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The North Carolina Winegrape Grower's Guide

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Editor

E. Barclay Poling
Professor and Small Fruit Specialist, Department of Horticultural Science, North Carolina State University, Raleigh, NC

Authors

Amy-Lynn Albertson (Chapter 3)
Davidson County Extension Agent, Lexington, NC

R. Andy Allen (Chapter 3 and 4)
Extension Viticulturist, Institute for Continental Climate Viticulture and Enology, University of Missouri, Columbia, MO

Ryan Boyles (Chapter 4)
State Climatologist and Director, State Climate Office (SCO) of North Carolina, Raleigh, NC

Carlos E. Carpio (Chapters 2 and 4)
Assistant Professor, Department of Applied Economics and Statistics, Clemson University, Clemson, SC

Jean Harrison (Chapter 8)
Yancey County Extension Agent, Burnsville, NC

Wayne E. Mitchem (Chapter 8)
Horticulture Extension Associate, North Carolina State University, Raleigh, NC

E. Barclay Poling (Chapters 1, 2, 3, 4, and 11)
Professor and Small Fruit Specialist, North Carolina State University, Raleigh, NC

Charles D. Safley (Chapter 2)
Professor and Extension Economist, North Carolina State University, Raleigh, NC

Turner B. Sutton (Chapter 8)
Plant Pathology Professor, North Carolina State University, Raleigh, NC

Tony K. Wolf (Chapters 5, 6, 7, 9, 10, and 12)
Director, Alson H. Smith Jr. Agricultural Research and Extension Center, Winchester, VA

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Figures and photos 4.1 on page 65, 4.2 on page 47, 5.2 on page 66, 5-3 on page 69, 5.4 and 5.5 on page 70, 5.6 and 5.7 on page 71, 5.8 on page 72, 6.1 and 6.2 on page 75, 6.3 on page 76, 6.4 on page 80, 6.5 on pages 82 through 84, 6.7 on page 85, 6.8 and 6.9 on page 87, 6.10 on page 88, 6.11 and 6.12 on page 89, 7.1 on page 92, 7.2 on page 94, 7-3 on page 98, 8.6 on page 123, 9-1 on page 139, 10.1 on page 151, 10.2 on page 152, 10.3 on page 153, and 12.1 on page 175 were previously published in the Mid-Atlantic Winegrape Production Guide, © 1975, NC State University.

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Chapter 1

Introduction

New and current grape growers will find practical information on site appraisal, establishment, and operation of commercial winegrape vineyards in the North Carolina Winegrape Grower's Guide. This publication focuses on production of vinifera and hybrid wine grapes.

We are greatly indebted to Dr. Tony K. Wolf, Director and Professor of Viticulture, Virginia Polytechnic Institute, for his original development of the Mid-Atlantic Winegrape Grower's Guide in 1995, a guide that has proven to be an indispensable resource to anyone interested in learning about grape production in North Carolina. The climates, soils, and growing conditions in Virginia and North Carolina have many similarities, and the guidelines on vineyard site selection, pruning and training, canopy management, and vine nutrition have stood the test of time remarkably well. In this new publication, we have kept intact most of the cultural information presented in the Mid-Atlantic Winegrape Grower's Guide.

The new budget in chapter 2, Costs of Growing Grapes, by Carlos Carpio and Charles Safley, Department of Agriculture and Resource Economics, NC State University, reflects current costs and returns for *vinifera* grapes grown in North Carolina. If you are interested in evaluating the potential of raising winegrapes, and specifically *vinifera* grapes, as an alternative farming enterprise, you can use this new production budget to compare the economic profitability of winegrapes with alternative farm and non-farm investments.

Your analysis will not be complete, however, without careful consideration of the market for winegrapes. Contact your local Cooperative Extension agent for more information about wineries in your area, and current prices being paid for different winegrape varieties. Unless you have a contract from a winery for a variety only that winery wants, it is better to grow varieties that are in demand.

In chapter 3, Choice of Varieties, you will find a great deal of new information on *vinifera*, hybrid, and native American winegrape varieties based on the practical observations of Andy Allen, Extension Viticulturist, NC Cooperative Extension Service (2001-2004). This chapter also includes an up-to-date listing of grapevine suppliers compiled by Amy-Lynn Albertson, Extension Horticulture Agent in Davidson County. Albertson and several other Extension agents in counties with vineyards and wineries have provided invaluable assistance to the entire winegrape industry over the last 2 years since Allen's departure for the Institute for Continental Climate Viticulture and Enology, University of Missouri. Dr. Sara Spayd, a viticulture and wine quality expert from Washington State University, assumed duties of state viticulture specialist with the North Carolina Cooperative Extension Service in March 2006.

The original chapter 4, Vineyard Site Selection, in the Mid-Atlantic Winegrape Grower's Guide, has been greatly expanded to address a critical issue in site selection: damaging spring frosts. A new methodology is introduced to assess the frost risk of potential vineyard sites. The importance of good site selection, as well as careful pruning, training, and canopy management, cannot be underestimated if the goal is to produce consistent, premium quality wine. This chapter will help you better appreciate the importance of other climatic factors, such as extreme summer heat, that can adversely affect grape and wine quality. High daytime temperatures, coupled with high nighttime temperatures, can reduce fruit pigmentation, aroma, and acidity with certain varieties. New information from a research vineyard in North Carolina's central piedmont illustrates how warmer summer temperatures in this region affect juice pH. With the exception of a lesser known red wine variety, Tannat, the majority of winegrape varieties tested, including seven *vinifera* varieties (and clones), had average juice pH levels that exceeded 3.65 for the 3-year period, 2003 to 2005; a more desirable pH range at harvest for white wine varieties is 3.1 to 3.3, and 3.2 to 3.4 for red wines (Gauntner, 1997). Theses studies sponsored by the NC Grape Council, Inc. (now called the NC Wine and Grape Council), are showing the viticultural merit in evaluating unknown *vinifera* varieties (and hybrids), that can, with good vineyard management, produce well-balanced musts from vines that do not have issues with excess vigor, despite the warm, humid summer weather that characterizes the central piedmont region of North Carolina.

The number of wineries has more than doubled in North Carolina in the last five years, from 21 in 2000 to 53 in 2005. And an important concern raised by Dr. Wolf in 1995 appears to be an even greater issue now. This has to do with the *trend towards selecting locations for vineyards (and associated wineries), more on the basis of favorable demographics than the viticultural suitability of the site for growing grapes.* This is becoming a particularly serious issue in North Carolina as more and more inquiries from people interested in growing *vinifera* grapes are coming from the lower piedmont, an area with excellent demographics. Unfortunately this is a region of the state where the major obstacle to growing *V. vinifera* grapes is Pierce's disease (PD) (*Xylella fastidiosa*). PD is a killer of grapevines that is spread by certain kinds of leafhopper known as sharpshooters.

Appropriately, the newly revised chapter 8, Pest Management, has a new section on Disease Management, written by Turner Sutton, professor and plant pathologist, NC State University, that includes complete information on Pierce's disease. PD is not only an obstacle to growing *vinifera*, but it will also infect hybrid and native American bunch grapes in the warmer climatic conditions found in North Carolina's coastal plain, sandhills, and lower piedmont.

An entirely new section on weed management has also been added to chapter 8. It is written by Wayne Mitchem, Regional Weed Specialist, Fruit Crops, and it provides extensive information on vineyard floor management.

The authors of the new North Carolina Winegrape Grower's Guide welcome and encourage your feedback on this publication. It is a publication that is best used with other sources of information. And, one of the very best ways for your to learn about the ins and outs of grape production, as stated on the NC Wine & Grape Council Web site, www.ncwine.org, is to talk with people already operating vineyards and wineries, as well as to attend important educational programs and trade shows, such as the NC Winegrowers Association's annual meeting. If you do not have a great deal of experience in grape growing and/or winemaking, you can obtain additional training through the Viticulture and Enology curriculum at Surry Community College, which is designed to prepare individuals for various careers in the grape growing and wine making industry (http://www.surry.cc.nc.us/). The Department of Horticultural Science at NC State University offers *General Viticulture*, HS-590A, to students and adult learners on and off campus. For more information on this and other classes, visit http://distance.ncsu.edu/registration/ or http://www.cals.ncsu.edu/hort_sci/.

E. Barclay Poling, Editor
Professor and Small Fruit Specialist
NC Cooperative Extension Service
Department of Horticultural Science
NC State University

Reference

Gauntner, Donald A., Making Consistently Good Wine, American Wine Society Journal, Winter Issue, 1997, pp 131-134.

Chapter 2

Cost and Investment Analysis of Chardonnay (*Vitis Vinifera*) Winegrapes in North Carolina

Growing Chardonnay grapes, the number one vinifera variety grown in North Carolina, can be a profitable venture in certain areas of the state. The profitability analysis in this chapter, based on 2005 costs, shows that it will take an estimated $12,876 per acre to bring a vineyard up to full production in the fourth year. The vineyard would begin to yield $1,097 per acre in the eighth year, and the producer may be able to break even by the eighth year.

If you are considering planting Chardonnay, use the estimated production and harvesting figures along with the investment analysis in this chapter as a starting point. The monthly production sequence; the equipment, material, and labor input requirements needed to complete each operation; and the estimated costs per acre are based on a representative 10-acre vineyard. With some modifications for vine cost, crop value, and certain cultural practices, you could also apply this budget to other types of wine grapes and table grapes. You will also want to consult an expanded version of this chapter on the Web at www.ncwine.org along with other publications and resources on the cost of investment and operation of a winery.

Procedure and Assumptions

Vineyard Layout, Training, and Trellis System. In this hypothetical 10-acre vineyard, vines are spaced 7 feet apart in the rows and the row width is 10 feet for a total of 622 grapevines per acre on relatively flat terrain. Vines are trained in a bilateral cordon system with vertically shoot-positioned (VSP) canopies to optimize fruit and foliage exposure. The system modeled in this budget was assumed to have three sets of 13-gauge catch wires, a 9-gauge wire to secure the cordon, and a fixed 12.5-gauge wire at the top of the post (Figure 2.1).

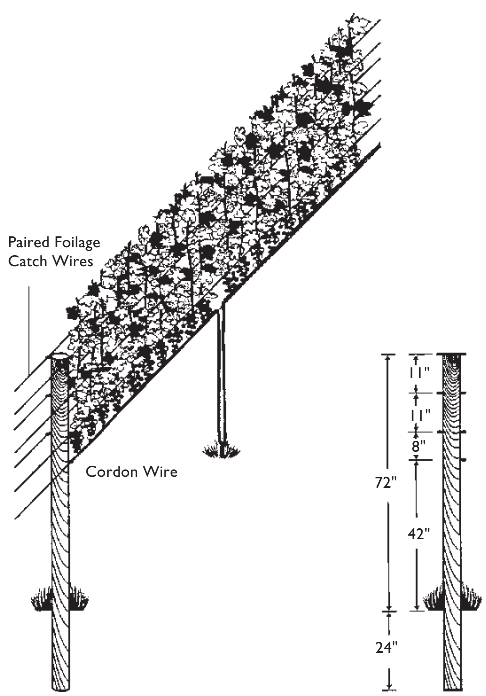


Figure 2.1 Bilateral cordon-trained vine with vertically shoot-positioned (VSP) canopies.

An internal end-post brace assembly was employed, as shown in chapter 5, Vineyard Establishment. A listing of the materials and the estimated costs of each component needed to construct the 10-acre trellis system are listed in Table 2-1. Not surprising, posts and bracing timbers were the major expenses accounting for slightly over 58 percent ($12,816) of the total materials costs, while the wire was the second most costly item comprising over 35 percent ($7,756) of the total. In addition, the equipment and labor requirements cost $1,400 and $5,197, respectively.

Production Practices. It was assumed that the vineyard management would be near optimal and that all currently recommended pest management practices in chapter 8 would be followed. Of course, the actual production practices are site specific, and you will need to adapt your actual practices in coming up with your own costs.

The comprehensive summary of the cost of materials used is found in Table 2-2 is based on 2005 prices from local dealers who regularly supply North Carolina grape growers. Tables 2-3 through 2-7 show the detailed production and pest control programs that were modeled in this budget.

The task that should be accomplished and the estimated amount of labor needed to complete each activity are also listed by production year and month in these tables.

Table 2.1 Estimated Costs of the Materials, Labor and Equipment Requirements Needed to Construct a 10-acre Trellis System for the Chardonnay Vineyard

Item	Quantity	Unit	Cost per unit	Total costs ($)
Construction Materials				
Vineyard posts, treated, 4-in.-by-8-ft	1,560.00	each	5.00	7,800.00
Brace & support posts, treated 6-in.-by-8-ft	528.00	each	7.00	3,696.00
Bracing timbers, treated, 4 in.-by-4-in.-by-6-ft	264.00	each	5.00	1,320.00
Wire, 100-lb rolls of # 9 galvanized	30.00	rolls	74.00	2,220.00
Wire, 100-lb rolls of #13 galvanized	65.00	rolls	74.00	4,810.00
Wire, 4,000-ft rolls of # 12.5	11.00	rolls	66.00	726.00
Wire clips	13,080.00	each	0.06	784.80
Staples	50.00	lb	0.80	40.00
Markers (posts and vines)	8,928.00	each	0.07	624.96
Total Materials				**22,021.76**
Equipment Requirements by Operation				
Tractor, 60HP & trailer (to distribute posts)	30.00	hrs	8.51	255.30
Tractor, 60HP & post driver (to set vineyard posts)	78.00	hrs	10.01	780.78
Tractor, 60HP & auger (to set brace posts)	44.00	hrs	8.27	363.88
Total Equipment Costs				**1,399.96**
Labor Requirements by Operation				
Mark rows and post locations	50.00	hrs	8.25	412.50
Distribute posts	36.00	hrs	8.25	297.00
Set vineyard posts (2 workers at 3 min/post)	156.00	hrs	8.25	1287.00
Set brace posts (2 workers at 5 min/post)	88.00	hrs	8.25	726.00
String, attach & tighten wire	300.00	hrs	8.25	2475.00
Total Labor Cost				**5,197.50**
Total Construction Costs				**28,619.22**

Table 2.2 Costs of the Materials used for Chardonnay Wine Grape Production

Material	Package Size	Package Price ($)
Fertilizers		
Lime	1.0 ton	38.50
10-10-10	100.0 lb	12.00
Boron (20% Solubor)	50.0 lb	35.00
Triple Superphosphate	50.0 lb	8.50
Herbicides		
Roundup WeatherMax 5.5 SL	2.5 gal	175.00
Gramoxone Max 3SL	2.5 gal	120.00
Chateau 51 WDG	1.0 lb	100.00
Poast 1.53 EC	2.5 gal	195.00
Rely 1L	2.5 gal	185.00
Princep 4L	2.5 gal	37.50
Surflan AS	2.5 gal	270.00
Select 2C	1.0 gal	175.00
Insecticides		
Sevin 80 WP	10.0 lb	63.00
Lorsban 4E	2.5 gal	40.00
Kelthane WP	3.0 lbs	46.00
Imidan	4.0 lbs	36.50
Fungicides		
Captan 50 WP	5.0 lb	17.00
Nova 40W	20.0 oz	80.00
Topsin M 70 WSB	5.0 lb	95.00
Abound 2.08 SC	1.0 gal	265.00
Dithane DF (Mancozeb)	12.0 lb	36.00
Sulfur WP	50.0 lb	18.00
Elevate 50 WDG	1.0 lb	30.52
Endura	1.0 oz	6.00
Pristine	1.0 oz	1.78
Other materials		
Flags	zbundle	10.00
Tall Fescue (cover crop)	1.0 lb	1.00
Grape Vines	each	3.50
Commercial grow tubes (blue x vine shelter)	each	0.64
Harvest Lugs (30 lb)	each	6.80

Table 2.3 Fertilization Program for Chardonnay Wine Grapes

Production Year	Time of Applications	Fertilizer	Application Rate
0 (preparation)		Lime, phosphate (P_2O_5) and potash (K_20)	3 tons lime and 120 lb triple superphosphate (0-45-0)[a] per acre
1	Mid-May	10-10-10	4 oz per vine
2	Late April	10-10-10	8 oz per vine
3	Mid-April & again in mid-May	10-10-10	6 oz per vine per application
4 through 20 (mature vines)	Mid-April & again in mid-May	10-10-10	8 oz per vine per application

[a] Actual application rates should be based on actual soil tests.

Table 2.4 Insect Control Program for Chardonnay Wine Grapes

Production Year	Time of Application	Insecticide	Application Rate (per acre)
1	June & again in July	phosmet (Imidan 70 WP)	1.33 lb per application
2	June & again in July	phosmet (Imidan 70 WP)	1.33 lb per application
	June	carbaryl (Sevin 80 WP)	1.25 lb
3 and thereafter	May (prebloom)	carbaryl (Sevin 80 WP)	1.00 lb
	June (second cover to Veraison)	carbaryl (Sevin 80 WP)	1.25 lb
	July (35 days to harvest)	chloropyrifos (Lorsban 4E)	4.50 pt
	Early September (postharvest)	dicofol (Kelthane 35 WP)	1.33 lb

Table 2.5 Disease Control Program for Chardonnay Wine Grapes

Production Year	Time of Application	Fungicide	Application Rate (per acre)
1	May	mancozeb 75 DF +	3.0 lb
		Nova 40W	4.0 oz
	June	mancozeb 75 DF +	2.5 lb
		Nova 40W	4.0 oz
	June	Abound 2SC	11.5 oz
	July	captan 4 L +	2.0 qt
		Endure	8.0 oz
	August	captan 4 L	2.0 qt
	Early September	mancozeb 75 DF	3.0 lb
2 and thereafter	April (bud break)	mancozeb 75 DF zzzzzzz	3.0 lb
	April (1-2 in. shoot)	mancozeb 75 DF +	3.0 lb
		sulfur	4.0 lb
	May (10-in. shoot)	mancozeb 75 DF +	3.0 lb
		sulfur	4.0 lb
	May (prebloom)	mancozeb 75 DF +	3.0 lb
		Nova 40W	4.0 oz
	May (bloom)	Elevate 50 WDG	1.0 lb
	May (fruit set)	Abound 2SC	11.5 oz
	June (shatter)	mancozeb 75 DF +	3.0 lb
		Nova 40W	4.0 oz
	June (first cover to veraison)	captan 50WP +	3.0 lb
		sulfur	4.0 lb
	June (second cover to veraison)	captan 4L	2.0 qt
	July (veraison)	captan 4L	2.0 qt
	July (veraison to harvest)	captan 4L	2.0 qt
		Endure	8.0 oz
	August	Pristine	10.5 oz
	Early September (postharvest)	mancozeb 75 DF	3.0 lb

Table 2.6 Weed Control Program for Chardonnay Wine Grapes

Production Year	Time of Application	Herbicide	Application Rate (per acre)
0 (preparation)		glyphosate	2.8 pt
1	May	oryzalin (Surflan 4 AS)	2.0 qt
	June	oryzalin (Surflan 4 AS)	2.0 qt
		+paraquat (Gramoxone Max 3 SL)	1.7 pt
	August	clethodim (Select 2EC)	6.0 oz
	September	clethodim (Select 2EC)	6.0 oz
2 and 3	May	oryzalin (Surflan 4 AS)	2.0 qt
		+paraquat (Gramoxone Max 3 SL)	1.7 pt
	June	paraquat (Gramoxone Max 3 SL)	1.7 pt
	August (spot treatments)	glyphosate (Roundup WeatherMax 5.5 SL)	1.4 pt
	September (spot treatments)	glyphosate (Roundup WeatherMax 5.5 SL)	1.4 pt
4 and thereafter	Mid-March	flumioxazin (Chateau 51 WDG)	6.0 oz
		+ glyphosate (Roundup WeatherMax 5.5 SL)	1.4 pt
	June (early)	flumioxazin (Chateau 51 WDG)	6.0 oz
		+ glyphosate (Roundup WeatherMax 5.5 SL)	1.4 pt
	July	paraquat (Gramoxone Max 3 SL)	1.7 pt
	August	paraquat (Gramoxone Max 3 SL)	1.7 pt
	September	simazine (Princep 4 L)	2.0 qt
		+paraquat (Gramoxone Max 3 SL)	1.7 pt

Table 2.7 Budgeted Chardonnay Wine Grape Dormant Pruning and Canopy Management Programs in North Carolina

Activity	Production Year	Month	Activity Description	Labor Requirements (hours/acre)
Dormant Pruning	0 (preparation)			
	1	———	No dormant pruning	0.0
	2	March	Pruning and tying of canes prior to bud break	10.0
	3 and thereafter	March	Spur pruning and cane removal	31.0
		April	Cordon training and tying vines	10.5
Canopy Management	1	June	Flower cluster removal	2.0
		July	Shoot thinning	21.0
	2	June	Flower cluster removal	8.0
		June	Shoot thinning and tying vines	10.0
		July	Shoot thinning and tying vines	10.0
		August	Shoot thinning and tying vines	10.0
	3 and thereafter	June	Shoot thinning	10.0
		June	Shoot positioning and tying vines	30.0
		July	Leaf removal	20.0
		August	Vine trimming/hedging	10.0

Wildlife and Frost Control. Losses due to bird feeding, browsing by deer, and frosts vary from year to year, between locations, and by grape varieties. Control options are also diverse**.** Assess the economic costs and benefits of the different alternatives before selecting a specific control method for these problems.

Bird Control. Bird netting was incorporated into the budget for bird control. Bird netting is probably the best choice where total, environmentally friendly control is desired. Researchers at the University of Oregon have estimated that the investment costs for bird netting is $800 per acre (Seavert and Castagnoli, 2004). This cost estimate was used in the budget and it was assumed that 45 hours of labor would be required annually to install and remove the nets.

Deer Control. Browsing by deer can be a serious problem, especially in the establishment years when it can delay fruit production by a year or more. The most effective way to eliminate browsing by deer is to enclose the area with a fence that is at least 7.6 feet high (Roberson, 1985). Lower fences, such as 4-foot-high chain-link, and decorative, wood or metal fences will reduce, but not eliminate deer problems. Repellents like systemic insecticides, human hair, soap, other chemicals, outdoor lighting, and artificial noise, are unreliable. While perimeter fencing can be installed to control deer, this expense was not included in the budget.

Frost Control. Frost is a problem in many areas, especially in the piedmont where vineyards are highly prone to damage by spring frosts. Chardonnay's early budbreak is a major weakness, making it susceptible to frost damage crop, especially in areas of lower elevation with poor cold air drainage. Wind machines, or fans, can provide active frost protection for many *vinifera* vineyards (see chapter 11). Although a wind machine was not used in this budget in 2005, some producers in North Carolina spent approximately $2,800 per acre to install a gasoline-fueled fan system. It is also estimated that this wind machine would be used 50 hours per year for frost control (approximately 5 to 6 nights of protection per season).

Drip Irrigation System. Chardonnay wine grapes need 3 gallons of water per vine per week the first year, 6 gallons of water per vine per week the second year, and 9 gallons of water per vine per week the third and subsequent years. It was assumed that the water source would be a pond and that the irrigation system would provide 2.33 gallons of water per vine per hour. It was also assumed that irrigation system must be operated 3 weeks in May, 4 weeks in June, 4 weeks in July, and 1 week in August.

It would cost an estimated $22,743 to purchased and install the equipment required for the 10-acre drip irrigation system (Table 2-8). Annual taxes were estimated to be 1.0 percent of the initial equipment cost; insurance cost was 0.5 percent of the initial cost; and the annual repair cost was 5.0 percent of the initial cost. It was also assumed that the annual labor requirements to

Table 2.8 Cost to Buy and Install Drip Irrigation for the 10-Acre Chardonnay Vineyard

Item	Cost ($)
Design of the irrigation system	250.00
5-HP electric pump	1,999.83
18-in. media filter set	3,418.85
44 compensating in-line drip tubing (1,000-ft coil)	5,896.00
Other materials	4,178.24
Installation	7,000.00
Total	22,742.92

operate the irrigation system would total 6 percent of the total irrigation time (Turner and Anderson, 1980). The energy costs were based on $0.08 per kilowatt hour.

Labor Costs. The estimated hours of labor needed for each operation that involved machinery and equipment were increased by a factor of 1.2 to account for the time needed to set up, adjust or calibrate, and move the equipment to the vineyard (Edwards, 2002). Full-time employees were paid $8.25 an hour, and when required payroll expenses, e.g. workers' compensation, unemployment, and FICA taxes, and other overhead expenses were included, the hourly cost was $10.56 an hour. It was also assumed that temporary employees would be hired to help construct the trellis and would be paid $8.25 per hour.

Machinery and Equipment Costs. The estimated hourly operating costs of the machinery and equipment required for the production of Chardonnay grapes are shown in Table 2-9. It was assumed that all the machinery and equipment were purchased new at 2005 purchase prices. The machinery and equipment used in this budget reflect machinery components that can be used for other farming enterprises in addition to growing grapes on a typical diversified farm. Therefore, the hours of annual use and the resulting costs per hour reflect the equipment costs for a total farm business and not just for grape production. The exceptions to this are the blast sprayer, wind machine, and the irrigation equipment, which are used solely for winegrape production.

The hourly operating cost includes property taxes (1.0 percent of the purchase price), insurance (0.5 percent of the purchase price), repair costs, and fuel and lubricants costs. Fuel costs per

Table 2.9 Estimated Machinery and Equipment Costs Needed for the Production of Chardonnay Wine Grapes in North Carolina

Year	Machinery Description	Purchase Price ($)	Salvage Value ($)	Years of Life	Annual hours	Cost per hour ($)
0	Tractor, 60hp	25,000	5,000	20	500	11.91
0	Spot sprayer 26 gal	190	72	12	50	0.56
0	Fertilizer spreader/seed broadcaster	395	99	12	100	0.94
0	Tine chisel plow, 7 ft	2,500	625	15	125	3.57
0	Disc, 9 ft	3,500	875	15	125	4.69
0	Utility trailer	2,000	500	15	100	2.39
0	½-ton pickup	25,000	6,250	10	650	12.47
	Total preparation	**58,585**				
1	Soil auger + drive connector, 10 in.	498	125	15	50	1.30
1	Post driver	2,374	594	15	50	6.21
1	Boom sprayer, 60 gal	700	266	12	100	1.03
1	Pruning equipment	1,000	100	12	100	-
1	PTO blast sprayer, 110 gal	4,000	1,520	12	100	5.90
1	Rotary mower, 7 ft	2,000	500	10	100	3.38
1	Drip irrigation system & pump	See Table 2-8	-	20	300	6.56
	Total first year	**10,572**				
3	Bird netting	8,000	0	7	-	-
	Total third year	**8,000**				

hour were estimated using a price of $2.39 per gallon for diesel fuel and $2.13 per gallon for gasoline, while lubricant costs were assumed to be 15 percent of the fuel costs. The time required for the application of all the pesticides was assumed to be 20 minutes per acre.

Harvesting Costs, Yields, and Prices. The projected yield pattern over the 20-year life of the vineyard assumed that there would be no adverse weather or production setbacks and that there would be no marketing difficulties throughout the life of the vineyard. The initial yield in the second year was expected to be 1.5 tons per acre, and it would increase to 3.0 tons in the third year of production, and peak at 4 tons per acre in the fourth through twentieth years.

The harvest was assumed to be started and completed in early September (in warmer piedmont areas, Chardonnay harvest typically begins in late August). A custom harvest rate of $100 per ton was charged to the vineyard operation for custom hand picking, and the price the growers were assumed to receive for their grapes was $1,400 per ton.

Land, Management, and Overhead Charges. Since every commodity should contribute to the financial success of a farm, a fee was charged to the vineyard for the overall farm overhead expenses and operating capital. Because land values vary throughout the region a land charge was not included in this budget. However, growers should include a land charge that is representative of current land values in their area. Owners should also charge a management fee to the vineyard operation to account for their managerial ability in supervising the overall business.

Results and Discussion

Monthly Labor Estimates

The monthly and annual labor estimates required to produce an acre of Chardonnay wine grapes are presented in Table 2-10. Slightly more than 6 person-hours of labor are needed per acre in the preparation year (year 0), 147 hours per acre in the first year, 83 hours per acre in the second year, 194 hours per acre in the third year, and

Table 2.10 Estimated Annual and Monthly Labor Requirements Needed to Grow an Acre of Chardonnay Grapes in North Carolina

	Person-hours by Year				
Month	**0**	**1**	**2**	**3**	**4**
January					
February					
March		63.40	11.20	32.20	32.60
April		33.70	6.59	12.19	12.19
May		6.03	3.05	3.98	3.58
June		5.20	22.45	54.34	44.37
July	2.20	23.30	13.61	53.32	53.72
August	3.07	2.27	12.35	12.43	12.53
September		6.79	5.29	23.19	25.19
October					
November			2.00	2.00	2.00
December	1.00				
General activities		6.00	6.00	6.00	6.00
Total	**6.27**	**146.69**	**82.54**	**193.65**	**192.17**

192 hours per acre after the vines reach full production in the fourth year.

In the first year, 63.4 hours were spent constructing the trellis and digging vine holes in March, while 33.7 hours were needed to plant vines and install growth tubes in April. In the second year, over 74 hours of the labor was needed from March through September. By the third and fourth year, almost all of the approximately 190 hours are needed from March through September. In fact, the only significant activity that does not occur in these months is trellis repair in November. Keep in mind that labor requirements in September are underestimated because, as was previously discussed, it was assumed that the labor needed to harvest the grapes would be hired at a custom rate of $100 per ton.

Costs of Establishing the Chardonnay Vineyard

If a grower has to purchase all of the machinery and equipment as the vineyard is established, the capital investment was estimated to total $58,585 in the preparatory year, $10,572 during the first production year and $8,000 in the third production year. Of course, as was previous discussed, most of this equipment can also be used for other farming operations in a diversified farm.

The estimated cost per acre was $2,862 for the trellis system and $2,275 for the drip irrigation system. Annual operating costs to run the machinery and equipment, purchase the materials, and hire the labor that was needed to prepare the site, plant and maintain the vineyard until the vines reached full production in the fourth year totaled $12,876 per acre.

Monthly Expenses

Monthly operating costs are summarized in Table 2-11. Over 95 percent of the total estimated cost in the preparation year was spent in August and December to pay for the Chardonnay grape vines and the trellis supplies. In the first year, March accounted for 42 percent of the total cost per acre, primarily due to trellis construction, and the expenses in April comprised 21 percent of the total cost, mainly as a result of planting the vines and installing the growth tubes. A large portion of the expenses was incurred in June and July during

Table 2.11 Estimated Monthly and Annual Production Costs Needed to Grow and Harvest an Acre of Chardonnay Grapes in North Carolina

		Total Costs ($/acre)			
Month	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Years 4-20**
January					
February					
March		1,343.60	118.27	340.03	396.67
April		753.95	154.04	189.46	198.79
May		289.34	205.30	263.36	216.04
June		209.13	372.59	599.94	639.49
July	55.40	346.86	314.24	700.37	717.46
August	2,428.38	62.77	182.47	186.14	185.25
September		93.60	246.86	564.17	680.24
October					
November			21.12	21.12	21.12
December	2,212.74				
Annual charges	35.00	70.00	70.00	70.00	70.00
Seasonal charges	41.82	104.56	104.56	104.56	104.56
Total Year	4,773.34	3,273.81	1,789.45	3,039.15	3,229.63

the second year primarily because the flower clusters must be removed and the shoots should be thinned during these months. Starting in the third year, over 93 percent of the total costs per acre were incurred from March through September.

You will need to estimate your monthly cash flow requirements before planting the wine grapes to ensure that you will know how much money you will need to meet financial obligations. If you will be borrowing money, a lending agency may require detailed information to determine the appropriate repayment schedule.

Annual Production Costs for Mature Vines and Returns to Land and Management

For mature vines the total cost of producing and harvesting Chardonnay grapes was estimated to be $3,230 per acre. This estimate includes $249 for operating the equipment and machinery, $593 for materials, $1,987 for hired labor, and $400 for the custom harvest. In addition, the cost of establishing the vineyard should be included in this estimate. Therefore, the establishment costs of the vineyard were allocated over the productive years of the enterprise (years four through twenty) using the cost recovery (annuity) method as suggested by the American Agricultural Economics Association (2000). These calculations assumed a 20-year amortization period and a 7 percent nominal interest rate. In this situation the cost recovery for the establishment costs was $1,273 per year.

Net returns depend on marketable yield and the price growers receive for their grapes. Including the cost recovery for the establishment costs, the annual variable costs associated with producing and harvesting Chardonnay wine grapes was $3,075 per acre and the annual fixed costs were $1,428. Assuming a yield of 4 tons per acre and a market price of $1,400 per ton, the net returns to land and management from producing these grapes was $1,097 per acre.

Given the same yield, the breakeven price, i.e. the price that just covers the total production costs, for this vineyard operation was $1,125.64. Moreover the shutdown price, i.e. the price that only covers the variable production costs but not the annual fixed costs, was $725.05. If the market price ever reaches the shutdown price, it would be better to cease production rather than continue growing grapes. However, both the breakeven and shutdown prices are below the assumed market price of $1,400 per ton.

As in most farming operations, you will have a tremendous influence on your crop yield. The more you know about your crop and the better job you do in caring for your crop, the more likely you will be to have a good yield of top quality fruit. On the other hand, local markets will determine the maximum price for which you can sell your grapes. To analyze the sensitivity of different yield assumptions, revenues and

Table 2.12 Estimated Returns in Dollars per Acre for Chardonnay Grapes by Prices and Marketable Yields

Price ($/ton)	Yields (ton/acre)					
	3.60	**3.80**	**4.00**	**4.20**	**4.40**	**Breakeven Yield**
800	-1,582.55	-1,442.55	-1,302.55	-1,162.55	-1,022.55	5.86
1,100	-502.55	-302.55	-102.55	97.45	297.45	4.10
1,400	577.45	837.45	1,097.45	1,357.45	1,617.45	3.16
1,700	1,657.45	1,977.45	2,297.45	2,617.45	2,937.45	2.56
2,000	2,737.45	3,117.45	3,497.45	3,877.45	4,257.45	2.16

breakeven yields were calculated assuming different prices (Table 2-12).

Market prices were varied from a low of $800 per ton to a high of $2,000 per ton, while the yield estimates were 5 percent and 10 percent above and below the average yield of 4 tons per acre for mature vines. Total expenses per acre were adjusted to account for the varying yields. At the average assumed price of $1,400 per ton, growers would receive a positive return only if their yields are above 3.16 tons per acre. With prices equal to or below $1,100 per ton and a yield of 4 tons per acre or less, growers will always receive negative returns. In fact, growers would have to sell 4.1 tons per acre to breakeven if the market price was $1,100 per ton and 5.86 tons per acre if the market price was $800 per ton.

Chardonnay Vineyard Profitability

When judging the profitability of an enterprise, it is important not only to see how many dollars the enterprise yields but also when the dollars come in and the returns available in other enterprises. There are two principles to consider. First, the sooner a dollar of revenue comes in, the sooner it can be used to earn more revenue. Second, for any two enterprises of equal risk, the one yielding the higher rate of return is usually preferable. We will look at the flow of funds for the Chardonnay vineyard to show both profitability and cash position (solvency).

After subtracting expenses from revenues in each year, the flow-of-funds, or net cash flow, pattern emerges as it appears in Table 2-13. Growers establishing a new Chardonnay wine grape vineyard will experience net cash outflows in the preparatory year, and the first and third years of production. The income stream is positive in the fourth through twentieth year.

The net accumulated cash flow is also shown in Table 2-13. The breakeven year, or payback year, is the year in which growers finally get their investment back in terms of cash flow. The breakeven year for the Chardonnay vineyard modeled in this study was 8 years. The breakeven year is important when arranging financing because you must secure loans that cover the period in which the enterprise operates in a deficit cash position. Only during the breakeven year will you have generated enough revenues to cover start-up expenses.

The next step is to compare the net revenue stream with other opportunities. There are two ways to do this. The first way is to assume that farmers could invest their money elsewhere at a given interest rate, such as 6 percent, and compare the Chardonnay vineyard with this other investment. The interest rate selected for this analysis should represent the best low risk alternative, such as a long-term certificate of deposit, available for off-farm investments. For a single enterprise, the essence of the net present value (NPV) approach is that the project should be accepted if its NPV is greater than zero. This procedure uses the discounting procedure to compare the value of a dollar at the time of the planting decision with a dollar received for grapes at some future time. Discounting is based on the concept that a dollar received in the future is worth less than a dollar received today. For example, $1,000 received 10 years from now is worth $558 received today at a 6 percent interest rate.

Today's cash equivalent value of applying land and management to Chardonnay grapes for a 6 percent interest rate is $8,807 per acre. This figure is interpreted in just one way, but the interpretation can be phrased in several ways. At an interest rate of 6 percent, for example: a) a new, 1-acre Chardonnay vineyard as described in this analysis is worth $8,807 per acre today, or b) if a farmer was just about to establish a Chardonnay wine grape vineyard, someone would have to pay $8,807 per acre to bribe him or her to forget the plans. Under these assumptions, establishing the vineyard looks profitable.

Table 2.13 Annual Cash Flow for 1 Acre of Chardonnay Grapes over a 20-year Period (6% discount rate)

		Annual Operating Costs			Capital Investment				
Year	Yield (ton/acre)	Equipment	Materials	Labor	Machinery[1]	Total Cash Expenses ($/acre)	Revenue	Net Case Flow	Accumulated Cash Flow
0	0.00	52.25	4,629.58	91.51	1,091.70	5,865.04	0.00	-5,865.04	-5,865.04
1	0.00	310.65	894.34	2,068.82	2,845.73	6,119.54	0.00	-6,119.54	-11,984.57
2	1.50	225.54	528.53	1,035.37	32.64	1,822.09	2,100.00	277.91	-11,706.66
3	3.00	246.57	521.29	2,271.28	848.96	3,888.11	4,200.00	311.89	-11,394.77
4	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	-9,024.40
5	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	-6,654.03
6	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	-4,283.66
7	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	-1,913.29
8	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	457.08
9	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	2,827.45
10	4.00	249.41	593.10	2,387.12	1,205.00	4,434.63	5,600.00	1,165.37	3,992.82
11	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	6,363.19
12	4.00	249.41	593.10	2,387.12	387.60	3,617.23	5,600.00	1,982.77	8,345.96
13	4.00	249.41	593.10	2,387.12	48.96	3,278.59	5,600.00	2,321.41	10,667.37
14	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	13,037.74
15	4.00	249.41	593.10	2,387.12	73.08	3,302.71	5,600.00	2,297.29	15,335.03
16	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	17,705.40
17	4.00	249.41	593.10	2,387.12	800.00	4,029.63	5,600.00	1,570.37	19,275.77
18	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	21,646.14
19	4.00	249.41	593.10	2,387.12		3,229.63	5,600.00	2,370.37	24,016.50
20	4.00	249.41	593.10	2,387.12	-964.45	2,265.19	5,600.00	3,334.81	27,351.32
								Net Present Value	8,807.64
								IRR	12.67%

[1] Since the machinery and equipment can be used for other farming enterprises, the capital investment reflects only the percentage of the machinery and equipment purchase prices that were charged to the vineyard and not the complete costs of each item with the exception of the blast sprayer and the irrigation system. These percentages were calculated based on the amount of time each item was projected to be used for grape production relative to the estimated total hours of usage.

The second method for financial comparison of the vineyard with other opportunities is to calculate the internal rate of return (IRR) on the total investment of the Chardonnay wine grape operation and then compare this rate of return with the interest yields on other investments. In this analysis the Chardonnay vineyard was compared to Treasury bonds, which are typically a 20-year low risk investment. The IRR to an investment in the Chardonnay vineyard was 12.67 percent. With dividends on Treasury bonds currently yielding around 4.25 percent, the vineyard operation returns look relatively good. Of course, the revenues from grapes are more risky due to price fluctuations and weather conditions.

Conclusions and Recommendations

Profitability analysis revealed that Chardonnay grape production under the assumed costs and conditions could be a profitable venture in North Carolina. The annual operating costs to run the machinery and equipment, purchase the materials and hire the labor that is needed to prepare the site, plant, and maintain the vineyard until the vines reached full production in the fourth year added up to an estimated $12,876 per acre.

Under the assumed yield and market price the estimated return to land and management starting in the fourth year was $1,097 per acre. Cash flow analysis also demonstrated that the breakeven year can be achieved in the eighth year, while the net present value of the investment was estimated to be $8,807 per acre and the internal rate of return was 12.67 percent.

This budget is only a guide and is not a substitute for calculating your own costs. Costs can vary from one producer to another because of market conditions, labor supply, age and condition of the machinery and equipment, education, managerial skills, and many other factors. It should also be noted that the profitability analysis did not incorporate any effects of lower yields, higher production costs, or fluctuating market prices, which could have a negative impact on the results. The analysis also did not take into account any negative effects that may be associated with increased supplies of wingrapes or increased competition in the wine industry. Since every grower's situation is different, it is highly recommended that you estimate your individual production, marketing, and harvest costs, and conduct a profitability analysis based on your own production techniques, price expectations, and local market situation.

References

Buchanan, J.R. and T.L. Cross. 2002. Irrigation Cost Analysis Handbook. Agricultural Extension Service, The University of Tennessee, PB1721. August 8, 2005. http://www.utextension.utk.edu/publications/pbfiles/PB1721.pdf.

Capps, E.R., A.H. Smith, Tony K. Wolf, A. H. Smith and B. J. Walker. 1998. The Economics of Wine Production in Virginia. Virginia Cooperative Extension, Virginia State University. Publication Number 463-008. November 28, 2005. http://www.ext.vt.edu/pubs/viticulture/463-008/463-008.html.

College of Agriculture and Life Sciences, NC State University. 2005. 2005 North Carolina Agricultural Chemicals Manual. August 3, 2005. http://ipm.ncsu.edu/agchem/agchem.html.

Edwards, W. 2002. Estimating Farm Machinery Costs. Iowa State University. August 3, 2005 www.extension.iastate.edu/agdm/crops/html/a3-29.html.

Mortensen, J.A. 1981. Irrigation System for Grapes. Proc. Viticult. Sci. Symp. Florida A&M Univ. 3:7-12.

Noguera, E., J. Morris, K. Striegler, and M. Thomsen. 2005. Production Budgets for Arkansas Wine and Juice Grapes. Arkansas Agricultural Experiment Station. Research Report 976.

Roberson. S.F. 1985. Deer-proof Fencing. Caesar Kleberg Wildlife Research Institute. Texas A&I Univ. 41 pp.

Seavert, C.F. and Castagnoli, S. 2004. Establishing and Producing Wine Grapes in Hood River County. Oregon State University, Extension Service.

Turner, J.H., and C.L. Anderson. 1980. Planning for an Irrigation System. American Association for Vocational Instructional Materials. 2nd Ed. Athens, Georgia. 120 p.

Chapter 3

Choice of Varieties

North Carolina has one of the most varied climates of any eastern state, and a diverse number of grape species and varieties can be grown. But to be a successful commercial winegrape grower, it is critical that you select varieties that grow well in your region and that have an established market.

This chapter includes recommendations for winegrape varieties that have performed satisfactorily in the piedmont and mountain regions of North Carolina, including a number of popular Vitis vinifera varieties as well as a few French hybrid grapes. Information is also presented on winegrape varieties that will likely be adapted in the future but may require additional testing or improved market development.

