84/88	1.4	4.0	1.75	50	3.50

Table 2. **Winter injury assessment of cultivars grown in the grape production regions of Oregon, 1990-1991 (cont.).**

Region	Cultivar/Age/Training	Vineyard #	Low Dec '90 (°F)	% Budbreak Total	% Budbreak 1°	Cane/Trunk Dmg (% ≥ 3)	Avg. Shoot Fertility (clusters/1°+2°)	Estimated Yield (T/A)	Yield at Harvest (T/A)	% Fruit Thinned	Potential Yield at Harv. + Fruit Thinned
NWV	CH '82 - UC4	4		82	55	24	1.4	7.0	4.00	50	8.00
	PN '78 - UC4			90	73	20	1.5	9.6	2.50	30	3.57
NWV	CH '82 - UC	5		85	54	28	1.5	4.4	2.50	33	3.73
NWV	PN '73 - UC, gd	15		95	70	0	1.9	4.2	3.20	45	5.82
	GW '73 - UC, gd			90	63	8	2.1	4.2	3.95	0	3.95
	WR '80 - UC, gd			92	58	0	2.7	10.7	5.80	0	5.80
	MT '73 - UC, gd			88	56	8	2.0	7.5	6.70	0	6.70
	CH '80 - UC, gd			84	50	0	1.9	7.0	3.60	43	6.32
NWV	MT '85 - UC	16	11	90					3.50	0	3.50
NWV	PN '76	43	4	84	13	90/80	1.0	0.9	0	--	---
	PN '84			84	47	20/50	1.5	2.9	3.61	0	3.61
MWV	PN '79 - UC	6	5	97	60	20	1.7		2.25	50	4.50
MWV	PN '82 - SW	7	5	95	78	8	1.6	1.9	2.0	65	5.71
	CH - no dmg								3.0	65	8.57
	PN '87 - no dmg										
MWV	MT '83 - GDC	8	0-6	90	46	12	2.5	3.0	4.0	0	4.0
	PN '83 - GDC			91	54	16	1.6	4.0	2.5	0	2.5
MWV	CH/St. Gg. '80 - UC	13	-7	20	3	100/90	0.6	0.45	0	--	
	CH/St. Gg. '80 - UC			23	4	96/90	0.9	0.60	0	--	
MWV	CH - SW	14		94	87	0	1.9		2.5*	0	2.5
	PN - no dmg										
MWV	CH (108) '81 - UC	31	6	81	36	52	1.6	4.1	7.2	0	7.2
	PN '82 - UC			85	36	68	1.3	3.7	3.98	0	3.98
	GW '81 - GDC			78	36	64	1.2		0.35	0	0.35

Table 2. **Winter injury assessment of cultivars grown in the grape production regions of Oregon, 1990-1991 (cont.).**

Region	Cultivar/Age/Training	Vineyard #	Low Dec '90 (°F)	% Budbreak Total	1°	Cane/Trunk Dmg (% ≥ 3)	Avg. Shoot Fertility (clusters/1°+2°)	Estimated Yield (T/A)	Yield at Harvest (T/A)	% Fruit Thinned	Potential Yield at Harv. + Fruit Thinned
MWV	CH - UC	32		76	38	0	1.3		7.0	0	7.0
	PN - UC			94	60	0	1.9		3.9	0	3.9
MWV	CH '83 - UC	33	4	76	28	64	1.1		2.40	8	2.61
MWV	CH '83 - UC	34	8	82	54	0	1.6		4.66	18	5.68
	PN '83 - UC			92	73	0	1.2		4.15	15	4.88
	SB '84 - UC			92	56	0	1.6		3.19	10	3.54
	CS '84 - UC			71	28	0	1.2		3.36	8	3.65
MWV	PN - Cd	35	8	96	99	10		2.7-5.4 4.05		0	
	PN - UC			92	85	40		2.1-4.1 3.1	2.00	0	2.00
	CH - UC			88	64	30		4.8-9.5 7.5	4.50	0	4.50
MWV	PN - no dmg	36							5.80	0	5.80
	CH - no dmg								4.54	0	4.54
MWV	PN - no dmg	37							2.70	80	13.50
	PN - no dmg								3.88	80	19.40
MWV	PN - consid dmg	38							0	--	---
	CH - consid dmg								0	--	---
MWV	PN-UC; PN-SW, CH-SW, MT-GDC; Pb-UC; Pg-UC - no dmg	39									2.72
MWV	CH - UC - no dmg	40									
	PN - UC - no dmg										
MWV	CH - SW	42	<0	70	18	52/10	0.7				
MWV	PN '70 - UC	43		86	32	44	1.6	2.4	2.90	5	3.05
	GW '84 - UC4			83	20	64	0.8	3.2	1.55	0	1.55