With the wide range of grape types and varieties that can be grown in North Carolina, it can be challenging to decide on what winegrape varieties are best to grow for your area and market, especially if there is little local information or experience to draw from. When choosing a variety, consider grape type and regional adaptation, Pierce's disease susceptibility, and marketplace demand.

Grape Type and Regional Adaptation

There are five basic types, or categories, of grapes grown in North Carolina (Table 3.1). Figure 3.1 shows the four major Viticultural Zones, areas in which each type of grape grows best. Climatic conditions, and especially the frequency of damaging low winter temperatures, are among the most important factors influencing the types of grapes and varieties that can most reliably be produced in each area.

Table 3.1 Grape Species Grown in North Carolina

Vitis vinifera	The Old World or European grapes. Popular varieties: Chardonnay, Viognier, Cabernet Sauvignon, Cabernet Franc, and Merlot. Viticultural Zones 2 and 3.
French hybrid	Varieties resulting from crosses of *vinifera* and native American species made by French breeders. Popular varieties: Chambourcin, Seyval blanc, and Vidal blanc. Viticultural Zones 2 and 3.
American hybrid	Hybrid varieties have resulted from crosses made by North American breeders, and include Traminette and Chardonel from New York State Agricultural Experiment Station in Geneva, NY. Viticultural Zones 2 and 3.
Native American varieties	This category comprises grapes of native American origin. Chief among the native American species is *V. labruscana* ("fox grapes"), and includes well-known Concord and Niagara. Another species of note in North Carolina is *V. aestivalis,* and the variety Norton (aka Cynthiana). Viticultural Zones 2, 3, and possibly some areas in Zone 4 for *V. labruscana* varieties.
Muscadine	(*V. rotundifolia*). Muscadines are at home in the warmer conditions found in the coastal plain, sandhills, and lower piedmont (Zones 1 and 2), and have winter hardiness levels similar to *V. vinifera.* Carlos (white wine) and Noble (red wine) are the leading varieties. Muscadines have the advantage of not being as seriously affected by Pierce's disease as the bunch grapes listed above.

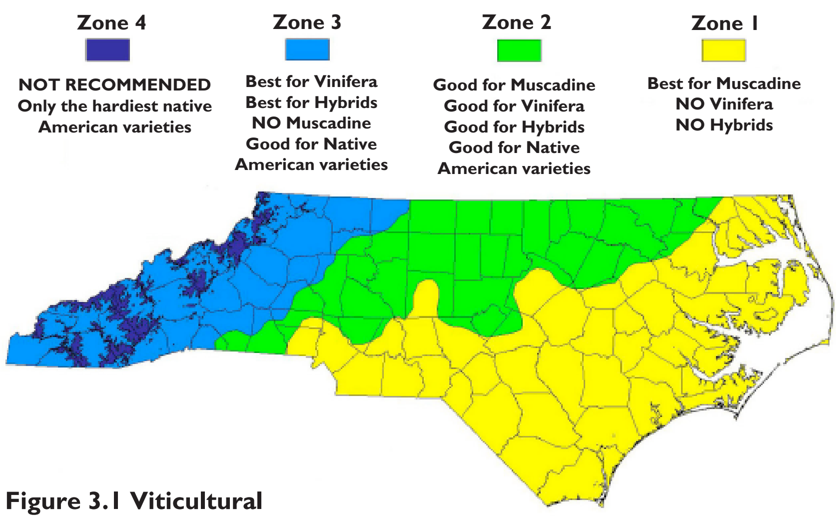


Figure 3.1 Viticultural suitability in North Carolina

If your goal is to produce premium quality *vinifera* grapes, it is best to first find a prime winegrape growing property in Viticultural Zone 3 (best zone for *vinifera*), or possibly a property on the northwest edge of Zone 2 with desirable site characteristics for *vinifera* (see chapter 4). Unfortunately, many people do it in reverse. They start with a piece of property that may have attractive demographics for a winery, and then try to grow varieties that are not well matched to the growing conditions.

Before committing to planting *vinifera* grapes in a given location, consult the climatological maps found on the Web site of North Carolina Wine and Grape Council, Inc. (http://www.ncwine.org/siteSuitability/siteSuitability.html). Notice the important details on the average occurrence of temperatures of -8°F per decade (1970 to 2000). Controlled freezing tests in Virginia have led to the use of a critical temperature of -8°F as a guide for predicting the onset of significant cold injury in *V. vinifera* varieties (Wolf, 2003). Locations that experience -8°F three or more times per decade are not considered to be appropriate for *V. vinifera* production (Wolf, 2003). The critical temperature ranges provided in Table 3.4 are for greater than 50 percent dormant bud kill of vines that are fully dormant (including 6 *vinifera* varieties); however, it should be emphasized that these temperature ranges could be *slightly higher* in North Carolina than Virginia (Wolf, 2003). In this regard, it is perhaps noteworthy that grape experts in Arkansas consider *V. vinifera* and *V. rotundifolia* (muscadines) to have comparable winter hardiness levels, and in Arkansas it is recommended that *vinifera* should be planted in regions where winter temperatures *stay above 0ºF* (Noguera et al., 2005). At the North Carolina Wine and Grape Council's Web site, you will also find a North Carolina climatological map that shows the frequency of occurrence of temperatures of 0°F for the same three decades (1970-1980, 1980-1990, and 1990-2000).

The French hybrids and American hybrids (collectively referred to in this publication as 'hybrids'), are more widely adapted across Viticultural Zones 2 and 3 than *vinifera* because of their greater winter hardiness and higher tolerance to spring frosts. In general, the hybrids fit somewhere between the *V. vinifera* varieties and native American grapes in terms of susceptibility to winter injury (Noguera et al., 2005). In the higher mountain elevations where winter temperatures can be severe (Viticultural Zone 4), grapevine cold hardiness and the threat of crown gall must be taken into consideration. In these areas only the hardiest native American bunch grapes like Niagara should be considered.

Pierce's Disease Pressure

North Carolina lies on the border of the warmer Southern states, where Pierce's disease (PD) limits successful grape production to muscadines, and the cooler northern states where this disease is not a problem. The dividing line between areas of high risk and low risk of PD runs through the central piedmont region. The farther south or east you go, the greater the risk of PD. Bunch grapes can be grown successfully in the central and eastern piedmont, but periodic minor to *severe* vine losses to PD may occur, especially in warmer winters. In the eastern piedmont of North Carolina, Turner Sutton, NC State plant pathologist, has observed PD affecting up to 50

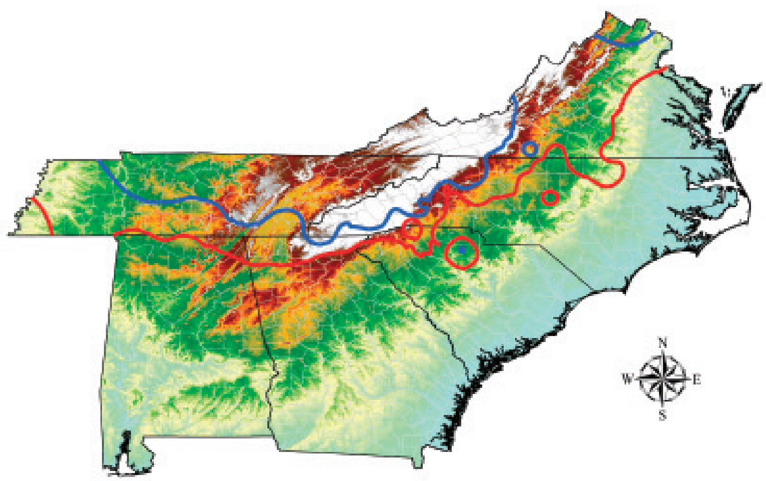


Figure 3.2 Risk of Pierce's disease is based on days during winter with temperatures at or below 10°F. There is an increasing risk south and east of the red line, less risk between the red and blue lines, and low risk north of the blue line.

percent of *V. vinifera* vines within several years of planting. The potential for loss is significant if you are interested in a commercially successful vineyard.

As you move farther north or west into higher elevations where winter temperatures are colder, the threat of PD becomes less, until you get into the mountains, where the threat of PD is very low most years. In the higher mountain elevations, however, where winter temperatures can be severe (Viticultural Zone 4), winter injury can predispose vines to crown gall. See chapter 8, for more complete information on PD and crown gall.

Marketplace Demand–An Evolving Story

As stated in the chapter 1, your analysis of the potential for a winegrape enterprise will be incomplete without a careful consideration of *markets for winegrapes*, but before undertaking consideration of current and future markets, it may be helpful to understand how North Carolina arrived at the point of being the twelfth largest wine production state in the U.S., and tenth in grape acreage in 2004.

Past Marketplace Trends

From a historical perspective, it is interesting to note that only native American grapes (*V.*

Table 3.2 Viticulture in the Old North State

1600s–Discovery of the original 'Scuppernong' vine (*V. rotundifolia*) by Sir Walter Raleigh's colony when they landed on Roanoke Island (c.1584)
1810 census–1,368 gallons made in Washington County
First commercial winery–Medoc Vineyards in Brinleyville, established in 1835 with 6 acres
1840–North Carolina **leading wine-producing state in U.S.**
1865–25 wineries by time of Civil War
1880–North Carolina is second-largest wine-producing state in the South with 2,639 acres of vineyards
1900 census–1.2 million vines and 12.3 million pounds of fruit
1900–North Carolina is one of six eastern states to win awards at the Paris Exposition
1903–Virgina Dare's inventor, Paul Garret, has five wineries in North Carolina
1909–North Carolina goes dry (Prohibition)

labruscana), or muscadines (*V. rotundifolia*) were being grown in North Carolina at the turn of the 20th century. The abundant, native muscadine grape fueled the early growth of the wine trade centuries ago. In the 1840 census, North Carolina was the leading wine state in the U.S. (Table 3.2).

Modern Revival

As Lucie Morton said, "The eastern wine industry was so effectively ruined by Prohibition and its aftermath that today the region's vineyards and estate wineries are objects of surprise and curiosity." When this statement was made in 1985, North Carolina had only four wineries (compared to 53 in 2005), and only two of these had plantings of *vinifera*, namely Biltmore Estates in Asheville, and Westbend Vineyards near Winston-Salem. *Vinifera* production in the eastern U.S., and particularly in North Carolina, was still so new in 1985, that relatively few people could appreciate at this time that the world's dominant species of grape, *V. vinifera* would also become North Carolina's leading category of bunch grape for wine processing in the new millennium. Westbend Vineyards opened a lot of eyes in 1994 to the possibility that North Carolina could grow first-rate *vinifera* grapes when its Chardonnay won the gold medal at the Eastern International Wine Competition —ahead of a second-place Kendall-Jackson (Table 3.3).

Current Marketplace Trends

In assessing current opportunities and conditions in the marketplace, you should consult with buyers to ensure that there is a demand for the fruit you plan to produce. Your Cooperative Extension agent may be able to assist you in obtaining information about: 1) local wineries and grower cooperatives, 2) current prices being paid for different varieties of winegrapes, 3) whether contracts are available, and 4) typical yields to expect from local vineyards. A vineyard enterprise is a very long-term commitment (20-plus years), and you will also need to assess future demand (and prices) for the types of grapes and varieties that you are thinking about growing. This is not a simple process! As stated by Al MacDonald in the *Oregon Winegrape Grower's Guide* (1992), "Today's high prices for one variety may attract more planting of that variety, creating an oversupply and lowering prices. Consumers may hit on a hot new variety, creating more demand, thereby increasing the price for that variety."

It is interesting to note that when this chapter was initially drafted in the 2004 growing season, it read, "If you are planning to grow grapes for sale to commercial wineries, you must grow the varieties that they are seeking…(and), while Niagara grows well here, there is not much

Table 3.3 Modern Revival

1972–Westbend Vineyards founded (plantings included *Vitis vinifera* varieties)
1975–Biltmore Estate Vineyards founded (plantings included *Vitis vinifera* varieties)
1976–Duplin Wine Cellars opened (*V. rotundifolia* varieities only)
1985–Biltmore Winery opens to public
1985–4 wineries (2 *vinifera*, 1 native American grapes, 1 muscadine)
1986–North Carolina Grape Council created (today known as the North Carolina Wine & Grape Council)
1988–Westbend becomes a bonded winery
1994–Westbend's Chardonnay wins 1st place gold medal Eastern International Competition
1995–10 wineries in North Carolina
1999–15 wineries in North Carolina; Shelton Vineyards established
2002–With 25 wineries, North Carolina ranks 12th in wine production and 14th in grape acreage
2004–Yadkin Valley is North Carolina's first American Viticultural Area (AVA)
2004–45 wineries in North Carolina; 12th in wine production U.S. and 10th in grape acreage
2005–53 wineries in North Carolina; Duplin Winery bottles its millionth case of wine

demand for it from the wineries." But, the authors of this chapter did not appreciate that a winery in the northern piedmont would, based on a successful test market of Niagara wines in 2004, proceed in 2005 to pay as much per ton for Niagara grapes as for a leading red hybrid grape, Chambourcin.

Future Trends

Predicting demand for North Carolina-grown winegrapes is about as challenging as trying to interpret global warming's impact on North Carolina's principal viticultural zones in the coming decades. It is probably safest to say that the winegrape variety situation in North Carolina will continue to be quite dynamic in the near future, as state winemakers continue to experiment with test marketing of new varietals like Niagara and explore the potential of wine *blends* derived from more than one species, or type of grape (e.g. hybrid x *vinifera*, or even *vinifera* x muscadine). Most industry experts do agree that top quality grapes will be needed for a continued healthy expansion of North Carolina's wine industry.

Are You Planning a Winery?

If you are planning to make your own wine, plant varieties based on the types of wine you plan to make and sell. As an individual grower and winemaker, you have much more flexibility to explore planting lesser known *vinifera* varieties and/or hybrids that show great promise, but lack name recognition (Table 3.5). Check the industry newsletter *On-the-Vine* (http://www.onthevine.net), for current news of specialty niche-market wines.

If your grapes are going to be sold to commercial wineries, however, you must grow the varieties that they are seeking. Carefully study varieties in Table 3.4 that are identified as having "good" to "high" winery demand. Although a number of hybrids and native American grapes can be easily grown in Viticultural Zones 2 and 3, it is important to realize that most wineries are more likely to be seeking popular *vinifera* varieties like Chardonnay, Cabernet Sauvignon, Cabernet Franc, Merlot, and Viognier. In addition to determining the grape variety, you must also determine the quantity they will want when your vineyard comes into production. Unless you have a contract from a winery for a variety that only that winery wants, it is better to grow varieties used by several potential buyers.

Vinifera Challenges

The history of successful *vinifera* production in the eastern U.S., and particularly in North Carolina, is relatively short. *Vinifera* grapes are susceptible to many pests and problems, and this has limited their commercial viability in the East. Phylloxera, or grape root louse, prevented the establishment of successful *vinifera* vineyards in the East since the time of the early colonists until the 1970s when phylloxera-resistant rootstocks, improvements in viticultural and canopy management techniques, and improved pest management materials have opened the door for *vinifera* culture in areas that are climatically suitable for *vinifera* production. Table 3.4 lists *Vinifera* varieties that have reliably produced quality crops on good to excellent sites in Viticultural Zones 3 and 2.

The remainder of this chapter examines the strengths and weaknesses of each of these varieties. Nurseries are listed at the end of this chapter. Unfortunately, very little is known at this time about appropriate clonal selections (clones) of *vinifera* varieties for North Carolina. In this context, a "clone" differs from the standard type for a variety due to mutations for one or more characteristic. Examples of these differences may include higher or lower yield, larger or smaller

Table 3.4 Recommended Winegrape Varieties for North Carolina

Type/variety	Wine Color	Winery Demand[a]	Use[b]	Yield Potential (ton/acre)	Harvest Season[c]	Vigor	Growth Habit	Winter Hardiness (°F)[d]
Vinifera								
Chardonnay	White	High	V	3.5 to 5	Early	High	Upright	0 to -10
Viognier	White	Good	V	2.5 to 3.4	Early	Moderate	Upright	-5 to -15
Muscat Ottonel	White	Low	V,D,B	2.5 to 3.4	Very early	High	Upright	0 to -10
Cabernet Sauvignon	Red	High	V,B	3.5 to 5	Very late	High	Upright	0 to -10
Cabernet Franc	Red	High	V,B	3.5 to 5	Late	V. high	Semi-upright	-5 to -15
Merlot	Red	Good	V,B	3.5 to 5	Midseason	High	Semi-upright	5 to -5
Hybrid								
Chambourcin[e]	Red	Good	V,B	3.5 to 5[f]	Mid to late	Moderate	Semi-upright	-5 to -15
Seyval	White	Moderate	V,B	3.5 to 5	Very early	Mod/low	Semi-upright	-5 to -15
Native American								
Niagara	White	Low	D	>5	Midseason	High	Trailing	-10 to -20

[a] This is a subjective evaluation of the current demand by state wineries for specific varieties, and it assumes that the grapes are of good quality and will produce a juice for winemaking that is balanced with respect to soluble solids or Brix (19° to 24°), titratable acid (0.6 to 0.9), and pH (3.25 to 3.65). Grapes from warmer sites or in warmer seasons have *lower T.A.* and *higher pH* than wine grapes from cooler sites or cooler seasons.
[b] V=varietal wine; D=dessert wine; B=blends
[c] At the Upper Piedmont Research Station in Reidsville, the harvest season for very early varieties is usually the 3rd week in August; early varieties like Chardonnay ripen in the 4th week of August; midseason varieties like Merlot ripen in the 1st week in September; late varieties like Cabernet Franc ripen in the 2nd week of September, and very late varieties like Cabernet Sauvignon would likely be ready at the end of September/early October. (Cabernet Sauvignon is not grown in this vineyard).
[d] This is a relative index based on cold hardiness research studies of Dr. Tony Wolf. The temperatures shown are the approximate range where dormant bud kill might be expected in mid-winter under optimal acclimation and cold hardiness conditions in northern Virginia. Critical temperature ranges may be slightly higher in more southerly areas. Research is needed in North Carolina to determine these relative temperature ranges for fully dormant vines of the nine varieties shown in this table, as well as for vines that have de-acclimated after a warm spell in winter.
[e] Cluster thinning is strongly recommended.
[f] Chambourcin yields are considered good, but vine vigor must be maintained with adequate pruning and cluster thinning.

Table 3.5 Winegrape Varieties with Potential for North Carolina

Type/variety	Wine Color	Potential Demand[a]	Use[b]	Yield Potential (ton/acre)	Harvest Season[c]	Vigor	Growth Habit	Winter Hardiness (°F)[d]
Vinifera								
Syrah	Red	High	V	3.5 to 5	Mid to late	Very high	Semi-upright	na
Petit Verdot	Red	High	V	2.5 to 3.4	Late	High	Upright, Semi-upright	0 to -10°F
Sangiovese	Red	High	V	3.5 to 5	Late	High	Semi-upright	na
Mourvèdre	Red	High	V	3.5 to 5	Very late	High	Upright	-5 to -15°F
Tannat	Red	Mod/high	V	3.5 to 5	Midseason	Mod/high	Semi-upright	na
Petit Manseng	White	High	V	3.5 to 5	Late	High	Semi-upright	na
Hybrid								
Traminette	White	Mod/high	B,V	2.5 to 3.4	Midseason	Very high	Semi-upright	-10 to -20°F
Chardonel	White	High	V,B	3.5 to 5	Very early	High	Semi-upright	-10 to -20°F
Vidal blanc	White	Mod/high	B,V	3.5 to 5	Early	Mod/low	Semi-upright	-5 to -15°F
Native American								
Norton	Red	M-E	V,B	<2.5	Very late	Mod/low	Trailing	-10 to -20°F

[a] This is a subjective evaluation of the current demand by state wineries for specific varieties, and it assumes that the grapes are of good quality and will produce a juice for winemaking that is balanced with respect to soluble solids or Brix (19° to 24°), titratable acid (0.6 to 0.9), and pH (3.25 to 3.65). Grapes from warmer sites or in warmer seasons have *lower T.A.* and *higher pH* than wine grapes from cooler sites or cooler seasons.
[b] V=varietal wine; D=dessert wine; B=blends
[c] At the Upper Piedmont Research Station in Reidsville, harvest season for very early varieties is usually the 3rd week in August; early varieties like Chardonnay ripen in the 4th week of August; midseason varieties like Merlot ripen in the 1st week in September; late varieties like Cabernet Franc ripen in the 2nd week of September, and very late varieties like Cabernet Sauvignon would be ready the end of September/early October.
[d] Relative index based on cold hardiness research studies of Dr. Tony Wolf. The temperatures shown are the approximate range where dormant bud kill might be expected in mid-winter under optimal acclimation and cold hardiness conditions in northern Virginia. Critical temperature ranges may be slightly higher in more southerly areas, but more research is needed in North Carolina to determine these relative temperature ranges for fully dormant vines in this table, as well as for vines that have de-acclimated after a warm spell in winter.

Rootstocks

One of the innovations that makes *vinifera* grape production possible in North Carolina is the development of phylloxera-resistant rootstocks. Phylloxera feed on grapevine roots, weakening and eventually killing the vine. Varieties of *Vitis vinifera* are highly susceptible to the root-feeding form of this pest, while native American grape species have varying degrees of resistance to it. All *vinifera* varieties should be grafted onto a resistant rootstock. Even hybrid and native American varieties have been shown to benefit from grafting in terms of improved vigor and productivity.

While there are many rootstocks available, we only have experience with a relative few. The most widely used rootstock is Couderc-3309 (C-3309). It is well adapted and is not excessively invigorating. Mgt 101-14 is a rootstock with a similar genetic background. These rootstocks work well with all varieties, but are especially recommended for the more vigorous varieties, such as Cabernet Sauvignon and Syrah. Two other commonly used rootstocks are SO4 and 5BB. These tend to produce much more vigorous vines and are best used with low- to moderate-vigor vines. If used with vigorous vines like Cabernet or Syrah, then a divided-canopy trellis is recommended to manage the resulting excessive vigor.

berry or cluster size, better fruit quality, or slightly different harvest dates. There may be only a relatively few available clones of some varieties, such as Syrah, to several hundred clones of other varieties, such as Cabernet Sauvignon. The key to a variety's success may depend upon choosing the appropriate clone. Likewise, a poorly adapted variety (such as Pinot noir) may never be successful irregardless of what clone is utilized. Because clonal evaluations have not yet been performed in North Carolina and information on specific clone performance is lacking, the following variety descriptions do not address clonal recommendations.

Recommended Varieties

The following are some of the more commercially successful *Vitis vinifera* varieties recommended for Viticultural Zones 2 and 3 in North Carolina. When considering a variety, also review the information in Table 8.2, Relative Susceptibility of Varieties of Bunch Grapes to Fungal and Bacterial Diseases.

Chardonnay

The number one *vinifera* variety in North Carolina. Chardonnay is a dependable, high quality white grape. It has performed well in all areas of the state where *vinifera* can be successfully grown, from the mountains to the piedmont. Several clones are available. Chardonnay starts the season early, in terms of both growth and harvest. It is the first variety to break bud and one of the first to be harvested, usually starting in mid- to late-August in the piedmont. Demand is good for high quality Chardonnay grapes and wines. Its strengths are its high quality and utility, since it is adaptable to many wine styles and provides good yields. Weaknesses include early budbreak, which make it susceptible to frost damage, susceptibility to many diseases, including mildew, and susceptibility to cold injury. Proper site selection is critical to minimize spring frost damage. Vines are generally vigorous, so consider a divided canopy training system such as the Lyre or Smart-Dyson.

Viognier

The leading alternative to Chardonnay, Viognier is a white *vinifera* that produces wines with a very fruity aroma and flavor. It appears to be well-adapted to all of the *vinifera*-producing areas of the state. It has a more open cluster structure than Chardonnay, which helps decrease bunch rot problems. It ripens just before or with Chardonnay. Demand is currently very good. It weaknesses are early budbreak (just after Chardonnay), susceptibility to cold injury, modest yields, and weak growth, especially in the establishment years. With moderately invigorating rootstocks, such as 3309C or 101-14 MGT, a simple low-cordon VSP trellis should suffice.

Muscat Ottonel

Muscat Ottonel is one of the Muscat group of *vinifera* varieties, a group noted for the very distinctive floral aroma and fruity taste of its wines. It has a later budbreak than Chardonnay, thus making it less frost susceptible. It ripens very early in the season, several days in advance of Chardonnay, and has good resistance to fruit rots. It is only moderately productive, and its weakest point currently is low demand. It can be used to make a varietal semi-dry or dessert wine or as a blending agent to impart fruitiness to more neutral wines.

Cabernet Sauvignon

The number two *vinifera* variety in North Carolina, Cabernet Sauvignon is the leading red *vinifera*. Cabernet Sauvignon has a later budbreak, which gets it past most of the frost danger. It makes a high quality dry wine and is in high demand for premium wine production. Vines are high-yielding when properly managed, and fruit is more resistant to rots. Several clones are available. It has performed well in all *vinifera* areas of North Carolina. It has a late season harvest date, ripening in mid- to late September. Its weaknesses include susceptibility to winter injury and crown gall and excessive vegetative growth. Avoid planting in lower areas where winter injury may occur. It should be planted on wider (8-foot) in-row spacings and/or trained on a divided canopy trellis, such as the Lyre, especially if more vigorous rootstocks are used. Excessive vegetative growth with Cabernet Sauvignon dictates more canopy management in order to avoid fruit quality problems.

Cabernet Franc

Cabernet franc is a red *vinifera* variety that has steadily gained popularity in the east. It is similar to Cabernet Sauvignon in many respects. It breaks bud earlier than Cabernet Sauvignon and ripens a week earlier, in mid-September. The earlier budbreak may be a concern on more frost-prone sites. The vine has a greater cold hardiness than Cabernet Sauvignon. The fruit has some rot resistance, and yields are good. It is highly vigorous, requiring wider spacing and/or divided canopy training. Demand is currently high.

Merlot

When this guide was first written in 1995, Merlot was not recommended due to its higher sensitivity to winter injury compared to more cold tolerant *vinifera* varieities (e.g. Chardonnay, Cabernet Franc, and Cabernet Sauvignon). Experience to date has shown that milder growing areas in the northwestern piedmont do not pose as great a risk of vine winter injury to Merlot, as would be the case in Virginia, or areas further west and north of this region in North Carolina. Still, it should be planted on more protected sites. Merlot is a leading *vinifera* variety in the Yadkin Valley, which is North Carolina's first federally recognized American Viticultural Area. Merlot acreage is currently similar to that of Cabernet franc.

Merlot is a thinner-skinned red *vinifera* variety with milder tannins that is good as both a varietal wine or as a blend. It is in good demand and has good yields. Budbreak is early, just after Chardonnay, and harvest is in early to mid-September. Its susceptibility to disease is similar to Chardonnay, but it is more resistant to bitterroot. It can be very vigorous and divided canopy training systems are recommended.

Varieties With Potential

Syrah

Syrah has attracted a lot attention in recent years. It is being grown at several vineyards in North Carolina, and while it is still too early to tell, it appears to being doing well. It is reported to have some problems in Virginia because of the colder winters and shorter season. It has an early budbreak, two or three days after Chardonnay, and ripens in mid-September with Cabernet franc. It is highly vigorous and should be trained on divided canopy systems. Recommended rootstocks are 3309C and 101-14 MGT. Where

SO4 rootstock has been used, vines have been excessively vigorous with many bull canes.

Petit Verdot

A recommended variety in Virginia, Petit Verdot has not as yet been planted extensively in North Carolina. It is drawing increasing interest here, and is reported to have exceptional fruit quality and very good yields. It ripens late in the season, with Cabernet Sauvignon. It is very susceptible to bitter rot. It is currently used primarily as a blending agent to strengthen the color of red wines, due to its thick anthocyanin content. Vines are moderately vigorous.

Sangiovese

Sangiovese has very large clusters, large berries, and high yields, with a tendency to overcrop. Choice of smaller-fruited clones or careful crop load adjustment may be necessary to avoid thin-bodied, poorly-colored wines. Nevertheless, it is gaining interest in the eastern U.S. It has been planted in a few piedmont vineyards. It has an early season budbreak, and is noted for cold-tenderness. It ripens around the same time or slightly later than Syrah. The vine is very vigorous. It is best trained to a divided canopy system and may be better suited for a high-cordon system, such as the Geneva Double Curtain.

Tannat

New information from a research vineyard in Reidsville would indicate that this lesser known red *vinifera* variety has the potential to not only produce relatively high yields, but may also produce a well-balanced juice for winemaking in much of North Carolina, which has a regional macroclimate that is classified as very hot (see Table 4.1 in chapter 4, Site Selection). Tannat had an average juice pH of 3.56 over three years of testing, compared to pH of 3.84 for Merlot, and its Total Acidity (TA) fell into a far more desirable range for red wine varieties (Gauntner, 1997) than Merlot (Table 4.3). Tannat ripens mid-season, and vines are only moderately vigorous compared to Cabemet Franc, Cabemet Sauvignon Mourvèdre. Due to its thick anthocyanin content, Tannat can be used as a blending agent to strengthen the color of red wines. It is no coincidence that the name Tannat evokes "tannins." Tannat's home is in the southwest of France where it is the most important component in the wines of Madiran (about 75 miles south of Bordeaux and 43 degrees northerly latitude). It is felt that Tannat's potential lies in warmer rather than cooler regions. Under cooler conditions, Tannat can have very high TA, but under warmer conditions its color, pH, acidity are very desirable. Varietal Tannat wines are being marketed as Uruguay's flagship wines.

Mourvèdre

Mourvèdre has a very late budbreak and extremely late harvest, one to two weeks after Cabernet Sauvignon in Virginia. In North Carolina, it should ripen in early to mid-October. Clusters are extremely large and yields are good. It is very susceptible to bitter rot. Wine color can be poor. It is cold-tender and should only be planted in warm areas with long growing seasons.

Vinifera Varieties Not Recommended

Some *vinifera* varieties have had very poor results in North Carolina, usually due to bunch rot or other fruit defects. Pinot noir, Gewürtztraminer, Riesling, and Sauvignon blanc have been grown and mostly discarded due to excessive fruit losses to rot. Pinot gris and Zinfandel are also being attempted with similar results.

Native and Hybrid Varieties

The native American grape species have contributed many varieties to U.S. grape culture. Chief among the contributors has been *Vitis labrusca*, or "fox grape." Many authors also consider these *V. labrusca x V. vinifera* hybrids (i.e. *V.* x labruscana), since they have large bunch size and are perfect-flowered. *V.* x *labruscana* includes the well-known Concord and Niagara grapes we all grew up with, thanks to Welch's grape juice and jelly. Other American species of note are Norton (aka Cynthiana), a *V. aestivalis* variety. Like Lenoir (Black Spanish), Norton may also involve hybridization between *V. aestivalis* and *V. vinifera.* Catawba is a probable *labrusca x vinifera* natural hybrid found growing wild in Buncombe County. Until the mid-20th century, native varieties where the backbone of eastern U.S. grape and wine production because of their ability to grow and produce reliably with our erratic weather and their tolerance to the diseases encountered here.

The French-American hybrids were developed by French grape breeders in the late 19th and early 20th centuries to counter the devastating effects of grape diseases and pests that inadvertently found their way to Europe from the U.S., in particular the phylloxera, or grape root louse, a root-feeding insect that nearly destroyed the French wine industry. The hybrids were developed by crossing pest-resistant American species and varieties with the high quality *Vitis vinifera* varieties that the French wine industry had been based on for centuries. As it became known that the high quality *vinifera* varieties could again be successfully grown in Europe by grafting onto hybrid rootstocks, the use of hybrid varieties declined to the point that they are seldom used today in European wine production.

ADVANTAGES. Despite the popularity of *vinifera* wine production in the U.S., the hybrid and native varieties are still widely used because they tolerate much colder temperatures and break bud later in the season, so growers are less likely to lose their crops to frosts. Even when they are frost damaged, hybrids are still likely to produce a crop because of their fruitful secondary buds. Their resistance or tolerance to many of the common diseases that plague grapes also contribute to their popularity. The hybrid varieties were bred to be resistant to downy and/or powdery mildew. As a whole they are safer and more reliable to produce in the often erratic climate of North Carolina.

DISADVANTAGES. As noted already, the only real disadvantages to growing the native and hybrid species are related to demand. Wineries use less native and hybrid varieties than *vinifera* grapes, and consequently, they bring a much lower price per ton. Hybrids and natives don't have the market name recognition of a Chardonnay or Merlot. Some consider the wines made from these grapes to be inferior, but in the hands of a good winemaker they make good to excellent wines.

The Varieties

Chambourcin

Chambourcin is the only red hybrid of any true commercial importance being currently produced in North Carolina. It makes an excellent quality wine, comparable to *vinifera*. It has good cold hardiness, good resistance to fruit rots, and resistance to the foliar diseases downy and powdery mildew. It matures mid- to late-season. It has good yields and needs to be cluster thinned to prevent overcropping. Weaknesses are early budbreak (3 days after Chardonnay) and weak growth. Yields can be poor if vine vigor is not maintained. It will benefit from grafting to an invigorating rootstock. It has more winery demand than most hybrids, but is not universally desired. Chambourcin may be trained to either high- or low-cordon systems. If ungrafted vines are used, non-divided canopy systems are suitable. Chambourcin is sensitive to sulfur.

Norton

Norton is the only commercially grown variety derived primarily from *Vitis aestivalis*, and is grown primarily in Missouri, Arkansas, and Virginia. There are currently only a handful of small commercial plantings in North Carolina. Clusters and berries are small and very attractive to birds. Yields are typically low, but can be increased with divided canopy training. Vines can be very vigorous and rangy in growth habit and should be high-trained, preferably to a Geneva Double Curtain trellis. Wines are typically very high quality. Vines are very cold hardy, surviving down to -20°F. Extremely good disease resistance means that crops can be produced with fewer sprays than *vinifera*. It does not require grafting. Weaknesses are lower yields, early bud break (4 days after Chardonnay), and currently little market in North Carolina. Like Chambourcin, Norton is also sensitive to sulfur.

Seyval

Seyval is the leading white hybrid produced in North Carolina and is grown by several vineyards. It has low to medium vigor and can benefit from grafting. It has exceptionally fruitful buds and can easily overcrop. *It requires careful cluster thinning to prevent overcropping and stunted vine growth.* It breaks bud mid-season 6 days after Chardonnay and ripens before Chardonnay. Bunches are large and compact and prone to bunch rots. It is moderately cold hardy. Demand is light, but better than other white hybrids. It is suitable for single curtain trellising systems, such as VSP.

Vidal

Vidal blanc is the second most-planted white hybrid in North Carolina, but it does not represent much acreage. It has good cold hardiness and a late bud break (9 days after Chardonnay), so winter injury and frost damage are not much concern. It has very good yields and has some resistance to fruit rots. It has a tendency to overcrop and requires cluster thinning. It ripens

late in the season, just before Cabernet Sauvignon. It is susceptible to tomato and tobacco ringspot virus, so get certified virus-free vines, preferably grafted onto a nematode-resistant rootstock like 3309C. Market demand is not very high.

Niagara

Niagara is the only native American grape being both grown and used in any quantity in winemaking in North Carolina. It is a white variety with a distinctive floral aroma and flavor and is used in making excellent sweet dessert wines. It has good cold hardiness and is very vigorous and productive. Like most American varieties, it has a pendulous growth habit and is best suited for high-wire cordon training systems, such as the Hudson River Umbrella or Geneva Double Curtain. It ripens in mid-season and has good rot resistance. It is highly susceptible to black rot and downy mildew and susceptible to crown gall. Demand appears to be improving recent years.

Hybrid Varieties with Some Potential

The following high quality varieties have been very successful in other parts of the country, although they have not had extensive testing here. While there may potential for them in the North Carolina wine industry, particularly in the colder mountain region, there is currently very little demand for them from the wineries. They are mentioned here strictly to make you aware of them.

Traminette

Traminette is a white hybrid from the breeding program at the New York State Agricultural Experiment Station at Geneva. It is a very high quality hybrid that produces excellent wines. It has at least 50 percent *vinifera* in its parentage, so it may benefit from grafting for phylloxera protection. Vines are highly vigorous on rootstocks. Foliage and fruit are moderately resistant to powdery mildew, black rot, and bitter rot, and somewhat resistant to downy mildew. Yields are high with excellent fruit quality. It has good cold hardiness and a later budbreak (7 days after Chardonnay) and ripens late in the season, around the time of Cabernet Sauvignon and Petit Verdot.

Chardonel

Chardonel is a cross between Chardonnay and Seyval from the New York State Agricultural Experiment Station at Geneva. It has high yields, and vines do not require much thinning to maintain quality. It has very good fruit quality. Wines from Chardonel are very similar to Chardonnay. Cold hardiness is good. It requires good soil drainage and is slightly susceptible to phylloxera and crown gall. It benefits from grafting to phylloxera resistant rootstock. It breaks bud 5 days after Chardonnay and ripens shortly after Chardonnay.

Sources of Grapevines

The following listing of suppliers is provided as a convenience to you and does not imply endorsement of their products or criticism of products sold by other suppliers. You are strongly encouraged to consult trade magazines and other sources of nursery advertisement to learn about other sources.

KEY: A=native American varieties; V=vinifera varieties; H=hybrid varieties; T=seedless table varieties; R=rootstocks

American Nursery (V,H,R)
PO Box 87B1
Madison, VA 22727
(540) 948-5064

Arkansas Berry & Plant Farm (A,H,T)
22339 N. Hwy 71
Winslow, AR 72959
Phone: 501-634-7120
www.alcasoft.com/arkansas

Asgard Vineyards (A,H,V)
106 Johnny Couch Road,
Elkin, NC 28621
336-835-6736

BC Vine Biotechnology
101-596 Martin St., Penticton
BC V2A 5L4 CANADA
(250)-490-3697
(888)-490-8758
Fax: (250)-490-3678
www.bcvinebiotechnology.com,
info@bcvinebiotechnology.com

Bien Nacido Vineyards (V)
4705 Santa Maria Mesa Rd.
Santa Maria, CA 93454
(805) 937-2506
Fax: (805) 937-4368 (fax)
info@biennacidovineyards.com

Blossomberry Nursery (T)
Rt. 2 Box 158A
Clarksville, AR 72830
(501) 754-6489

Boordy Nursery (H)
Box 38, 7812 Ruxwood Rd.
Riderwood, MD 21139
(410) 823-4624

California Grapevine Nursery, Inc. (V)
1085 Galleron Rd. •
St. Helena, CA 94574-9790
(707) 963-5688 or (800) 344-5688
Fax: 707 963-1840
www.californiagrapevine.com

Casa Cristal Nursery (V)
Terrel West
1998 Road 152
Delano, CA 93215
(661) 792-6468
Fax: (661) 792-6891

Congdon & Weller Wholesale Nursery (A,T)
P.O. Box 1507
North Collins, NY 14111
(800) 345-8305

Double A Vineyards (A,V,H,T)
10275 Christy Rd.
Fredonia, NY 14063
716-672-8493

Duarte Nursery, Inc. (V)
1555 Baldwin Road
Hughson, CA 95326
(209) 531-0351; (800) GRAFTED
Fax: (209) 531-0352
www.duartenursery.com

Euro Nursery & Vineyards, Inc. (V)
3197 Culp Rd.
Jordan, Ontario L0R 1S0 CANADA
(905) 562-3312
Fax 905-562-5810

Foster Concord Nurseries (A,V,H,T)
10175 Mile Block Rd.
North Collins, NY 14111
(800) 223-2211
Fax: (800) 448-1267
www.concordnursery.com

Ge-No's Nursery (V)
12285A Road 25
Madera, CA 93637-9113
(209) 674-4752

Grafted Grapevine Nursery (V,H)
2399 Wheat Rd.
Clifton Springs, NY 14432-9312
(315) 462-3288
Fax: (315) 462-5234
www.graftedgrapevines.com, amberg@fltg

Dr. Konstantin Frank Nursery (V)
9749 Middle Rd.
Hammondsport, NY 14840
(800) 320-0735
Fax: 607-868-4888
www.drfrankwines.com,
info@drfrankwines.com

Madera Nursery (R)
Kendall-Jackson Winery Ltd.
421 Aviation Blvd.
Santa Rosa, CA 95403,
(707) 544-4000
Fax (707)-544-4013

Miller Nurseries (A,H)
5060 West Lake Rd.
Canandaigua, NY 14424-8904
(800) 836-9630
www.millernurseries.com

Novavine (V,H,R)
6735 Sonoma Highway
Santa Rosa, CA 95409
(707) 539-5678
Fax: (707) 539-2819

Gregory Stiling, East Coast Sales Manager
(located in Mocksville North Carolina)
(336) 998-2004 office & fax
(336) 918-4843 mobile
www.novavine.com, gstiling@novavine.com

Pense Nursery (A,H,T)
16518 Marie Lane
Mountainburg, AR 72946,
(501) 369-2494 phone & fax
ppense@cei.net, www.alcasoft.com/pense

Ponderosa Nurseries (V)
464 South Mooney Blvd.
Tulare, CA 93274.
(559) 688-6626
www.ponderosanursery.com

Carl Remkus Nursery (A,H,R)
858 Bank St.
Painesville, OH 44077
216-354-8817

Ripley County Farms (A,H)
Harrison Wells
P.O. Box 614
Doniphan, MO 63935
(573) 996-3449 phone & fax
www.ripleycountyfarms.com, rcf@semo.net

St. Francois Vineyards (A, H, Seedless)
1669 Pine Ridge
Trail Park Hills, MO 63601-8223
(573) 431-4294.
www.stfrancoisvineyard.com

Sunridge Nursery (V,R)
441 Vineland Rd.
Bakersfield, CA 93307
(661) 363-8463
Out-of-state Sales Rep: Mike Thomas (559) 217-9778
Fax: (661) 366-4251
www.sunridgenurseries.com

University of Texas Lands (V)
PO Box 553
Midland, TX 79702
(915) 684-4404

Vintage Nurseries (V,T,R)
Dave Haggmark, Sales (Eastern States)
3230 Geneseo Rd.
Paso Robles, CA 93446
(805) 237-8914 telephone & fax
Mobile: 805 391-0905
www.sonomagrape.com,
dave@vintagenurseries.com

Herman J. Wiemer Vineyard, Inc. (V)
PO Box 38
Dundee, NY 14837
(800) 371-7971
Fax: 607-243-7983
www.wiemer.com, wines@wiemer.com

References

Gountner, D.E. 1997. Making Consistently Good Wine. American Wine Society Journal, Winter Issue, 131-134.

Howell, G.S., et al. 1998. Wine Grape Varieties for Michigan. Michigan State University Extension Service, East Lansing, MI.

Morton, L.T. 1985. Winegrowing in Eastern America, Cornell Univ. Press, Ithaca, NY, p. 53

Noguera, E., et al. 2005. Production Budgets for Arkansas Wine and Juice Grapes. Arkansas Agricultural Experiment Station, Fayetteville, AR. http://www.uark.edu/depts/agripub/Publications/bulletins/976.pdf

Reisch, B.I., et al. 1990. 'Chardonel' Grape. NY Food and Life Sciences Bulletin 132. NY State Agric. Exp. Sta., Geneva, NY.

Reisch, B.I., et al. 1993. Wine and Juice Grape Varieties for Cool Climates. Cornell Cooperative Extension, Ithaca, NY.

Reisch, B.I., et al. 1996. 'Traminette' Grape. NY Food and Life Sciences Bulletin 149. NY State Agric. Exp. Sta., Geneva, NY.

Wolf, T.K. and E.B. Poling. 1995. The Mid-Atlantic Winegrape Growers Guide. North Carolina Cooperative Extension Service, Raleigh, North Carolina.

Wolf, T.K. and M.K. Warren. 2000. Crop yield, grape quality, and winter injury of eight wine grape cultivars in northern Virginia. J. Amer. Pomol. Soc. 54:34-43.

Wolf, T.K. and M.K. Miller. 2001. Crop yield, fruit quality, and winter injury of 12 red-fruited wine grape cultivars in northern Virginia. J. Amer. Pomol. Soc. 55:241-250.

Wolf, T.K. and J.D. Boyer. 2003. Vineyard Site Selection. Publication Number 463-020, Virginia Polytechnic Institute and State University, Blacksburg, VA. http://www.ext.vt.edu/pubs/viticulture/463-020/463-020.html

Chapter 4

Vineyard Site Selection

Grapes grown in North Carolina are sometimes exposed to unfavorable climatic conditions and biological pests that can reduce crops and injure or kill grapevines. Climatic threats include low winter temperatures, late spring frosts, excessive summer heat, and unpredictable precipitation. Biological pests include fungal pathogens and insects that attack the foliage and fruit of vines, as well as birds, deer, and other wildlife that consume fruit and shoots. Vineyard site selection greatly affects both the frequency and severity of these problems and is one of the most important factors affecting profitability in viticulture.

This chapter has been greatly expanded to address a critical issue in site selection: damaging spring frost. Your first and best defense against damaging spring frost is to avoid sites that are subject to repeated spring frosts. The information added to this section will help you understand the types of weather events that will damage succulent new grape shoots, critical temperatures for cold injury, and how a site's relative elevation, or local relief from a valley bottom, affects cold air drainage. This information will help you use a new methodology to assess the frost risk of potential vineyard sites. Planting less susceptible winegrape varieties, using cultural practices that reduce the likelihood of frost damage, and even installing mechanical devices for frost control are also discussed in this chapter.

In practice, vineyard site selection involves compromises, as few sites are ideally suited to grape production. Furthermore, there are two general categories of individuals who will choose a site for vineyard establishment: those who already own their land, and those who are seeking to purchase land on which to grow grapes. The concepts described in this publication apply to both categories. However, you will have more options if you use vineyard site-selection concepts to purchase land specifically for grape production than if you are restricted to choosing the best location on a site that you already own. If you are interested in eventually establishing a winery, recognize that the best vineyard sites might not necessarily be the most accessible to potential customers.

Climate and Topography

Climate refers to the long-term prevailing weather of a region or site. The climate of a vineyard is influenced by temperature, precipitation, winds, and other meteorological conditions. The proximity of large land forms (for example, mountains) and large bodies of water also affects a site's climate. Climate and topography are discussed together because topography has such a profound impact on the local climate of a vineyard.

The importance of site selection becomes clear when we examine the climatic factors that can adversely affect grape production and grape quality in this region.

1. EXTREME HEAT can reduce grape and wine quality, particularly after the onset of rapid fruit ripening (véraison). In general, wines produced from grapes grown in a hot climate can lack the fruitiness and complexity characteristic of wines from the same variety grown in a cooler climate. Many sites in North Carolina, particularly those of the piedmont and coastal areas, experience very hot growing seasons. Selected climatological indices for 12 Carolina cities are shown in Table 4.1. Use the data of Table 4.1 only for relative comparisons. Climatological data from your own vineyard site can differ significantly from those of nearby weather reporting stations, particularly in the case of temperature extremes.

A commonly used index of the relative warmth of a grape-growing region is the cumulative growing degree days (GDD) between April 1 and October 31. That index was refined for grapevines at the University of California, Davis, and was used to define five regions (1 to 5) (Winkler et al., 1974). Using that system, we can see that many of the sites listed in Table 4.1 would be classified as regions 4 or 5. Another viticultural index of a region's temperature is based on the mean temperature of the warmest month—July in our case (Smart and Dry, 1980). Using that index, almost all of North Carolina would be classified as a very hot grape-growing region, with the exception of town of Jefferson.

2. FLUCTUATING TEMPERATURES characterize winters in North Carolina, except perhaps in the coastal areas. Occasionally, temperatures are cold enough to injure vines, particularly the cold-tender *Vitis vinifera* varieties. The potential for cold-injury is increased when relatively warm autumns and early winters are followed by rapid or extreme temperature drops in midwinter.

3. SPRING FROSTS that occur after grapevines have broken bud and commenced shoot growth are not uncommon. Frosts can kill shoots and significantly reduce the fruit crop for the year. The problem is most acute when unseasonably warm temperatures promote earlier-than-normal budbreak and shoot growth. Spring frosts do not generally kill the vine; secondary shoots soon break bud and produce sufficient foliage to maintain vine health. Even a second frost can be compensated for by growth of latent buds on the vine. However, secondary shoots typically have less than half the fruiting potential of primary

Table 4.1 Selected Climatological Indices for 12 Locations in North Carolina[a]

	Elevation	Temperature in July[a]			Record	# Days Minimum Temperature Lower than 0° F			Days With Temperature		UCD		
Location	(ft)	Max	Min	Ave	Low (F)	1970-79	1980-89	1990-99	>90° F	<32° F	GDD[b]	Class[c]	MTWM[d]
Jefferson	2,770	81.3	58.0	69.7	-15	8	5	5	1.3	127.6	2561	2	warm
Asheville	2,240	84.3	63.5	73.9	-17	6	3	3	11.3	81.2	3560	4	very hot
Hendersonville	2,160	84.3	63.7	74.0	-14	5	2	2	11.9	88.5	3500	3	very hot
Marion	1,466	86.7	65.0	76.1	-11	2	1	0	23.4	85.1	3614	4	very hot
Morganton	1,160	88.7	64.6	76.7	-9	1	2	2	40.8	91.2	3982	4	very hot
W Kerr Scott R.	1,070	87.7	63.4	75.6	-10	4	2	4	32.8	108.2	3682	4	very hot
Mt. Airy	1,041	86.3	64.0	75.2	-10	4	5	6	27	102.4	3932	4	very hot
Shelby	920	87.6	66.0	76.8	-11	0	2	0	35.4	77.2	4423	5	very hot
Reidsville	890	88.2	66.4	77.3	-9	4	3	4	30.5	82.7	4171	5	very hot
Yadkinville	875	88.1	64.6	76.4	-8	4	3	4	40.9	93.2	4225	5	very hot
Lexington	750	89.1	67.1	78.1	-6	1	3	0	43.3	80.6	4565	5	very hot
Raleigh-NCSU	400	87.9	69.4	78.7	-6	0	2	0	37.3	63.3	4770	5	very hot

[a] NOAA U.S. Climate Normals for NC, 1971-2000 (information in this table provided by Ryan Boyles, State Climatologist and Director, State Climate Office of North Carolina)
[b] Cumulative Growing Degree Days (50° F base) for the period from April 1 through October 31
[c] Heat summations for climatic regions are 1=less than 2,500 degree-days; 2=2,501 to 3,000 degree-days; 3=3,001 to 3,500 degree-days; 4=3,501 to 4,000 degree-days; 5= 4,001 or more degree-days
[d] Mean Temperature of the Warmest Month (July) system of classification of grape growing regions (Smart and Dry, 1980); less than 69.8° F (warm); 69.8 to 73.2° F (hot); and greater than 73.4° F (very hot).

For more information on climatic data, contact Ryan Boyles, State Climatologist and Director, State Climate Office of North Carolina, sco@climate.ncsu.edu, 1005 Capability Drive, Suite 240, Research III Building, Centennial Campus, Box 7236, North Carolina State University, Raleigh, North Carolina 27695-7236 shoots, and latent "base" buds usually have no preformed fruit clusters. Spring frosts are especially damaging in early budburst *vinifera* varieties like Chardonnay. Other interspecific hybrid varieties (for example, Seyval and Vidal blanc) often have very fruitful secondary and base buds. Thus, the consequences of a frost are not as severe with most hybrid varieties as they are with *vinifera* varieties.

4. A HOT, HUMID GROWING SEASON promotes the incidence of disease. Excessive moisture in the fruit maturation period (late August to early October) often causes berry splitting and fruit decay.

Climatologists refer to the climate of a large geographic region as the *macroclimate* of that region. Most of North Carolina, for example, is dominated by a *continental macroclimate*. Continental climates have temperature and precipitation patterns that are modified by large land masses (continents). For example, most high-pressure frontal systems that affect our region have first moved across Canada or the Midwest. One feature of a continental climate is air temperatures that can fluctuate rapidly from day to day because land does not readily affect, or buffer, air temperatures. *Maritime climates*, on the other hand, are macroclimates directly influenced by their proximity to large bodies of water. Basically, warm water tends to warm colder air, and cold water cools warmer air. Water absorbs heat from the sun and releases that heat and moisture to the atmosphere. Thus, cold air that blows across seas, unfrozen lakes, and other large expanses of water in the winter is warmed and, in turn, warms air temperatures on the leeward side of the water. The moisture absorbed over open water is also likely to affect precipitation patterns on the leeward side. The depth and salinity of bodies of water determines, in part, how much heat they absorb and how much heat they can release before freezing. As air temperatures rise in the spring, large bodies of water warm at slower rates than the surrounding land. Air is thus cooled as it blows over cold water. The cooled air retards spring plant development on the leeward side of the water and reduces the risk of frost injury. The fruit-growing regions bounding the Great Lakes benefit from their proximity to those deep, expansive lakes. Similarly, the temperature-moderating influence of the North Sea contributes to the success of grape growing in northern Germany at a latitude comparable to that of Hudson Bay in Canada. In North Carolina, the tidewater and eastern shore counties are subject to a maritime climate because of their proximity to the Atlantic Ocean. No other bodies of water in North Carolina are large enough to affect regional climate significantly.

Mesoclimate, or the local climate of a site, is more specific than the macroclimate. The mesoclimate is primarily the climatic conditions within 10 feet of the ground. Climatologists frequently use the term *microclimate* to describe the climate in this zone; however, we will reserve the term *microclimate* to describe, in the next paragraph, an even more specific climate. A site's mesoclimate is affected by factors such as the compass orientation of the site (aspect), the degree of inclination (slope), the relative elevation, and the barriers to air drainage.

Microclimate as used here refers to the very specific environment within grapevine canopies. Grapevine canopies consist of the shoots—stems and leaves—present during the growing season. The microclimate within vine canopies can be significantly different from that outside the canopy, particularly with respect to the quantity and quality of sunlight, air temperature, wind speed, and humidity. Typically, the interior region of dense vine canopies will be shaded, will be more humid, and will have slower air movement than will the climate on the exterior of the vine canopy. Experienced grape growers recognize the impact of canopy microclimate on fruit quality and use canopy management practices that promote a favorable canopy microclimate. (See chapter 7.)

Temperature

Grapevines require a minimum of about 165 frost-free days to mature their crop and to cold-harden (acclimate) their tissues before a killing frost occurs. Most sites in North Carolina's lower mountains, foothills, and piedmont will meet that minimum requirement, but it would be wise to review available information on the average growing season for the locations you are evaluating (Perry, 1998c).

Once you know that a site meets the minimum growing season, you need to consider three other aspects of temperature in selecting a vineyard site: the potential for spring and fall frosts, midwinter low temperatures, and summer heat.

Frosts

A goal of site selection is to locate sites with a relatively low likelihood of spring and early fall frost (Wolf and Boyer, 2003). Spring frosts chronically injure some vineyards and are more frequent in some parts of the state than in others, even those with good site selection. The expanded section, *Avoiding Spring Frost Damage,* beginning on page 44, explains the potential seriousness of spring frost damage to vines, offers you a way to evaluate the potential for problems on a particular site, and discusses passive and active systems (discussed in chapter 11, *Spring Frost Control)* to minimize potential damage.

Early fall frosts affects grapevines by arresting sugar accumulation; it is desirable for grapevine leaves to naturally senesce, rather than being frosted off the vines, in order to maximize carbohydrate (sugars and starch) reserves in perennial portions of the vine (Wolf and Boyd, 2003). Generally, you can expect a strong correlation between occurrences of spring and fall frost (Wolf and Boyd, 2003). Sites having relatively low frost risk in spring should also be less prone to frosts in fall. The same active frost protection techniques described in chapter 11, *Spring Frost Control,* for managing radiation frosts (both hoar frosts and black frosts) in the spring can be applied to prevent leaf damage on sites that are prone to early fall frosts. This can be done to improve cane hardening and improve the vine's winter hardiness.

Minimum Winter Temperatures

One of the chief limitations to grape production in this region is damage to vines resulting from severe midwinter low temperatures. Cold injury can include the usual cane tip dieback, death of dormant buds, and the occasional death of canes and trunks. The temperature required to injure vines varies with the variety, the specific tissue, the time of the season, and the particulars of the low-temperature episode (prior temperatures, cooling rate, low temperature attained, and duration of the cold). It is therefore impossible to state precisely what temperature is required to injure vines. Experience, as well as numerous controlled freezing tests in Virginia, have led to the use of a critical temperature of -8°F as a guide for predicting the onset of significant cold injury in *V. vinifera* varieties (Wolf and Boyer, 2003). When well-managed vines in central Virginia are exposed to -8°F, growers can expect to see greater than 50 percent primary-bud injury and perhaps cane, cordon, and trunk injury, depending on the freeze conditions (Wolf and Boyer, 2003). As stated in chapter 3, before committing to planting *vinifera* grapes in a given location in North Carolina, consult the climatological maps found on the North Carolina Wine and Grape Council's Web site (http://www.ncwine.org/siteSuitability/siteSuitability.html). The maps provide important details on the average occurrence of temperatures of -8°F per decade (1970 to 2000). In Virginia, Tony Wolf does not advise commercial production of *V. vinifera* in regions that experience -8°F three or more times per decade.

Like spring radiation frosts, midwinter low temperatures are significantly affected by the relative and absolute elevation of a vineyard site. Cold air ponds in low areas as readily in the winter as it does in late spring or early fall. It is not surprising, therefore, that many vineyards that chronically suffer spring frost injury also suffer frequent winter cold injury. Thus, the concepts of air drainage that apply to frost protection also apply to avoiding winter injury.

Winter cold injury can be significant at altitudes greater than 2,000 feet. A vineyard at such a high elevation is more subject to advective freezes and generally gains little benefit from temperature inversions.

Maximum Summer Temperatures

Maximum rates of photosynthesis in grape leaves occur from 85 to 90°F. Unless the growing season is short, there is little advantage in exposure to higher temperatures. Many locations in North Carolina routinely exceed this temperature range on many days during the growing season. High daytime temperatures, coupled with high night-time temperatures, can reduce fruit pigmentation, aroma, and acidity and cause rapid development of sugars, reduced acids, and very high pHs with some varieties. As a consequence, the juice is often unbalanced with respect to sugar, acid, and pH (Jackson and Schuster, 1987).

One of the goals of a recent research effort at the Upper Piedmont Research Station in Reidsville has been to identify *vinifera* and hybrid varieties that will hold their acidity while achieving a 22+ Brix level. In this relatively warm growing region of the central piedmont, we have been impressed by Tannat (*vinifera*) in regard to its fruit chemistry:

- ❑ Titratable Acidity (TA) levels (as a percentage of tartaric acid) have averaged 0.9 over the three-year period, 2003 to 2005.
- ❑ Brix levels have averaged 20.6.

Table 4.2. Comparison of Characteristics of 14 Winegrape Varieties for Harvest Dates, and Average Yield and Fruit Quality Components 2003 to 2005 at the Upper Piedmont Research Station in Reidsville[a]

Variety	Harvest Date 2003	Harvest Date 2004	Harvest Date 2005	Tons/acre (mean)	Tons/acre (standard deviation[c])	Brix (mean)	Brix (standard deviation[c])	pH (mean[d])	pH (st dev[c])	Titratable Acidity[d] (mean)	Titratable Acidity[d] (standard deviation[c])
Cabernet franc cl. 332	Sept 3	Sept 13	na	1.60	0.27	19.37	2.13	3.96	0.11	0.47	0.08
Chardonnay cl. 76	Aug 29	Aug 25	Aug 28	2.43	1.28	19.60	0.00	3.84	0.12	0.56	0.06
Chardonnay cl. 96	Aug 27	Aug 25	Aug 28	4.29	1.58	19.63	0.61	3.91	0.10	0.56	0.06
Merlot	Sept 3	Sept 1	Sept 5	3.96	0.51	18.47	1.31	3.84	0.08	0.42	0.07
NC74CO44-32	Sept 8	Sept 1	Sept 1	2.44	0.62	22.35	1.75	3.57	0.14	0.69	0.02
NY 73.0136.17	Sept 24	Sept 1	Sept 12	4.06	0.93	18.03	0.90	3.64	0.09	0.64	0.06
Petit Verdot	Sept 24	Sept 21	Sept 18	3.03	0.68	20.27	1.65	3.74	0.17	0.66	0.05
Sangiovese	Sept 8	Sept 13	Sept 18	4.39	1.11	18.00	1.85	3.83	0.14	0.55	0.06
Seyval blanc	Aug 25	Aug 20	Aug 22	4.24	1.50	20.03	0.05	3.67	0.10	0.57	0.03
Syrah	Sept 8	Sept 21	Sept 18	3.56	0.81	16.53	0.82	3.91	0.11	0.51	0.09
Tannat	Sept 24	Sept 5	Sept 12	4.28	0.79	20.57	0.66	3.56	0.15	0.91	0.13
Tempranillo	Aug 29	Sept 13	Sept 12	2.47	0.53	18.50	1.88	4.13	0.07	0.69	0.08
Traminette	Sept 24	Aug 25	Sept 5	3.11	1.25	19.57	0.40	3.82	0.09	0.59	0.09
Viognier	Aug 29	Sept 1	Aug 28	1.43	0.67	20.17	1.11	4.04	0.06	0.54	0.05

[a] Winegrape vineyard planted in 2001 to test various varieties/selections for adaptability to upper piedmont, North Carolina (elevation 890 ft, 36° 23' N; 79° 42' W); spacing is 7 ft in-the-row and 10 ft between rows; low bilateral cordon training with pruning to 17 to 18, 2-node spurs spaced roughly 4 to 5 in. apart per vine (or 8 to 9 spurs per cordon); canopy management practices consisted of shoot positioning, thinning and selective leaf removal on the north side *(the VSP trellis requires extensive canopy management techniques because it is not designed to handle the vigor of NC growing conditions)*. All varieties are on 3309C rootstock.
[b] Titratable acidity as % tartaric acid.
[c] Standard deviation measures the amount of variation in the data; lower standard deviations indicate that data values over the three years were within a range close to the reported mean.
[d] We gratefully acknowledge the contributions of Joanna Foegeding, Research Analyst, Food Science, NC State University, who conducted the analysis procedures for juice pH and TA.

- pH levels have averaged 3.56
- Yields have averaged 4.3 tons per acre for the same period (Table 4.2).

Gladstones (1992) suggests an optimal mean daily temperature of 64 to 70°F in the final month of ripening (August through October, depending on location and variety). For three years at this research vineyard in the central piedmont, we monitored the relationship between heat accumulated during the 30 days prior to harvest (using a base of 71.6°F), and readings for pH, TA, and Brix (Table 4.3). The heat units for the 30 days prior to harvest were 126, 32, and 210 units for the years 2003, 2004, and 2005, respectively. In the warmest seasons (2003, 2005), the TA levels for Chardonnay cl.76 were lower than in 2004 (relatively mild temperatures in August), but the seasonal trends in TA were not as clear-cut for the other Chardonnay clone (cl. 96), Merlot, or Viognier (Table 4.3). A reasonable standard for percent TA is from 0.6 to 0.9 (Amerine, 1980), and it may be viewed as a concern that the acid contents for all each of these *vinifera* varieties were *below 0.6* TA, except Chardonnay cl.76 in 2004 and Chardonnay c1.96 in 2003. Perhaps more alarming were the undesirably high pH levels recorded for all of the winegrape varieties and selections tested in this central piedmont location, with the exception of Tannat which had an average pH of 3.56 over three years (Table 4.2). Tannat's pH is relatively close to being in an acceptable range for full-bodied red wines (Table 4.4). Tannat is a variety that has become Uruguay's flagship red varietal wine, and it is important to note that this South American country's humid climate and heavy soils promote excessive vigor in most varieties (causing a

Table 4.3. Comparison of Selected *Vinifera* Winegrape Varieties for Harvest Dates, Yield Performance, and Fruit Quality Components for 2003, 2004, and 2005 Seasons at the Upper Piedmont Research Station at Reidsville[1]

	Harvest Date[2]			Tons per Acre			Brix			pH			Titratable Acidity (% Tartaric Acid)		
Variety	**2003**	**2004**	**2005**	**2003**	**2004**	**2005**	**2003**	**2004**	**2005**	**2003**	**2004**	**2005**	**2003**	**2004**	**2005**
Chardonnay cl. 76	Aug 29	Aug 25	Aug 28	0.78	2.61	3.89	19.6	19.6	19.6	4.00	3.78	3.73	0.53	0.65	0.50
Chardonnay cl. 96	Aug 27	Aug 25	Aug 28	2.06	5.34	5.48	18.9	20.4	19.5	3.88	3.81	4.04	0.61	0.59	0.48
Merlot	Sept 3	Sept 1	Sept 5	3.41	4.64	3.83	17.8	20.3	17.3	3.81	3.95	3.76	0.52	0.38	0.37
Tannat	Sept 24	Sept 5	Sept 12	4.27	3.32	5.26	19.7	20.7	21.3	3.76	3.51	3.40	0.80	1.09	0.83
Viognier	Aug 29	Sept 1	Aug 28	1.21	0.74	2.33	18.6	21.0	20.9	3.98	4.13	4.01	0.62	0.50	0.51

[1] Winegrape vineyard planted in 2001 to test various varieties/selections for adaptability to upper piedmont in North Carolina. Spacing is 7 ft in the row and 10 ft between rows; low bilateral cordon training with pruning to 17 to 18, 2-node spurs spaced roughly 4 to 5 in. apart per vine (or 8 to 9 spurs per cordon). Canopy management practices consisted of shoot positioning, thinning, and selective leaf removal on the north side. All varieties are on 3309C rootstock.
[2] Heat accumulated during the 30 days prior to harvest , using a GDD base of 22 C (71.6 F), were 126 units in 2003, 32 units in 2004, and 210 units in 2005.
[3] Titratable Acidity as % tartaric acid.

Table 4.4. Recommended pH, Titratable Acidity, and Brix for Grape Harvest[1]

Grape Type	pH	TA	Brix
White	3.1 to 3.3	0.70 to 0.90	19 to 20
Red	3.2 to 3.4	0.65 to 0.80	21 to 23

[1] Adapted from information from North Carolina Viticulture & Enology Information Packet, assembled by Tania Dautlick, Executive Director, The NC Grape Council, Inc. Summer/Fall 2003 (after the article, *Making Consistently Good Wine,* Donald E. Gauntner, American Wine Society Journal, Winter Issue, 1997, pp 131-134).

reduction in quality), with the important exception of Tannat (Teubes and Wiese, 2003).

Thus, there may be some advantage to locating vineyards where mean summer temperatures are relatively cool. In North Carolina, sites having cooler daytime temperatures are generally located at higher elevations (Table 4.1). Air temperature is reduced approximately 3°F for every 1,000-foot increase in altitude. Other factors being equal, a vineyard located 1,500 feet above sea level will have slightly cooler average daytime air temperatures than a vineyard located at 500 feet. There is a limit to the benefit achieved with increased altitude, however. Vineyards located above 2,000 feet are more subject to low-temperature injury during the winter.

Slope

The *slope* of a site refers to the degree of inclination of the land. A slight to moderate slope can be beneficial because it accelerates cold air drainage. Generally, the steeper the slope, the faster cold air moves downhill, assuming there are no barriers to air movement (Figure 4.1). Steep slopes, however, can create problems. Machinery is difficult if not dangerous to operate on steep slopes, and the potential for soil erosion is increased. Make every attempt to minimize soil loss, and avoid slopes greater than approximately 15 percent (a 15-foot drop in elevation for each 100-foot horizontal displacement). Consult the local Soil Conservation Service office for advice on erosion control measures.

Aspect

The *aspect* of a slope refers to the compass direction toward which the slope faces (north, south, east, or west). Eastern, northern, and northeastern slopes are probably superior to other aspects. Often, however, other factors such as the presence of woods, steep slopes, and exposed rocks dictate that another aspect must be used. The preference for eastern and northern aspects relates to heat load differences between various slopes. Southern and western exposures are hotter than eastern and northern exposures. Southern exposures warm earlier in the spring and can slightly advance budbreak compared to northern slopes. The consequence of advanced budbreak is increased potential for frost damage. Southern aspects can also lead to more extensive vine warming on sunny winter days than on northern slopes. The consequences could be reduced cold resistance and subsequent cold injury. Bark splitting and trunk injury to the southwest sides of fruit trees is occasionally observed and is related to trunk warming on sunny winter days with subsequent, rapid cooling. Southern and western aspects can also be expected to be hotter during the summer than northern and eastern aspects. Eastern aspects also have an advantage over western aspects because the eastern slopes are exposed to the sun first. Vines on an eastern slope will dry (from dew or rain) sooner than those on a western slope, potentially reducing disease problems. The basic effects of slope orientation on vine performance are summarized in Table 4.5.

Precipitation

Precipitation rates are not generally considered in site selection, but they greatly affect grape production. The water requirements of grapevines vary with their age, the presence or absence of competition from weeds, and the evaporative conditions to which the vines are exposed. Mature vines can use the equivalent of 24 to 30 inches of rainfall per year. Precipitation records indicate that most North Carolina locations average between 40 and 50 inches of precipitation per year. Unfortunately, average records can be misleading because they do not provide a measure of rainfall frequency. Even monthly precipitation averages can be misleading because much of the summer precipitation occurs during thunderstorms. Thunderstorms often affect only a

Table 4.5 Relative Effects of Compass Direction of Site (Aspect) on Various Climatological and Vine Developmental (Phenological) Parameters

Climatological or Phenological Parameter	Aspect			
	North	South	East	West
Time of bud break	Retarded	Advanced	Retarded	Advanced
Daily maximum vine temperature	Less	Greater	Less	Greater
Speed of foliage drying in morning	—	—	Rapid	Slow
Radiant heating of fruit in summer	Less	Greater	Less	Greater
Radiant heating of vines in winter	Less	Greater	Less	Greater

restricted area. Because of their intensity, less of the moisture is absorbed by the soil than when equal amounts of precipitation fall over longer periods. Avoid sites that chronically experience water shortages during the growing season, or consider supplementing natural precipitation with irrigation.

Soil

The soil supplies vines with most of their essential nutrients and water. Grapevines tolerate a wide range of soil types. Furthermore, vines can be grafted to pest-resistant rootstocks that can extend the margins of soil suitability to some extent. However, the soil must meet certain minimum qualifications. Chief among soil requirements are adequate depth and internal drainage. Potential vineyard sites should have a minimum of 30 to 40 inches of permeable soil. Soils that have a shallow hardpan restrict root development and limit the vines' ability to obtain water during extended dry periods.

Roots also require good aeration. The growth of roots and the welfare of the vine are reduced when soils are waterlogged during the growing season. Well-drained soils are essential for vineyards. The color of the subsoil gives some indication of its internal drainage: well-drained soils generally appear uniformly brown or grade into yellow-orange clay at 15 to 20 inches. The subsoil of poorly drained soils may appear mottled or uniformly gray. Soil drainage can be improved by installing drainage tiles, but the process is expensive. Consult Soil Conservation Service soil survey maps to help determine the suitability of your soil for crop use. County soil survey reports are available through most Cooperative Extension Centers or Soil Conservation Service offices.

Vineyard soils ideally should be of moderate fertility. Experience suggests that very fertile soils can complicate vine management because they promote excessive vegetative growth. Conversely, impoverished soils are liabilities if large quantities of nutrients must be routinely applied to support adequate vine growth. Collect soil samples before planting vines to determine soil pH and macro-nutrient levels. (See chapter 9.) Soil test guidelines are available through county Cooperative Extension Centers.

Despite popular opinion, we are largely ignorant about how different soil types affect wine quality. It seems reasonable to assume, however, that the major effect of soil type is indirect; that is, the effect of soil can be gauged by the impact the soil has on above-ground growth of the vine (for example, excessive versus optimal vegetative growth, balanced nutrition versus nutrient deprivation, or adequate water versus drought). However, one recently published book, *Soils for Fine Wines,* does provide additional information on the importance of vineyard soil conditioner (White, 2003).

Proximity to Vineyard Pests

In addition to the physical features of a potential site, consider the proximity of wildlife and other pests that can pose a threat to grapes. Chief among those pests are deer and various species of birds. Deer will browse the young, green shoots of the vines and eat the fruit as it matures. Deer are most destructive when vineyards are located close to woods or other deer habitat. If the potential for severe deer depredation exists, some deer protection measures should be used. Commercial chemical repellents, bars of soap, human hair, tankage, and shooting by permit all offer a temporary remedy to deer damage. Experience, however, suggests that electrified deer exclusion fencing is the only means of providing secure, long-term protection of vineyards.

Birds, particularly flocking species such as starlings, can cause serious crop loss by consuming fruit. Unfortunately, there are no cheap, legal, effective means to combat birds. Sites that are situated near heavy woods in otherwise open country appear to suffer the most damage. Several bird-scaring devices are commercially available, including recorded distress call emitters, propane cannons, Mylar ribbon, and bird-eye scare balloons. Again, experience suggests that those scare tactics offer only temporary crop protection. Bird netting is cumbersome to apply and remove but offers near-perfect exclusion. The overhead netting of entire vineyard sections is more convenient than is the netting of individual rows.

Sites that are, or were in recent years, wooded or planted to fruit trees should be cleared, cultivated, and planted to a grass sod or cereal grain for one or more years before grapes are established. During that period, rid the site of old roots, rocks, and broad-leaved weeds. Certain broad-leaved weeds and some fruit trees are alternative hosts for nematodes that can also attack grapevines. Nematodes are microscopic, wormlike parasites of which several genera, notably *Xiphinema*, can transmit viruses to grapevines. Soil assays for the presence of these nematodes can be arranged through your local Extension center. Soils that contain *Xiphinema* species can be fumigated, but the efficacy and economics of fumigation are uncertain and not recommended. As an alternative, infested soils should be maintained in a non-host grass or cereal grain for several years before vines are planted.

Coastal areas of North Carolina are not recommended for bunch grape production because of the occurrence of Pierce's disease. This bacterial disease is transmitted to grapevines by leafhoppers and severely limits grape production in regions where winter temperatures are warmer. The only practical control method is to avoid bunch grape production in regions where the bacteria is endemic. (See chapter 8.)

Consideration must be given to existing neighbors when contemplating a commercial vineyard. Equipment such as air-blast pesticide sprayers and bird-scare cannons are noisy and can generate complaints from neighbors. Also consider the possibility of pesticide drift from your vineyard onto neighboring property and vice versa. Pasture owners frequently use 2,4-D herbicides for thistle and other broadleaf weed control. Grapevines are very sensitive to 2,4-D injury. You must inform your neighbors of your intentions to grow grapes and diplomatically request that they avoid using 2,4-D or that they use only low-volatile 2,4-D formulations, preferably before grape budbreak.

Avoiding Spring Frost Damage

The best way to avoid frost hazard is to do a good job with site selection. It has been said, "The more effectively site selection rules are obeyed, the less need remains to consider additional frost measures" (Martsolf and Peart, 2003). Since the initial publication of the *Mid-Atlantic Winegrape Grower's Guide* in 1995, winegrape growers in both North Carolina and Virginia have been encouraged to rely primarily on *passive control* of frost by selecting sites that are elevated above a valley floor in hilly and mountainous terrain.

A new methodology introduced in this chapter assesses the *frost risk* of potential vineyard sites by using *predicted phenology* and *long-term temperature records.* It is recommended that you follow this approach, or another appropriate method, to gain a fuller understanding of the risk of spring frost associated with sites you are considering for commercial grape production. Having a complete understanding of the frost hazard associated with a potential vineyard site *before you plant* may help you to:

- ❑ Reject sites that that are highly frost-prone. Sometimes the *best* decision is to pull up and walk away rather than attempt to grow grapes on sites that are subject to repeated spring frosts. (These are sites that typically have chronic problems with winter injury as well.)
- ❑ Purchase and develop frost-free sites even though you can expect to pay extra for such sites. The extra cost for the land may be offset when you don't have to install frost control systems (e.g., heaters, overvine sprinklers and ponds, or wind machines) and pay to operate these systems (fuel for heaters is now prohibitive).
- ❑ Purchase and develop sites with a relatively low risk of frost damage (probability of frost in 1 or 2 years out of 10); especially if you:
    1. Plant *vinifera* varieties with later budbreak characteristics and avoid early budburst varieties like Chardonnay.
    2. Plant interspecific hybrids like Chambourcin, which can produce a good crop even if primary shoots are killed.
    3. Use cultural practices to reduce the likelihood of frost damage (e.g., delayed and double pruning, and/or removing impediments to cold air drainage, such as dense shrubbery and windbreaks).
- ❑ Assess the potential profitability of a site that will require a mechanical system for frost control. Several commercial vineyards in North Carolina have used wind machines over the last decade and can attest to their value on sites with chronic radiational frost problems. Wind machines use the inversion that develops under radiational cooling conditions. A wind machine may be able to raise the temperature 1 to 3°F over 7 to 10 acres of flat or rolling vineyard. On sites where there is a 20 percent or higher probability of spring frost during early stages of new shoot growth, it may prove profitable to invest in a wind machine.

Types of Cold Weather Events in Late Winter and Spring

There are three general types of cold events that can occur in North Carolina vineyards during the late winter and spring. The most common cold event is a *frost,* which is technically termed a *radiational frost*. Radiational frosts occur during calm weather when skies are clear and temperatures near the surface are below freezing. Selecting vineyard sites that have a reduced risk of spring radiation frosts is the primary focus of the rest of this chapter.

The second type of cold event that can occur is a *freeze.* Technically, *freezes* are termed *advective* or *windborne freezes. Freezes* are associated with the passage of large frontal systems of very cold air over an entire region, or state. It is virtually impossible to find sites that are unaffected by windborne freeze events. When the National Weather Service (NWS) issues a warning for a *freeze,* this means that there is potential for a very dangerous weather event with subfreezing temperatures and winds exceeding 10 miles per hour. Fortunately, *advective* or *windborne freezes* occur only rarely in the period following budbreak, as this type of cold event can devastate a vineyard.

While people use the terms *frost* and *freeze* interchangeably, the terms refer to cold weather events with very different characteristics and properties.

There is a third type of cold event called a *frost/freeze*, which combines the characteristics of both a *radiational frost* and a *freeze. Frost/freezes* are only briefly mentioned in this section, but they are discussed more fully in chapter 11 (*Spring Frost Control)*. As defined by the NWS, a *frost/freeze* warning indicates the potential for a cold event with winds of less than 10 miles per hour and temperatures lower than 32°F. Although the NWS does not set an official lower limit for the wind speeds associated with a *frost/freeze,* it might be inferred that the winds associated with a *frost/freeze* are in the range of 5 to 10 miles per hour, as Perry (1998) has defined a *radiation frost* event as having winds of less than 5 miles per hour. *Frost/freeze* events are more likely to occur before spring budbreak, but if you are planning to grow *vinifera* grapes in the mountains, especially early budbreak varieties like Chardonnay, it may be prudent to also evaluate the potential for spring *frost/freeze* events in addition to spring *radiation frosts*.

The information presented in this section on *Avoiding Damage from Spring Frosts* focuses on assessing potential vineyard sites for the risk of more common radiation frost events (winds of less than 5 miles per hour and temperatures of 32°F, or colder) in the early weeks following budbreak. We generally recommend planting grapes in relatively warm thermal zones, which are belts that develop upslope where cold air can drain away from the vineyard to avoid damage from radiation frosts. Plants growing in the valley floor zone are frosted if the air is cold enough to freeze susceptible tissues.

Whether the cold event is a radiation frost, frost/freeze, or freeze, vine injury can occur if susceptible tissues (for example, green shoots) are cooled below a temperature critical for their survival. The critical temperatures for tissue freezing are discussed in detail in the following section on *Understanding Critical Temperatures.*

SLOPES DRAIN COLD AIR. Radiational frosts occur as the earth loses heat to the sky during the night. As the ground cools, it also cools the air immediately next to the ground. Cold air is heavier than warm air and will flow down the slope, much like a liquid. *The sinking, cold air displaces warmer air, which rises to higher elevations producing thermal inversions and thermal belts that provide a measure of protection from the coldest air in the valley floor sites* , as is illustrated in Figure 4.1 The rise in temperature with increase in elevation is referred to as a temperature or radiation inversion. Above the warm air layer of radiation inversion, air temperatures decrease with increased altitude.

The relative elevation of a proposed vineyard will have a major impact on the frequency of frost damage. Vineyards located in low frost pockets will be affected by frequent frosts; vineyards located at higher elevations, relative to surrounding topography, will be affected by fewer spring or early fall frosts. Most of us have experienced the ponding of cold air in low areas by strolling, at dusk, from a high hill to an adjacent creek-bottom or gully. The decrease in air temperature as we move downhill is most dramatic on calm, clear evenings. The relationship between relative elevation and air temperature is illustrated in Figure 4.1. The figure also illustrates how barriers to cold air drainage can create localized cold spots in a vineyard. Where possible, vegetation or other impediments to cold air drainage should be removed below the proposed vineyard site. We strongly recommend locating vineyards only on sites affording good cold air drainage.

More strongly sloping ground tends to give stronger inversions. A strong inversion is one in which temperatures above flat ground are at least 7 to 10 degrees warmer than temperatures at the surface, or in the case of a vineyard located on sloping ground, temperatures midway up the slope may be 10 degrees warmer than in the valley below (Figure 4.1).

One of the most remarkable characteristics of the topography in western North Carolina where the piedmont plateau transitions into the Blue Ridge Mountains, is the great variations in elevation that generate strong inversions. For many years "thermal belt" has been used to describe certain sections of North Carolina that "enjoy a more equitable climate" (Hurt, 1923). These thermal areas favoring apple, peach, and grape production have been enjoyed by many generations of fruit growers in North Carolina. In Virginia, historical weather data and grower experience in the piedmont and Blue Ridge Mountain areas have revealed a greater frequency of damaging spring radiational frosts below elevations of 800 feet than at heights of 800 to 1,800 feet, assuming that the higher sites have good relative elevation (Wolf and Poling, 1995).

In assessing vineyard sites in the higher altitudes of western North Carolina, it is very important to consider a site's absolute elevation above sea level. On average, temperature changes 1.1°F per 330 feet of elevation (Jones and Hellman, 2000), and *at some point the benefits of higher absolute elevation are lost.* More recently, Wolf and Boyer (2003) have found that the upper limit of a thermal belt can range from 1,500 feet above sea level in northern Virginia to approximately 2,200 feet in southern Virginia.

Similar guidelines have not been determined for the northern, central, and southern latitudes of western North Carolina, but you may wish to check the North Carolina Wine and Grape Council Web site (www.ncwine.org) for *Vineyard Suitability Maps*. Using a software program and database created by John Boyer, a Virginia Polytechnic Institute and State University geographer, former NCSU viticultural Extension associate Andy Allen generated these maps for potential sites in the mountains, foothills, and piedmont of North Carolina. The program utilizes a series of physical, digitized databases to assess the potential for spring frost on a proposed vineyard site. The validation of maps is ongoing, and refinements will, no doubt, occur.

One limitation of this program that pertains to piedmont counties (Allen—personal communi-

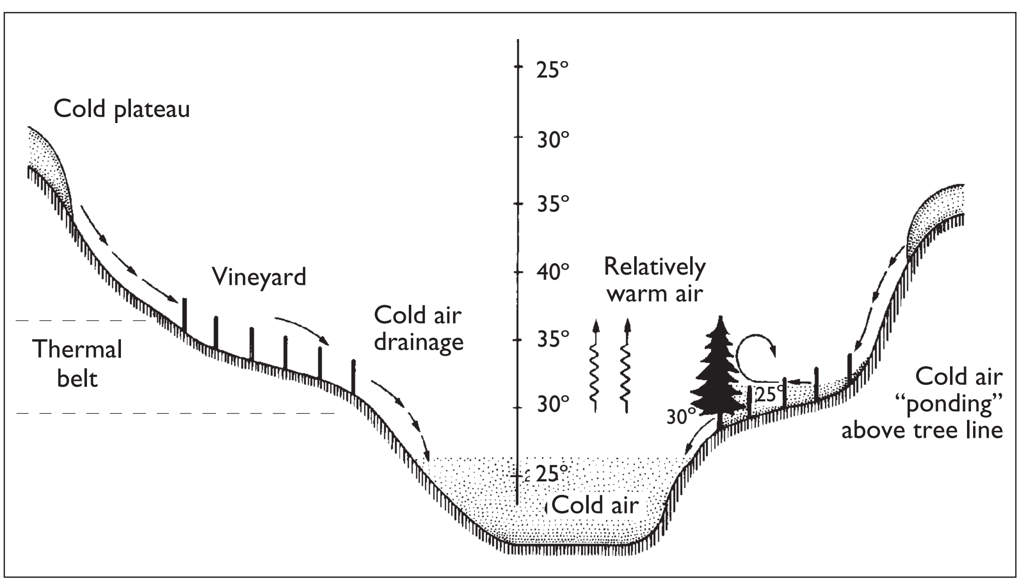


Figure 4.1 Effect of vineyard site topography on air temperature stratification during a radiational cooling period characterized by calm winds and clear skies.

cation). The program assigns its best vineyard ratings to those sites found at the highest absolute elevations in the county. Sites located at lower absolute elevations in the county, despite outstanding local relief features, are not rated as highly. However, Allen has observed that 100 feet in hight can generate highly beneficial thermal zones for relatively frost-free grape production in most seasons in the North Carolina piedmont, provided there is a broad enough valley floor below the vineyard for cold air to collect. The site also must not have any downslope natural or manmade impediments that would block cold air drainage, like dense shrubbery, windbreaks, and buildings at the bottom of a slope (see Figure 4.1).

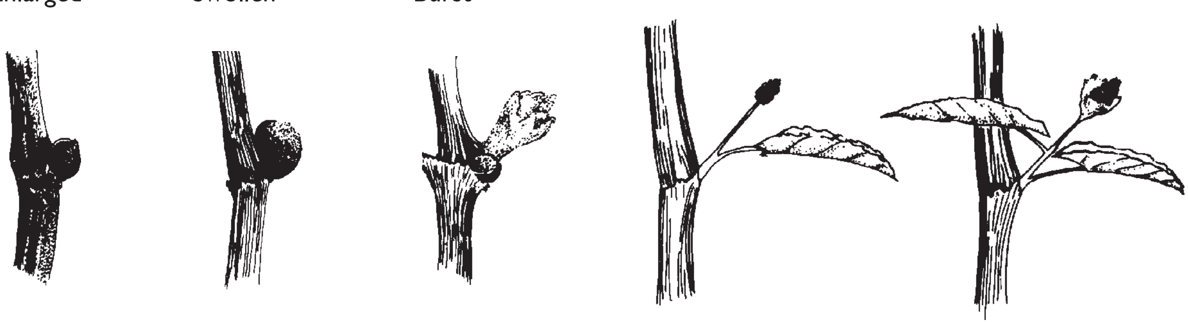
Understanding Critical Temperatures

As grapes develop from budburst to the various shoot development stages, the plant tissues become more susceptible to cold injury. Figure 4.2 shows the chances that Pinot noir buds and shoots will be killed at various temperatures.