Table 2. Winter injury assessment of cultivars grown in the grape production regions of Oregon, 1990-1991 (cont.).

Region	Cultivar/Age/Training	Vineyard #	Low Dec '90 (°F)	% Budbreak Total	1°	Cane/Trunk Dmg (% ≥ 3)	Avg. Shoot Fertility (clusters/1°+2°)	Estimated Yield (T/A)	Yield at Harvest (T/A)	% Fruit Thinned	Potential Yield at Harv. + Fruit Thinned
U	CS '80 - GDC, Cd	9	0?	92	79	0	1.8	6.6	3.67	0	3.67
U	CS/St. Gg. '90 - UC	10	-6	5	0.5	100/4	1.0	1.0	0	--	0
U	CH '72 - SH	11	4	43	10	40	0.5	0.9	1.45		
	PN '72 - UC4			68	34	28	1.4	1.8	3.60		
U	CS - GDC	30		53	20	16	1.4	2.3			
	CS - Ly			51	25	28	1.6	2.7			
	PN - Ly			52	42	10	1.9	4.1			
	PN - GDC - no dmg										
	CH - Ly - 20% dmg										
SO	CH '84 - UC	12	<0	60	30	56	1.2	1.3	1.5	0	1.5
	PN '84 - UC			67	44	24	1.7	2.5	3.0	0	3.0
	PN '84 - UC			89	72	12	1.7	4.2	3.5	0	3.5
SO	CS, PN, SB, CH - no dmg	22									7.8
	MI '80 - UC			70	4	0	1.5	3.5	7.8	0	
SO	SB '83 - Ly, Cd	23	-2 to -4	90	35	70, 10*	1.4	5.9	7.0	0	7.0
	Sm '73 - Cd			74	31	10, 10*	1.0	2.1	7.0	0	7.0
	Sm '73 - Ly			54	21	10	1.2	2.1	3.3	0	3.3
	PN '73 & '84 - Ly,Cd,bf			15	3	92, 20*	2.4	0.9		0	
	PN '73 & '84 - Ly,Cd,af			39	25	52, 28*	0.7	1.8	6.5		6.5
	CH - no dmg										
SO	MI '87 - UC	24	-4 to -6	57	22	4	1.2	1.0	2.38	0	2.38
	GW - no dmg										
	PN - no dmg								6.50	0	6.50

Table 2. **Winter injury assessment of cultivars grown in the grape production regions of Oregon, 1990-1991 (cont.).**