Although Pinot noir is poorly adapted to growing conditions in North Carolina, you may use this variety's information on critical temperatures for similar popular *vinifera* varieties like Chardonnay, Merlot, and Cabernet Sauvignon (Evans, 2000).

However, ambient temperatures and humidity may interact to influence *actual* freezing points of newly expanding grape shoots. For example, under very dry atmospheric conditions in the vineyard, Wolf and Boyer (2003) report that injury to grape shoots may not occur until air temperatures reach 25 to 26°F, which is several degrees colder than the critical temperature points reported for young shoots in Figure 4.2. When the humidity is low and cooling is gradual, newly developing grape shoots have the ability to supercool (drop below their normal freezing

Figure 4.2 Critical temperatures of Pinot noir buds and shoots at six stages of development in spring.[a]



STAGES	Dormant Enlarged	Dormant Swollen	Shoot Burst	First[b]	Second
	CRITICAL TEMPERATURES FOR BUDS AND SHOOTS				
50% Killed	–14.0°C 6.8°F	–3.4°C 25.9°F	–2.2°C 28.0°F	–2.0°C 28.4°F	–1.7°C 28.9°F
None killed	— —	— —	–1.0°C 30.2°F	–1.0°C 30.2°F	–1.0°C 30.2°F

[a]Source: Gardea, A.A. "Freeze damage of 'Pinot noir' (*Vitis vinifera L.*) as affected by bud development, INA bacteria, and bacterial inhibitor" Oregon State University, Corvallis.
[b]Shoot stages defined by the number of flat leaves, those that had expanded enough to have an orientation nearly perpendicular to the ground.

points) and not freeze. However, it is very difficult to determine whether grape shoots will supercool during a given freeze event.

The temperature at which grape plant tissues freeze can also be affected by the presence of moisture on the plant surface. Essentially, dry plant tissue freezes at lower temperatures than wet plant tissues. Johnson and Howell (1981) have shown how the presence of hoar (white) frost, dew, ice, or water from precipitation or irrigation will elevate the critical temperatures of developing buds of Concord grapevines by more than 5°F at budburst stage (Table 4.6). Similar data is not reported for early shoot development stages by these authors, but it is very possible that in the presence of moisture the critical temperature of a second flat leaf stage could be closer to 31°F, and not 28.9°F, as shown in Figure 4.2 for Pinot noir.

Another area of some confusion has to do with the time interval required to damage a swollen bud or newly developing grape shoot. Authorities in Oregon (Sugar et. al, 2000), note that "beyond budbreak, damage may occur when developing shoots experience temperatures of 31°F or lower for *one-half hour or longer.*" However, Evans cautions "…that whenever ice forms in the plant tissue, there will be damage regardless of how long it took to reach that point" (2000).

Given the uncertainties and complications associated with pinpointing critical temperatures and durations required for cold injury in grape tissues, it may be safest simply to adopt the *higher end* critical temperature reported for budburst of 28°F by Perry in North Carolina for 50 percent kill (1998a). For early shoot stages, a critical tissue temperature of just below 32°F may be most appropriate, especially under hoar (white) frost conditions.

Table 4.6 Critical Temperatures (°F) for Developing Buds of Concord Grapevines[1]

Stage of Development	Influence of Surface Moisture[2]	
	Wet	Dry
Scale crack	22.1	14.9
First swell	23.9	17.6
Full swell	25.7	19.4
Burst	26.6	21.2

[1] Values are T_{50}; 50 percent of buds will be lost.
[2] Indicates presence of hoar frost, dew, ice, or water from precipitation or irrigation.

New Approach for Assessing Potential Vineyard Sites for Spring Frost Risk

In this publication, we have adapted a method used in New Zealand (Trought et al, 1999) that is based on the *predicted phenology* [1] (i.e., budbreak) of the vine and *estimates of frost probabilities* to assess the frost risk potential of a vineyard site. The *estimates of frost probabilities* are derived from *long-term temperature records*, such as the climate data[2] that can be provided by the State Climate Office of North Carolina. The State Climate Office (SCO) has long-term temperature records (30+ years) for more than 90 weather sites across North Carolina (almost one for each county). This source is felt to be the first choice for quality controlled climate data by many experts in the meteorology field. You may check the Web site at www.nc-climate.ncsu.edu/econet to obtain contact information for the SCO or call 1-877-718-5544 (toll free) to speak with a state climatologist. The actual procedure for generating frost probability estimates from minimum temperature observations for specific locations and periods is not automated, and it is going to be important for you, or your Extension agent, to

[1] Phenology is a branch of science dealing with the relations between climatic and periodic biological phenomena. And from the standpoint of understanding critical temperatures, it is important to know that the temperatures that grape buds and shoots will endure without injury changes with each developmental stage. Grape phenological stages are also very important in the timing of vineyard pest control sprays.

[2] The terms *climate* and *weather* are frequently used interchangeably, but it should be understood that *weather* refers to the current state of the atmosphere, such as temperatures or wind speeds, but *climate* refers to the average or normal weather of a particular location for a specified period of time, usually 30 years (Perry, 1999).

contact this office directly to obtain this information.

Our modification of the New Zealand model for assessing the frost risk of potential vineyard sites involves three steps:

1. Predicting *bud phenology* (i.e., forecasting budbreak for the varieties you wish to grow).
2. Making *probability estimates* for spring frosts from *long-term temperature records* based on information you receive from SCO. Alternatively, where a risk analysis of a new site is required, a limited temperature data set can be used by relating the new site to a nearby SCO station with long-term temperature data. See *Short-term Temperature Records* to learn how to do a direct temperature survey for a minimum of one season (and preferably two).
3. Doing an *investment analysis* to determine whether active frost protection may be economically justified.

To show how the New Zealand approach works, we have utilized phenology information for Chardonnay cl. 96 from an existing research vineyard location (Upper Piedmont Research Station, Reidsville) and SCO climate data from a weather station that is a quarter mile from the vineyard. Even though this vineyard in Reidsville has *so far* been frost-free (2001 through 2005), we can gain considerable insight about the longer-term frost risk of this particular site (shown in Figure 4.3) by analyzing historical temperature records.[1]

Step 1. Collect Data for Stages of Growth in Your Area

At the Upper Piedmont Research Station in Reidsville, Chardonnay cl. 96 passes through the phenological stages of *budbreak, 1- to 2-inch shoot,* and *10-inch shoot* in an approximate 3-week period (mid-April through first week of May). Chardonnay normally reaches budbreak stage in mid-April in Reidsville (Table 4.7), and in just one more week it reaches the 1- to 2-inch shoot stage.

Based on the critical temperature data in Figure 4.2, the threshold temperature for frost damage (50 percent kill) will increase from 28°F (budburst) to 28.9°F (second flat leaf), in approximately one week's time. At a later stage (fourth flat leaf), Chardonnay shoots can potentially be damaged at 31°F. However, for reasons previously given, it may be safest simply to adopt the *higher end* critical temperature reported for early shoot stages of just below 32°F (Trought et al., 1999), and this is the assumption we have made in characterizing the frost sensitivity of young

Figure 4.3. This Reidsville site has not experienced any damaging radiational frosts or frost/freezes in five years of observation. The vineyard has excellent local relief and unimpeded downslope cold air flow patterns. It has a gentle slope and lies approximately 100 feet above a frosty creek bottom at an elevation of 870 feet (top of vineyard). On still nights in April that favor heavy white frost formation on crops growing near the creek bottom (such as strawberries), the vines in this vineyard have been unaffected. (Photo taken March 14, 2005, by Joe French, Superintendent, UPRS).

Table 4.7 Dates for Key Growth Stages in Chardonnay for Frost Occurrence and Pest Management Considerations at the Upper Piedmont Research Station, Reidsville, NC*

Budbreak**	April 15
1 to 2-inch Shoots	April 22
10-inch Shoots	May 5
Prebloom	May 15

*Weather shelter elevation is 890 feet, 36° 23' N. latitude; 79° 42' W. longitude, and is a quarter mile from the vineyard location (elevation: 870 feet)

**Budbreak is defined as the time when the dormant buds open and newly formed leaves are seen (Wolf and Boyd, 2003)

[1] From 1901 to 1999, two Reidsville gages were provided by the National Weather Service and monitored each day by volunteers; today the gage is on the Agricultural Research Station, and temperatures are reported every day by staff. An automated gage on the research station provides hourly data and many other measurements, but it has only been in operation since May 1999.

Short-term Temperature Records

Even if you have longer-term climatic records for a site, we encourage you to assess the potential for frost on possible vineyard sites by doing a direct temperature survey for one season and preferably two. Frost events during critical growth periods in the early spring *are more strongly influenced by a site's local topography and possible barriers to air drainage* than by regional climatic factors.

The effect of local topography on air stratification during radiational cooling can be demonstrated by positioning thermometers that record maximum and minimum temperatures in shelters at various elevations on the proposed vineyard site. It is not unusual to find temperature differences of 3 to 5°F over a 50-foot difference in elevation. Two or three recording thermometers can provide considerable data on temperature variations at the site. High quality maximum/minimum recording thermometers are recommended; avoid inexpensive U-shaped maximum/minimum thermometers because instrument errors are large (Jones and Hellman, 2000). Mount the thermometers 5 feet above the ground and shield them from the sky with a roof painted white. If you plan to use low cordon training (the most popular training method for *vinifera* in North Carolina), it may be more advisable to position your temperature sensing device at a 3-foot level, and not 5 feet (standard weather shelter height). It is helpful to remember that swollen buds and shoots that are 3 feet from the ground will be colder (and more subject to injury) on a typical night of radiational cooling than shoots trained to a height of 5 feet.

Alternatively, an on-site weather station that records spring temperature minimums as well as wind speeds, relative humidity, and precipitation can be a valuable tool for making a more complete assessment of the actual radiational frost and advective freeze hazard of any site you are considering for grape production. Weather stations can range from simple devices to complex multi-instrument stations, but some authorities recommend a housed temperature sensor (thermister), which is calibrated and positioned mid-slope (Jones and Hellman, 2000). Your Cooperative Extension center can furnish you with current information on the many types of instrumentation available for evaluating a site's temperature characteristics. Recently, portable Mini Weather Stations costing less than $600 have become available. They are designed for use in harsh outdoor environments, and can store daily high and low temperature readings and temperature readings at 30-minute intervals for up to 180 days. These Mini Weather Stations also have an LCD display, which allows you to check current temperatures without connecting to a computer.

When doing your direct temperature survey, it is especially important that you record the dates when temperatures are 32°F, or lower. Also evaluate the height, frequency of occurrence, and strength of the inversion layer of each particular site. As discussed later, it is the warmer air above the vineyard that is used by wind machines (and/or helicopters) to warm the air around the vines.

Chardonnay grape shoots from April 22 (1- to 2-inch shoots) through early May (10-inch shoots).

Information regarding the range in budbreaks for winegrape varieties in North Carolina is quite limited,[1] but your Extension agent and/or local growers may already know and be able to tell you the approximate budbreak dates for popular varieties like Chardonnay, Merlot, or Cabernet Sauvignon. Just knowing when Chardonnay normally breaks bud in your area will help you predict budbreak for other varieties. Cabernet Sauvignon, for example, is usually two weeks later in budburst and development than Chardonnay. In the next step, *Estimate Probability of Spring Frost Events*, we will compare the average date of budbreak of Chardonnay to the dates of significant frost events at the Reidsville research vineyard using long-term temperature records.

Step 2. Estimate Probability of Spring Frost Events

Past observations are an essential ingredient to predicting future conditions for your vineyard. The frost probability estimates you receive from long-term temperature observations from the North Carolina State Climate Office can help you assess the statistical probability that a spring frost will damage the varieties you plan to grow. With the assistance of a qualified state climatologist, you can investigate the so-called *frost climatology* of the vineyard sites you are evaluating for commercial production. You should expect to pay a modest fee for these services, especially in situations requiring extensive analysis to generate useful frost probabilities.[2]

As discussed earlier, at the Reidsville research station, Chardonnay buds typically pass from dormant to budbreak stage in mid-April, and by around April 22, the stage of 1- to 2-inch shoots

[1] Models that can be used to predict budbreak have been developed by Moncur et al. (1989) and have been used in New Zealand (Trought et al., 1999).

[2] The commercial company SkyBit (www.skybit.com) can also provide historical probability analysis of the frequency of specified temperature(s) at a site based on the site's location and elevation (Wolf and Boyer, 2003).

Table 4.8. Percentage of Chardonnay Vines at Various Stages by Date and Weekly Frost Probabilities for Reidsville Site in April and Early May*

Temperature Threshold	Percent Dormant Buds Swollen April 8-14	Percent Budburst, or Shoot Burst April 15-21	Percent at 1- to 2-inch Shoot Stage April 22-29	Percent Shoots Elongated to 10 Inches April 30-May 5
32°F	53.4	21.0	5.7	2.6
31°F	34.0	16.1	3.4	0
30°F	23.1	12.5	2.1	0
29°F	17.1	10.6	1.6	0
28°F	9.9	5.2	0	0

* The daily probabilities of frost occurrence in the months of April and May were first calculated using Reidsville temperature records from 1902 through 2005. Then this data was then "smoothed," using a 5-day moving average. The smoothed daily probabilities of frost occurrence (at set temperatures of 28, 29, 30, 31, and 32°F) were then summed to generate the weekly frost probability estimate shown. Daily smoothed frost probability estimates provided courtesy of North Carolina State Climate Office.

has been reached (Table 4.7). Now let's review frost probabilities during this critical period.

LAST SPRING FROST DATE for Reidsville. Traditionally, 32°F is used in assessing the frost potential of a site, and Perry (1998b) notes that the average date of the last spring air temperature of 32°F (50 percent probability of frost later than this date) for this location is *April 7*. More recent calculations of the average date of the last spring frost (also called the *last spring frost date*) by Ryan Boyles, state climatologist, for 1962 through 2005 showed a 50 percent probability that the temperature would be as cold or colder than 32°F on *April 7*. But, with Chardonnay budburst coming a full week after the so-called *last spring frost date,* we are naturally more concerned about the probability of damaging frost during the second half of April.

EVALUATING FROST PROBABILITY LEVELS after budbreak. What is the probability of temperatures of 28°F or colder occurring *after budbreak* (at budburst we are assuming a critical tissue temperature of 28°F). We found from analyzing temperature records for the 103-year period of 1902 to 2005 that there is only a 5.2 percent probability of observing a temperature this cold, or colder, in the week of April 15 through 21 (Table 4.8). Essentially, this means is that a temperature of 28°F or colder during this particular week occurs about once every 20 years (Perry, 1998b).

In the next week, April 22 through 29, the probabilities of observing an air temperature as cold, or colder than 32°F, is only 5.7 percent (Table 4.8). If you assume a critical temperature for the 1- to 2-inch stage that is lower than 32°F, you will note that the probability of temperature as cold, or colder, than 31°F is 3.4 percent; for 30°F, the probability is 2.1 percent.

In assessing the frost climatology of a site, you may also investigate some *worse-case* scenarios. One such scenario involves atmospheric conditions that favor rapid radiation heat losses at night in newly developing grape shoots. Under low humidity and calm wind conditions, plant tissues can become 3 to 5°F *colder* than the surrounding air. Explained another way, plants cool themselves (by radiating their heat) to the point that they can cause their own damage (Evans, 2000). Thus, when a weather shelter sensor 5 feet above the ground records an air temperature of 34°F, the actual temperature of a young grape shoot at 5 feet could already be below 31°F (or possibly colder), which is potentially injurious.

Thus, given the potential divergence of air temperatures and grape tissue temperatures, with plant tissues potentially being 3 to 5 degrees colder than the air, you can examine frost probability estimates associated with a slightly higher air temperature of 34°F (for comparison to the standard 32°F threshold). This technique may keep you from underestimating the real threat of frost damage to the vineyard under radiation frost conditions with low atmospheric humidity.

In our sample case, we evaluated climate data for Reidsville for 1962 through 2005 using an air temperature threshold of 34°F and found a 30 percent chance of an air temperature of 34°F, or colder, occurring after April 21 (Table 4.9). In contrast, if we use a standard 32°F air temperature threshold, there is only a 10 percent probability of a temperature this cold, or colder, after April 21. *The first scenario predicts damaging frost once every three years; the second, once every ten years*. But, an air temperature observation of 32°F at the weather shelter height (5 feet) under radiational cooling conditions may be related to grape tissue temperatures of less than 29°F (at 5 feet), which could be very damaging to primary shoots of Chardonnay.

Without more data on atmospheric conditions associated with minimum temperature observations at Reidsville for 1962 through 2005 (especially relative humidity and dew points), we cannot really be certain of whether the risk of damaging frosts will occur with a frequency of three times in 10 years (30 percent probability), or only once per decade (10 percent). However, the vineyard uses vertical shoot positioning (VSP) canopies with a cordon height 3 feet, which makes frost damage more likely than if another system were used, so the level of frost risk would be greater than 10 percent for this location. Under radiation frost conditions, the height of the bud or newly developing shoot alters the potential frost hazard (Dethier and Shaulis, 1964). Researchers in New Zealand, for example, have reported that buds on a high cordon training system (Geneva Double Curtain) at 6.5 feet can be approximately 7°F warmer than those on a standard 3-foot VSP cordon, and 13°F warmer than the temperature at ground level (Trought et al, 1999).

Thus, it is worth remembering that any frost climatology data from official state weather stations that you use to estimate frost probabilities for a specific location are based on air temperature measurements made at 5 feet above the ground, and that bud and shoot temperatures at 3 feet for VSP training will be colder under radiational cooling conditions. Furthermore, it may be prudent to use a 34°F threshold to take into account the phenomenon that grape tissues may be 3 to 5 degrees lower than air temperatures on chilly nights with low relative humidity and little air movement (Trought et al., 1999).

Let's summarize our findings about the budbreak and early shoot development of Chardonnay at this central piedmont location, as well as the information we generated on spring frost probabilities:

1. *Predicted phenology.* At the Reidsville research vineyard, Chardonnay cl. 96 breaks bud

Table 4.9. Probability of Daily Lows at Reidsville Weather Station Based on Data Collected 1962 Through 2005

Temperature (°F)	Probability of Later Date in Spring Than Indicated										
	99%	90%	80%	70%	60%	50%	40%	30%	20%	10%	1%
36	3/31	4/6	4/11	4/15	4/18	4/21	4/24	4/28	5/2	5/7	5/10
34	3/23	3/30	4/5	4/08	4/11	4/14	4/16	**4/21**	4/24	4/30	5/7
32	3/16	3/23	3/28	4/1	4/4	4/7	4/9	4/13	4/16	**4/21**	5/4
28	3/7	3/12	3/16	3/20	3/22	3/25	3/27	3/30	4/2	4/7	4/20

in mid-April and reaches the 1- to 2-inch shoot stage around April 22. Thus, the potential for frost damage in most spring seasons will be highest in the second half of April.

2. *Making probability estimates from long-term temperature records.* Historical temperature records (1902 to 2005) collected at a meteorological station near the Reidsville vineyard were analyzed using an air temperature threshold of 28°F (or colder). It was found that the probability of a damaging frost in the week following budbreak (second week of April) was only 5.2 percent. Using an air temperature threshold of 32°F for the 1- to 2-inch shoot stage, the data show only a 5.7 percent risk of cold injury in third week of April. A 5 percent risk can be interpreted as a vineyard that would have a significant frost in 1 out of 20 years.

However, these risk levels may present an overly optimistic a picture of the actual frost hazard at this location. To take into account the phenomenon that grape tissues may be several degrees lower than air temperatures on still nights of radiational cooling and low relative humidity, we examined an air temperature threshold of 34°F. In evaluating climate data for Reidsville for the period 1962 through 2005, it was found that there is a 30 percent chance of an air temperatures of 34°F or colder occurring after April 21. In contrast, if we use a standard 32°F air temperature threshold, there is only a 10 percent probability of temperatures this cold or colder after April 21. In the end, a **20 percent risk of frost injury** may be an appropriate compromise as the canopy is just 3 feet high, and bud and shoot temperatures at 3 feet above ground level can be significantly colder under springtime radiational cooling conditions than for higher cordon training systems of 5 feet or higher.

From the information gathered about the potential risk of frost damage to Chardonnay at the Reidsville location, we can now undertake an investment analysis that will address the question of whether an active frost protection system may be economically warranted.

As you will see in the following section, once you determine from long-term temperature records that a site has frost risk greater than 20 percent (2 out of 10 years), it can become economical to consider an investment in a wind machine. Over-vine sprinkling systems offer a higher degree of frost protection than wind machines, but their fixed-rate design delivers more protection than generally necessary in most vineyards. (See chapter 11 for a more complete consideration of various active frost protection methods and their relative advantages and disadvantages.)

Step 3. Decide if a Frost Protection System Makes Economic Sense

While frost protection methods can be expensive, an active protection system, or combination of systems, may allow the grower using a frost-prone site to have more consistent crops and improved cash flow in years with potentially damaging frost events. An informed decision on whether an investment in a wind machine (or any other type of mechanical protection system or combination of systems) can be profitable requires economic analysis.

CROP LOSSES. First we need to consider potential crop losses in Chardonnay. If the primary shoots of *vinifera* varieties are killed by spring frost, secondary and tertiary shoots will grow, but the resulting clusters are fewer in number and are delayed in ripening past the normal harvest season. In a frost-free season, Chardonnay has a potential yield of 4-plus tons per acre, but a spring frost destroying the primary shoots of this variety could reduce yield by 50 percent or more. At Reidsville, we determined that in 2 out of 10 years we may experience damaging frost events in this early budbreak variety.

Economic impact of 50 percent crop loss at Reidsville. Even with a price per ton of $1,400 for Chardonnay grapes, a yield of 2 tons per acre will generate only $2,800, which is barely enough revenue to cover annual vineyard operating expenses of $2,675.[1] However, operating costs vary, and actual total costs of production on this site were estimated to be $4,103 per acre in 2006.[2]

Economic Benefits of a Wind Machine

Wind machines have proven valuable in combating radiational frosts at several commercial vineyards in North Carolina over the last decade (Figure 4.4). Table 4.10 shows the estimated cost of installation of a 125 HP gasoline-powered wind machine 35 feet tall with a 19-foot fan.

Figure 4.4. This Orchard-Rite wind machine stands 35 feet above the vineyard floor and has a 125 HP gas-powered engine that turns the 19-foot fan. It protects a 7-acre vineyard in Davidson County. (Photo taken by Barclay Poling, December 18, 2005)

To analyze the long-term consequence of frost events in a vineyard with and without a wind machine, Table 4.11, which shows the effect of the reduced crops due to frost events in the 10-year average returns of the vineyard. The average returns are calculated for different probabilities of having frost damage. For example, the Reidsville vineyard had a 20 percent probability of frost damage, which would cause two 50 percent yield losses every 10 years.

A wind machine adds $180 per acre. From Table 4.11 you will note that if no frost occurs in the 10-year period, the average net return in the vineyard without the wind machine is $294 per acre higher than the average net return in the vineyard with the wind machine. But, if there is a 20 percent risk of frost, as in the Chardonnay vineyard in Reidsville, the average net returns of the vineyard with the wind machine will be $180 per acre higher than the vineyard with no active frost protection. On a vineyard prone to spring frost in only one out of ten seasons (10 percent probability of frost damage), the wind machine would not produce a positive net return (-$56 per acre). Thus, on sites where temperature records indicate that there is a 20 percent or higher probability of spring frost during critical early stages of budbreak and new shoot growth, the investment in a wind machine may result in higher average net returns, better cash flows, and potentially improved vine health and management (Evans, 2000).

Over-vine Sprinkler Irrigation Systems

Relatively few of these systems have been installed in North Carolina, and you are advised to choose this method only if you have determined that your vineyard site is highly prone to frost and frost/freezes and that you have enough water to provide three consecutive frost/freeze nights of protection (about 155,000 gallons of water per acre).

Heaters

For years the principal method of frost protection in fruit crops was burning fuel to create heat. But burning diesel or propane as the sole means of frost protection has become prohibitively expensive. At $2.50 per gallon for

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[1] This represents variable costs without harvesting costs.

[2] Total costs except harvesting are $4,103, and this is made up of variable costs of production without harvesting ($3,075) + fixed costs of production ($1,428). Note that annual fixed costs of production include mainly the establishment costs ($1,273) and also machinery depreciation and other items that are incurred regardless of the level of production of the operation.

Table 4.10. Estimated Costs of Installation and Use of a Wind Machine in a 10-acre Vineyard

Item/description	Cost ($)
Initial cost of equipment	28,000
Annual total ownership (fixed) cost*	294/acre
Operating costs/hour**	2.17/acre
Labor costs***	10.50/hr

* Includes depreciation, interest, taxes, and insurance costs. It assumes 20 years of life of the equipment and a salvage value of zero.
** Includes fuel and repair costs. Repair costs equal 50 percent of the initial costs during the 20 years of use (this implies average annual costs of $700). Fuel and lubricants calculated at $380 per year.
*** Annual hours of labor = 1/3 of the machinery annual hours.

diesel, the cost of burning 40 heaters per acre would be $100 per hour. You must also figure in the cost for labor to light the heaters, put them out in the vineyard, and refill them for the next night of frost protection. *However, they remain an effective method of adding extra heat during nights when temperatures may fall below the capacity of wind machine protection* (Perry, 1998d).

Helicopters

Helicopters are an expensive method of frost protection, and their use is often limited to special cases and emergencies. Typically, these include times when a cold event is forecasted that will require significantly more protection **than a wind machine can provide** (not usually reliable for more than 1 to 3°F protection), and the potential for crop loss is high enough to justify it. Hourly costs ranging from $825 to $1,600, depending on the size of the helicopter, and availability. Usually, the grower is asked to guarantee at least 3 hours of work.

Table 4.11 Average Net Returns of Vineyards With Different Probabilities of Frost Damage (assumes 40 hours of wind machine use in years with frost)

	10-year Average Net Returns($/acre)		Difference in Average Net Returns	
Probability of Frost Damage (%)	Vineyard with Wind Machine	Vineyard Without Wind Machine	$/acre	$/10-acre Vineyard
0	803.00	1,097.00	-294.00	-2,940.00
10	780.32	837.00	-56.68	-566.80
20	757.64	577.00	**180.64**	1,806.40
30	734.96	317.00	417.96	4,179.60
40	712.28	57.00	655.28	6,552.80
50	689.60	-203.00	892.60	8,926.00
60	666.92	-463.00	1,129.92	11,299.20
70	644.24	-723.00	1,367.24	13,672.40
80	621.56	-983.00	1,604.56	16,045.60
90	598.88	-1,243.00	1,841.88	18,418.80
100	576.20	-1,503.00	2,079.20	20,792.00

Passive Methods for Managing Spring Frost Risk

Short of an investment in an active frost control method (wind machine, irrigation system, heaters, and helicopters) for sites determined to be prone to spring frosts, you may wish to consider three methods of passive frost protection:

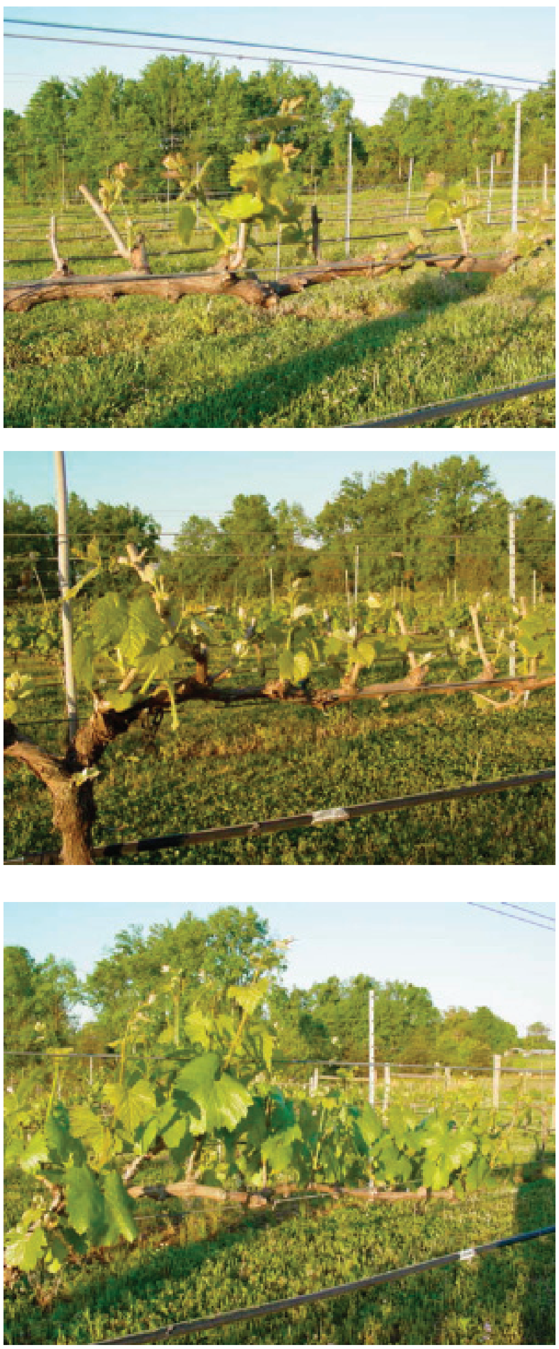


Figure 4.5. Variety makes a difference. Compare the 3-inch shoots in Verdejo (top) with the 5-inch shoots in Traminette (center) and the 8-inch shoots in Chardonnay (bottom). All three photos were taken April 28, 2005, at the research station in Reidsville. (Photos by Ashley Johnson, research technician, UPRS, Reidsville.)

- ❑ Select varieties with later budburst and shoot development.
- ❑ Select a hybrid with very fruitful secondary buds (not a *vinifera*).
- ❑ Use cultural techniques that minimize frost damage.

VARIETY SELECTION. Chardonnay clones are the first to break bud at the Reidsville research vineyard location, and by the end of April you can see a considerable range in average shoot development among varieties. Chardonay cl. 96 is an early budbreak variety, compared to two later breaking *vinifera* varieties (Figure 4.5). Chose a variety with a later budbreak, and you may be able to escape frost damage and use a frost-prone site. From a frost-control perspective, grape varieties that are 1 or 2 weeks later in budbreak would be better matches for the Reidsville vineyard location than Chardonnay. Given the frost climatology of any site, it would be best to identify varieties that do not break bud until the probability of damaging frosts is significantly reduced in the final week of April. There is currently little information on possible differences in frost resistance of *vinifera* varieties at the same stage of development.

SELECTING TYPES OF GRAPES OTHER THAN *VINIFERA*. Another strategy for sites particularly prone to frost may be to consider *interspecific hybrids,* which produce more fruitful secondary buds than *vinifera* varieties after primary shoots are injured by cold. At the Reidsville vineyard site, Chambourcin, an interspecific red hybrid (see chapter 3), breaks bud a week later than Chardonnay. Its later budburst reduces the chance of damage from spring frosts, and it also has fruitful secondary shoots should a frost damage the vine. With the risk of a late April or early May frost, an interspecific hybrid like Chambourcin may be a better match for locations with frost risk characteristics similar to the Reidsville research vineyard.

While much of the current discussion in this chapter concerns susceptibility to spring frosts, grape varieties like Cabernet Sauvignon, which mature their fruit and wood relatively late in the season, should be avoided in areas that are subject to early fall frosts.

CULTURAL TECHNIQUES. In addition to making sure that a site does not have either natural or manmade down-slope impediments to cold air drainage (e.g., dense shrubbery, windbreaks, and buildings), use these cultural strategies to minimize frost damage:

- ❑ Select a northern or eastern aspect for early budbreak varieties. The same varieties on a southern aspect can break bud up to 7 days earlier (Wolf and Boyd, 2003).
- ❑ Cleanly cultivated vineyards are usually 1 to 2°F warmer than vineyards covered by sod or ground cover. Vegetation reduces the amount of heat absorbed by the ground during the day and inhibits release of heat at night (Sugar et al., 2000). However, do not cultivate the soil just before a frost or freeze because it loosens and dries the soil.
- ❑ Maintain a moist, compact soil that is able to store more heat during the day than a loose, dry soil. Moist, compact soil has more heat to transfer to the crop at night.
- ❑ Mow sod closely in spring. It has been found in Oregon that sod mowed close to the ground with a flail mower is nearly equivalent to a clean-cultivated vineyard floor (Sugar et al., 2000).
- ❑ Train varieties with a procumbent (trailing) growth habit to a high cordon to lessen the frost hazard, as the closer buds are positioned to the ground, the greater the frost hazard (see Table 3.2).
- ❑ Prune vines in the dormant season, but leave those canes that are ultimately to become bearing spurs at their unpruned length; return to prune them to the desired number of buds when the terminal buds have sprouted 2 to 4 inches (Sugar et al., 2000).

Summary

The first three chapters in this guide have considered a large number of factors that are important to the success of the grape-growing enterprise, including economic and market considerations as well as careful variety selection. Consistent production of high yields of quality fruit will be more easily attained if you plant your vineyard on a good site. The information in this chapter gives you a solid starting point to work from in evaluating the suitability of potential grape sites. Once vines are in the ground, it is prohibitively expensive to relocate them. Mistakes made in site selection can be very costly. Weigh the many factors in selecting a site; focusing on one feature to the exclusion of others is a serious mistake.

Compromises must inevitably be made because few sites are ideal in all regards. However, you should not compromise on good soil depth and internal drainage, and on having good local relief. We have observed that even 100 feet in local relief can generate highly beneficial thermal zones for relatively frost-free grape production in most seasons, provided there is a broad enough valley floor below the vineyard for cold air to collect. This chapter provides considerable information on the important first step of *how to* evaluate the probability of damaging frost events for potential vineyard sites. We encourage you to take advantage of climate information available from the North Carolina State Climate Office , where experts can provide historical probability analysis of the frequency of temperature events below 32°F (or, 34°F, if you wish to identify the potential for cold injury under low atmospheric humidity conditions) for a number of locations across the piedmont, foothills, and mountains. Your county Extension agent can assist you in this initial phase of site evaluation and may also be able to furnish you with information regarding the range of budbreak dates in your area for winegrape varieties you are interested in growing.

While it is still possible to identify slopes and hillsides that have a lower risk of spring frost, it is also important to recognize that the hazards of a late spring frost, or frost-freeze, cannot be entirely avoided. Rather than adopt a view that all forms of active frost protection are too costly, a more practical approach may be to first pinpoint the frost hazard may be associated with a particular site, and then to consider the most economical methods for reducing these potential losses.

Short of investing in an active frost protection system, consider passive protection approaches for a site that may be too frost-prone for an early budbreak variety like Chardonnay. For example, at the Reidsville test vineyard site, we identified a *vinifera* variety that breaks bud later than Chardonnay, and by growing this variety, we would significantly reduce the need for active frost protection. If substitution of varieties or types of grapes is not an option, it is very important that you evaluate different types of active frost protection. In using an economic investment analysis, we demonstrated that for vineyard sites with a probability of radiational frost in 2 years out of 10, a wind machine could be a profitable risk management tool.

Realizing that many potential grape growers do not have the financial flexibility to purchase prime vineyard sites with minimal frost hazard, chapter 11, *Spring Frost Control,* provides further information on each of the major methods of active frost protection. Several commercial vineyards in North Carolina's piedmont have used wind machines over the last decade and can attest to their cost-effectiveness on relatively frost-prone sites.

References

Amerine, M. A., H.W. Berg, R. E. Kunkee, C. S. Ough, V. L. Singleton, and A. D. Webb. 1980. The Technology of Winemaking. 4th edition. AVI Publishing Co. Inc. Westport, CT.

Dethier, B.E. and N. Shaulis. 1964. Minimizing the hazard of cold in New York vineyards. Cornell Extension Bulletin 1127. 8pp.

Evans, R. G. 2000. The art of protecting grapevines from low temperature injury. Proceedings of ASEV 50th Anniversary Annual Meeting, Seattle WA, June 19-23, pp 60-72.

Gardea, A. A. 1987. Freeze damage of 'Pinot noir' (*Vitis vinifera* L.) as affected by bud development, INA bacteria, and bacterial inhibitor. M.S. Thesis, Oregon State University, Corvallis.

Gladstones, J. 1992. *Viticulture and Environment.* Winetitles, Adelaide, Australia. 310 pp.

Hurt, W. N. 1923. Thermal belts and fruit growing in North Carolina. U.S. Department of Agriculture's Monthly Weather Review Supplement, No. 19.

Jackson, David, and Danny Schuster. 1987. The Production of Grapes & Wine In Cool Climates. Butterworths of New Zealand (Ltd), Wellington, New Zealand, p. 5.

Jones, G. V., and E. Hellman. 2000. In: Oregon Viticulture, Site assessment, ed., E.W. Hellman, Oregon State University, pp 44-50.

Johnson, D. E., and G. S. Howell. 1981. Factors influencing critical temperature for spring freeze damage to developing primary shoots of Concord grapevines. American Journal of Enology Viticulture. 32. 144-149.

Martsolf, J. David, and Robert M. Peart. 2003. Frost control rules. Proceedings of the Florida State Horticultural Society. FAES J. Series No. N-02253, 115.

Moncur, M. W., K. Rattigan, D. H. McKenzie and G. N. McIntyre. 1989. Base temperatures for budbreak and leaf appearance of grapevines. American Journal of Enology Viticulture. 40:21-26.

Perry K. B. 1998. Basics of Frost and Freeze Protection for Horticultural Grapes. Hort Technology. 8(1) 10-15.

Perry, K. B. 1998a. Guide to deciding when to start and stop irrigation for frost protection of fruit crops. Horticultural Information Leaflet 713, North Carolina Cooperative Extension Service, NC State University, Raleigh, NC.

Perry, K. B. 1998b. Average Last Spring Frost Dates for Selected North Carolina Locations. Horticultural Information Leaflet 707, North Carolina Cooperative Extension Service, NC State University, Raleigh, NC.

Perry, K. B. 1998c. Average Growing Season for Selected North Carolina Locations. Horticultural Information Leaflet 709, North Carolina Cooperative Extension Service, NC State University, Raleigh, NC.

Perry, K. B. 1998d. Basics of frost and freeze protection for horticultural crops. *HortTechnology* 8:10-15.

Perry, K. B. 1999. Weather and climate information for North Carolina. Horticultural Information Leaflet 706, North Carolina Cooperative Extension Service, NC State University, Raleigh, NC.

Smart, R. E., and P. R. Dry. 1980. A climatic classification for Australian viticultural regions. Australian Grapegrower and Winemaker 17: 8-16. Ryan Publications Pty Ltd., Ashford, Australia.

Sugar, D., R. Gold, P. Lombard, and A. Gardea, 2003. In: Oregon Viticulture, Strategies for frost protection, ed., E.W. Hellman, Oregon State University, pp.213-217.

Teubes, Andrew and Johan Wiese. 2003 (Nov). Practical Viticultural Experience of Certain "New" Cultivars: Viognier, Petit Verdot, Tannat, Mourvédre Part 4. Wynboer – A Technical Guide for Wine Producers, Suider-Paarl, South Africa http://www.wynboer.co.za/recentarticles/1103cultivar.php3.

Trought, M.C. T, G. S. Howell and N. Cherry. 1999. Practical considerations for reducing frost damage in vineyards, Lincoln University, New Zealand, 43 pp.

White, R. E. 2003. Soils for Fine Wines, Oxford University Press, New York, NY.

Winkler, A. J., J. A. Cook, W. M. Kliewer, and L. A. Lider. 1974. General Viticulture. University of California Press, Berkeley, CA.

Wolf, T. K., and J. D. Boyer. 2003. Vineyard Site Selection. Publication Number 463-020, Virginia Polytechnic Institute and State University, Blacksburg, VA. http://www.ext.vt.edu/pubs/viticulture/463-020/463-020.html.

Wolf, T. K., and E. B. Poling. 1995. The Mid-Atlantic Winegrape Grower's Guide. North Carolina Cooperative Extension Service, NC State University, Raleigh, NC.

Chapter 5

Vineyard Establishment

Vineyard establishment involves careful planning, thorough site preparation, vineyard design, planting, and trellis construction. Unlike dormant pruning or other annual activities, designing and establishing a vineyard must be done correctly the first time. In addition, the process must be tailored to the particular site and the grower's intentions. This chapter discusses the basic steps in establishing a vineyard and offers suggestions for practical methods and materials. There are many alternatives. Although this chapter may be used as the sole source of information for vineyard establishment, it is advisable to obtain and compare information from additional sources before beginning. References provided here include more detailed information on particular aspects of vineyard establishment, such as trellis construction. It is also helpful to visit existing vineyards to examine their design, compare trellising materials, and discuss plant and row spacing.

Preparing the Site

The first step is to prepare the vineyard site. The main objectives are to correct deficiencies in soil pH and nutrient availability and to prepare a level, clear surface on which to establish the cover crop, vines, and trellises. Some sites are wooded, in which case considerable effort will be needed to prepare for planting. In contrast, cultivated land or well-managed pastures can sometimes be planted to vines with very little preparation.

Soil Testing

Physical soil features should be evaluated in the site selection process. (See chapter 4.) Most important, the soil must meet minimum standards of depth and internal water drainage. Soil survey maps should be consulted to determine the agricultural suitability of any proposed site. The history of crop production at the site can provide some indication of its potential for grape production. Sites that have been cultivated recently are usually in better condition than pasture or abandoned farmland. Heavily wooded sites are the most difficult to bring into grape production, and grape growth often varies across the site because soil has not been mixed by cultivation. Wooded sites may be suited for little else because of their steepness, rockiness, or poor soil.

Detailed soil analyses must be made before a vineyard is established so that pH and fertility can be adjusted if necessary. Procedures for conducting soil tests and interpreting the results are discussed in chapter 9.

Brush and Rock Removal

The vineyard site must be cleared of any trees, brush, and loose rocks before cultivation. The removal of large trees should be followed by subsoiling 18 to 24 inches deep to remove large roots and incorporate lime if applied. It is generally more efficient to hire an experienced bulldozer or loader operator to clear trees and rocks from the site rather than trying to do this task by hand. During site preparation, any impediments to air movement into and out of the vineyard should be removed, which might entail removing adjacent overgrown fencerows or pushing back the edge of shading woods. To avoid shading and root competition, do not plant vines close to adjacent woods or tree lines. As a rule, vines should be planted no closer to shading objects than the average height of these objects. Also enough land should be cleared to erect an electric deer exclusion fence if deer are known to use adjacent cover. The construction of deer fences is a specialized task; see the sources of information listed at the end of chapter 8.

Cultivation

In certain cases, existing pasture can be planted directly to vineyard rows without destroying the groundcover between the rows. This option is feasible if (1) soil tests demonstrate an acceptable pH for the intended grape species and (2) the existing vegetation is suitable as a vineyard cover crop. In this case, the vineyard rows are marked off (see "Marking Off the Vineyard") and a 24-inch sod strip in the row is killed with a postemergence herbicide, usually in the fall before planting. To foster root development, rows can be ripped with a 18- to 24-inch single-shank ripper before planting.

More frequently, the need for soil pH and nutrient adjustment or perennial weed eradication will require soil cultivation. Various schedules can be used in establishing a vineyard. One logical sequence for preparing and planting a partially wooded site is as follows:

Late winter: Complete the tree, brush, root, and rock removal process.

First spring: Adjust soil pH and fertility; plow and disk the site; plant a cereal crop, such as spring wheat or oats.

Summer: Spot treat residual perennial weeds with herbicides.

Late summer: Apply additional lime if necessary; plow in the cover crop residue; plant a perennial cover crop.

Second spring: Apply a postemergence herbicide to vine rows; auger holes and plant the vines.

Summer: Set posts and construct trellises.

Regardless of the time frame or approach followed, it is important to rid the site of persistent weeds, brambles, brushy trees, and other unwanted vegetation before setting vines. In some cases, weed eradication might require the planting and cultivation of cover crops for a period of two years rather than one as outlined above. Chisel plowing to a depth of 12 to 24 inches helps to incorporate lime and loosens compacted soil. It may be possible to reduce costs by employing the services of a local custom equipment operator. Operations such as plowing and disking may be needed only during the establishment phase and thus it may not be necessary to purchase specialized equipment.

In most North Carolina vineyards, perennial cover crops are planted between the rows. A perennial cover crop, as the name implies, is one that is retained from year to year. Grasses are preferred because they do not serve as alternative hosts for nematodes and because grass retains its foliage during the winter, reducing soil erosion. Nematodes are tiny worms that can damage vines by their feeding or by transmitting virus diseases. If the intended vineyard site has been used for grape or other fruit production within the last five years, the soil should be tested before planting to determine nematode populations. Instructions for nematode assays are available from county Cooperative Extension centers.

Cover crops offer several important advantages over clean cultivation (leaving the soil bare).

Soil erosion control: Cultivated agricultural acreage loses about 8 tons of soil per acre per year. This loss is greater on hilly terrain where vineyards are often located. Grass sod reduces erosion by lessening the impact of rain and slowing the movement of surface water, thus allowing greater water infiltration.

Increased vineyard accessibility: A permanent cover crop makes it possible to enter the vineyard with equipment sooner after a rain than if the soil is bare. The sod increases the rate of soil moisture loss and provides greater traction for machinery.

Moderation of vine vigor: Cover crops can reduce vine growth rates, which can be either an asset or a liability, depending on available moisture, vine size, and vine vigor. Grapevines grown in our region — particularly grafted vines —often produce more leaf area than the trellis and training system can expose to sunlight. This situation is referred to as high vigor. The excess growth can lead to an undesirable degree of canopy shading, reducing fruit quality. Competition for water and nutrients by cover crops can reduce the vegetative growth of vines, thereby reducing canopy shading problems. Unfortunately, cover crops can adversely affect weak vines, particularly during droughts. Mowing and keeping a 3- to 4-foot-wide area in each vine row relatively weed-free is recommended. Please see in chapter 8, Pest Management, for new recommendations on specimen selection and management.

Most grasses will establish better if sown between mid-August and mid-September rather than during the spring. Most seed distributors can provide specific recommendations on seeding methods. Nitrogen fertilizer broadcast at 35 pounds of actual nitrogen per acre when grass is sown can stimulate growth.

If an existing vineyard is to be replanted, the old vineyard should be cleared and planted to grass or cereals (for example, oats or barley) for a minimum of two years. This fallow period will help reduce populations of grape root pests, perennial weeds, and concentrations of preemergence herbicides that might be present.

Designing the Vineyard

If all vineyard sites were level, clear parcels of land and had ideal soil conditions, vineyard establishment would be relatively straightforward. It would be necessary only to mark the rows (posts and vine locations) using suitable spacings, and then dig holes and plant the vines. Not all vineyard sites, of course, are equal. Proposed sites are commonly on slopes; sometimes they are partially or completely wooded and others are characterized by irregular knolls and depressions.

Vineyard design starts with evaluating how the vineyard will conform to existing topographic features and property boundaries. Vineyard planning should achieve these primary goals:

- ❑ prevent soil erosion (intentionally ranked highest in priority)
- ❑ use land area efficiently
- ❑ optimize vine performance
- ❑ facilitate vine management and equipment operation.

Partitioning the Vineyard into Blocks

Vineyards larger than several acres are generally partitioned into "blocks." A block might represent a single variety or, on uneven terrain, blocks might reflect the allowable planting area. Division of a large vineyard into blocks is also convenient for keeping records of inputs (such as pesticides and labor) and returns (fruit yields) for cost-accounting purposes. Figure 5.1A illustrates a vineyard partitioned into several blocks. The blocking pattern used was intended to keep most rows running perpendicular to the existing slopes. Dividing a vineyard into blocks might also be necessary because of existing fence lines, roads, or natural features like streams or rock outcroppings. In designing the vineyard, reserve the highest locations of the site for varieties that are sensitive to winter cold and for those that break bud early in the spring (Figure 5.1B). Initial vineyard design should include sketches of the property with plantable areas drawn in or superimposed on clear plastic overlays.

Row Orientation

On level sites, orient rows to maximize length and minimize number. Such an orientation minimizes the number of expensive end-post assemblies. Most sites are not level, though. Rows should be oriented across, or perpendicular to, the predominant slope of the site to minimize soil erosion. Do not contour or curve rows around hills; the trellises of curved rows are structurally weak. In cases where the site is hilly, it is sometimes best to position the rows in a herringbone pattern. Low areas and gullies should be left open and sodded to serve as erosion barriers or traffic alleys. Some advantage can be gained by orienting rows parallel to prevailing summer breezes to aid vineyard ventilation. A further consideration is to maximize sunlight interception by the vine canopies. Field research and computer simulation studies have shown that rows oriented in a north-south direction receive more sunlight and produce slightly higher yields than those oriented east to west. Thus, if other factors are equal, it is desirable to align rows as closely as possible to a north-south axis. Generally, however, orientating the rows to minimize soil erosion should take precedence over other considerations.

Row Spacing

Maximum vineyard productivity is attained when most of the available sunlight is intercepted by grapevine leaves. Sunlight striking the ground can be thought of as wasted energy. Research shows that vineyard productivity and grape quality are maximized when grapes are grown in rows with their foliage trained to thin, vertical canopies. Row spacing in such a design (the distance between two adjacent rows) should be no less than the intended canopy height to minimize row-to-row shading of adjacent canopies.

Most trellises are constructed with 8-foot line posts set 2 feet into the ground, thus providing a 6-foot-high trellis supporting about 4 feet of canopy. Thus, for conventional nondivided canopy training systems, the row spacing should be no less than 4 feet. Conventional vineyard equipment widths, however, usually limit the minimal row spacing to 8 to 10 feet. Equipment availability and operation should be considered carefully before deciding on row spacing. A relatively wide spacing (10 to 12 feet) is advised on steeper terrain (5 to 15 percent slope) or where horizontally divided canopy training systems are planned. (See "Trellis Construction.")

Vine Spacing

Perhaps no other aspect of vineyard design leads to as much difference of opinion as vine spacing: the distance between adjacent vines along the same row. Vine spacing of 6 to 8 feet is most common in North Carolina. From an economic standpoint, close vine spacing (less than 4 feet) increases the yield per acre in the initial years of production. However, that accelerated return can be offset by higher costs for materials (vines and training stakes) and labor (planting and training). There is no evidence that close spacing improves vineyard yields or fruit quality, and there is ample evidence that it complicates canopy management. On the other extreme, wide vine spacing (greater than 10 feet) can result in poor trellis fill (the amount of trellis occupied by foliage), particularly with cane-pruned vines or after winter injury to trunks and cordons. Therefore, a planting distance of 6 to 10 feet between vines is generally recommended for nondivided canopy training systems. However, a 7-foot spacing is recommended for most situations and a 6-foot spacing is recommended for low vigor vines grown in poorer soils. The 8- to 10-foot spacing is recommended for grafted vines in rich soils or where irrigation is used.

Headlands and Alleys

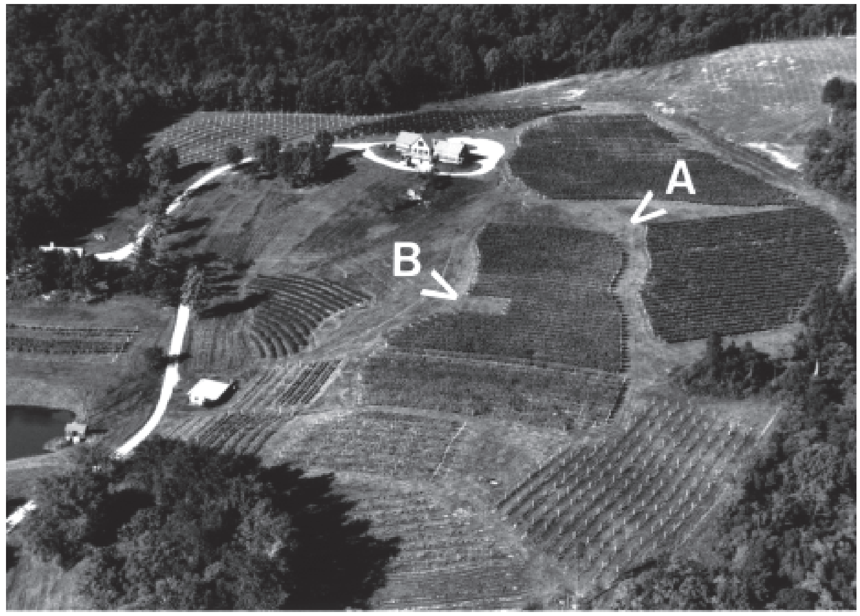
Ample room should be left at the end of vineyard rows (the *headland*) to provide space to turn equipment. Tractors with attached trailer-type air-blast sprayers require a minimum of 30 feet turning clearance (Figure 5.1a). Rows longer than 600 feet should be divided at the midpoint with a cross alley to facilitate movement of machinery and personnel.

Marking Off the Vineyard

Before vines are planted it is necessary to mark vine and post locations to ensure uniformly spaced vines and parallel rows. In the two methods described here, the vines are planted first in preaugered holes, followed soon afterward by pounding of posts and construction of trellises. Obviously, it is possible to reverse that order and pound or set posts before the vines are planted. In either case, it is extremely important to mark off straight and parallel rows. Figures 5.2a through 5.2c illustrate the basic steps involved in marking off an irregularly shaped vineyard block of about 4 acres.

The first step in marking the block is to choose a reference point—one corner of the vineyard block and one end of a reference row (point A in Figure 5.2a). The reference row is typically the first row in a block, but it can be any row. The reference point or corner is used to establish a grid upon which the vines and posts will be set. The reference point is also the location of the first vine of the first row. Therefore, leave an ample headland plus one-half a vine space behind the reference point to set an end post. The reference row is typically set parallel to an existing property boundary, fence line, ridgeline, or roadway. In Figure 5.2a, the reference row is set parallel to an existing fence line. On level land, the reference row can be oriented more arbitrarily or to a preferred compass direction (for example, north-south).

With a reference point chosen, the next step is to mark off a precise right angle. One leg of this angle is the reference row and the other leg



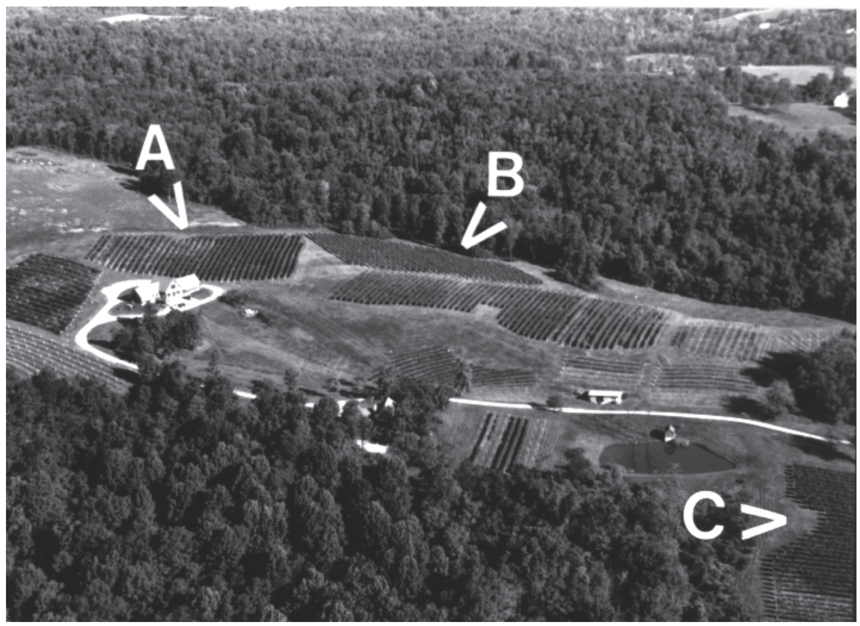
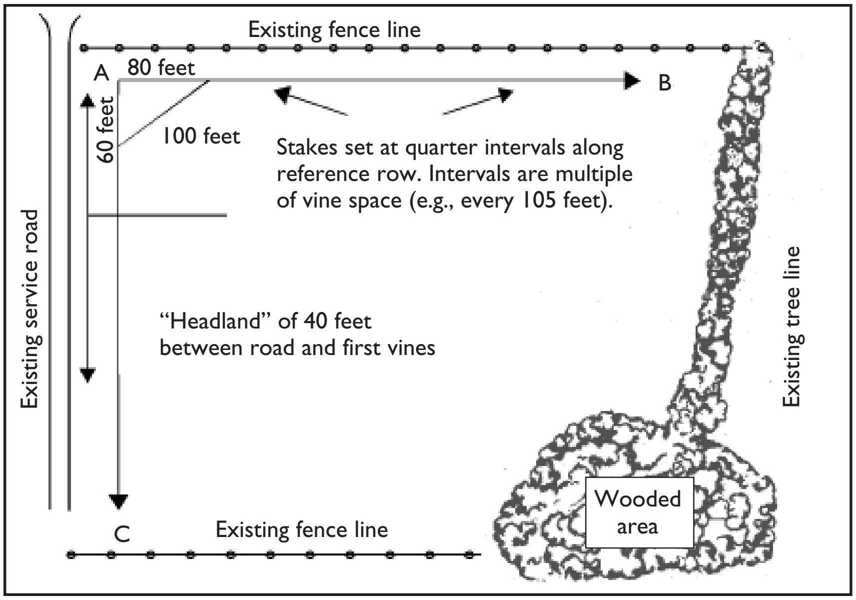
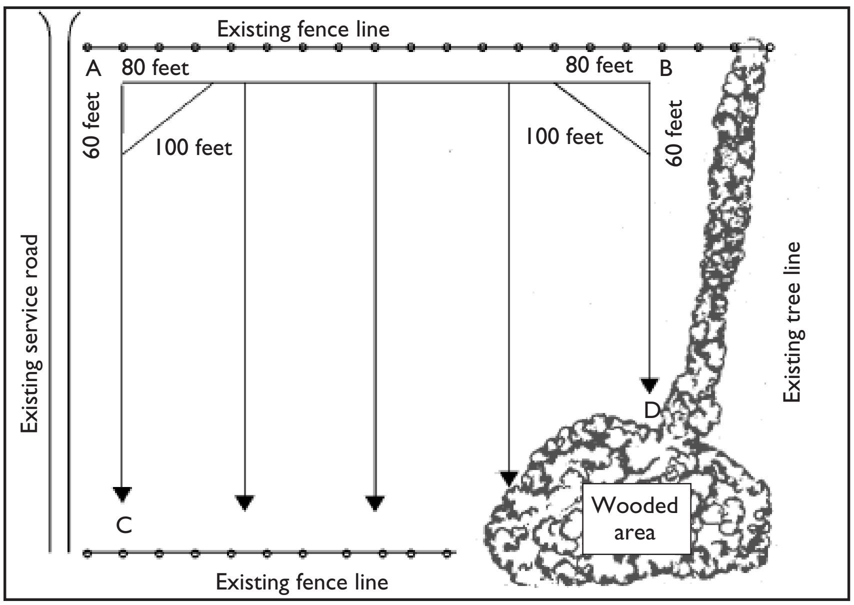


Figure 5.1a (top). The blocking pattern of this vineyard was designed to keep most rows running perpendicular to the prevailing slope. (A) Unplanted alley separates two blocks that have different row directions. (B) Inset area was considered too steep to plant.

Figure 5.1b (bottom). Varietal differences in time of bud break and cold hardiness were used to determine the relative elevation of vineyard blocks. The difference in elevation between highest (A) and lowest (C) blocks is approximately 100 feet. (A) Chardonnay: cold tender, early bud break. (B) Vidal blanc: cold hardy, late bud break. (C) Seyval: cold hardy, early bud break, good secondary crop potential.





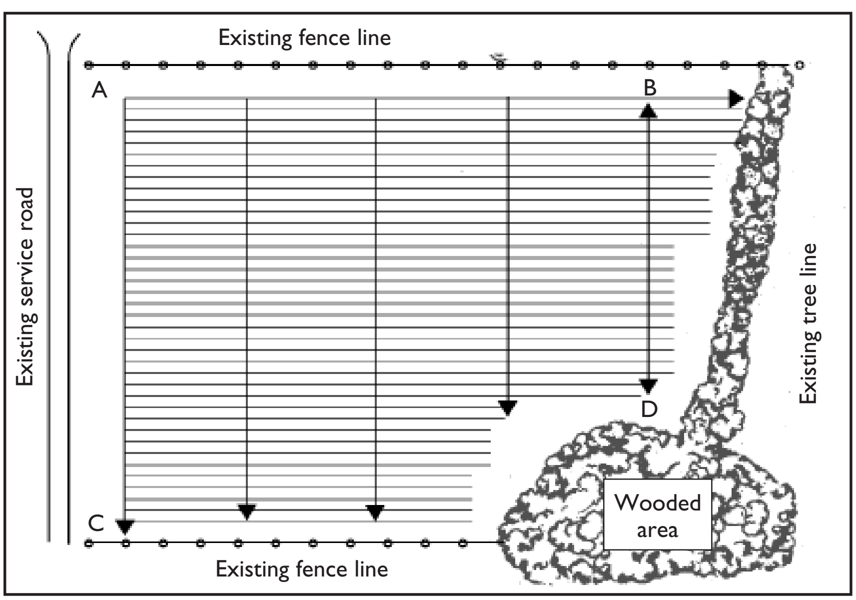


Figure 5.2a (top). Marking off vineyard: The reference point (A) is chosen to establish the first right angle corner of the vineyard.

Figure 5.2b (center). The second corner (B) of the vineyard is established. Grid lines are staked to further ensure that vineyard rows will be parallel.

Figure 5.2c (bottom). Vine locations are marked in each row by stretching a pre-marked wire between corresponding row ends.

defines the first vines in each of the following rows. It is critical that this first corner of the vineyard be a true right angle to achieve a square or rectangular pattern to the vineyard rows. A surveyor's transit is useful for establishing right angles and straight rows. Position and level the transit over the corner reference stake (point A in Figure 5.2a). Aim the transit down the intended length of row 1. The point of aim could be another stake (B in Figure 5.2a) set to form a line parallel to an existing landmark (that is, the fence line), or the line could be arbitrary. Set the transit dial compass (if equipped) to 0°. Sighting through the transit, have an assistant with a range rod set stakes (use 18-inch surveyor's stakes) at quarter intervals down the length of row 1. The stake intervals should be some multiple of the vine space distance. In Figure 5.2a, the stakes were set every 105 feet (7 x 15). Be sure that the tape measure used to determine these intervals is pulled taut and that it is held close to the ground.

Having marked the reference row, turn the transit 90° and sight down the row ends to point C (Figure 5.2a). Have an assistant with a tape measure set stakes at intervals corresponding to end-post locations (for example, every 10 feet). At this point, check the trueness of this first corner of the vineyard. This can be done by ensuring that the dimensions of the corner correspond to the 3:4:5 ratio of the sides of an accurate right triangle. Place a stake in the reference row 80 feet (4 x 20) from the corner stake (point "A"). Place another stake 60 feet (3 x 20) (the sixth row if using 10-foot rows) in the line of row-ends. The diagonal line between these two stakes will be 100 feet (5 x 20) if a true right angle has been established (Figure 5.2a).

Move the transit to the opposite end of row 1 (point B) and level it. Rezero the transit by sighting back down row 1. Turn the transit 90° and sight across the rows (point D in Figure 5.2b). Note that in Figure 5.2b the north end of vineyard rows is staggered to maintain a 30- to 40-foot headland between the row ends and the tree line. Point B was chosen as a reference point common to all rows above the wooded area. Have an assistant with a tape measure mark row widths as before. Repeat the process of ensuring that this second corner is a true right angle. Repeat the cross-row staking at the quarter-interval stakes along row 1. Check the distance between these grid lines at both ends to ensure that they are parallel and their corners are true right angles. The quarter-interval grids need not be marked off in small plantings.

Once vineyard row widths have been established, mark all vine locations in all rows, starting with row 1 (Figure 5.2c). Use a length of trellis wire long enough to extend the length of the longest row. Mark the wire at intervals corresponding to vine spacing with white paint or adhesive tape (for example, every 7 feet). Stretch the wire tautly between the row end markers of row 1 and mark each vine location (Figure 5.2c). The wire should be kept close to the ground when traversing depressions in topography. A good steel tape measure can be used in lieu of premarked trellis wire. Vine locations can be marked by dropping 1/4 cup of lime at the desired spots or by spraying a spot of white paint on the ground.

Repeat the above process to mark vine locations in all remaining rows. Remember to leave one-half a vine space behind the first and last vine of each row to later place the end posts. Post locations can be determined in a similar fashion either before or after vines have been planted.

Planting

Vines are usually planted in the spring, generally between the first of April and the end of May. It is not necessary to delay planting until after the threat of spring frosts. Fall planting is also permissible if arrangements can be made to receive vines from the nursery during that period. Be sure that vines planted in the fall were recently dug and are in a dormant condition. Vines that have been in cold storage over the summer are apt to commence growth if planted in the fall and subsequently exposed to unseasonably warm weather. In that event, the vines would be susceptible to severe winter injury. It is also desirable to hill up soil around fall-planted vines to reduce heaving that can occur with repeated freezing and thawing of loosened soil.

Nursery Stock

The number of vines to order depends upon row and vine spacing. For small plantings, divide the row length by the vine spacing, round up to a whole number if necessary, and multiply by the number of rows. For larger plantings, first determine the area of the vineyard (multiply the length by the width) and divide that figure by the area occupied by a single vine (the row spacing multiplied by the vine spacing). Add 1 percent extra vines to allow for poor vines or loss during the first year. The extra vines can be planted closely in a nursery and used later as needed.

Vines should be purchased only from reputable nurseries that offer certified disease-free stock. Nurseries that specialize in grapes generally offer better prices and quality than nurseries that sell a variety of plant species. Vines should be ordered well before the intended planting date. For spring planting, order vines no later than October or November of the previous year. In some cases—for example, if a particular rootstock is desired—it might be necessary to order vines one to two years before planting. For unusual varieties, it may be preferable to order the budwood from a certified source, such as the Foundation Plant Materials Service (FPMS.ucdavis.edu) at Davis, California, and have the budwood delivered to a reputable grafter or nurseryman for grafting or rooting.

Receiving Stock

Arrange to have stock delivered several days to a week before the intended planting date. Remember, there is no guarantee that planting conditions will be suitable at the time the vines are delivered. For that reason, provisions should be made to hold the vines in a cool, shady place upon delivery. Upon receiving stock, open the shipping containers and ensure that the roots are moist. Keep the vines cool and roots moist until planting time. It is critical that the roots of unplanted vines not be exposed to freezing temperatures. The vines should arrive in a dormant condition and, depending on temperature, should not break bud for one to three weeks.

Setting Vines

Holes for vines should be augered as an independent operation before the day of planting. Auger holes using a 9- to 12-inch-diameter auger. The holes should be about 12 to 18 inches deep. Holes augered in heavy clay soils often have glazed, impermeable sides, particularly if the soil was wet when drilled. The smooth surfaces of glazed holes can restrict root growth. The sides of auger holes should therefore be scored with a hoe or hand trowel before planting. The soil should be moist on the day of planting. Wet soil is apt to compact; dry soil can desiccate tender roots.

The roots of the young vines should not be trimmed; however, trimming the roots is better than twisting the roots to fit the hole. (The ideal way to accommodate large roots is to drill a larger hole.) The vine roots must be kept wet during planting. Even brief periods of drying can injure the roots. A convenient method of keeping roots wet while carrying vines in the field is to place 10 to 20 vines in a 5-gallon plastic pail half filled with water. Grafted grapevines should be set in the hole with the graft union several inches above the soil level (Figure 5.3). Soil settling should result in the graft union being an inch or so above the soil line. If set too deep, the scion, or fruiting, portion of grafted vines will develop roots that will be difficult to remove. Such vines can become susceptible to phylloxera attack. Nongrafted grapevines should be set with the crown (junction of older wood and newer canes) 1 or 2 inches above the soil line (Figure 5.3). Spread the roots in the hole and backfill with soil. Firm the soil but do not pack it. Water the vines thoroughly as soon as possible after planting. In this regard, a preestablished irrigation system offers a decided advantage.

Mechanical Planting

Planting by hand, as outlined above, is suitable for small (1- to 10-acre) plantings. For larger plantings, the speed of mechanical planting makes it more attractive. Mechanical tree planters can be rented for this purpose.

Initial Vine Training

Vines should be pruned back after the last threat of spring frost to a single cane of two to three buds. At that time it is desirable to place a 4- to 5-foot stake at each vine (Figure 5.3). Bamboo stakes are available for this purpose and are relatively inexpensive. Stakes serve two purposes: they clearly mark vine locations and they serve as a support to which developing shoots can be tied. The stakes should be set 10 to 12 inches deep and should be long enough to be tied to the first wire of the trellis system. First-year vine training is similar regardless of the intended training system. Training systems are discussed in chapter 6.

Constructing the Trellis

Research and experience have led to specialized methods and materials for trellis construction, many of which are adapted from modern fence-building concepts. Some excellent information is commercially available on this subject. (See the sources listed at the end of this chapter.) The vineyard trellis must be strong enough to support large crops as well as to bear the force of occasional high winds. Consider that the trellis will represent a major investment and should serve for 20 or more years with routine maintenance. The following discussion pertains to the construction of a typical nondivided canopy training system with three to seven wires.

Posts

Pressure-preservative-treated yellow pine or other softwood posts are the most commonly used and recommended for vineyards in this region. Eight-foot posts are standard; when set 2 feet deep, they provide a 6 foot-high trellis. Longer posts are desirable only for deeper placement, as with end posts or brace assemblies. Round posts are preferred to square-cut posts; round posts have much greater shear strength than square-cut posts of comparable size.

Wood posts should be treated with a preservative for in-ground use and should last for up to 20 years. "Preservative" means any chemical used in treating wood to retard or prevent deterioration or destruction caused by insects, fungi, bacteria, or other-wood destroying organisms. The pressure-treating process results in a post with a lifespan 10 to 15 years greater than that of a post simply dipped in the same preservative. Most wood preservatives are highly toxic, and workers should wear gloves and protective eyewear when handling or cutting posts. It is inadvisable to use untreated posts in the vineyard. Locust or cedar posts, debarked and painted with a wood preservative on the ground-contact portion, can be used; however, the labor required to prepare these posts usually makes commercial posts more attractive.

Non-wood alternatives, such as metal posts, are increasing in popularity. Steel posts offer the following advantages:

- ❑ Easier to install than wood posts.
- ❑ Easier to use than wood posts.
- ❑ Ready to use once they are driven into the ground; just string your wires, making them more versatile than wood posts.
- ❑ Better for grounding lightening strikes than wood posts.
- ❑ Wire clips, staples, etc., are not needed.
- ❑ Quality is more consistent than wood posts.

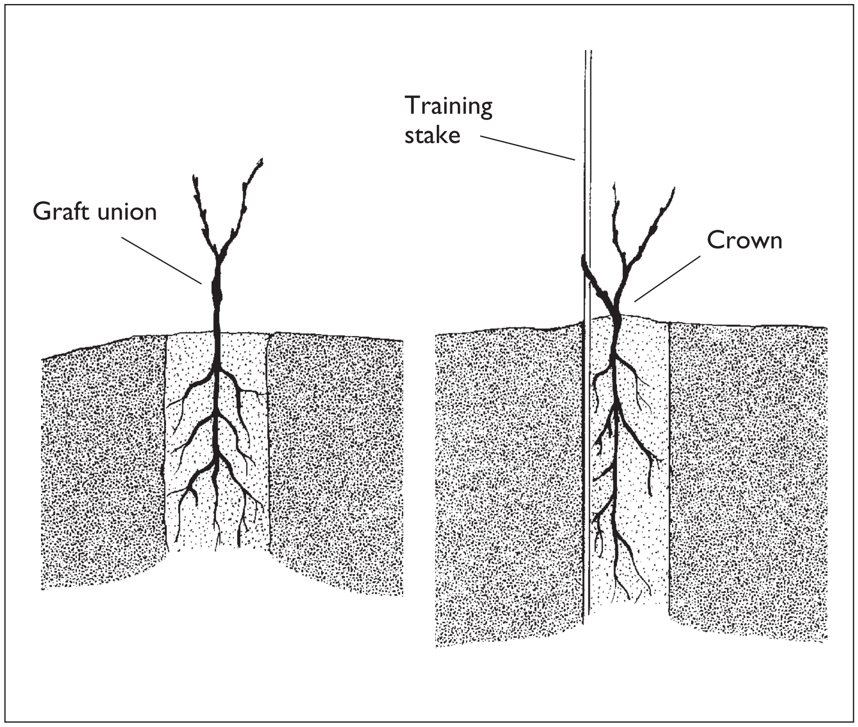


Figure 5.3 Correct planting depth for grafted (left) and nongrafted (right) grapevines.

Line posts (as opposed to row-end posts) should be at least 3 inches in diameter at their smaller end. End posts should be at least 5 inches in diameter and are often 1 or 2 feet longer than line posts so that they can be set deeper. Posts can be set in either of two ways: they can be driven with a post pounder or they can be set in augered holes and backfilled. Driving posts is much faster; by one estimate, two people can drive six posts in the time required to auger a hole and set one post. Furthermore, because the driving disturbs less soil, the driven post is more stable than a post set in an augered hole. Most posts have a slight taper. The smaller end should

Figure 5.4 (top). External end-post brace assembly suitable for non-divided canopy trellises with row lengths less than 600 feet.

Figure 5.5 (bottom). External end-post brace assembly used for divided canopy trellises and rows greater than 600 feet.

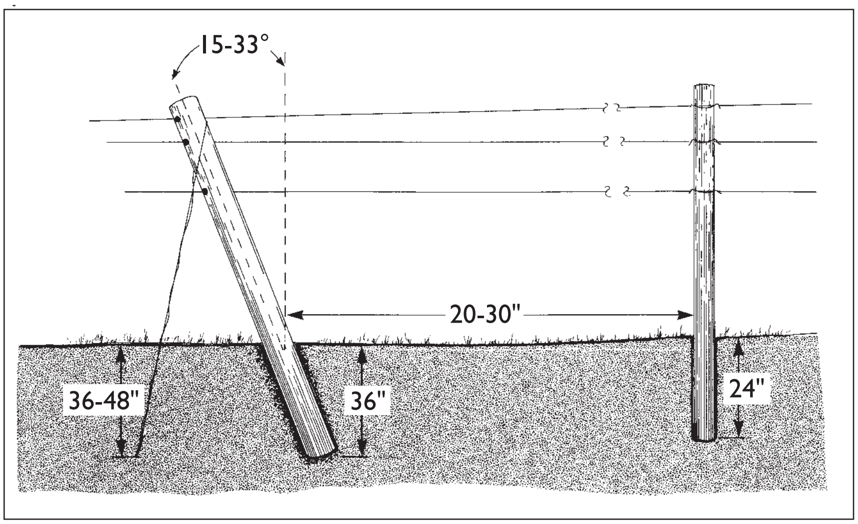
be driven into the ground. In heavy or stony soils, it might be necessary to saw a bevel on the end of the post to facilitate driving. Driving is also easier if the soil is moist. If posts are to be set in augered holes, the end of the post set in the ground is less important.

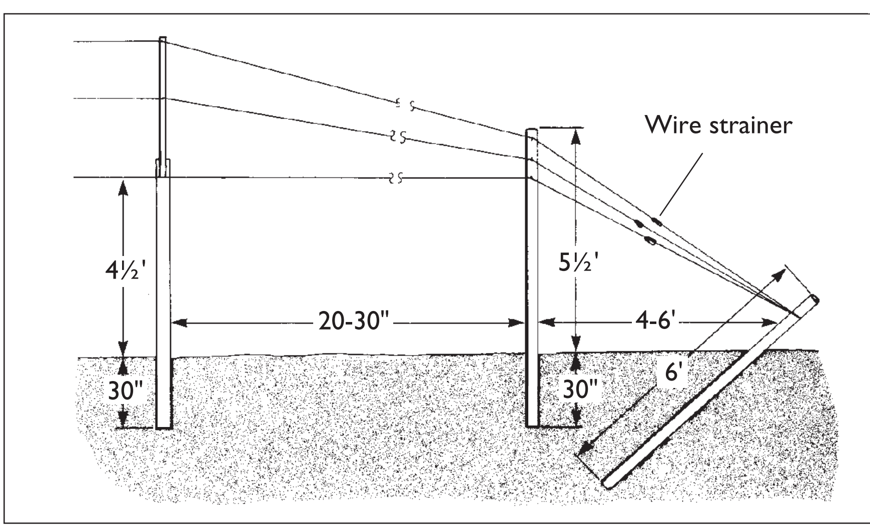
Wire

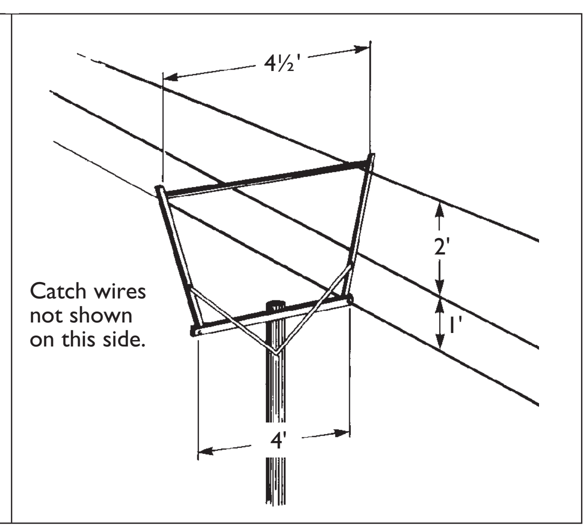
Many different types of wire have been used in grape trellises. Before about 1970, the most commonly used type was soft, galvanized 11- or 12-gauge wire. More recently, high-tensile (HT) galvanized steel wire has been preferred because of its greater strength and longevity. The HT wire should have class III galvanizing and possess a breaking strength of at least 170,000 pounds per square inch. Wire gauges of 11 to 12.5 are acceptable; 12.5 is the most common. HT wire, which can be stretched to 250 pounds of tension, is preferable to softer wire. At that tension, expansion and contraction with changes in temperature is minimized, reducing time spent in tightening loose trellis wires. The greater tension that can be applied to HT wire also permits a relatively wide post spacing (20 to 30 feet) without wire sagging. HT wire is hard and coiled under tension. Wear gloves, appropriate clothing, and eye protection when handling it. Hold the wire ends firmly when pulling, and stick loose ends into the ground until fastened to the trellis to prevent recoiling.

Brace Assemblies

Strong row-end braces are critical to the strength of a trellis. A common means of bracing the row end is an external brace, as shown in Figure 5.4. The external or tie-back brace is generally suitable for nondivided canopy trellises with row lengths up to 600 feet. The end post should be at least 5 inches in diameter and 9 feet long and should be set or driven 3 feet into the soil at 15 to 30° off vertical (away from the row). The post is then anchored with a "deadman." Steel screw-







type anchors (for example, 4- to 6-inch screw on a 5/8-inch by 48-inch galvanized shaft) are commonly used. The deadman anchor is braced to the end post with a double loop of 9-gauge bracing wire. Bracing wire is soft and can be twisted without breaking. A "twitch stick" placed in the loop and turned will take up the slack in the brace wire. Be sure to twist the brace wire in the same direction that was used to screw the anchor into the ground (clockwise). A variation of the external brace uses an 8-foot post driven 6 feet into the ground rather than a steel anchor (Figure 5.5). This stronger anchoring is recommended for divided canopy training systems to support the weight of heavier crops. One disadvantage of external bracing is the exposed brace wire or wires which can be hit by tractor tires or trip the unwary worker. An internal brace assembly (Figure 5.6) avoids this problem and is stronger than a steel-anchored brace. The internal brace is more expensive, however, because several posts are required for each assembly.

Construction

It is generally most efficient to construct the trellis in steps over the entire vineyard rather than completing the trellis row by row. The trellis posts, row-end braces, and at least one wire should be installed during the first growing season. Install end posts or end brace assemblies first. Then mark the line post locations (as was done earlier with vine locations) by stretching a premarked wire between the corresponding end posts of a given row and marking each post location with a stake, lime, or paint. The post spacing was determined when the vine spacing was measured. Use a multiple of the vine spacing distance for post intervals, but do not exceed 30 feet (20 to 30 feet is common). Remember that the first and last vines of a row are only one-half a vine space from their respective end posts. With post locations marked, drive posts by working across the rows. As an alternative, rows can be straddled with the tractor and posts pounded by row if the staking of vines is delayed until the posts are set. Use a builder's level to plumb the postdriver to ensure that each post is driven vertically.

Wires are strung and stapled after the posts have been installed. At least one wire, usually the lowest, should be strung in the first season to facilitate vine training. The wire heights can be marked on the post by using a notched or marked template with the desired wire locations. The number of wires and their locations varies with the intended training system. (See chapter 6.) Use a wire jenny or spool to dispense the coiled wire

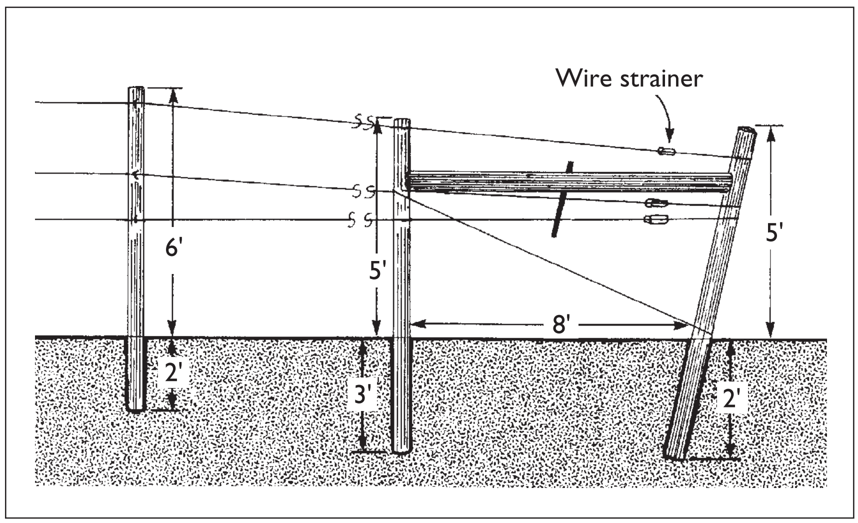


Figure 5.6 (above). Internal end-post brace assembly.

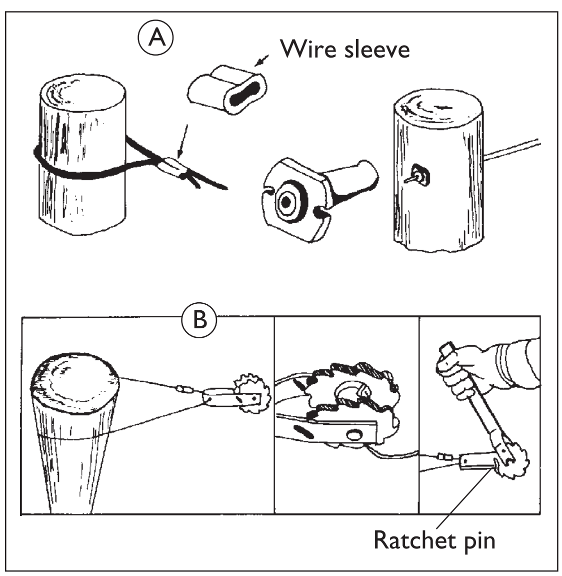


Figure 5.7 (left). Methods of fastening wire: compressible wire sleeves and "wire vise" (A) and in-line wire strainer (B).

and prevent tangles. Position the jenny at one end of the row and pull the loose end of the wire to the opposite end of the row on the windward side of the row to which it will be stapled. Attach the loose end of wire to the end post with two compressible wire sleeves (Figure 5.7) at the appropriate height. Cut the opposite end from the coil and attach it to the corresponding end post by one of three methods, depending on row length (Figure 5.8). The wire can be fitted with an in-line strainer, inserted in a wire vise, or tied off with wire sleeves (Figure 5.8). In the last case (for row lengths greater than 500 feet), an in-line strainer is mounted at the midpoint of the row. Do not completely take up the slack wire until the wire has been stapled to all posts. Wire vises are recommended only for rows less than 200 feet long and for foliage catch wires. In-line strainers should be used for cordon support wires in rows 200 to 500 feet long. For rows greater than 500 feet in length, splice in-line strainers in the middle of the row to tension the wire effectively over its entire length. Wires can be extended beyond the end post and tied to earth anchors (Figure 5.5).

For paired catch wires, pull the wire around the opposite end post and draw it back to the starting point to form a continuous loop. Secure the loop at the far end of the row with a loose staple. With this method, wire vises or another type of tensioner is needed only at one end of the row.

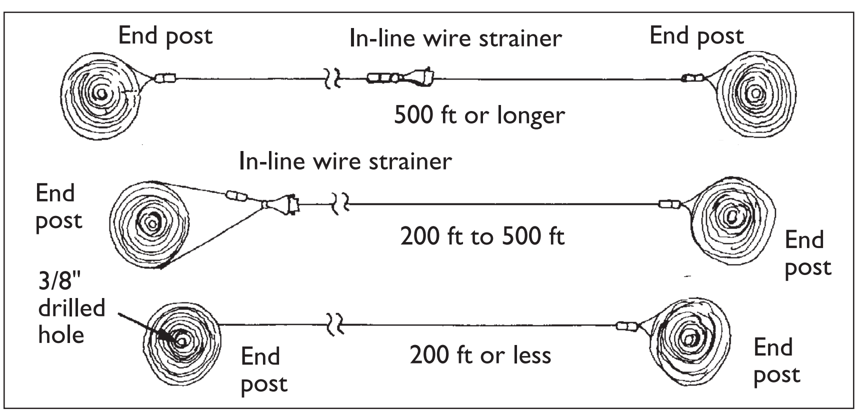


Figure 5.8 Three methods of fastening and tensioning trellis wire.