Region	Cultivar/Age/Training	Vineyard #	Low Dec '90 (°F)	% Budbreak Total	% Budbreak 1°	Cane/Trunk Dmg (% ≥ 3)	Avg. Shoot Fertility (clusters/1°+2°)	Estimated Yield (T/A)	Yield at Harvest (T/A)	% Fruit Thinned	Potential Yield at Harv. + Fruit Thinned
SO	PN '81 - UPd	25	0 to -3	55	30	20	2.1	10.1	2.50	0	2.50
	CH '81 - UPd			44	15	70	1.3	6.7	2.50	0	2.50
	MT '81 - UC			0	0	98	0	0	0	0	0
	GW '81 - UC			10	0	90	0	0	1.25	0	1.25
	WR, Pg - no dmg										
SO	PN '76 - UC, bf	26	-3	31	5	40	0.7	0.5	0.75	0	0.75
	PN '76 - UC, af			61	32	20	1.8	4.7	4.00	0	4.00
	PN '76 - UC, af, spur			72	16	40	1.1		4.00	0	4.00
	CH '81 - UC, af			68	35	20	1.9	8.9	5.50	0	5.50
	MT '81 - UC, bf			24	11	70	1.6	4.8			
	MT '81 - UC, af			54	23	80	1.1	9.6			
SO	GW - af - no dmg	27	0 to -2						0	0	0
	CH '74 - af - no dmg								6.00	0	6.00
	MI '74 - af - no dmg								6.00	0	6.00
	CS '74 - af - no dmg								4.00	0	4.00
SO	CH '81 - UC	28	-9	58	21	48	1.0	2.6	2.35	0	2.35
	PN '83 - no dmg								4.50	0	4.50
SO	CS '76 - UC, bf	29	-5	74	41	20	1.7	1.7	3.25	0	3.25
	CS '72 - UC, af			91	63	0	1.7	2.8	2.6	0	2.60
	CS '72 - UC, af, spur			86	46	20	1.0				
	CH '74 - UC, bf			85	63	0	1.7	4.2	1.0	0	1.0
SO	MI '86 - UC, bf	41	-5	30	4	25/58	1.3	0.12	0	--	0
	MI '86 - UC, af			49	12	0/83	1.3	1.4	0	--	0
HRD	WR - Cd	17		98	74	4	1.7	6.3	4.20	3	4.33

Table 2. Winter injury assessment of cultivars grown in the grape production regions of Oregon, 1990-1991 (cont.).

Region	Cultivar/Age/Training	Vineyard #	Low Dec '90 (°F)	% Budbreak Total	% Budbreak 1°	Cane/Trunk Dmg (% ≥ 3)	Avg. Shoot Fert. (clusters/1°+2°)	Estimated Yield (T/A)	Yield at Harvest (T/A)	% Fruit Thinned	Potential Yield at Harv. + Fruit Thinned
HRD	PN '88	20	-15	64	24	40/88	1.4	1.7	1.25	0	1.25
	WR '83 - Ly, Cd			87	34	0, 52*	1.8	11.1	7.50	0	7.50
	CH '83 - Ly, Cd			68	3	40, 20*/16	0.4	5.0	1.25	0	1.25
	CS '83 - Cd			70	12	32, 36*/24	1.1	1.9	3.22	0	3.22
HRD	CH '82 (Wente) - Cd	21	-8	62	24	33,67*	1.5	2.4	1.83	0	1.83
	CH '82 (108) - Cd			54	1	38	1.4	3.8			
EO	WR '84 - Cd	18	-12	72	40	0, 8*	1.7	2.1	6.0*	0	6.00
	CS '84 - Cd			25	12	76*/68	---	0.4	0.8	0	0.80
	Sm '84 - Cd			14	2	24*/28	---	0.1	0.1	0	0.10
	Flame '84 - Cd			0	0	100/100	---	0	0	0	0
	Ml '84 - Cd			2	0	100/95	---	0	0	0	0
	PN '84 - Cd			73	4	44*/44	---	0.2	0.2	0	0.2
EO	WR '84 - Cd	19	-12	28	0.5	48, 44*/56	1.3	2.0	4.5*	0	4.5
	GW '84 - Cd			3	0.3	72*/84	---	0.1	0.1	0	0.1

*Not harvested due to hail damage.

Table 3. **Bud and cane damage of wine grape cultivars in Oregon following 1972, 1989, and 1990 freezes (in order of increasing damage) at 0 to -13°F (from Strik and Lombard, 1992b).**

Least Damage ↓	1)	Foch (1989, 1990) Riesling (1972, 1989, 1990)
	2)	Cabernet franc (1990) Muscat Ottonell (1990) Sauvignon blanc (1990) Auxerrois (1990) Cabernet Sauvignon (1989) Semillon (1990)
	3)	Pinot noir (1972, 1989, 1990) Pinot gris (1990) Chardonnay (1972, 1990) Gamay noir (1990) Fresca (1990) Cabernet Sauvignon (1990)
	4)	Pinot blanc (1990) Cabernet Sauvignon (1972) Limberger (1990) Nebbiolo (1990)
	5)	Chardonnay (1989) Muscat blanc (1989)
	6)	Gewurztraminer (1972, 1989, 1990) Syrah (1990) Muscat blanc (1972)
	7)	Chenin blanc (1989) French Columbard (1972) Merlot (1989, 1990)
Most Damage	8)	Malbec (1990)

Table 4. **Injury to grapevines at the Southern Oregon Experiment Station following freezing temperatures during December 1990.**

Increasing Hardiness	Cultivar	Mean Injury Rating[1,2]
↓	Tempranillo	1.28a
	Shiraz (Syrah)	1.62ab
	Sangiovese	1.72ab
	Dolcetto	1.92abc
	Viognier	2.12abcd
	Graciato (Morastel)	2.50bcde
	Refosco	2.64bcde
	Cabernet Sauvignon	2.84cdef
	Nebbiolo	3.00def
	Nebbiolo Fino	3.04def
	Petite Verdot	3.22efg
	Pinot blanc	3.26efg
	Limberger	3.28efg
	Nebbiolo Lampia	3.52efg
	Cabernet franc	3.76fg
	Gamay noir	3.84fg
	Pinot gris	3.90fg
	Fresia	3.90fg
	Chardonnay	4.12g

[1]Grapevines were evaluated on May 13, 1991 using the following rating system:

0 = no live buds
1 = buds sprouting at trunk base, trunk cambium brown
2 = buds sprouting at trunk base, trunk cambium green
3 = secondary buds sprouting on upper trunk
4 = primary buds sprouting on upper trunk (1-10 buds)
5 = primary buds sprouting on upper trunk (>10 buds)

[2]Values represent means of mean ratings of 5 replicate groups of 5 plants each for each cultivar. Values followed by the same small letter are not significantly different (Duncan's *P* = 0.05).

Cultural practices. There were not enough sites to accurately assess the effect of cultural practices on winter injury. At site #2, irrigated Chardonnay has less 1° bud damage than non-irrigated. However, this was not apparent in Pinot noir at the same site (Table 2). At site #30, Pinot noir trained to a lyre had 42 percent 1° bud break, whereas Pinot noir trained to a GDC had no damage. At the same site, Cabernet Sauvignon trained to a lyre or GDC showed no difference in winter injury (Table 2).

Time of pruning affected the amount of winter injury observed. Pinot noir (site #23), Cabernet Sauvignon (site #29), and Merlot (site #41) had more winter injury when pruned before the freeze than after (Table 2). Also, at site #27, a block of Gewurztraminer pruned after the freeze had no damage (Table 2), whereas a block pruned before the freeze had 60 percent damage (data not shown as detailed counts were not taken).

There are very few established vineyards on rootstock in Oregon. However, Chardonnay (site #3) and Cabernet Sauvignon (site #10) grafted on St. George, a rootstock promoting late fall growth, had more winter injury than self-rooted vines at nearby vineyards (Table 2). Possibly, St. George delayed vine maturation and acclimation, thus increasing susceptibility to an early cold spell.

Although the data in Table 2 allow for observations to be made about cultural/ training effects on winter injury, the data were too variable to make recommendations with confidence. Thus, data were pooled across training/pruning methods within cultivars and regions (Table 5).

Regional effects. In the northern Willamette Valley, bud break, including percent 1° bud break, was quite good. Although growers tended to not thin White Riesling, Muller Thurgau, or Gewurztraminer, they did thin Pinot noir and Chardonnay, on average. Except for White Riesling, many vineyards in this region had what appeared to be severe cambium or xylem damage to the fruiting canes. Thus, the cool, wet spring may have delayed bloom, but it may also have "saved" vines that had cambium damage, as it apparently allowed vines to recover from this cane damage (Figures 2 and 3, Table 5).

Muller-Thurgau and Gewurztraminer suffered considerable damage in the mid-Willamette Valley (Table 5). Yields were low and growers did not thin fruit. Lower yields appeared to be due to damage to 1° buds even though bud break was quite high. Percent 1° bud break averaged 46 and 28 percent for Muller Thurgau and Gewurztraminer, respectively. Cane damage was also relatively high in Gewurztraminer.