Wires should be stapled loosely to the line posts so that they can move freely through the staples. Hold the wire against the post with the body while using both hands to hold and drive the staple. Avoid denting or crimping the wire during stapling. Some prefer to place staples in the posts before stringing the wire. In this case, the wire is threaded through the staples as it is dispensed. Wires are tensioned after stapling is completed. If multiple wires are installed, tension the highest wire of the trellis first, followed by successively lower wires.

Divided Canopy Training

Grapevine canopies represent the three-dimensional arrangement of foliage on the grape trellis. Canopy division is a method of exposing more of the vine's foliage to sunlight and can be a beneficial means of improving yields and fruit quality with large vines. Canopy division is cost effective only if the vines are expected to be large and if the principles for management of divided canopy training are understood and recommended practices are followed.

Two divided canopy systems that could be used in North Carolina are the Geneva Double Curtain (GDC) and the open U, or *lyre*, system. Both systems are described in chapter 6. Specialized materials are available for these systems, which will probably be cost effective considering that less labor is required for construction and their longevity is greater. Row spacing should be increased to 12 feet with either of these divided canopy systems unless narrow vineyard equipment is used. More sophisticated end brace assemblies are recommended for divided canopy systems to support the greater crop loads possible with those systems (Figures 5.5 or 5.6).

Summary

This chapter has presented practical techniques and materials for vineyard establishment. These techniques and materials may be further refined, and other alternatives are available. Prospective growers should visit existing vineyards and review vineyard design and construction techniques. Some questions to address in those visits are:

- ❑ Is there evidence of soil erosion resulting from row orientation?
- ❑ Is land efficiently used?
- ❑ Does the vineyard design facilitate equipment and personnel movement?
- ❑ Are row end brace assemblies secure?
- ❑ Are trellis components in good repair?

Most established growers can comment on at least one or two items that they would do differently if they were to re-establish their vineyards. Once vines and posts are in the ground, it is difficult to correct design flaws.

Publications on Trellis Construction

❑ *How to Build Orchard and Vineyard Trellises*
Available from:
Kiwi Fence Systems, Inc.
RD 2 Box 51-A
Waynesburg, PA 15370

❑ *Directory of Vineyard and Winery Products Suppliers* Available from:
Vineyard and Winery Management
103 Third St., P.O. Box 231
Watkins Glen, NY 14891

❑ *Sunlight into Wine*
Available from:
Practical Winery and Vineyard Magazine
15 Grande Paseo
San Rafael, CA 94903

❑ *Oregon Viticulture (2003)*
Available from:
Oregon State University Press
500 Kerr Administration
Corvallis, OR 97331
1-800-426-3797; fax 541-737-3170
http://oregonstate.edu/dept/press

Chapter 6

Pruning and Training

This chapter discusses the principles of grapevine dormant pruning, reviews reasons for vine training, and describes systems appropriate for use in North Carolina.

Profitable grape production requires that grapevines be managed so that a large area of healthy leaves is exposed to sunlight. Such vines are likely to produce large crops of high-quality fruit each year. Grapevines must be trained and pruned annually to achieve this goal. The training system chosen generally dictates how the vines are pruned. Thus, pruning practices and training systems are discussed together in this chapter.

Dormant pruning is probably the single most important task you will perform routinely in the vineyard. The term *dormant pruning* refers to the annual removal of wood during the vine's dormant period. Grapevines are pruned primarily to regulate the crop but also to maintain a vine conformation consistent with the desired training system. As we will see, pruning has both a short- and long-term effect on crop quantity and quality.

Training positions the fruit-bearing wood and other vine parts on a trellis or other support. Except for renewal of damaged vine parts or system conversion, vine training is largely complete by the third year. Training should uniformly distribute the fruit-bearing units (nodes) in the vine's row space to facilitate perennial vine management, including pruning, and to promote high fruit yield and quality.

Definitions

Knowledge of the terms used to describe a grapevine is necessary to understand pruning and training concepts. The current season's crop is borne as one to several clusters on *shoots* that develop from dormant *buds* (Figures 6.1 and 6.2). Most buds are located at *nodes*, the conspicuous joints of shoots and canes (Figures 6.1, 6.2, and 6.3). Buds are also present at the bases of shoots and canes. Also, buds can remain latent at the less

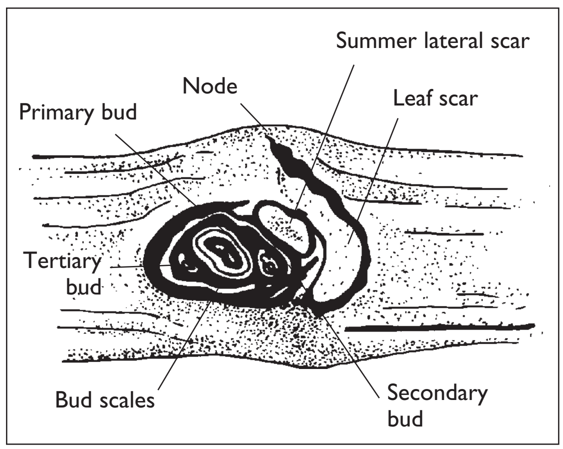
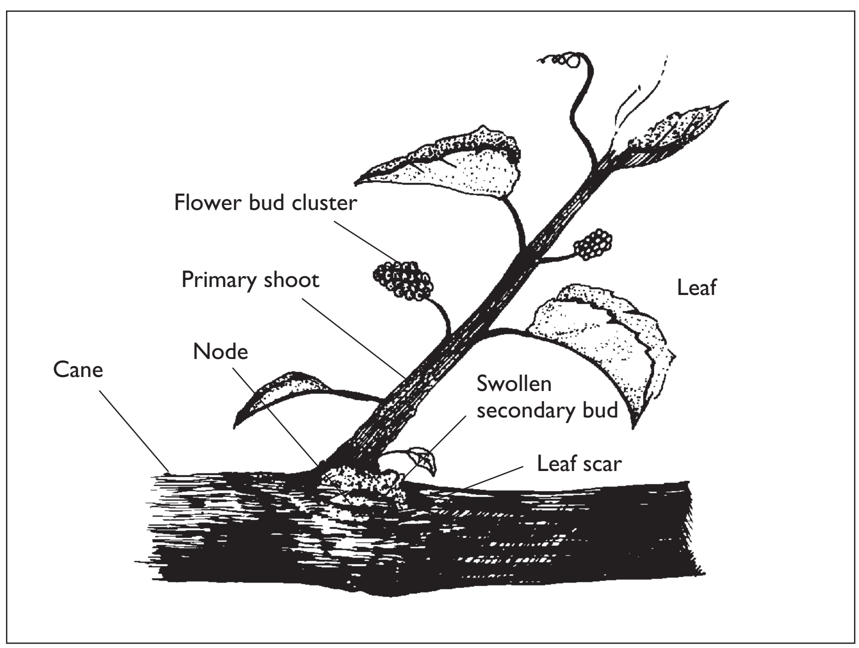


Figure 6.1 (left). Dormant bud and node of one-year-old cane. The compound bud has been cut cross-sectionally to reveal the arrangement of the bud's inner structures. Compare with Figure 6.2.

Figure 6.2 (below). Recently emerged primary shoot at node of one-year-old cane.



conspicuous nodes of trunks and other perennial parts of the vine. Buds not borne at clearly defined nodes of canes are referred to as *base buds* (Figure 6.3), and their shoots, which are often unfruitful, are termed *base shoots.* Shoots stop growing in late summer and become brown and woody during the *acclimation*, or hardening, process. Shoots are termed *canes* after leaf-fall. Lateral shoots often develop at the nodes of primary shoots. They, too, can become woody and persist after fall frosts. Buds borne at nodes are *compound*. Compound buds consist of several growing points, or *primordia*. The primary bud is the largest primordium, the first to break bud (emerge) in the spring, and it usually bears more flower clusters than do shoots developing from secondary or tertiary buds (Figures 6.1 and 6.2).

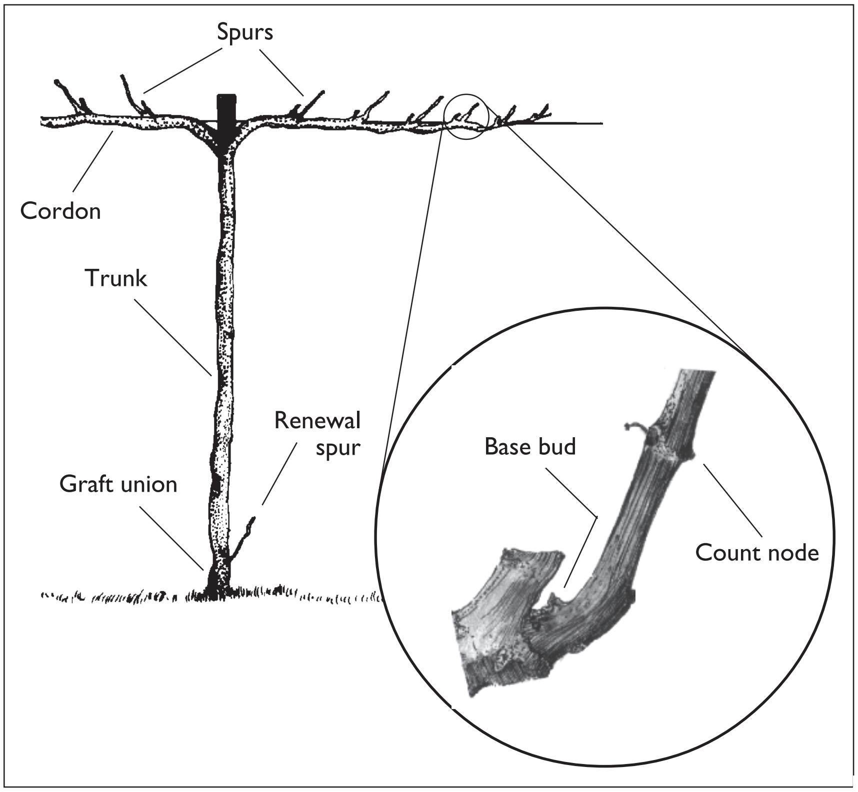


Figure 6.3 Structure of dormant, grafted grapevine. Vine has been spur-pruned; in spur close up, base bud and count node are shown.

Additional terms describe grapevine parts in the context of a particular training system's integration with a trellis or other support. The *vine trunk* is the vertical support structure that connects the root system and the fruit-bearing wood of the vine (Figure 6.3). Trunks can have horizontal extensions of two-year-old or older wood. These extensions might be short *arms*, as in the umbrella kniffin system or long *cordons*, as in the bilateral cordon system. Arms and cordons, in turn, usually bear *spurs* (canes that have been pruned to 1 to 4 nodes) or canes (8 to 15 nodes). Trunks, arms, and cordons are generally retained for years. The shoots of a vine and their leaves represent the *canopy* of the vine. The *renewal region* is that region of the canopy where buds for the next season's crop develop. The renewal region is often, but not always, the fruiting region of the canopy.

Dormant Pruning

Reasons for Pruning

Dormant pruning is the primary means of regulating crop. If other factors do not limit productivity, vines pruned correctly are likely to produce large crops of high-quality fruit. Pruned incorrectly, vines and crop will ultimately suffer. It is important to understand how many nodes to retain as well as which nodes are associated with good cold hardiness and fruitfulness.

A mature, unpruned grapevine can have more than 400 buds. Overcropping would occur if all of these buds were allowed to grow and bear fruit. There are both immediate and long-term effects of overcropping grapevines. Immediate effects are observed in the current year. Symptoms can include reduced sugar accumulation in fruit and reduced pigmentation in berry skin. Rather than maturing into woody canes, the shoots of overcropped vines typically die back completely to older wood, or they may mature only one or two basal nodes (toward the base of the shoot). Poor wood maturation occurs because the maturing fruit competes for the necessary carbohydrates.

The long-term effect of overcropping is reduction of vine vigor (rate of shoot growth) and vine size (pruning weight). Vine size reduction due to overcropping can occur without a noticeable degree of cane dieback. Although wood might appear to be mature, stored starch reserves in vines stressed by overcropping can be so low that the next year's vegetative growth and crop will be severely reduced.

Although dormant pruning is the primary means of controlling the crop, it will not provide adequate control in all situations. Additional control through thinning of flower or fruit clusters is generally required with young vines (two years old or younger), with very fruitful varieties such as some of the interspecific hybrids, and in any case where the vine vigor and vine size are insufficient to fill the available trellis space.

Number of Nodes to Retain

Eighty to 90 percent of the one-year-old wood is removed from vines at dormant pruning. Before pruning mature grapevines, the vineyardist must decide how many nodes to retain. Overcropping and excessive canopy density will occur if too many nodes are retained. On the other hand, the crop will be needlessly reduced if too few remain. Furthermore, severely pruned vines are apt to produce excessively vigorous shoots because all of the stored energy in the trunks and roots is available to relatively few growing points. Excessive shoot vigor can reduce fruit set and delay shoot maturation in the fall.

Balanced pruning was developed to help vineyardists determine the appropriate number of nodes to retain. This method is based on the concept that a vine's capacity for vegetative growth and fruit production is a function of the vine's size. The size of a vine is determined by the extent of growth of roots, shoots, and perennial wood. Because the growth of roots and other perennial wood cannot be conveniently measured, vine size is measured by weighing the one-year-old wood (canes) removed at pruning. Essentially, we balance the number of nodes retained against the weight of pruned canes: more nodes should be retained on a large vine than a on small vine because the large vine has a greater capacity for both vegetative growth and crop production. Pruning formulas for many varieties have been developed to calculate the number of nodes to be retained for a given pruning weight (Table 6.1). A pruning formula of 20 + 20, for example, would require leaving 20 nodes for the first pound of canes removed, plus an additional 20 nodes for each additional pound above the first. A 3.2-pound vine would therefore retain 64 nodes if the 20 + 20 schedule were used at pruning. Weighing is done to the nearest tenth of a pound. With all pruning formulas, these are minimum and maximum numbers of nodes that must be retained. For example, a minimum of 15 nodes should be retained on vines that are two years old or older. Given 15 or more shoots, small vines will require some degree of cluster thinning to prevent

Table 6.1. Suggested Pruning Formulas for the Balanced Pruning of Selected Grapevine Varieties

Variety	Pruning Formula*
Cabernet Sauvignon	20 + 20
Cabernet franc	20 + 20
Chardonnay	20 + 20
Seyval	5 + 10
Vidal blanc	15 + 10
Other hybrids	20 + 10
Delaware	20 + 10
Niagara	40 + 10

*The first number in the pruning formula indicates the number of nodes to retain for the first pound of cane prunings; the second number indicates the number of nodes to retain for each additional pound of cane prunings after the first. See text.

overcropping, but the shoots and leaf area are needed to increase vine size. The maximum number of nodes to be retained on mature vines should be on the order of 4 to 6 nodes per linear foot of row space (for example, 32 to 48 nodes for vines spaced 8 feet apart in the row). The lower number would be more appropriate for large-clustered varieties; the higher number would be acceptable for varieties with small- to medium-sized clusters.

Nodes, specifically *count nodes*, are the units counted in the pruning formulas. Count nodes have clearly defined internodes in both directions on the cane (Figure 6.3). Once the appropriate pruning formula has been determined, the vine size is visually estimated and the number of nodes that should be retained on the pruned vine is calculated on the basis of that estimate. This requires some experience, but 5- to 6-foot canes average about 0.1 pound. The vine is then pruned, leaving 10 to 15 extra nodes as a margin of estimation error. The cane prunings are weighed with a hand-held scale and their weight is entered into the pruning formula to determine accurately the number of nodes to be retained. Nodes in excess of that number are then removed. Commercially, it is neither necessary nor practical to weigh cane prunings from every vine. In practice, most pruners acquire an ability to estimate the pruning weights and node retention closely. Thereafter, only an occasional vine is weighed to check estimates.

Pruning formulas (Table 6.1) allow for additional shoots to develop from noncount node locations (base buds). Generally, the native American and vinifera varieties do not produce many base shoots unless the vines have been pruned too severely. Many of the interspecific hybrid varieties, however, produce numerous, fruitful base shoots, even with moderate pruning. Balanced pruning of hybrid varieties has limited utility. Crop control with some hybrid varieties, notably Seyval, must be achieved through a combination of fairly severe pruning and shoot or fruit cluster thinning. (See chapter 7.)

There are other, more arbitrary means of determining the number of nodes to retain at pruning. Node retention figures are sometimes based on the linear row space or the square area a vine occupies. For example, mature vines trained to conventional, nondivided canopy training systems should generally retain four to six nodes per linear foot of row. Expressing node retention on the basis of the linear measure of row or the square area of vineyard is convenient; however, it ignores individual variation in vine capacity and can lead to overcropping of small vines or undercropping of large vines. It is not as precise as balanced pruning and is therefore not a recommended procedure where variation in vine size is great.

When to Prune

Vines can be pruned any time between leaf fall and bud break the following spring. However, there is evidence that fall-pruned vines are more susceptible to winter injury than vines pruned in late winter or early spring. Delaying pruning until late winter makes it possible to evaluate bud injury and compensate by increasing the number of nodes retained. Spring pruning does not harm vines, even when sap bleeding is observed; however, swollen buds and young shoots are extremely susceptible to breakage. Therefore, the removal of unwanted wood from the trellis should be completed before bud swell. Experienced pruners require 30 to 40 hours to cane-prune an acre of vines. Somewhat less time is required for spur-pruned vines. Cane pruning and spur pruning are described in the section on grapevine training.

Double-pruning of vines is sometimes practiced in areas where spring frosts are common. At the initial pruning in late winter or early spring, canes or spurs are retained with two to three times the desired number of nodes. Buds nearest the pruning cut develop shoots as much as seven days earlier than the basal buds of the same cane or spur. To correct shoot density, a second pruning cut is made after the threat of frost before appreciable shoot growth has occurred.

What to Retain

The selection and retention of suitable fruiting canes and spurs is extremely important. Select only canes or nodes that show good wood maturation. This criterion is far more important than selecting wood strictly on the basis of its location in relation to a desired training system. Generally, dark brown canes with short internodes (4 to 6 inches long) are superior to lighter colored canes that have internodes longer than 6 inches. Canes that have internode diameters of ¼ to ½ inch are superior to canes outside that range. The diameter of a person's small finger is an appropriate guide for a desirable cane diameter. Well-matured lateral canes or spurs can be retained as fruiting wood if needed; however, medium diameter canes lacking persistent laterals are superior to large canes bearing many persistent laterals. Canes associated with good bud fruitfulness and cold hardiness are located toward the exterior of the canopy where they received more sunlight than those canes that developed within the canopy.

Complications Due to Cold Injury

In many years, assessing and compensating for cold injury is an important aspect of pruning grapevines in this region. The retention of nodes is based on the assumption that buds of retained nodes are viable. If buds have been killed by freezing or other causes, the number of retained nodes must be increased to compensate for the injury.

Bud injury is assessed before pruning by evaluating the viability of a representative sample of buds from a given variety. Dead buds are identified by a browning of their primordia, which occurs after the frozen buds are allowed to warm for a few days. To determine if a bud is dead, make several consecutively deeper cross-sectional cuts through the bud to expose the individual primordia (primary, secondary, and tertiary buds of Figure 6.1). A sharp, single-edged razor is the best tool for this purpose. The primary bud, located between the secondary and tertiary buds, is most susceptible to cold injury. Dead buds will appear brown, whereas live buds will be a light green color. If buds are sectioned too deeply, the primordia may be missed, exposing the green tissue beneath the bud. The novice should gain some experience by cutting live buds (such as those of a cold-hardy variety) to learn to recognize the individual primordia of a bud and to become familiar with the green appearance of live primordia.

Buds can be examined for viability on the vine, but it is generally more comfortable to collect 10 to 20 canes at random through a varietal block and examine the buds indoors. Collect only canes and nodes that might otherwise be retained at pruning. If there are large differences in elevation (30 to 40 feet) within a vineyard block, sample the regions separately because injury will probably be greater at the lower elevation. Examine 100 to 200 buds of each variety and record the percentage of dead primary buds.

If your bud assessment reveals 40 percent bud injury on a vinifera variety, then a 20 + 20 pruning schedule should be increased 40 percent to 28 + 28 or, for convenience, 30 + 30. Pruning adjustment is roughly proportional to primary bud injury with vinifera and native American varieties. Because many of the interspecific hybrid varieties have fairly fruitful secondary and base shoots, death of primary buds alone might not significantly reduce yields. The compensation for primary bud injury is therefore not as generous as with native American and vinifera varieties. Low temperature can also kill canes and trunks. Figure 6.4 shows in cross-section a portion of a three-year-old grapevine trunk. Trunk tissues include (from exterior to interior): a corky *periderm* or *bark*; the *phloem*, or food-conducting tissue; the *vascular cambium*; the *xylem*, or water-conducting

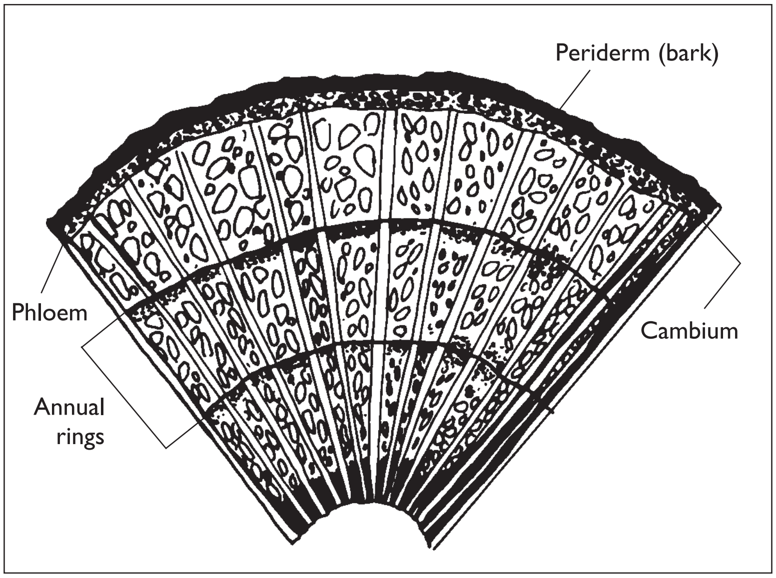


Figure 6.4 Cross-sectional view of a portion of a three-year-old grapevine trunk. (Redrawn from Esau, K. 1948. Phloem structure in the grapevine and its seasonal changes. Hilgardia 18:217-296.)

tissue; and a central *pith*. The vascular cambium is a region of cell differentiation and division that produces new xylem and phloem cells annually. Canes have the same tissues as trunks but lack the annual rings of xylem. Cambium and phloem tissues are generally the most susceptible to cold injury. These tissues, like buds, will brown after being killed and subsequently rewarmed. Injury to the vascular cambium reduces or prevents the development of new xylem and phloem tissues. The old xylem tissue might sustain the initial water-conducting needs of the developing shoots in early spring. However, cold-injured vines often wilt and die in midsummer because the transpirational loss of water from leaves exceeds the ability of the impaired vascular system to transport water.

Cane and trunk cold injury is diagnosed by making shallow, longitudinal cuts into the wood and examining the phloem and cambial regions for browning. These tissues form a thin cylinder immediately beneath the bark. Browning or darkening of these tissues indicates injury. If wood injury is observed, retain extra canes at pruning. Injury will not be uniform and some canes will be unaffected. Some of these extra canes can be removed or shortened after bud break if too many shoots are present. Trunk injury is also diagnosed by making shallow, longitudinal cuts into the wood. Injury is usually most severe near the ground.

Cold-injured trunks frequently split or are affected by crown gall one to two years after the cold injury occurred. Vines will ultimately die if they must depend on a single, cold-injured trunk. Multiple trunking is therefore highly recommended to assure the long-term survival of vines (see the section on grapevine training). Split, heavily crown-galled, or otherwise defective trunks should be sawn off and replaced with a cane that arises near ground level but above the graft union (Figure 6.3). This strategy will ensure a continuous supply of shoots and canes to replace injured trunks.

Grapevine Training

Like dormant pruning, grapevine training is essential for high-quality grape production. There are numerous training systems used worldwide, and no single system is appropriate for all situations. The training system used will depend upon the variety, the frequency of cold injury, the degree of vineyard mechanization, and the availability of skilled labor. An acceptable training system will

- ❑ promote maximum exposure of leaf area to sunlight
- ❑ create a desirable environment within the canopy (microclimate), particularly in the renewal region
- ❑ promote uniform bud break, especially with those varieties that exhibit pronounced apical dominance (described in the section on initial training of grapevines)

- ❑ promote efficient vineyard operation with respect to equipment traffic, fruit harvesting, pesticide application, and dormant pruning
- ❑ be economical.

Initial Training

The growth potential of grapevines and the conditions under which vines are grown is never uniform. Other factors being equal, however, vines grafted to vigorous, pest-resistant rootstocks generally develop faster and usually grow larger than nongrafted vines. Variation in moisture and nutrient availability within a vineyard can cause differences in the extent of growth for a given variety. Training grapevines, therefore, requires evaluating the growth of individual vines during their establishment. Regardless of the intended training system, the initial training of grapevines has the following goals:

YEAR 1: To develop large, healthy root systems;

YEAR 2: To establish the initial components of the intended training system, including at least one semipermanent trunk; and to harvest a very light crop on vines that grew extensively in the first year.

YEAR 3: To develop or complete the training system, harvest a partial crop, and establish a second trunk.

These goals can be achieved by several methods. The following text and illustrations describe one means of establishing a low, bilateral cordon-trained vine using two semipermanent trunks. The training method described here is but one of several possible approaches.

YEAR 1: Erect the trellis posts and at least the lowest of the training wires before or during the first growing season. This wire, and a slender stake set next to individual vines, will provide a support for shoot growth. Allow two to three shoots to develop on vines during the first year (Figures 6.5a and 6.5b). Train these shoots vertically to the support stake. They may eventually be tied loosely to the training wire if their growth warrants it. Lateral shoots on these primary shoots can be pruned off to promote elongation of the primary shoots. Lateral shoot growth will be minimized if shoots are positioned upright and fastened to the support stake. Leaving several shoots on the first-year vine provides an abundant leaf area. Root growth is dependent on food produced in the leaves. Thus, the greater the leaf area, the greater the root growth that will occur in late summer. Eliminating all but one shoot can also lead to an excessive rate and duration of shoot growth, especially if the vines have large root systems when planted. Rapid and continued growth late into the fall can result in incomplete wood maturation, increasing the susceptibility to cold injury. In addition, retaining several shoots, rather than one, provides some measure of compensation for possible wind damage, deer browsing, and other factors that can retard the development of young vines.

It is essential that young vines be protected from fungal diseases by applying the appropriate fungicide. Powdery and downy mildews in particular can severely reduce the photosynthetic (food manufacturing) capabilities of leaves and retard the establishment of the training system. Deer, Japanese beetles, weeds, and other pests — as well as drought — also have greater impacts on young vines than on older vines and must be diligently controlled. Young vines do not have the food storage reserves afforded by the large root systems and trunks of older vines.

YEAR 2: Complete the trellis before bud break of the second growing season. Training in the second year starts by evaluating the extent of growth achieved during the first year (Figure 6.5c). If no canes reach the first wire, remove all but one cane. Prune this cane to three or four buds and secure it to the training stake. Treat such a vine as a one-year-old vine.

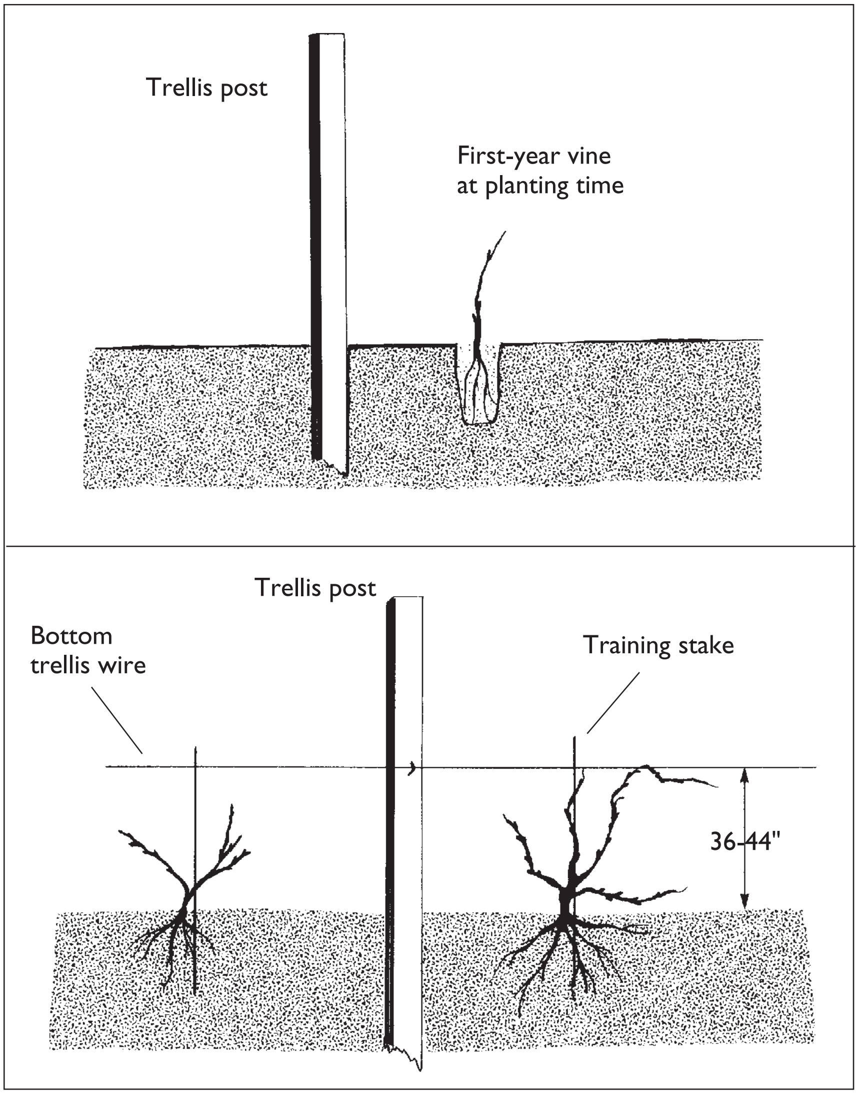


Figure 6.5a (top). Development of bilateral cordon-trained grapevines. Year 1: spring, at planting.

Figure 6.5b (bottom). Year 1: fall, at end of growing season. Vine on left has demonstrated weak growth. Vine on right grew vigorously and attained a greater size.

Vines that grew extensively in their first year will likely have one or more canes suitable for retention as a trunk. If a cane is long enough to reach the lowest trellis wire and is of adequate diameter at the wire, retain the cane as a trunk. The distal portion (the end towards the tip) of such canes can be trained horizontally along the training wire to serve as the basis for establishing the cordon (Figure 6.5c). If you elect to use a high training system, tie the cane vertically to the top wire of the trellis to form a trunk. In addition to the first trunk, retain a renewal spur of one or two buds that originates near the soil line but above the graft union (Figure 6.5c). If a second cane is large enough to serve as the second trunk, it can also be retained.

Cordon Establishment

The process of establishing cordons can begin in the first or second season, depending on the first year's shoot development. In either case, establish cordons over a two-year period. Long canes (8 to 15 nodes) often exhibit poor shoot growth at midcane nodes. Shoots that develop near the terminal, or distal, end of a cane produce growth-regulating hormones that retard the development of midcane shoots. This so-called apical dominance of distal shoots is greatest when the cane is oriented vertically up and is minimized when the cane is trained vertically down. To establish 4-foot-long cordons, use a 24-inch-long cane (or trunk extension) in year two (Figure 6.5c) and complete the cordon in year three with another 24-inch-long cane that originates near the distal end of the short cordon (Figure 6.5e). Canes used to establish cordons should be wrapped loosely around the trellis wire and securely tied at their terminal end with wire. The tying process will prevent the cordon from rotating or falling from the wire. If canes are wrapped too tightly around the cordon wire (greater than about two rotations in a 4-foot length), they may grow into the cordon wire within a few years. This does not impair vine performance, but it does prevent the cordon wire from being properly tensioned as it stretches with time.

During the second growing season, thin the shoots of vigorous vines that originate below the lowest trellis wire to one or two near the graft union (Figure 6.5d). Retain shoots that originate on the developing cordon. Retain 10 or more shoots, if possible, in year two. Treat small or weak vines as first-year vines during the second growing season (Figure 6.5d). Remove all flower clusters. Where exceptional growth was achieved in year one, it may be desirable to leave several fruit clusters per vine in the second growing season to slow vegetative growth. This token crop can be removed quickly in early summer if growth is less than expected.

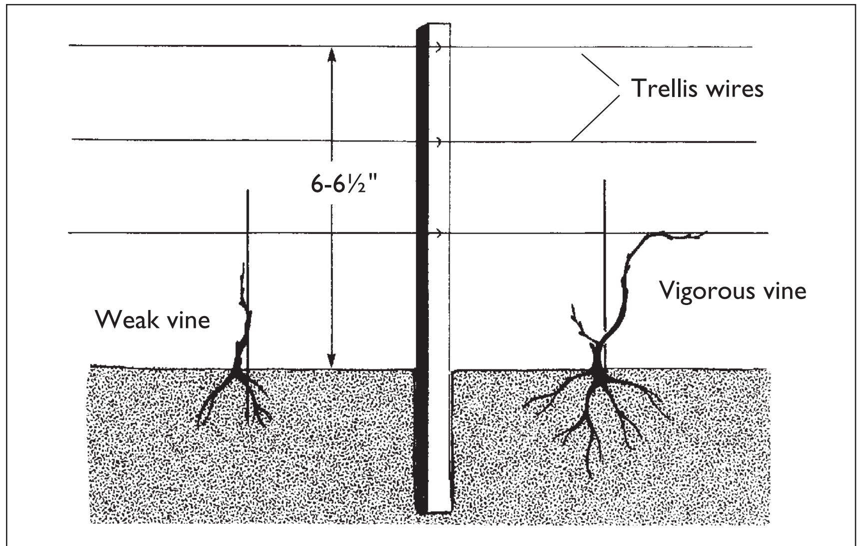


Figure 6.5c. Development of bilateral cordon-trained grapevines. Year 2: spring, after pruning. Vine on left has demonstrated weak growth. Vine on right grew vigorously and attained a greater size.

Shoots that develop in year two should be positioned and tied to the trellis wires to maximize sunlight exposure of their leaves. For cordon training, these shoots will form the spurs for shoot development during the following year (Figure 6.5e).

YEAR 3: Complete the basic elements of the training system during the third year. For low cordon-trained vines, prune the canes that arise from the upper side of the cordon to one- or two-node spurs (Figure 6.5e). For high cordon-trained vines (Figure 6.6), retain the spurs on the lower side of the cordon. Spurs should be spaced 4 to 6 inches apart. Develop a second trunk and cordon from a cane that originates near the graft union; follow the procedure outlined for the initial trunk. Retain a small crop (for example, one cluster per two shoots) on vines that had at least 1 pound of cane prunings from second-year growth. Position and tie the shoots to the upper trellis wires, as necessary, during the growing season. Treat weak vines as second-year vines and remove all crop.

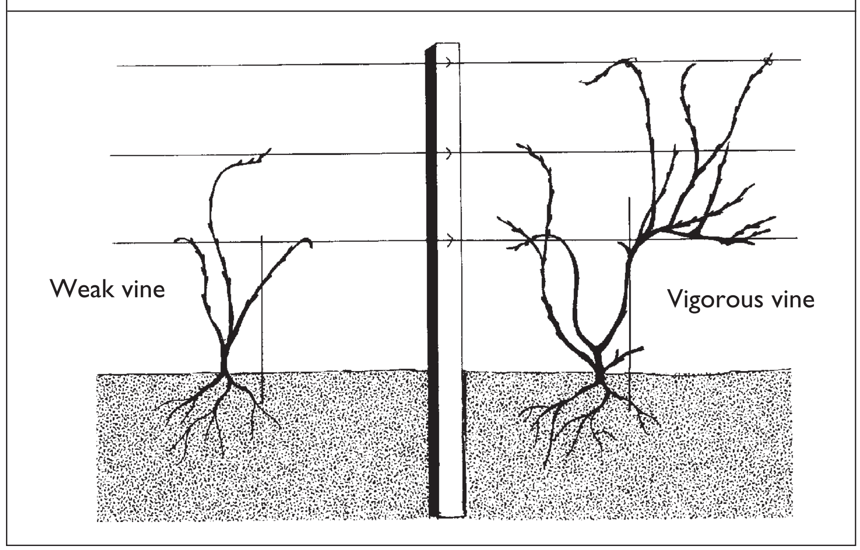


Figure 6.5d. Development of bilateral cordon-trained grapevines. Year 2: fall, at end of growing season. Vine on left has demonstrated weak growth. Vine on right grew vigorously and attained a greater size.

Multiple Trunking, Trunk Renewal, and Graft Union Protection

Growing cold-tender grapevine varieties introduces problems not experienced in regions with mild or more constant winter temperatures. Some degree of bud injury occurs regularly with cold-tender varieties but can generally be compensated for by retaining additional buds at dormant pruning. It is much more difficult to compensate for cane and trunk injury. In some situations (such as cold-tender varieties planted in poor sites) complete vine loss has been experienced. Even in good to excellent sites, it is wise to anticipate cold injury to better compensate for its occurrence. In addition to winter injury, other forms of injury can occur to vines, such as disease and mechanical damage by vineyard equipment. The experienced grape grower recognizes that the only permanent part of living vines is the root system.

One of the best ways to compensate for trunk injury is to use multiple-trunk training systems. This recommendation applies to cold-tender vinifera or more hardy hybrids. All of the training systems illustrated here can be established using two or three trunks, as opposed to one. Cold injury or death of trunks is often not uniform.

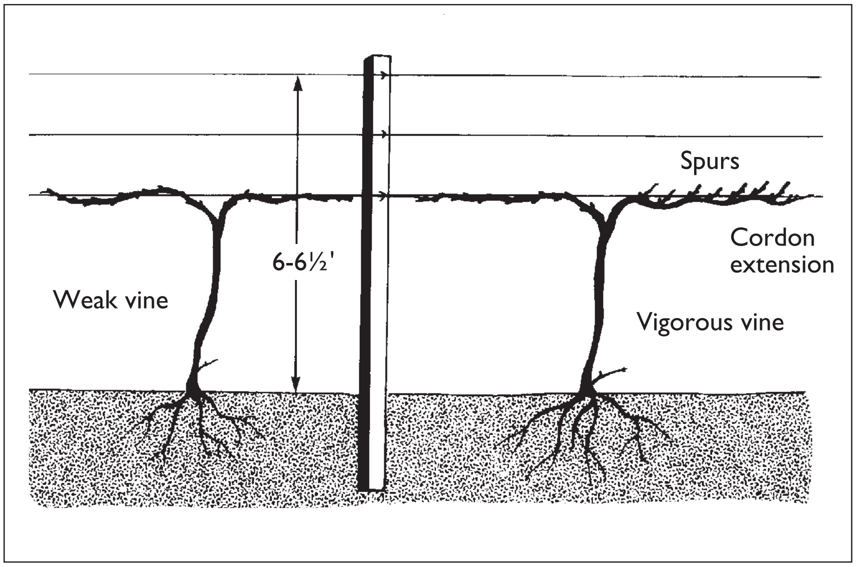


Figure 6.5e (left). Development of bilateral cordon-trained vines. Year 3: spring, after pruning. Vine on left has demonstrated weak growth. Vine on right grew vigorously and attained a greater size.

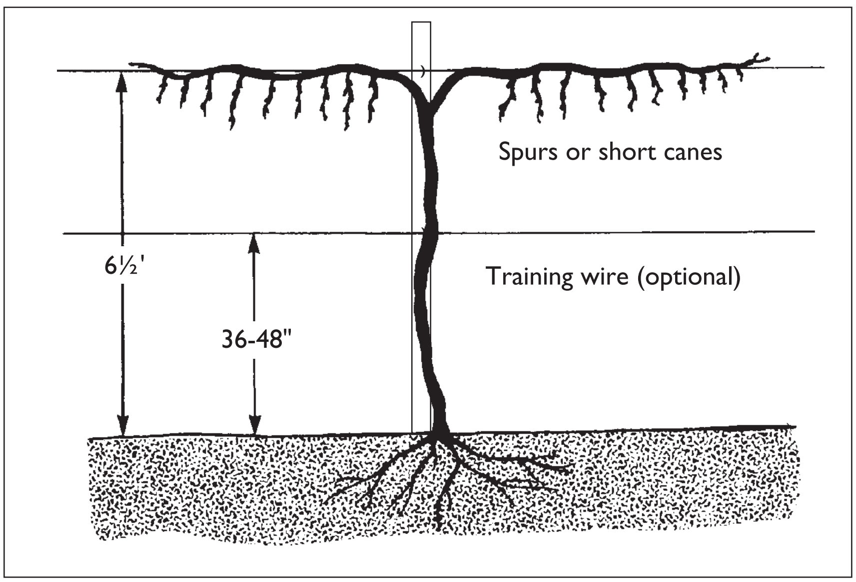


Figure 6.6 (above). High-wire cordon training system.

Frequently, only one trunk of a two- or three-trunk vine is killed. Similarly, the development of a wood-rotting disease such as eutypa dieback (see chapter 8) may be observed initially on only one cordon or trunk. In either case, removing one of two trunks does not eliminate grape production from the affected vine. Furthermore, it is usually easier to reestablish the lost unit from an existing trunk. A multiple-trunk training system can be developed starting in the first year as described above for a bilateral cordon system. Alternatively, a second or third trunk can be added in any year by training up a shoot originating near the graft union. Old trunks should not be replaced unless they are mechanically damaged, diseased, or cold injured. The continual removal of shoots (suckers or waterspouts) from the base of the trunk will exhaust the latent buds that could be used to develop new trunks, and with such vines it is sometimes difficult to establish new trunks. Therefore, the maintenance of a one- or two-node renewal spur at the base of the vine, while adding labor, does provide a continual supply of shoots and potential new trunks. A new shoot is trained up before a planned trunk removal or at any time after an unpredicted trunk loss. Note that with grafted vines, any suckers that develop from below ground level usually arise from incompletely disbudded rootstock wood. These shoots can be recognized as rootstock variety by their distinctive leaf appearance. They are of no value in reestablishing the training system.

An additional way to compensate for winter injury of grafted vines is to protect the graft union and a portion (several inches) of the trunks with mounded soil in the fall. Hilling up of graft unions, which can be done mechanically with tractor-mounted implements, protects a portion of the trunks from low temperatures. By providing a continuum with the relatively warm soil beneath the vine, the hilled soil insulates up to several inches of the trunk, including latent buds, above the graft union. The insulating layer of soil must be carefully removed (dehilled) in early spring to prevent permanent scion rooting. In the event of very low winter temperatures, injury may occur to all exposed portions of the vine. This is a rare occurrence, but it has — and will — occur, especially in poor vineyard sites. If such damage occurs, the training system can be reestablished by dehilling the vine and bringing up shoots that had been protected as buds by the soil. This tactic is faster and cheaper then replanting the vineyard. Hilling and dehilling is an insurance practice, and its utility says much about the vineyard site. Hilling is definitely recommended if a variety's hardiness or the suitability of a site is in question. Hilling is not recommended, however, if long-term experience (seven or more years) suggests that severe winter injury is unlikely. Hilling and dehilling have resulted in considerable soil erosion in some vineyards. That problem, combined with some inevitable mechanical damage to vines, has made the practice of dubious value in good to excellent vineyard sites. On the other extreme, if a grower finds that vines are often severely injured, the site, the variety, or both are unworthy of further consideration.

Training Systems

Training systems for vertical trellises are categorized as having either divided or nondivided canopies. Training methods can be further divided into head-trained or cordon-trained systems and cane-pruned or spur-pruned systems. The following training systems are acceptable for vineyards in this region. Trellis dimensions and the number of foliage catch wires used are provided as guidelines and might differ slightly from other references. It is wise to visit many existing vineyards and formulate your own dimensions from a synthesis of those observations and discussions.

Nondivided Canopy Systems

Nondivided canopy training systems have a single curtain of foliage and are less expensive than divided canopy systems.

Head-Trained Vines

Umbrella Kniffin

Two- or three-wire trellises are used for umbrella kniffin training (Figure 6.7). A trunk extends to a point 4 to 6 inches below the top wire. Short arms bear the fruiting cane arched over the top wire and are tied to the lower wire of the trellis. Renewal spurs are retained in the head region to provide canes for the subsequent season. Large vines (for example, those that produce 3.5 pounds of cane prunings from vines spaced 8 feet apart in the row) might retain three or four canes. Smaller vines (for example, those producing 1 pound of cane prunings) might only retain two canes to provide the appropriate node number.

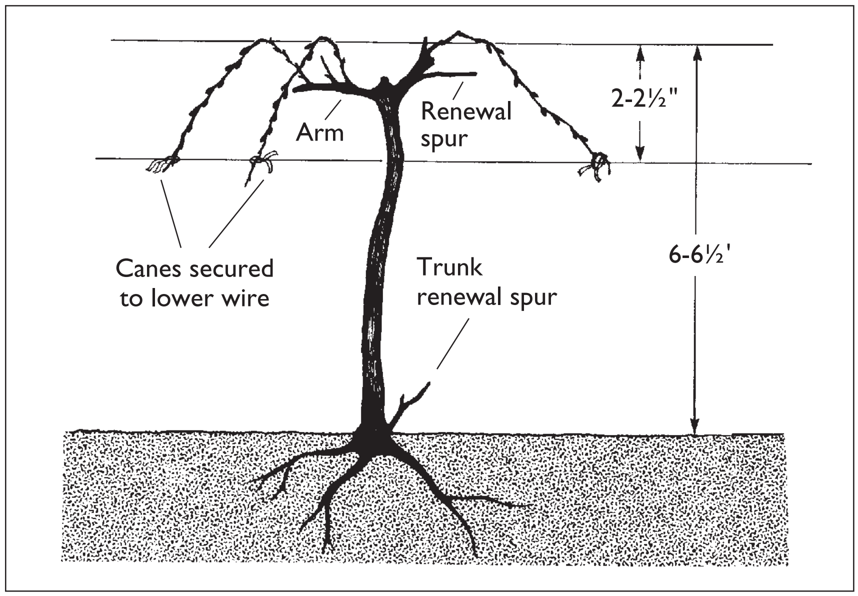


Figure 6.7. Umbrella kniffin training system.

ADVANTAGES

- ❑ A relatively simple, low-cost trellis is needed.
- ❑ Pruning decisions are easily learned.
- ❑ Apical dominance is reduced and more buds are positioned in a unit length of row by bending the canes over the top wire.
- ❑ The high renewal region promotes good fruitfulness and good fruit quality with small- to moderate-sized vines.

DISADVANTAGES

- ❑ As with all cane pruning systems, the mandatory tying of canes to trellis wires adds labor costs.
- ❑ Little provision is made for shoot positioning, and shoot crowding can lead to shaded fruit with large, vigorous vines.

Modified Keuka High-Renewal

This training system was developed in northern grape growing regions where frequent winter injury confounds the maintenance of large amounts of perennial wood and standardized training. The system's chief asset is that it permits flexibility in pruning and training. Multiple trunks extend to a midtrellis height (Figure 6.8). The vines are pruned to short canes originating from a dispersed head region. Canes are distributed and tied to trellis wires in a manner that promotes as uniform a shoot density as possible.

ADVANTAGES

- ❑ This system allows a flexible approach to winter-injury compensation.
- ❑ Short trunks minimize the maintenance of perennial wood.

DISADVANTAGES

- ❑ A considerable amount of time is expended with cane tying.
- ❑ Uniform canopy density is extremely difficult to achieve.
- ❑ The flexibility in training is difficult for inexperienced pruners to grasp.

Cordon-Trained Vines

Low Bilateral Cordon

The distinction between low- and high-trellis cordon systems depends upon the point on the trellis at which the cordon is established. Low cordons are typically 36 to 42 inches above the ground. Although cordons can be established even lower, 36 to 42 inches is a comfortable working height for most persons and is still low enough to permit development of 3 to 4 feet of canopy above the cordon. High cordons are established at the top of the trellis, typically 72 inches above the ground. The establishment of a low, bilateral cordon training system was illustrated earlier. At dormant pruning, one to three node spurs are retained at a uniform spacing along the upper side of the cordon (Figure 6.9). The vertically upright spurs encourage an upright growth habit to developing shoots. Cordons can extend either unilaterally or bilaterally from the trunks; in either case, cordons should ultimately span the distance between two adjacent vines in the row, leaving no gap between cordons of adjacent vines. Multiple sets of paired catch wires can be mounted on the trellis above the cordon to facilitate shoot positioning and to promote the development of a thin, vertical canopy. (See chapter 7.) Three pairs of catch wires are illustrated in Figure 6.9. The first pair of catch wires should be no more than 10 inches above the cordon. This height reduces the likelihood that shoots will fall or be blown down before elongating through the catch wires, and thus the amount of labor required to fasten shoots to wires is greatly reduced. The recommendation to use three sets of paired catch wires, as opposed to a lesser number, is guided by (1) the underlying principles of canopy management (see chapter 7) and (2) the conviction that the installation of wire is cheaper than the alternative labor of fastening shoots to wires to maintain the thin, vertical canopy.

ADVANTAGES

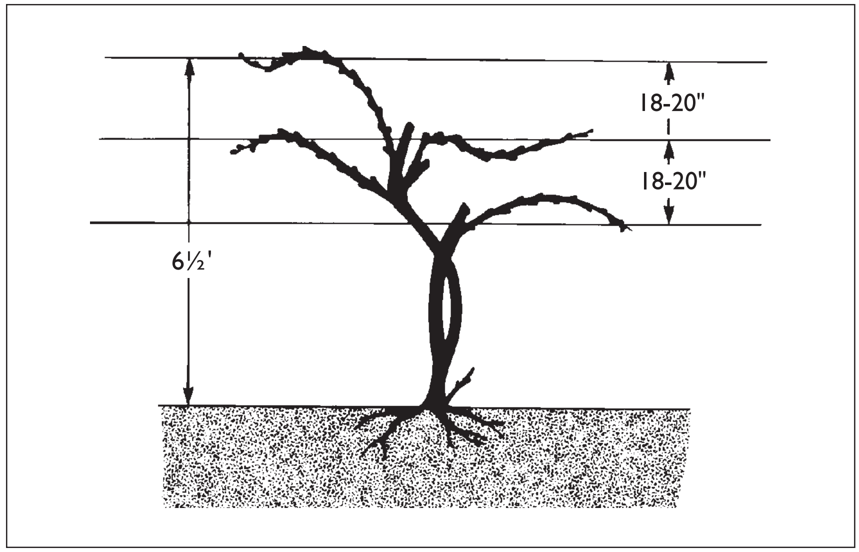
- ❑ Spur pruning minimizes the labor associated with cane tying.

- ❑ Fruit and renewal regions are at a uniform height, facilitating harvest and pruning.

DISADVANTAGES

- ❑ Basal nodes of a cane (those retained as a spur) are often not as fruitful as midcane nodes because of the characteristics of the variety or poor sunlight exposure during bud differentiation and development.
- ❑ Cordons, like trunks, must be renewed in the event of winter injury.

Long-term productivity of cordons can be a problem with varieties that are subject to winter cold injury or in situations where spurs have been pruned improperly. Cold injury or poor bud development can lead to areas of the cordon that lack spurs. Poor pruning can lead to displacement of the one-year-old spurs away from the cordon on older wood. The latter problem can be minimized by retaining, where possible, buds that originate close to the cordon and by retaining base shoots that arise directly from the old wood of the cordon. Cordons with poorly spaced spurs or wide gaps in spur positions should be renovated or replaced. If the cordon is free of disease, renovation may be all that is necessary to reestablish uniform distribution of spurs along the cordon. Renovation entails removing all one-year-old wood and spur extensions from the near-barren cordon. Leave a ¼- to ½-inch crown at the base of these extensions. The removal of this older wood stimulates a proliferation of base shoots from the retained crowns. The base shoots, which will be of low fruitfulness, can be trained and used to provide fruitful spurs for the following season. Severe pruning in renovation is necessary to stimulate base shoot development. Renovation temporarily reduces vine productivity, so it should be used only as needed and on a small proportion of vines in any one year. Replacement of cordons is advised if the cordon is diseased, cold injured, or otherwise undesirable. It is extremely difficult to establish a new, parallel cordon while the original cordon is still alive and present. Therefore, cut out the old cordon at the time the new cane is laid down. The new cane can originate near the graft union, anywhere on the trunk, or anywhere proximal to the diseased or barren region of the cordon. Do not attempt to establish a cordon using a cane originating from the opposing cordon of a bilaterally cordon-trained vine.



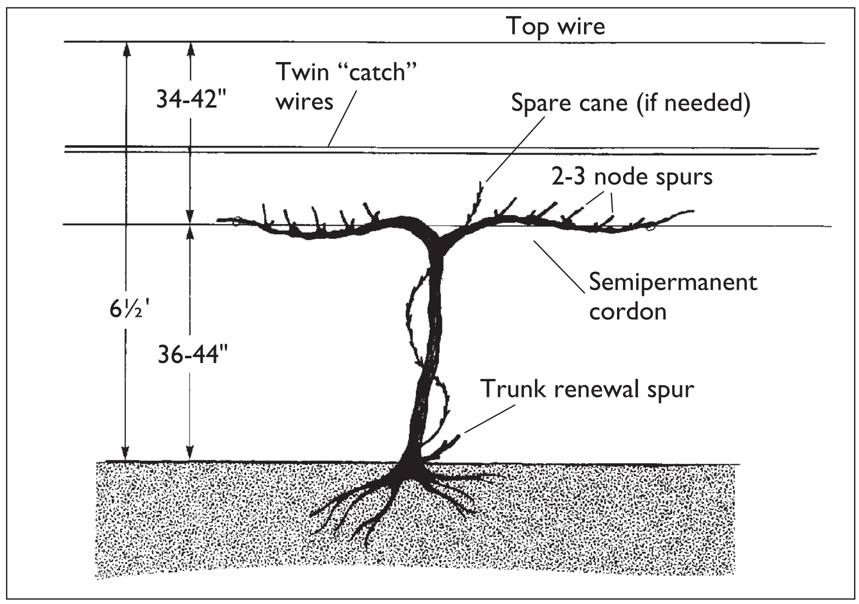


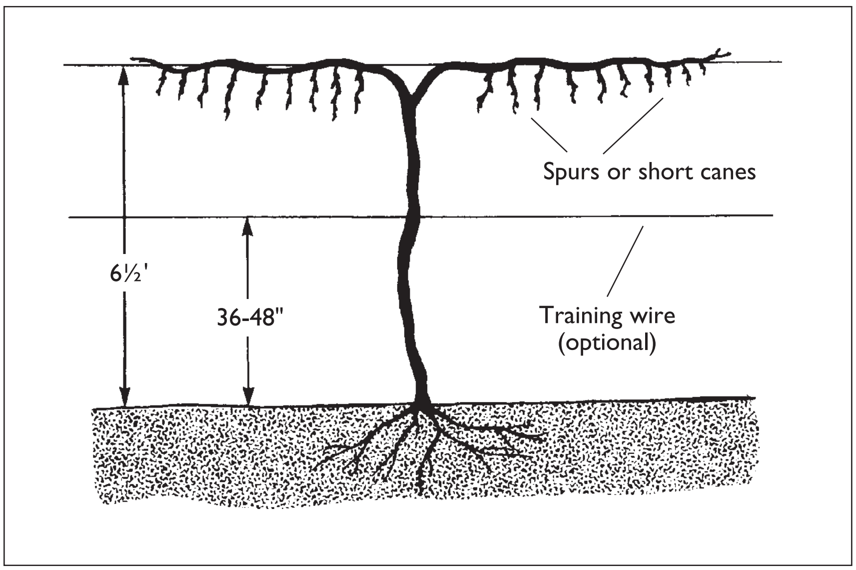
Figure 6.8 (top). Modified Keuka high-renewal training system.

Figure 6.9 (bottom). Low-wire bilateral cordon training system.

High Bilateral Cordon

Bilateral cordons are trained along the top wire of the trellis (Figure 6.10) in a manner similar to the low bilateral cordon system. Spurs or short canes are retained on the lower sides of cordons to promote downward shoot growth. Downward growth is further encouraged by positioning or "combing" shoots downward two to three times during the growing season. This positioning, which is first done near the time of bloom, is necessary to ensure sunlight penetration into the fruiting and renewal region of the canopy.

Figure 6.10. High-wire cordon training system.



ADVANTAGES

- ❑ This system uses a very low-cost trellis.
- ❑ High training is well suited to varieties that have a trailing growth habit, especially those of native American origin (for example, Norton).
- ❑ The fruiting and renewal region of the vine receives excellent illumination, provided that shoot positioning is performed.
- ❑ Pruning is rapid and cane tying is minimized.
- ❑ This system is well adapted to mechanical harvesting and pruning.

DISADVANTAGES

- ❑ A large area of perennial wood must be retained and exposed to possible winter injury.
- ❑ Varieties with upright growth habits can be difficult to manage.

Divided Canopy Systems

Divided canopy training systems consist of at least two curtains of foliage per unit length of row. Two systems, both having horizontally divided planes of foliage, are described here. Divided canopy training systems are more elaborate and more expensive to establish than nondivided training systems. Canopy division can be used to take advantage of the large surface area of leaves produced by large vines. Conversion of nondivided canopy vines to divided canopy training has resulted in significant yield increases and sometimes increased fruit and wine quality. Canopy division is not justified, however, when cane prunings average less than 0.4 pound per foot of row (for example, 3.2 pounds with vines spaced at 8 feet) in nondivided canopy training systems.

Because of the higher establishment costs, divided canopy training is not generally promoted for new vineyards: the same yield increases afforded by divided canopies can be achieved at lower cost by establishing more closely spaced, nondivided canopy rows. Similarly, the reduction in canopy density afforded by canopy division can be achieved by spacing vines farther apart in the row. The practicality of closely spaced rows hinges on the availability of narrow vineyard equipment. (See chapter 7.) Finally, it should be noted that the added costs of divided canopy training systems is wasted if the grower fails to maintain truly divided curtains of foliage.

Geneva Double Curtain

The top of the trellis is fitted with cross arms 4 feet wide (Figure 6.11). Cordon wires are supported on either end of the cross arms. Bilateral cordons extend from trunks that alternate, by vine, between one side of the trellis and the other. Cordons are pruned to spurs on their lower sides.

Shoot positioning is required to maintain canopy separation and to promote sunlight penetration into the fruiting and renewal region.

ADVANTAGES

- ❑ Yields and fruit quality can be increased significantly compared with nondivided canopy training systems.
- ❑ The Geneva double curtain system is well adapted to varieties having a trailing growth habit, such as those of native American origin.

DISADVANTAGES

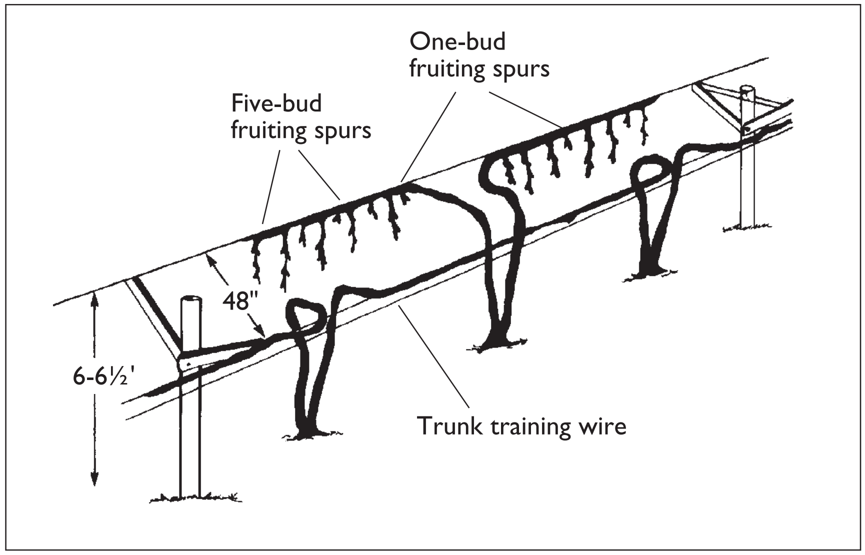
- ❑ A large amount of perennial wood must be maintained and exposed to winter injury.
- ❑ Considerable shoot positioning is required to achieve and maintain complete canopy division, especially with upright-growing varieties.

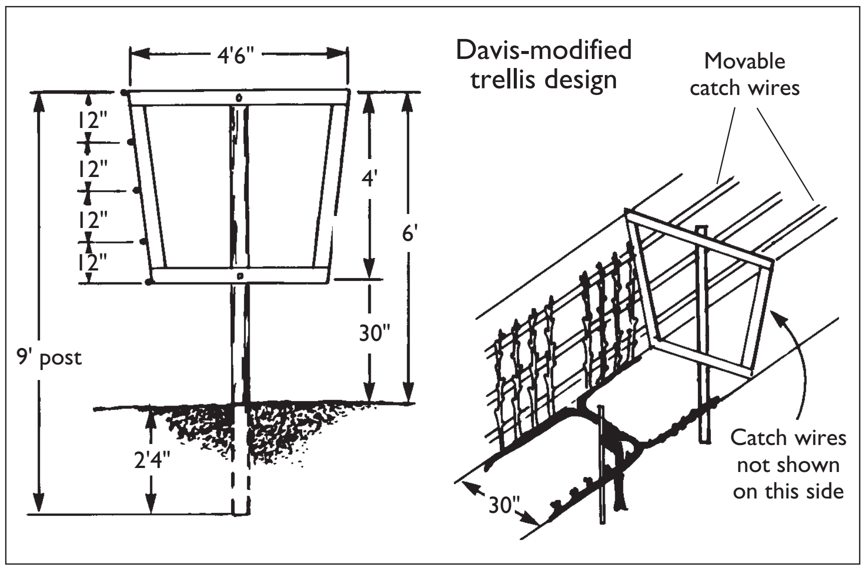
Lyre, or U-Shaped, Training

This design consists of a quadrilateral training system. Cordons are located 36 to 42 inches above ground (Figure 6.12). An elaborate trellis structure consisting of up to 16 catch wires is used to confine developing shoots to two independent and vertical curtains of foliage. The two curtains must be separated by at least 3 and preferably 4 or more feet at their bases. (A separation of 3.5 feet is illustrated in Figure 6.12.) Shoots are trained to the independent curtains with the assistance of multiple catch wires. Shoot topping is performed when shoot tops elongate much beyond the top wires. Inner catch wires can be movable to reduce the number needed. It is imperative to maintain two independent curtains of foliage by repeated shoot positioning and use of catch wires during the growing season.

ADVANTAGES

- ❑ This system is better suited than the Geneva double curtain system to varieties that exhibit a predominantly upright growth habit (for example, most vinifera varieties).





- ❑ Reestablishment of the training system after winter injury may be more rapid than with the Geneva double curtain.
- ❑ Greater yields can be achieved than with nondivided canopy training systems of the same row width.

DISADVANTAGES

- ❑ The initial costs of trellis establishment for Lyre Training are signficantly higher than conventional trellis systems.

Figure 6.11 (top). Geneva double curtain training system. Vines are spaced 8 feet apart in the row. (Adapted from Jordan et al., 1981.)

Figure 6.12 (bottom). U-shaped or open lyre divided canopy training system.

- ❑ Shoot positioning and tying is still necessary to maintain complete canopy separation.

In conclusion, several training systems are suitable for commercial grape production in North Carolina. Advantages and disadvantages can be cited for each. Evaluate the growth potential of your vines, the availability of vineyard labor, and the hazards of winter injury before choosing a particular system. Conversion of inferior existing systems to superior systems is possible. However, converting from a high training system to a low training system is much more difficult than converting from a low to high system. Conversion of nondivided training systems to more elaborate divided-canopy training systems is also possible if rows are wide enough.

References

Adelsheim, D. 1992. Spacing, training, and trellising vinifera grapes in western Oregon. In: Oregon Winegrape Grower's Guide, 4th Edition. Ted Casteel (ed.). pp 63 - 118. Oregon Winegrowers' Association, Portland, OR.

Jordan, T. D., R. M. Pool, T. J. Zabadal, and J. P. Tomkins. 1981. Cultural practices for commercial vineyards. Cornell University Extension Misc. Bulletin No. 111, Ithaca, NY.

McGrew, J. R. 1978. Basic guide to pruning. 14 pp. American Wine Society, Rochester, NY.

Shaulis, N. J., J. Einset, and A. B. Pack. 1968. Growing cold-tender grape varieties in New York. New York State Agricultural Experiment Station Bulletion No. 821.

Winkler, A. J., J. A. Cook, W. M. Kliewer, and L. A. Lider. 1974. General Viticulture. University of California Press, Berkeley, CA.

Chapter 7

Canopy Management

High-quality wines — those that command premium prices — can be produced only from high-quality grapes. Grape quality can be defined in various ways, but ripeness and freedom from rots are two of the chief qualities. Producing ripe fruit with minimum rot and maximum varietal character is not easy in North Carolina. As described elsewhere in this publication, the combination of climate, soils, and vine vigor often leads to excessive vegetative growth. For reasons that will be discussed, luxurious vegetative growth can reduce vine fruitfulness, decrease varietal character, degrade other components of fruit quality, and hamper efforts at disease control. Canopy management practices can help alleviate these problems.

Canopy management is a broad term used to describe both proactive and remedial measures that can be taken to improve grapevine canopy characteristics. In the broadest sense, canopy management can entail decisions regarding row and vine spacing, choice of rootstock, training and pruning practices, irrigation, fertilization, and summer activities such as shoot hedging, shoot thinning, and selective leaf removal.

This chapter presents grapevine canopy management principles and describes management practices that have been used successfully to enhance fruit and wine quality. Several excellent references on canopy management are cited at the end of the chapter, including the very informative text *Sunlight into Wine*.

Grapevine Canopies

The grapevine canopy is defined by the shoot system of the vine, including stems, leaves, and fruit (Figure 7.1). As described in chapter 6, vines can be trained to a single-canopy system (such as the bilateral cordon system) or to a divided-canopy system (such as the open lyre). And, just as cane pruning weights can be used as a quantitative measure of vine vigor (chapter 6), canopies can be described by various measures. We can, for example, measure them by their height, width, exposed leaf surface area, number of leaf layers, and shoot density (the number of shoots per unit length of canopy). These measures can then be compared to ideal canopy dimensions to decide whether corrective action is warranted.

Canopy Microclimate

The reasons behind many recommended canopy management practices can be better understood by recognizing that heavy, dense grapevine canopies can create a highly localized climate, distinctly different from that immediately outside the canopy. The climate within the canopy is referred to as the canopy *microclimate*. It is described in familiar terms such as temperature, humidity, wind speed, and amount of sunlight. Table 7.1 compares the microclimate of a sparse canopy or the region outside of a canopy with the microclimate inside a dense canopy.

Considerable progress has been made in understanding how grapevine canopies create unique microclimates that, in turn, affect vine and fruit physiology.

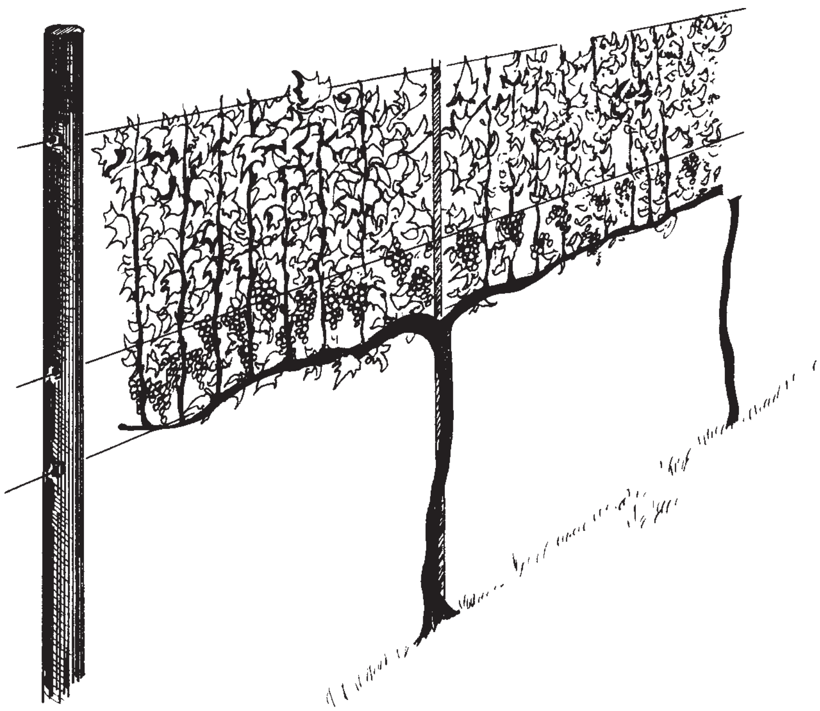


Figure 7.1. The grapevine canopy is defined by the shoot system of the vine, including stems, leaves, and fruit.

Radiation

Grapevine leaves absorb approximately 90 percent of the sunlight that strikes them. This sunlight is responsible for photosynthesis, the process by which green plants convert sunlight and carbon dioxide into sugars and other carbohydrates. The exterior leaves of the canopy absorb large amounts of sunlight but transmit very little to the leaves deeper within the canopy. Shaded leaves are often not photosynthetically productive because they receive less sunlight than they need to produce carbohydrates. In addition, shaded leaves may contribute excess potassium to developing fruit and impede ventilation in the fruit zone. Excess potassium can, under certain conditions, contribute to elevated fruit acidity, which can be undesirable for making wine. Shade also reduces the fruitfulness of developing buds. Thus, yields from vines with dense canopies can be significantly lower than those from vines having a sparser shoot distribution.

Temperature

The air temperature within a grapevine canopy does not differ greatly from the temperature immediately outside the canopy. However, the

Table 7.1 Characteristics of the Microclimates of Sparse and Dense Canopies

Characteristic	Sparse Canopy	Dense Canopy
Sunlight	Most leaves and fruit are exposed to sunlight.	Most leaves and fruit are in shade.
Temperature	Fruit and leaves can be warmed by sunlight. At night, outside leaves and fruit can be cooled.	Most leaves and fruit are interior so are close to the temperature of the ambient air day and night.
Humidity	Leaves and fruit experience ambient humidity values.	Humidity can build up slightly in the canopy.
Wind speed	Leaves and fruit are exposed to approximately the ambient wind values.	Wind speeds are reduced in the canopy.
Evaporation	Evaporation rates are similar to ambient values.	Evaporation rates are reduced in the canopy.

shade produced by the exterior leaves can affect the radiational heating and cooling of fruit and leaves. For example, fully exposed fruit can be *heated* by solar radiation to a temperature 20° to 30°F higher than that of the surrounding air. That warming can be used to advantage in cool grape regions to reduce fruit acidity. Conversely, on clear nights, exposed fruit and leaves can cool as much as several degrees below the ambient air temperature by radiational *cooling*.

Wind Speed

Vine canopies reduce wind speed. The reduction is greater for dense canopies than for sparse ones. Wind movement — even a slight breeze — is very helpful in reducing fungal infections of fruit and leaves. Many of the fungi that attack grapevines in the eastern United States require either the presence of free water or a period of high humidity to infect the plant. Air movement helps evaporate moisture and reduce humidity in the canopy, reducing the opportunity for fungal infections to occur. Furthermore, sparse canopies permit greater pesticide penetration and coverage when vines are sprayed. The combined benefits of increased ventilation and increased pesticide penetration are fundamental reasons for using canopy management practices that promote a uniformly sparse or open canopy.

Principles of Canopy Management

Richard Smart, who advanced our knowledge of the relationship between canopy characteristics and fruit and wine quality, has provided a convenient means of understanding canopy management by condensing the underlying research findings into five basic principles. Those principles are reviewed here in a slightly modified form to provide a basis for recommendations on assessing and modifying canopy characteristics.

PRINCIPLE 1: Vines should be spaced and trained to maximize the amount of leaf area exposed to sunlight. Furthermore, the canopy leaf area should develop rapidly in the spring. Principle 1 is derived from the observation that vineyard productivity increases when the percentage of available sunlight intercepted by vine leaves (rather than by the vineyard floor) increases. In essence, sunlight that falls on the vineyard floor is wasted. Studies have shown that grapevines receive the most sunlight when the vineyard rows are spaced fairly close and are oriented in a north-south direction. The canopies should be trained vertically to tall, thin curtains of foliage. Rapid leaf area development is promoted by retaining a relatively large number of short shoots on each vine, as opposed to a relatively few long shoots.

PRINCIPLE 2: Rows and canopies should not be so closely spaced that one canopy shades the renewal region of adjacent canopies. The ratio of canopy height (not trellis height) to alley width should not exceed 1 to 1. The *renewal region* of the canopy, as defined in chapter 6, is that portion in which buds for the following season's crop develop. The renewal zone is often the current season's fruit zone. Figure 7.2 illustrates principle 2 for vines trained to divided and nondivided canopies. The shade cast by one canopy on another reduces the photosynthetic function of the shaded leaves and reduces the fruitfulness of developing buds. The 1-to-1 ratio of canopy height to canopy or row width minimizes the shading of any canopy by adjacent ones. Note that principles 1 and 2 attempt to strike a balance between maximizing sunlight interception by grapevine leaves and minimizing intercanopy shade. In theory, principle 2 suggests that with a standard canopy height of 4 to 5 feet (where the height is measured from the bottom to the top of the canopy, not the trellis height), rows (or canopies) may be spaced as closely as 4 or 5 feet apart (Figure 7.2). In practice, equipment width often dictates that row spacing be about 8 to 10

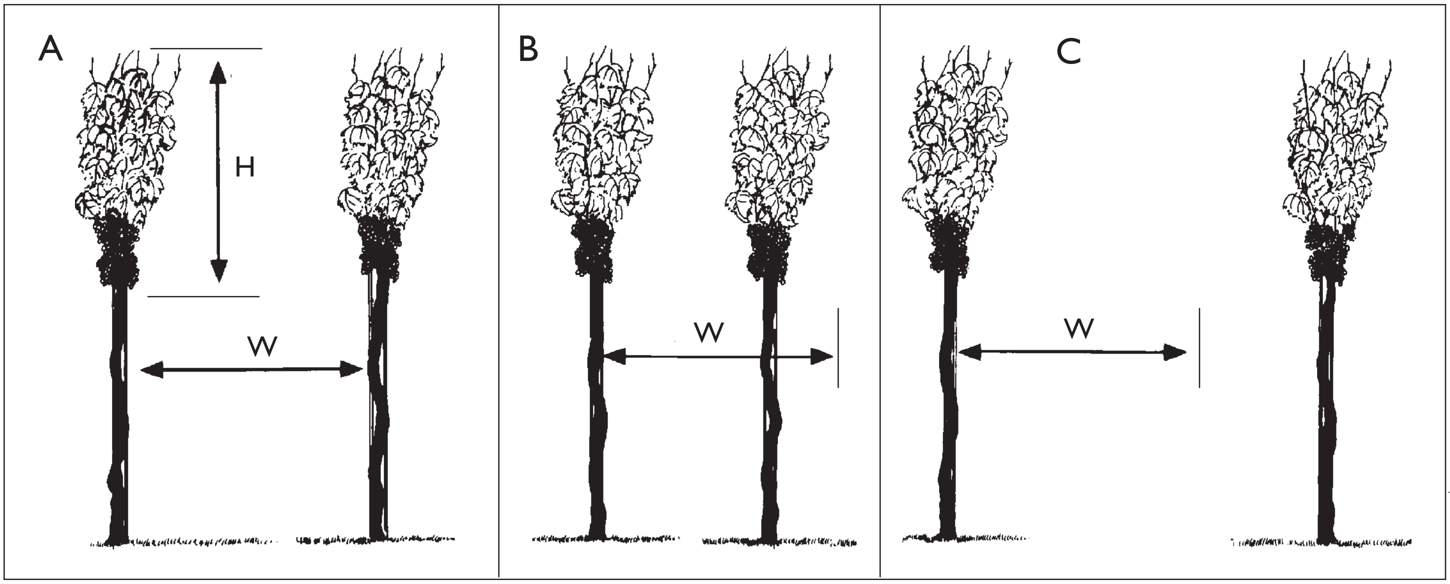


Figure 7.2. Canopy height (H) to width (W) ratio is 1:1 in A, less than 1:1 in B, and exceeds 1:1 in C. Canopies of A maximize sunlight interception by vine-yard. Canopies of B shade each other. Canopies such as C result in inefficient interception of sunlight.

feet. The advent of specialized, narrow vineyard equipment in the United States may permit reduction of row spacing and more efficient use of vineyard area.

PRINCIPLE 3: Canopy shade should be avoided, especially in the fruit and renewal zone. Leaves and fruit should be exposed to as uniform a microclimate as possible. Canopy shade can significantly reduce fruit and wine quality. The negative effects of shade on fruit composition include elevated levels of potassium, pH, and titratable acidity levels; reduced pigmentation; and reduced concentrations of phenols and soluble solids. Collectively, the altered fruit composition can significantly reduce wine quality. Shade can also retard the development of varietal character and impart vegetative characters to the fruit and wine. Furthermore, shade can promote fruit rot by reducing the resistance of fruit and leaves to infection and by reducing the rate of drying within the canopy. Shade also reduces bud fruitfulness. Buds that developed in shaded renewal zones tend to produce shoots with fewer and smaller clusters and reduced berry set, or those buds may fail to produce shoots at all.

PRINCIPLE 4: Shoot growth and fruit development should be balanced to avoid either too much or too little leaf area in relation to the weight of fruit. That is, vines should produce just enough foliage to ripen large crops of high quality grapes. Excessively vigorous vines produce large shoots (relatively large in diameter, with long internodes, large leaves, and a tendency to develop active lateral shoots), resulting in dense canopies. Insufficient vigor, on the other hand, typically results in stunted shoots that have insufficient leaf area to ripen the crop. Applying this concept of balance between shoot growth and crop weight requires some method of measuring the relationship between the two. One measure of balance for a given vine is the ratio of crop weight to cane pruning weight. That ratio is sometimes called crop load. (See the following section, "Assessing Canopy Characteristics.")

PRINCIPLE 5: Training systems and dormant pruning should promote uniformly positioned fruiting and renewal zones. Uniformly positioned vine parts greatly facilitate mechanization of vineyard operations and even simplify hand labor for certain practices. Shoots that arise from a uniform height on the trellis, for example, are easier to summer prune or hedge. Uniform positioning of fruit makes it easier to remove leaves selectively from the fruit zone, and the fruit can be more rapidly picked by hand than when the fruit is borne over a larger region of the canopy. Creating a uniformly positioned renewal zone is also desirable for physiological reasons relating to uniformity of bud break and shoot growth.

Assessing Canopy Characteristics

One of the most confusing aspects of canopy management for many growers, especially novices, is determining whether the density of their vine canopies is ideal, acceptable, or excessive — in other words, knowing how to decide when corrective measures should be applied. While experienced growers may rely on observation and experience, new growers can benefit — and gain confidence — by assessing canopy characteristics with quantitative methods.

Several inexpensive, rapid techniques are commonly used by vineyardists to assess vine canopies. A collection of eight visual observations has been compiled in the form of a scorecard. (see the book *Sunlight into Wine* listed in the references.) With a minimum of practice, the scorecard can be used to assess canopies and rate characteristics such as leaf size and canopy density by comparison with an ideal canopy. Canopy scoring is a very useful technique even if not all eight elements of the scoring system are used. Direct measurements are also useful and remove some of the subjectivity inherent in the scorecard approach. Some of the more commonly used measurements are (1) cane pruning weights, (2) crop load, (3) shoot density, (4) canopy transects, and (5) periodic measures of shoot length. Each is described and related to desirable ranges in the following sections.

Cane Pruning Weights

The weight of one-year-old wood (canes) removed from a vine during dormant pruning provides a measure of the vine's capacity for fruit and shoot growth in the following year. Thus, pruning weights can be used to determine the number of buds to retain at dormant pruning, as described in chapter 6. Pruning weights also indicate whether vines have insufficient or excessive vigor for their available trellis space. Well-balanced vines should have pruning weights ranging from 0.2 to 0.4 pound per foot of canopy. Thus, for vines spaced 8 feet apart in the row and trained to a nondivided canopy system, pruning weights should range from 1.6 to 3.2 pounds. If the majority of vines produce less than 0.2 pound of pruned canes per foot of canopy, consider stimulating vine vigor. These vines probably do not have sufficient vigor to fill their available trellis space with foliage, and crop yields will be unnecessarily constrained. Vine vigor and pruning weights can be increased in several ways, including crop thinning, application of nitrogen fertilizer, and irrigation. Conversely, if most vines produce more than 0.4 pound of prunings per foot of canopy, the vine size and vigor is probably too great and the canopy has been too dense. If other observations and measures support the conclusion that vine vigor and canopy density are excessive, thought should be given to reducing canopy density in the following year. (See the section "Canopy Modification" later in this chapter.)

The practice of summer pruning reduces dormant pruning weights and should be taken into account when evaluating pruning weight data. It is incorrect, for example, to judge a vine with 0.3 pound of prunings per foot of row or canopy to be balanced if that vine required repeated summer pruning during the previous growing season.

Crop Load

Crop load, as defined earlier, is the ratio between the weight of the crop and the weight of pruned canes produced during the same season. This ratio is one measure of whether vines are balanced between vegetative growth and crop production in accordance with principle 4. Determining crop load requires weighing both the fruit at harvest and the canes removed at pruning. For practicality, these measurements are usually limited to 10 or 20 representative vines per vineyard block. Unless damaged or killed, the same vines should be used each year to develop a long-term data base on the vineyard block's performance. The same vines might be used for the other canopy measures to be described here, and for crop estimation, as described in chapter 12.

Research on different varieties under varied growing conditions has shown that crop load ratios should range from 5 to 10. Thus, for vines with cane pruning weights of 2.5 pounds, crops should range from 12.5 to 25 pounds. Vines with crop-load ratios outside the range from 5 to 10 should be evaluated for conditions that might explain the disparity. Crop-load ratios less than 5 indicate excessive vegetation in relation to crop weight (although this condition is normal for young, nonbearing vines). Crop-load ratios greater than 10 are likely associated with overcropping. Symptoms of overcropping include delayed sugar accumulation, reduced fruit coloration, and delayed or reduced wood maturation in the fall. Information gained by measuring crop load in a given year can be used to adjust crops or shoots during the following growing season in order to move toward a more balanced vine.

Shoot Density

Shoot density is a measure of the number of shoots per unit length of canopy and usually relates well to overall canopy density: the greater the shoot density, the thicker, or denser, the canopy. Shoot density can be assessed at any point in the growing season, but it is often done after bud break. The count should be in the range from 4 to 6 shoots per foot of row or canopy. For vines spaced 8 feet apart in the row and trained to a nondivided system, the total number of shoots per vine should range from 32 to 48. The lower number is more suitable for large-clustered, very fruitful varieties such as Seyval and Sangiovese. The higher limit is suitable for small-clustered varieties such as Pinot noir and Riesling. As a starting point, most varieties will produce desirable yields of ripe fruit at a density of five shoots per foot of canopy.

Canopy Transects

Canopy transects are used to quantify canopy thickness (number of leaf layers), porosity (gaps in the foliage), and the percentages of fruit and leaves exposed to sunlight. Also called *point quadrats*, canopy transects consist of multiple, transectional probes of representative vine canopies with a thin rod. Contacts that the probe tip makes with leaves, fruit, or canopy gaps are recorded as the probe is passed from one side of the canopy to the other. Transects require at least two persons (one handling the probe and one recording data) and are done at or shortly after véraison. In practice, a thin rod is inserted horizontally and at regular intervals (for example, every 6 inches) into the fruit zones of representative vines. A metal tape measure or ruled wooden frame will serve as a guide for probe insertion. Aside from locating the point of probe insertion, the person using the probe should not watch its path through the canopy. An observer tracks the point of the probe and records the nature of all probe contacts as either a leaf (L), a cluster (C), or a gap (G). Gaps are recorded only where the probe fails to contact any leaves or fruit in its passage through the canopy. Contacts with shoot stems are generally ignored. Data are recorded as shown in Table 7.2. In this case, 50 probes were made and the calculations of canopy density were as follows:

Percentage of gaps = gaps ÷ number of probes (6 ÷ 50 = 12%)

Leaf layer number = leaf contacts ÷ number of probes (85 ÷ 50 = 1.7)

Percentage of exterior leaves = exterior leaves ÷ total leaf contacts (68 ÷ 85 = 80%)

Percentage of exterior clusters = exterior clusters ÷ total cluster contacts (15 ÷ 23 = 65%)

Table 7.2. Representative Canopy Transect Data Summarizing the Nature of Contact by 50 Passes of a Probe

Probe Pass	Nature of Contact*	Probe Pass	Nature of Contact	Probe Pass	Nature of Contact	Probe Pass	Nature of Contact	Probe Pass	Nature of Contact
1	LLFL	11	G	21	LL	31	F	41	L
2	LLL	12	LL	22	LLF	32	LL	42	G
3	FLL	13	FLLL	23	LFLL	33	FL	43	LF
4	LL	14	LL	24	F	34	G	44	LFL
5	G	15	LFFL	25	LL	35	LL	45	LLL
6	FL	16	LLL	26	LLL	36	LFL	46	LL
7	LF	17	LL	27	FLL	37	LLL	47	F
8	LL	18	LLL	28	LL	38	G	48	LF
9	F	19	FL	29	G	39	LFLL	49	LL
10	LL	20	LLL	30	LL	40	LLLF	50	LFL

*Nature of probe contact: L = leaf, F = fruit cluster, and G = gap. Contacts with shoot stems are ignored.

Canopy transects, if repeated at least 10 times in each vineyard block, can provide a considerable amount of information on canopy density. Again, these data can be compared to ideal canopy parameters to determine whether remedial action is necessary, either in the current or following year. For example, the percentage of canopy gaps recorded should be about 20 percent, the leaf layer number should range from 1.0 to 2.0, and the percentage of exposed leaves and fruit should be at least 80 percent and 50 percent, respectively. (See *Sunlight into Wine*.)

Shoot length and lateral shoot development should also be assessed. Ideally, shoots should grow rapidly to 15 or 20 nodes or leaves in length and then stop growing and develop few or no lateral shoots. In reality, shoots of vigorous vines often continue to elongate after fruit harvest and may exceed 50 nodes in length. The same shoots may also develop many persistent summer laterals. Shoot vigor should be assessed periodically throughout the growing season and the shoots hedged, if necessary, to prevent shoot tops from aggravating canopy density and canopy ventilation. (See the section "Summer Pruning" in this chapter.)