Primary bud break of Pinot noir ranged from 32 percent to nearly 100 percent (no damage), averaging 65 percent (Table 5). Also, damage to Chardonnay was variable with a range of 3 to 100 percent 1° bud break. The vineyard with 3 percent 1° bud levels was an eleven-year-old vineyard grafted onto St. George (site #3, Table 2).

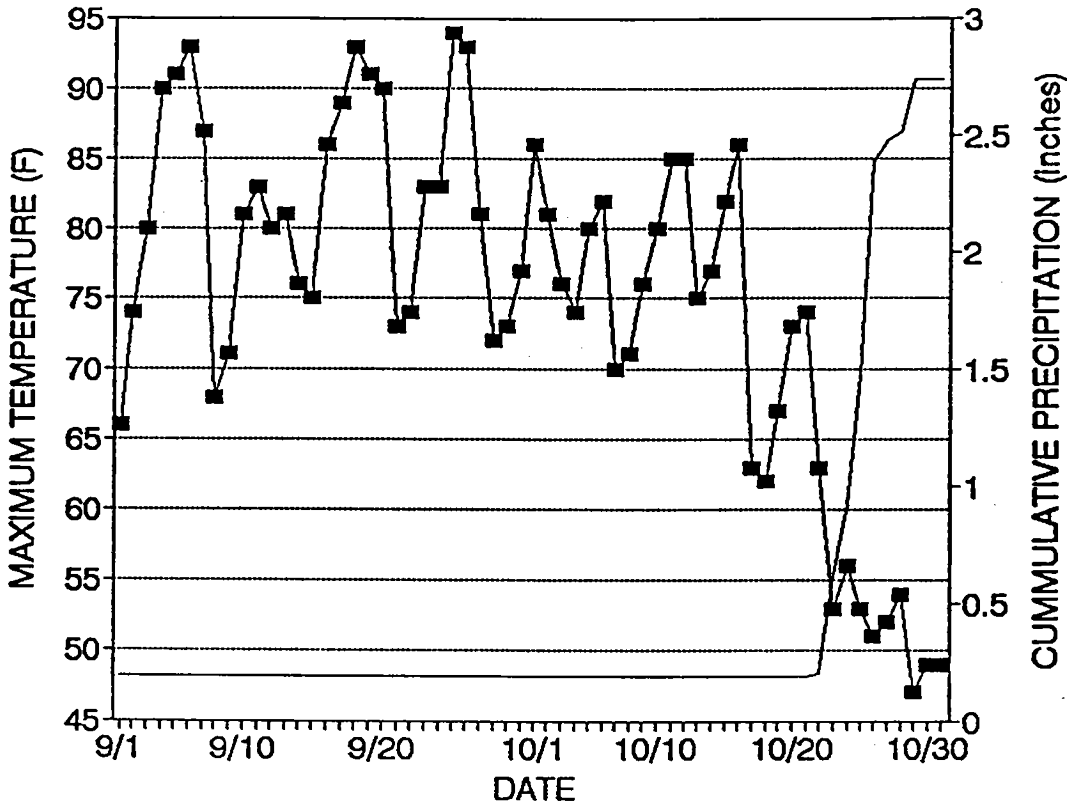

Figure 2. Maximum daily temperatures at Corvallis, Oregon from September through October 1991.

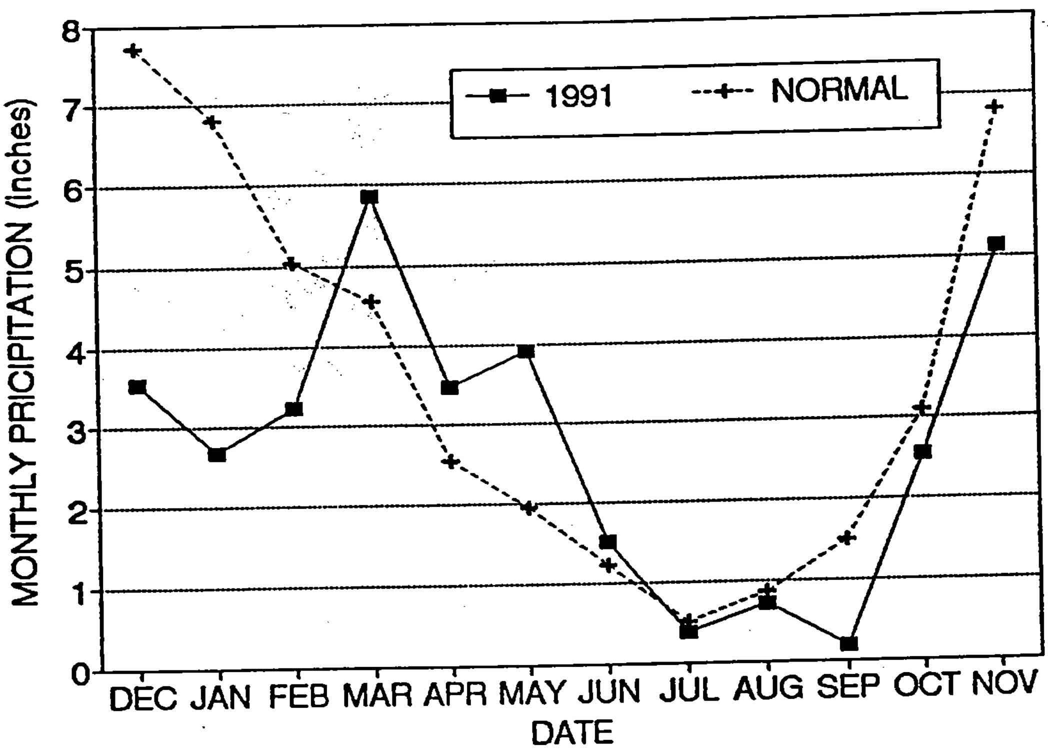

Figure 3. Monthly rainfall totals at Corvallis, Oregon in 1991 and the long-term average (normal).

Table 5. **Winter injury survey data for cultivars across pruning/training methods within growing regions, 1991.**

Cultivar	# Sites	% Budbreak Total	1°	Cane Damage	Harv. Yield	% Thinned
NWV						
PN (yng)	4	91	65	48	1.7	31
PN (old)	7	90	65	34	2.8	36
CH	5	85	52	21	3.2	35
WR	1	92	58	0	5.8	0
MT	3	89	58	4	5.5	0
Gw	1	90	63	8	4.0	0
MWV						
PN	9	92	64	18	2.9	15
CH	8	68	39	43	3.5	3
MT	1	90	46	12	4.0	0
Gw	2	81	28	64	1.0	0
U & SO						
PN	9	55	29	18	3.8	0
CH	5	64	27	12	2.6	0
CS	4	66	46	25	2.4	0
Ml	3	50	7	47	2.6	0
HR						
PN	1	64	24	8	1.3	0
CH	2	65	14	8	1.5	0
WR	2	93	54	2	5.8	2
EO						
WR	2	50	23	25	5.3	0
CS	1	25	12	76	0.8	0
Ml	1	2	0	100	0	0
PN	1	73	4	44	0.2	0

NWV = North Willamette Valley, MWV = Mid-Willamette Valley, U & SO = Umpqua and Southern Oregon, HR = Hood River/Mid-Columbia, EO = Eastern Oregon/Boardman.

There was little damage on the mid-Willamette Valley floor sites (including the Lewis-Brown Farm--site #36, Table 2). Woodhall III Vineyard (site #35, Table 2) showed good bud break in Pinot noir and Chardonnay, but had 10 to 40 percent cane damage. Fruit set was so good in 1991 that, despite the lower number of primary shoots, growers had to thin Pinot noir and Chardonnay by 15 and 30 percent, respectively, on average. In general, Sauvignon Blanc, Pinot gris, and White Riesling had little damage in this region.

In the Umpqua region and southern Oregon, effects of the freeze were extremely variable. Some vineyards had little damage on most cultivars, but a few were hit very hard. In general, growers surveyed did not thin crop loads. Although bud break was quite good in most cases, primary bud break of Pinot noir ranged from 3 to 72 percent, averaging 29 percent (Table 5). Damage to Chardonnay ranged from 10 to 30 percent of the primaries. Cane damage was relatively low: 18 and 12 percent for Pinot noir and Chardonnay, respectively. Only Merlot suffered considerable cane damage, with a percent 1° bud break ranging from 4 to 22 percent. There was little damage to Sauvignon Blanc. Bud break on Semillon was quite good; however, only 20 to 30 percent were primary shoots. Damage to White Riesling was spotty, but less compared to other cultivars. Also, Pinot gris and Cabernet Sauvignon came through quite well.

Damage from the freeze in the Hood River region and eastern Oregon was considerable, as temperatures were colder (Table 1). In the Hood River area, White Riesling suffered little damage, while Chardonnay and Pinot noir had 14 and 24 percent primaries, respectively (Table 5). Harvested yield was thus reduced proportionally.

Vineyards in eastern Oregon were damaged again, and growers were left wondering if growing *V. vinifera* in this region is economically feasible. Only White Riesling came through with a full crop despite having only 23 percent primaries. Chardonnay, Pinot noir, Merlot, Flame Seedless, Semillon, Cabernet Sauvignon, and Gewurztraminer produced no crop (Table 5).

State losses in production. Many of the cultivars grown produced a crop from 2° shoots (Table 2). For example, Chardonnay had, on average, 52 percent 1° shoots in the northern Willamette Valley (Table 5). However, the average crop harvested was 3.2 T/A, after 35 percent thinned. The good 2° shoot fertility combined with an exceptionally good fruit set and large cluster size compensated for the loss in 1° buds due to winter injury.

State losses in grape harvest due to the freeze of 1990-91 were estimated at 18 percent by the Agricultural Statistics Service (1992, Table 6). Much of this can be attributed to the considerable acreage in eastern Oregon that was not harvested. The crop losses were less than expected due to an exceptionally good fruit set. Also, the cool, wet spring (Figures 2 and 3) that delayed growth may have reduced collapse of shoots on damaged vines.

Table 6. **State losses in grape harvest from the freeze of 1990-1991 in Oregon (Williamson et al., 1992).**

	PN	CH	WR	Pg	CS	GW	MT	SB	Ml	Zin	Other	Total
Harv. (tons)	3027	2498	2101	479	410	279	423	217	66	41	270	9811
Total Potential	3454	3234	2201	495	679	528	528	317	126	51	330	11943
% Loss	12	23	5	3	40	47	20	32	48	40	18	18

The cultivars hit hardest in crop loss by winter injury were Merlot, Gewurztraminer, Cabernet Sauvignon, Zinfandel, Sauvignon Blanc, Chardonnay, Muller Thurgau, and Pinot noir. Pinot gris and White Riesling were the least affected (Table 6).

SUMMARY

The relationship of primary bud loss by winter injury to crop reduction indicates the importance of early assessment of primary bud damage. In general, vineyards that had fewer than 30 percent primary buds had lower than normal yields. Early assessment of damage from winter injury allows for adjustments in pruning.

Pruning before the freeze event in 1990-91 led to greater vine damage than pruning after the cold spell. Also, spur-pruned vines were less damaged than cane pruned vines. Thus, when compensating for winter injury, the grower may choose to not only leave more buds per vine, but may also spur prune rather than cane prune. Spur pruned vines have a higher number of basal buds, which are hardier than distal buds.

Cultivars were found to differ in hardiness with White Riesling being the most hardy, and Merlot amongst the least hardy.

The importance of good site selection to minimize the risk of cold injury was evident from this survey.

This survey offered little conclusive evidence of cultural effects on winter injury. However, research suggests that cultural practices can affect cold tolerance.

Cold damaged vines did not have as great a crop loss as predicted. A high cluster number on secondary shoots somewhat compensated for the loss in primary buds to cold injury. Also, the cool, wet spring of 1991 may have kept partially damaged shoots from collapsing. Finally, the excellent fruit set and thus above average custer size in 1991 somewhat compensated for crop loss due to winter injury.

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