Canopy Modification

An assessment of vine canopies using one or more of the methods described may show that the canopies are far from ideal. While drought, infertile soil, and vine disease can all contribute to low vigor and sparse canopies, the opposite condition — high vigor and excessive canopy density — is the more frequent situation, especially with grafted grapevines. Therefore, the canopy modifications described here are intentionally aimed at improving the microclimates of dense canopies. Some of these measures offer only short-term solutions, whereas others, such as canopy division, offer more lasting benefits.

Summer Pruning

Summer pruning, or *hedging*, involves removing vegetation during the growing season. Typically, this process involves removing shoot tops, retaining only the nodes and leaves needed for adequate fruit and wood maturation. Specific recommendations for hedging depend on the training system used. Hedging is probably most beneficial when applied to low- or mid-wire-trained vines that have upright-positioned shoots. Low-wire bilateral cordon training with upright shoot positioning is such a system. It is fairly easy with this system to top shoots once the shoots have cleared the top of the trellis and before they start to droop over and shade the original canopy. Depending on cordon or cane height on the trellis, shoots that have elongated a foot or so higher than the 6-foot-high trellis will generally have 15 to 20 leaves and can be hedged at a uniform level. Shoot topping does not have as much benefit with vines whose shoots are not positioned — at least not from the standpoint of providing ventilation of the fruit zone. The reason for that reduced response is illustrated by Figure 7.3 and is one of the bases for principle 5, cited earlier. Hedging the low-trained, shoot-positioned vines removes shoot tops that are shading the fruit zone of the original canopy (A). Hedging shoots on high-trained vines, in the absence of downward shoot positioning, does not appreciably improve ventilation in the fruit zone (B). In fact, hedging such vines can sometimes reduce fruit zone ventilation by causing greater lateral shoot growth in the fruit zone. A better canopy management strategy with high-trained vines is the downward "combing" or positioning of shoots during the growing season. Whether the shoot tops are ever removed is not as important as preventing them from growing horizontally.

Hedging should be delayed as long as feasible — preferably for 30 or more days after bloom. Retain a minimum of 15 primary (not lateral) leaves per shoot. It is not necessary to count leaves on every shoot, but with most varieties the shoots will average 4½ to 5 feet in length when they bear 15 to 20 primary leaves. Heavy-duty, scissor-type hedge shears are the most commonly used hedging tools. Gasoline or battery-operated cutter-bar hedgers have also been used. In either case, the process is less tiring if one works with arms at chest height by standing on an elevated platform such as a trailer.

Altered Training Systems

Training systems that promote ventilation of fruit zones have an advantage over those that tend to hide the fruit within shaded canopy interiors. The training system should promote maintenance of a thin canopy of foliage (no more than two leaf layers thick). For large, vigorous vines in established vineyards, conversion to divided canopy training might be the most practical way to achieve the desired canopy density. Canopy division should be considered when the majority of vines have average pruning weights in excess of 0.3 to 0.4 pound of prunings per foot of canopy in the absence of summer pruning. Several approaches to canopy division should be considered and specific guidelines sought before pursuing this course. The establishment of multiple trunks before the year of conversion makes the process much easier and avoids

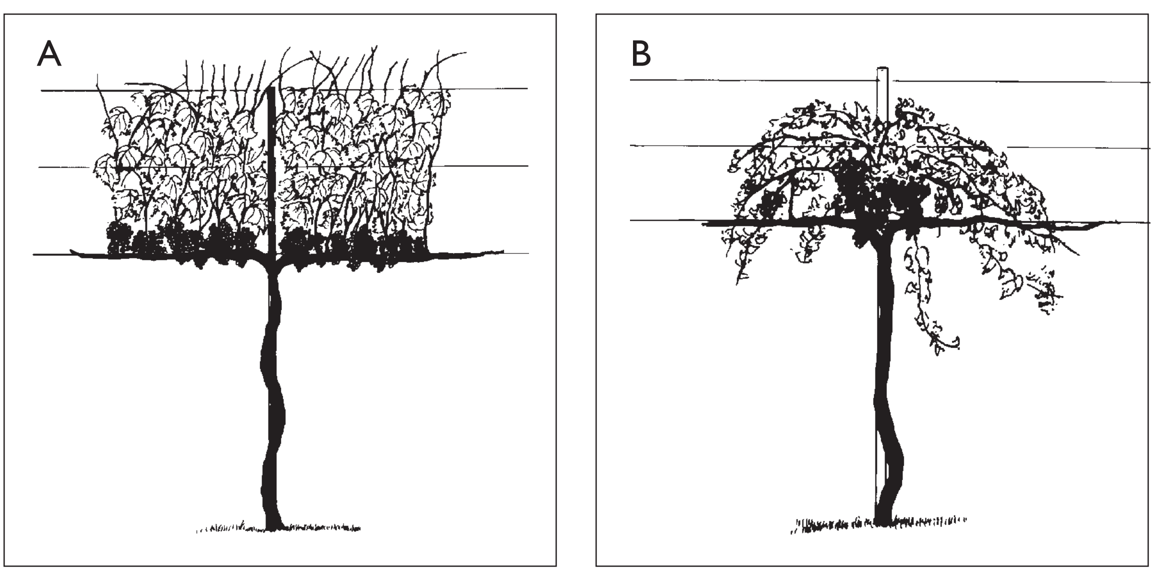


Figure 7.3. Gross effects of hedging shoot-positioned, vertically upright-trained canopies (A), compared with hedging of non-shoot-positioned canopies (B). The benefits of hedging on fruit zone ventilation (and exposure) are likely to be greater with (A) than with (B).

loss of crop in the conversion year.

Canopy division is not always practical for existing plantings. For nondivided canopies, bilateral cordon training coupled with upright shoot positioning (to be discussed later) is one of the more efficient systems in use in North Carolina, both in terms of pruning labor and canopy management. With low- to mid-wire cordon training (36 to 44 inches above ground), the shoots originate at a uniform height and fruit is borne in a fairly limited region of the canopy. Both of those features greatly facilitate canopy management practices such as shoot thinning, selective leaf pulling, and shoot positioning. Cordon training (either high or low) is less desirable, however, in situations where winter cold injury makes the perennial maintenance of cordons difficult or impossible.

Shoot Positioning and Shoot Thinning

Some shoot positioning should be an integral part of vineyard management. The objective of shoot positioning is to position the vine's shoots and foliage uniformly in the vine's available trellis space and minimize mutual leaf shading. For high-trained vines, shoot positioning entails combing the shoots down to form a curtain of well-exposed foliage. For low-trained vines (for example, those trained to a low, bilateral cordon system), the shoots should be positioned upright, again to form a thin, well-exposed canopy. Paired catch wires can be added to the trellis to sandwich the shoots and prevent them from being blown free once positioned. Also, various shoot tying or taping devices are commercially available. Shoot positioning is easier if done repeatedly rather than waiting until the shoots are very long and in need of substantial redirection. If the process is started at about bloom time, most shoots can be positioned without breakage and before their tendrils have secured the shoots to wires or other supports. Depending upon the number of foliage catch wires used on the trellis, some repositioning of shoots may be necessary between bloom and véraison to maintain the desired canopy dimensions.

Shoot thinning is also a good technique for maintaining a more open canopy. An added advantage of shoot thinning is that it can control crop in varieties that tend to overproduce (for example, Seyval). Shoot thinning is done soon after bud break and preferably before shoots are more than 18 to 24 inches long. Longer shoots are more difficult to remove. A convenient rule of thumb is to retain four to six shoots per foot of canopy (as recommended previously under "Shoot Density"). The choice of shoots to be retained should be made with regard to their spacing on the cordon or trellis and their fruitfulness. Except where needed for spurs the following year, unfruitful shoots should be removed in preference to fruitful shoots unless crop reduction is desired.

Selective Leaf Removal

The selective removal of leaves from the area around fruit clusters has been practiced increasingly in the United States in recent years. This practice can be an effective tool for fruit rot control. The leaves can be removed anytime between fruit set and véraison; however, early leaf removal may have to be repeated to keep fruit clusters open, and post-vérasion leaf pulling can result in the fruit being sunburned. The goal of leaf pulling is to increase ventilation and light penetration into the fruit zone. Generally, only one to three leaves per shoot are removed. It is not necessary to remove all leaves in the fruit zone. The objective is to have an average of one to two leaf layers remaining in the fruit zone after the leaves have been pulled. Leaf pulling is more efficient with training systems that have uniformly placed fruit zones (such as with bilateral cordon training), compared with systems in which one must hunt for the fruit clusters. With the latter systems, as with hedging, more basic canopy management techniques such as training system conversion and shoot positioning may be more useful than leaf pulling. Leaf pulling is most often done by hand, but some vineyards use tractor-mounted machines to increase the speed of operation.

References

Smart, R. E., J. K. Dick, I. M. Gravett, and B. M. Fisher. 1990. Canopy management to improve grape yield and wine quality: Principles and practices. South African Journal of Enological Viticulture 11:3-17.

Smart, R. E., and M. Robinson. 1991. Sunlight into Wine: A Handbook for Wine Grape Canopy Management. Winetitles, Adelaide, Australia.

Chapter 8

Pest Management

Grapes are subject to attack by many different pests, including nematodes, fungal, bacterial, and viral pathogens, insects, and wildlife, such as deer and birds. Weeds, which compete with the vines for soil moisture and nutrients, may also be included in this list. Recognizing and understanding the nature of these pests is essential to minimizing crop losses. This chapter briefly describes the major pests that routinely threaten bunch grapes in North Carolina and discusses control measures.

Many pest and disease problems can be managed by adjusting cultural practices to make conditions unfavorable for pests or pathogens. Despite use of cultural controls, however, chemical pesticides are usually required for effective control of many of the fungal diseases and some of the insects that attack many of the popular grape varieties. Pesticide recommendations change often because of changes in registrations, product manufacture, and product efficacy. Current information on chemical control measures for grapes can be obtained through your county Cooperative Extension center; however, understanding the biology of the pests helps greatly in using chemical control measures effectively. Some chemicals have very specific modes of action; they are therefore effective on some pests but useless against others. More detailed and comprehensive information on disease and insect identification may be found in the publications listed at the end of this chapter.

Diseases

Numerous diseases caused by fungi, bacteria, nematodes, and virus and virus-like organisms affect bunch grapes in North Carolina. While many of these diseases occur in other grape growing regions of the world, summer bunch rot diseases are more severe in North Carolina than in most other growing regions because of the state's warm and wet climate. Some vineyards have suffered losses of 50 percent or more due to bitter rot and ripe rot. Good sanitation, diligent canopy management to facilitate drying, and a rigorous, well-timed spray program are necessary to successfully manage fruit and foliar diseases of bunch grapes in North Carolina vineyards. Treatment options for bunch grape disease management can be found at http://www.smallfruits.org/SmallFruitsRegGuide/Guides/BunchGrapeSprayGuide.pdf.

Fungal Diseases

Anthracnose, Bird's-Eye Rot

Anthracnose is primarily important on American bunch grapes, and is favored by the rainy, warm climate. Epidemics are sporadic but can cause significant economic loss once established in a vineyard, reducing fruit quantity and quality and weakening the vine.

Anthracnose is most common on fruit and young shoots but may occur on all succulent plant material. Fruit lesions are small, circular, and red. As the lesions enlarge (up to 1/4 inch in diameter) and become sunken, the centers become gray (Figure 8-1) and are often surrounded by a reddish-brown margin, resulting in the typical "bird's-eye" symptom. Infected grapes often crack, leaving the seed exposed (Figure 8-1). If an early infection is arrested, the surface of the fruit can appear scabby. Lesions on shoots and leaves are similar in color to those on fruit, sunken, and have reddish-brown borders (Figure 8-2). Young leaves are more susceptible and can be malformed if veins are infected. Stem infections can cause cracking of stems and formation of callus tissue, and shoots can be girdled and die if the lesions coalesce.

Figure 8.1 Anthracnose on fruit.

Figure 8.2 Anthracnose on shoots.

Anthracnose is caused by the fungus *Elsinoe ampelina*. The pathogen overwinters in old lesions and as fruiting bodies (sclerotia) on infected canes. Sclerotia germinate in the spring after a 24-hour period of wetness, producing mycelium and eventually spores (conidia). Fruiting structures (ascocarps) can also form on infected debris to produce ascospores. Conidia and ascospores, both serving as primary inoculum, germinate and infect green tissue. Temperatures of 75 to 79°F are optimum for infection. Clusters are susceptible to infection prior to flowering until veraison. Once the fungus is established in the host, fruiting bodies (acervuli) form lesions that exude pinkish masses of conidia. Splashing rains spread the conidia to adjacent clusters resulting in secondary infections.

Management Options

Cultural - Sanitation is very important in anthracnose management. Because the fungus survives on canes, pruning out and destroying infected shoots, cluster stems, and fruit during the dormant season reduce the amount of primary inoculum of the pathogen in the vineyard. Canopy management that facilitates air circulation and reduces drying time, including shoot positioning and leaf removal, will also aid in disease control.

Chemical - Where the disease is a problem, apply lime sulfur during the dormant season to reduce the overwintering inoculum and apply fungicides every 10 to14 days from bud break until veraison.

Bitter Rot

Bitter rot is one of the most important summer bunch rot diseases of *Vitis* spp. in North Carolina, causing 10 to 30 percent loss of ripening fruit. Diseased fruit develops an unpleasant, bitter taste that affects the quality of wine produced and/or the ability to market the crop.

Leaf infections occur as tiny, sunken reddish-brown flecks with yellow halos. Lesions on stems and petioles are round to elliptical, slightly raised, and reddish-brown to black in color. Flecking of the sepals and blighting of the flower buds can also occur. Infected grapes soften and become completely covered with concentric rings of fruiting bodies known as acervuli. Light colored fruit often turn brown, while dark colored fruit appear roughened and sparkly when acervuli develop (Figure 8-3). Infected fruit may abscise, or may dry into mummies and stay firmly attached. Bitter rot is often confused with black rot, but the black rot pathogen primarily infects immature or green fruit before veraison while the bitter rot fungus infects fruit at maturity.

The fungal pathogen that causes bitter rot, *Greeneria uvicola* (syn. *Melanconium fuligineum*), overwinters on plant debris, canes, and mummified fruit. In the spring, spores (conidia) from acervuli are carried by rain to all green parts of the vine, including the pedicels. The pathogen invades the pedicels and becomes latent, or inactive, until fruit mature. Fruit become increasingly susceptible to infection from bloom to veraison. In the weeks leading up to harvest, the pathogen grows from the pedicels into the ripening fruit, causing them to rot and eventually become completely covered with concentric rings of fruiting bodies. Secondary infections can occur when conidia from infected grapes are rain splashed to fruit that has been mechanically wounded by birds, insects, or hail, or has cracked following heavy rains.

Management Options

Cultural - Good weed control and canopy management practices, including pruning, leaf removal, and shoot positioning, promote air circulation and light penetration, which improve drying of leaves and clusters and will result in a less favorable environment for bitter rot development. It is essential to prune out dead spurs and cordons and other infected plant material during the dormant season to reduce the inoculum carried over to the next season. Bunch grapes vary in susceptibility from resistant to highly susceptible.

Figure 8.3 Symptoms of bitter rot.

Chemical - Successful management of bitter rot involves protecting fruit with fungicides during favorable infection periods of warm wet weather from bloom to harvest. The spray program devised to control black rot will help to manage early season bitter rot activity, but to prevent fruit infections and subsequent rot, late season and preharvest fungicides should be applied.

Black Rot

Black rot is the most common early-season fruit rot disease of bunch grapes in North Carolina. Most varieties of vinifera, French/American hybrids and American bunch grapes are susceptible. Crop loss due to black rot can range from 5 to 80 percent, depending on weather conditions, level of inoculum, and susceptibility of the variety.

Black rot disease affects leaves, shoots, tendrils, and fruit of grapevines. Leaf spots are characteristically tan, circular lesions with small black fruiting structures (pycnidia) scattered within them (Figure 8-4). Infections on young shoots, tendrils, and petioles first appear as small dark lesions that later develop into elongated, often sunken lesions. Elongated black cankers may develop on shoots, and can eventually girdle them, causing a shoot blight. Lesions on fruit are initially small and scabby but as they expand they

Figure 8.4 Black rot lesions on a grape leaf.

become sunken. As the entire fruit becomes colonized, it turns light brown in color, and begins to shrivel (Figure 8-5). Numerous dark brown to black pycnidia develop over the surface. Eventually, the fruit dry and shrivel, turning into hard, blue-black mummies (and Figure 8-5).

Black rot is caused by the fungus, *Guignardia bidwellii*. The fungus overwinters on stem cankers, on clusters left hanging on the vine, and on

Figure 8.5 Black rot caused these grapes to dry and shrivel.

mummified fruit on the soil. During spring rains ascospores and/or conidia are ejected and carried by rain and wind to leaves, blossoms and young fruit. Lesions may develop on all young, green tissues when temperatures and duration of leaf wetness are favorable for infection. Infection may occur after 6 hours of wetness at 81°F, but at 50°F, 24 hours of wetness is required. Very little infection occurs above 90°F. Fruit are most susceptible to infection from mid-bloom to about 6 weeks after bloom, and become resistant to infection at maturity.

Management Options

Cultural - Mummified fruit and infected canes are the major source of primary inoculum for early season infections, and should be removed from the vine and vineyard floor before spring arrives; mummies may be disked into the soil. Good canopy management practices are essential for control of black rot. Shoot thinning, leaf removal, pruning, cluster thinning, and shoot positioning are all cultural practices that open the vine canopy to air and light, reducing the amount of moisture trapped within the canopy, and allowing better penetration and spray coverage of biological or chemical fungicides.

Chemical - Fungicide applications for black rot control are most critical in the prebloom and first two postbloom sprays. In vineyards where black rot is a problem, it may be necessary to initiate fungicide treatment 2 weeks earlier. Wetting and temperature requirements necessary for infection to occur have been defined for black rot on bunch grapes (Table 8-1).

Table 8.1 Hours of Continuous Leaf Wetness Required for a Black Rot Infection by Temperature.

Temperature	Hours
50	24
55	12
60	9
65	8
70	7
75	7
80	6
85	9
90	12

Source: R.A. Spotts, The Ohio State University.

Botrytis Bunch Rot, Gray Mold

Botrytis bunch rot is the most important bunch rot disease of grapes worldwide, and can cause serious losses in the vineyard and in transit or storage. *Botrytis* infection is favored by cool weather and free moisture on the surface of fruit. Bunch rot is most severe on varieties with thin skins or tight fruit clusters, under heavy canopies, and in areas of high humidity.

Leaf infection by the bunch rot pathogen, *B. cinerea,* occurs under cool, moist conditions in spring prior to bloom, and appears as a dull green spot that turns into a reddish-brown necrotic lesion. Young shoots and blossoms may also become infected, resulting in significant yield losses. Small brown patches may appear on pedicels or rachises that later turn black, causing portions of the cluster to shrivel and drop. The fungus infects and rots ripening berries, causing the fruit of white varieties to become brown and purple varieties to become reddish. The most common symptom of the disease appears when fluffy, gray-brown growth containing spores becomes visible, eventually spreading throughout the entire cluster (Fig 8-6).

The causal fungus, *B. cinerea,* overwinters on canes, bark, dormant buds, and debris on the vineyard floor as dormant mycelium, or as hard, resting structures (sclerotia) in berry mummies or on canes, which are resistant to adverse weather conditions. Conidia produced in the spring are rain-splashed and windblown to newly emerging leaves. Infection may occur at temperatures as high as 86°F, but the optimum temperature for infection is between 59 and 68°F. Tissue that is dead or has been injured by hail, wind, birds, or insects is usually colonized before healthy tissue. Early-season powdery mildew infected fruit are also more susceptible to infection. Since spore production and infection are favored by wetness and high humidity, fruit infection in North Carolina may occur throughout the season from bloom to closing, and after veraison when sugar concentrations increase in fruit. As harvest approaches, spores from infected fruit may spread to other fruit in the cluster as well as to other clusters.

Figure 8.6 Botrytis bunch rot.

Management Options

Cultural - Good botrytis control starts with good sanitation practices. Before spring arrives, it is extremely important to remove all of last year's fruit from the trellis, as well as canes, bark, and debris from the vineyard floor. Because *B. cinerea* thrives under moist conditions, good canopy management practices, including shoot thinning, leaf removal, pruning, cluster thinning, and shoot positioning, are essential for reducing humidity and increasing air circulation. Varieties of bunch grapes vary in their susceptibility (Table 8-2). The disease tends to be more severe on varieties and clones with tight clusters.

Chemical - Fungicide applications are most critical in the veraison and preharvest sprays, and if the season is wet, sprays may be necessary at bloom and closing as well. Additionally, it is important to prevent early season powdery mildew infections since infected fruit are more susceptible to infection by *B. cinerea.* If conditions become wet at harvest, picking early can reduce the amount of fruit lost to botrytis bunch rot.

Table 8.2 Relative Susceptibility of Varieties of Bunch Grapes to Common Fungal and Bacterial Diseases.

Sources: www.hort.purdue.edu/hort/ext/sfg/2003_pdfs/03complete.pdf- www.ext.vt.edu/pubs/viticulture/463-019/463-019pdf; www.nysaes.cornell.edu/hort/faculty/reisch/bulletin/table/tableindex2.html; attra.ncat.org/attra-pub/grape.html- www.nysaes.cornell.edu/hort.faculty/reisch/bulletin/wine/index2.html; Dr. David Lockwood, University of Tennessee

Variety	Black rot	Downy mildew	Powdery mildew	Phomopsis	Botrytis	Bitter Rot	Crown Gall
Baco Noir	++++	+	++	+	++		+++
Cabernet Franc	++++	++++	++++		+	+++	++++
Cabernet Sauvignon	++++	++++	+++	++++	+	+++	++++
Carmine							
Catawba	++++	++++	+++	++++	+		+
Cayuga White	++++	+++	++	+	+		+++
Chambourcin	++	++	+++	++	++	+	+++
Chancellor	++	++++	++++	+++	++		+++
Chardonel	++	+++	+++		+++		+++
Chardonnay	+++	++++	++++	++++	++++	+++	++++
Concord	++++	+	++	++++	+		+
Cynthiana (Norton)	+	++	+	+	+	0	+
DeChaunac	++	+++	+++	+++	+		+++
Delaware	++++	++++	+++	++++	++		+
Foch	++	+	+++		+		+
Fredonia	++	++++	+++	++	+		+
Gewurztraminer	++++	+++	+++		+++		++++
Himrod	+++	+++	+++		+		+
Malbec			++				
Marechal Foch	++	+	++	+	+		+
Melody	++++	++	++		+	+	+
Merlot	++++	++++	++++			+	
Mourvèdre						++++	
Moore's Diamond	++++	+	+++		+++		
Niagara	++++	++++	+++	++++	+		+++
Petite Verdot						++++	
Pinot Blanc	++++	++++	+++		+++		++++
Pinot Grigio	++++	++++	++++		+++		++++
Pinot Noir	++++	++++	++++		++++		++++
Reliance	++++	+++	++	+++	++		++++
Riesling	++++	++++	++++	+++	++++	+	++++
Rosette	+++	+++	++++	+++	++		+++
Rougeon	+++	++++	++++	++++	+++		+++
Sangiovese					+	+++	
Sauvignon Blanc	++++	++++	++++		++++	++	++++
Seyval Blanc	+++	+++	+++	+++	++++	++	+++
Syrah						+++	
Traminette	+	+++	+		+	+	++
Venus	+++	+++	+++		++++		+
Verdelet	+++	++	+++	+	+		
Vidal Blanc	++	+++	+++	+	+	++	+++
Vignoles	+++	+++	++++	++	++++		+++
Viogner						++++	
Villard Blanc	+++	+++	+++		+		
Villard Noir		+	+++		+		
Viognier	++++	++++	++++		+		
Zinfandel			++		++++		

KEY: 0= resistant, += slightly susceptible, ++= moderately susceptible, +++= very susceptible, ++++= extremely susceptible

Downy Mildew

Downy mildew affects most varieties of grapes in North Carolina. It is most important early in the spring and as temperatures cool in the late summer and fall.

The disease is characterized by yellowish-green lesions (oil spots) that form on the upper surfaces of leaves and turn reddish-brown, necrotic, or mottled, as they expand. A cottony mass of fungal mycelium develops on the underside of leaves (Figure 8-7) and gives the lesions a downy white appearance that is also characteristic of the disease. All green parts of the vine that have mature, functioning stomata, including fruit, leaves, and young shoots, can become infected and covered with a white, downy, sporulating mass of mycelium. Infections of young berries can be mistaken for powdery mildew. When cluster infections occur late in the season, grapes do not soften and appear mottled and light green to red in color. Severely infected leaves often fall prematurely.

The fungus that causes the disease, *Plasmopara viticola*, overwinters as oospores in leaf debris on the vineyard floor and as mycelium in buds and leaves. At about 10-inches shoot growth, the fungus becomes active during rainy periods, producing zoospores that splash to the undersides of leaves, encyst, and form germ tubes that invade the stomata when temperatures reach 52°F. Seven to 10 days after infection, yellowish-green lesions form on the upper leaf surfaces. During the evening, when humidity is greater than 95 percent, sporulating structures produce sporangia that are disseminated by wind and rain to susceptible tissue. The sporangia liberate zoospores that can initiate secondary infections. Epidemics develop through secondary spread of the fungus, which is most severe during periods when warm humid nights are followed by rain the next day.

Figure 8.7 Downy mildew on the underside of a grape leaf.

Management Options

Cultural - Ensure that soils are well drained, and use good canopy management practices to open the vine canopy to air and light to reduce the amount of trapped moisture and shorten the duration of wetting periods. Fallen leaves and vine debris that harbor overwintering inoculum should be shredded with a flail mower and then disked into the soil or removed from the vineyard. Most bunch grape varieties are highly susceptible to downy mildew (Table 8-2).

Chemical - Primary infections can occur from 2 to 3 weeks before bloom until fruit set, and fungicides are most critical during this time, particularly in problem vineyards. Fungicides should be applied either before infection conditions occur or within 5 days after a potential infection event (eradicant fungicides). Use the 10:10:24 rule of thumb to monitor for conditions that favor primary infection. According to the rule, favorable conditions for infection occur after 10 mm (approximately ¼-inch) of rain have fallen while temperatures are 10°C (50°F) or more over a 24-hour period. In order for infection to occur during the 10:10:24 event, the soil must have been wet for 16 hours, followed by rain, and then 2 to 3 hours of leaf wetting. Postharvest applications of fungicides are important for protecting foliage and preventing premature defoliation.

Macrophoma Rot

Macrophoma rot tends to be more important on muscadine than bunch grapes in North Carolina. Early-season infections remain latent and there are no visible symptoms until the fruit begin to mature. When fruit begin ripening, lesions develop that are dark, circular and flat, or slightly sunken (Figure 8-8). The centers of the lesions

Figure 8.8 Macrophoma rot.

develop a tan color and become embedded with scattered fruiting bodies called pycnidia. As the lesion expands the entire grape may develop a soft watery rot. Fruit eventually drop from the vine, becoming shriveled, hollow, and covered with pycnidia.

The causal fungus, *Botryosphaeria dothidea*, overwinters as pycnidia on infected stems and fruit. Conidia are released from the pycnidia throughout the growing season, and are dispersed to shoots and fruit by wind and rain. Infection is believed to occur from bloom until harvest.

Figure 8.9 Phomopsis infection on shoots.

Management Options

Cultural - To successfully manage macrophoma rot, begin by reducing the amount of over-wintered inoculum left on the trellis and ground from the previous season. Infected stems and fruit are the major source of primary inoculum for infections, and should be removed from the vine before spring arrives. Practice good canopy management for control of macrophoma rot. Shoot thinning, leaf removal, pruning, cluster thinning, and shoot positioning are all cultural practices that open the vine canopy to air and light, reducing the amount of moisture trapped within the canopy, and allowing better penetration and spray coverage.

Chemical - Fungicide applications to control macrophoma rot should begin after bloom and continue throughout the fruit ripening period.

Phomopsis Cane and Leaf Spot and Fruit Rot

Phomopsis is a fungal disease of canes, leaves, and fruit and was previously referred to as "dead arm." However, "dead arm" is now known to be two different diseases that may occur together: phomopsis canker and eutypa dieback. Eutypa dieback is characterized by cankers and dieback of the cordons, while phomopsis lesions and cankers on stems are shallow and do not result in dieback of the cordons. Bunch grape varieties vary in their susceptibility to phomopsis fruit rot (Table 8-2).

Phomopsis infections can occur on all green tissues. Distinct black elliptical lesions on shoots (Fig 8-9.) are the most common symptoms observed. If shoot lesions become numerous, they coalesce and appear blackened and scabby. Cracks may form in large lesions during periods of rapid shoot growth. Lesions on leaves are usually circular, while those on the petioles are elongated. Both appear brown or black and are often surrounded by a small yellow halo. Rachis infections are common and are characterized by necrotic circular to elongated lesions. Fruit rot does not occur in many grape-growing areas, but in North Carolina, the pathogen may infect fruit, causing it to turn brown and become covered with black, pimple-like fruiting bodies (Figure 8-10). These fruit eventually shrivel into mummies that are often confused with black rot mummies.

Phomopsis viticola, cause of phomopsis cane and leaf spot and fruit rot, overwinters as black fruiting bodies (pycnidia) on canes, wood, and fruit infected the previous season. In springtime, when weather is cool and wet, tiny spores (conidia) are released from pycnidia and are splashed by rain to young shoots and leaves. Distinct black lesions form on shoots and leaves, and if wet weather continues, serve as an additional source of inoculum for infections of rachises and young fruit. These infections may occur from just prior to bloom until fruit is pea-sized, at which time the fungus becomes latent due to the warmer summer temperatures. At harvest when grapes mature, the latent infections become active and the fruit eventually rot, turn brown and shrivel into mummies. Pycnidia are produced over the surface of the rotting fruit.

Management Options

Cultural - Good horticultural practices that facilitate drying within the canopy in conjunction with sanitation are key to successful management of phomopsis disease. Dead wood, rachises, diseased canes, and mummified fruit on the vine and ground are all overwintering sites for *P. viticola* and need to be carefully removed from the vineyard during the dormant season to reduce the inoculum carried over to the next season.

Chemical - The prebloom through postbloom sprays are most important for preventing fruit infections. In problem vineyards, fungicides may need to be started at 1-inch shoot growth.

Figure 8.10 Phomopsis fruit rot.

Powdery Mildew

Powdery mildew is one of the most common grape diseases worldwide. All varieties of *Vitis vinifera*, French-American hybrids, and *V. labrusca* grown in North Carolina are susceptible (Table 8-2). Severe infections can reduce vine growth and yield and predispose fruit to rot fungi. The disease is named for the ash-gray to white growth of the fungus on the surface of infected leaves and fruit. Infections on leaves first appear as small yellow green blotches, about 1/2 inch in diameter, on the upper leaf surface. As lesions enlarge they become covered with the diagnostic white mycelial growth (Figure 8-11). On some varieties, veinlets on the lower leaf surface turn brown beneath the lesions. Young heavily infected leaves may become distorted. Lesions tend to "disappear" during hot summer weather, often leaving darkened areas on the leaf where the infections

Figure 8.11 Powdery mildew on a grape leaf.

were present. Infections of fruit and cluster stems are characterized by ashy gray to white growth on the surface (Figure 8.12). Fruit infections later appear as web-like russet on the surface. Heavily infected fruit often split and crack as they mature.

Figure 8.13 Powdery mildew on fruit and cluster.

The causal fungus, *Uncinula necator*, overwinters as hyphae in dormant buds or on canes as sexual fruiting structures known as cleistothecia. Leaves emerging from infected buds are covered with whitish mycelium and conidia (spores) that are blown by the wind to emerging leaves and fruit clusters, initiating infections. Primary infections can also occur from ascospores produced in cleistothecia. These infections are most common on the lower leaf surface of leaves growing near the bark of the canes where the cleistothecia have overwintered. Temperatures of 68 to 81°F are optimum for infection, though infections can occur from 43 to 90°F. At optimum temperatures, lesions can develop in 5 to 7 days. Periods with high humidity (85 percent is optimum) without free moisture on the leaf surface favor disease development. Numerous secondary infection cycles can occur during the growing season. Fruit are susceptible from just before bloom until about one month after bloom. Inconspicuous "diffuse" infections on berries can increase the severity of berry rots at harvest. New leaves are susceptible through the growing season, though the disease usually becomes less active during the hot summer months, and becomes active again in the late summer and fall once temperatures cool.

Management Options

Cultural - Cultural practices are important in reducing disease severity. Select planting sites with good air circulation and good sun exposure. Training and pruning practices that open the vine canopy to allow air movement can help reduce disease severity. Choose a less susceptible variety (Table 8.2).

Chemical - Fungicide applications for powdery mildew control should begin at 3 to 10 inches of shoot growth (3 to 5 inches of shoot growth where powdery mildew has been a problem in the past) and continue on a regular schedule until 4 weeks after bloom. Sprays beyond this time may not be needed but vines should be scouted on a regular basis for new outbreaks. The disease often becomes a problem after harvest, and vines should be scouted regularly to determine if sprays are needed at this time. Failure to control postharvest outbreaks of powdery mildew may result in early defoliation, predisposing the vines to winter injury. Rotate fungicides and use the full labeled rate to avoid the development of resistance.

Ripe Rot

Ripe rot is one of the most important summer bunch rot diseases in North Carolina. As infected fruit mature, lesions first appear as slightly sunken or flattened rotted areas. Tiny black fruiting bodies (acervuli) develop within the lesion in a circular arrangement. Rotting fruit are characteristically covered with masses of sticky, pink or salmon-colored spores of the causal fungi (Figure 8.14). As lesions expand, the entire grape eventually rots, and may drop or become shriveled or mummified as it decays.

Ripe rot is caused by *Colletotrichum gloeosporioides*, *C. acutatum,* and *Glomerella cingulata.* These fungi overwinter in canes, pedicels, and mummies, and infect fruit and pedicels in the summer during any time of development. However, these infections remain inactive until the fruit ripen, after which acervuli develop and produce characteristic pink spore masses in wet weather. The disease increases rapidly and may cause severe losses as the fungus spreads from fruit to fruit during rainy periods.

Management Options

Cultural - Before spring arrives, remove overwintered mummies and pedicels, dead spurs, and weak or dead cordons. Shoot thinning, leaf removal, pruning, cluster thinning, and shoot positioning are all cultural practices that open the vine canopy to air and light, reducing the amount of moisture trapped within the canopy, and allowing better penetration and spray coverage of fungicides. Varieties vary in susceptibility. Seyval Blanc, Syrah, Cabernet Sauvignon, and Sauvignon Blanc are susceptible; Chambourain is among the most resistant.

Chemical - Fungicide applications are critical from bloom until harvest if the disease is a problem.

Sour Rot

Sour rot is a common disease of ripe grapes in North Carolina. The disease can be very destructive if rainy periods occur just prior to harvest. Affected fruit become soft and watery, and fruit of light-skinned varieties usually turn tan to light brown (Figure 8.15). Masses of black, brown, or green spores may cover the surface of the fruit. Clusters with sour rot often have a pungent vinegar-like odor.

The exact cause of sour rot is often impossible to determine. As harvest time approaches, many different microorganisms, including species of fungi, bacteria, and yeasts, may attack grapes. Fungi associated with sour rot include *Aspergillus*, *Alternaria*, *Penicillium*, and *Rhizopus*. These fungi are naturally present on plant surfaces and soil debris,

Figure 8.14 Ripe rot.

and are spread by wind, rain, or insects to ripening fruit. Ripening fruit begin rotting as soon as they are injured. Any type of crack in the skin can allow entry of the sour rot organisms, whether caused by birds, insects, hail, powdery mildew infections, or cracking due to fruit swell following heavy rains. Tight clustered varieties are particularly susceptible to sour rot. The vinegar-like smell is caused by the production of acetic acid by *Acetobacter* bacteria, which are carried by fruit flies and beetles to the clusters.

Management Options

Cultural - The best approach to control sour rot is to prevent fruit injury by birds, insects, and diseases like powdery mildew. Fruit damage due to growth-related causes can be prevented by cultural methods, including fruit thinning and

Figure 8.15 Sour rot.

canopy management, while closely monitoring irrigation and fertilizer use. If a rain period is forecast, and fruit are mature or nearly mature, harvesting prior to the rain will minimize fruit losses to sour rot.

Chemical - Fungicide sprays are generally not effective in preventing sour rot.

Figure 8.16 Zonal leaf spot.

Minor Foliar Diseases

Many foliar diseases of *Vitis* spp. occur periodically in North Carolina as a result of unusual weather conditions, in nonsprayed or poorly sprayed situations, or after the season is over and fungicides are no longer applied. These diseases generally do not cause a lot of damage, but under certain weather conditions, they may potentially cause considerable defoliation if not controlled.

Figure 8.17 Leaf blight.

Zonate Leaf Spot, Target Spot

Zonate leaf spot, caused by the fungus *Cristulariella moricola*, is characterized by large, circular lesions with a concentric zonate appearance (Figure 8.16). As the leaf spots age, the central portion may disintegrate and fall out. The fungus attacks the leaves of many woody plants in the forest, such as wild grapes, maple, sassafras, and service berry, and inoculum can spread from them into the vineyard. Infections can occur throughout the growing season. Cultural practices that increase air circulation such as shoot positioning and thinning aid in management of the disease. Following a standard spray program for grapes usually controls this disease.

Leaf Blight, Isariopsis Leaf Spot

Leaf blight is caused by the fungus *Pseudocercospora vitis*. The pathogen was named *Isariopsis clavispora* at one time and the disease is still often referred to as isariopsis leaf spot. On *V. vinifera*, hybrids, and *V. labrusca*, leaf blight is characterized by large, irregular shaped spots, which are initially dull red to brown in color but turn black and brittle with age (Figure 8-17). It is most common late in the season on poorly sprayed grapes. Cultural practices that increase air circulation such as shoot positioning and thinning aid in management of the disease. The disease is usually controlled when a standard spray program is followed.

Rupestris Speckle

Rupestris speckle is believed to be a physiological disorder, associated with *V. rupestris* and hybrids that have been derived from it (e.g. Chambourcin). The disorder is characterized by small, circular to irregular, necrotic spots, often surrounded by a yellow halo (Figure 8.18). Spots are more common on the older leaves. Although numerous spots may occur on leaves, little defoliation usually results. There is no control for this disorder.

Bacterial Diseases

Pierce's Disease

Pierce's disease is a potentially devastating disease of grapevine, and it is the principal limiting factor in the production of *V. vinifera*/French American hybrids and *V. labrusca* (American bunch grapes) in North Carolina. By midsummer, margins of leaves infected by the Pierce's disease bacterium develop a scorched appearance (Figure 8.19). Leaves may become yellow before scorching, while red varieties may show some red discoloration. The scorched leaf blades may eventually drop, leaving petioles attached to the cane. The bark on canes matures irregularly, leaving patches of green tissue (green islands) surrounded by mature brown tissue. Fruit clusters may ripen prematurely and become shriveled or "raisined." These symptoms are more extreme in hot dry weather, and some varieties are more susceptible than others. Severely infected vines may die within 1 year of infection or, in the case of chronically infected vines, may live for 5 years or more. In these vines bud break is delayed and new shoot growth is stunted.

Pierce's disease is caused by *Xylella fastidiosa*, a gram-negative bacterium that survives and multiplies within the water conductive system (xylem) of its plant hosts. *X. fastidiosa* has a diverse natural host range with over 100 herbaceous and woody plant species. Many of these plant species are thought to be symptomless hosts, yet may serve as reservoirs of inoculum for later insect transmission. Sharpshooter leafhoppers (Cicadellidae) and spittle-bugs (Cercopidae) acquire and transmit the bacterium as they feed in the xylem of plants. Two of the primary vectors of the Pierce's disease bacterium in North Carolina are the sharpshooters *Oncometopia ovloona* and *Graphocephala versuta*.

Figure 8.18 Rupestris speckle on a grape leaf.

Management Options

Pierce's disease management should involve several disease management practices:

- ❑ *Site selection* - The Pierce's disease bacterium does not survive cold winter temperatures in grapevines. Consequently, the risk of the disease is least in the mountains and increases from the piedmont to the coastal plain.
- ❑ *Variety selection* – All vinifera varieties are susceptible to Pierce's disease, yet some are more tolerant to the disease than others, and young vines are more susceptible than mature ones. There are a number of Pierce's disease-

Figure 8.19 Systems of Pierce's disease on leaves.

Figure 8.20 Crown gall.

resistant varieties, many of which were developed for production in Texas and Florida, but they have not been tested for suitability in much of North Carolina where the risk for Pierce's disease is high.

- *Vegetation management* - Since diseased vines are often found between 150 to 200 feet from the vector source, one management approach reduces the reservoir of inoculum by removing nearby reservoir hosts that are breeding sites for the various vectors and/or systemic hosts of *X. fastidiosa*. A large number of native plants harbor the *X. fastidiosa* bacterium in North Carolina, including oak, sycamore, hickory, sweet gum, wild cherry, Bermudagrass, pokeweed, wild grape, blackberry, Virginia creeper, wild rose, and sumac. It is still unknown which strains of *X. fastidiosa* infecting these native plants can also cause Pierce's disease on grape.
- *Removal of infected vines* - Infected vines should be removed as soon as they are detected, or should be flagged and removed the following spring if bud break is delayed to reduce the possibility of vine to vine spread in the vineyard.
- *Pruning practices* - When Pierce's disease symptoms are found only at the terminal end of canes, normal dormant pruning practices may remove infected wood. If infection is more severe, cutting the trunk off just above the graft union may generate symptom-free vines.
- *Insecticides* - Before insecticides can be used effectively in a management program, studies are needed to determine the species of leafhoppers responsible for transmitting the Pierce's disease bacterium in North Carolina.

Crown Gall

Crown gall is a common disease in all grape-growing areas of the world, but North Carolina's temperature fluctuations in the spring and fall have resulted in a high incidence of crown gall. Galls are likely to be found in or along cracks created by freezing injuries. As the wine industry further expands into areas where freezing temperatures frequently cause injuries, the incidence and severity of crown gall will dramatically increase.

Galls begin as small protuberances at the site of an injury, usually at the crown or soil line. Aerial galls can also develop at pruning injuries. Gall surfaces become rough as they age and enlarge to several inches in diameter (Figure 8.20). Crown gall infection at grafting and budding sites results in poor growth or death of scion shoots. Vines with galls may be weak and less productive, while younger vines may die. Bunch grape varieties and rootstocks differ in their susceptibility to crown gall disease.

Crown gall disease of grapevine is caused by a bacterium (*Agrobacterium vitis*) that may survive in the soil and grape roots for several years after vines are removed. The bacterium must enter into vines through wounds, which frequently occur as a result of frost injury. The crown gall pathogen can enter the vine at a wound site and be translocated throughout the vine, where it may induce galling at other wound sites.

Management Options

Site selection is an important consideration for limiting the occurrence of crown gall. Vineyards established in areas that are prone to seasonal temperature fluctuations and resulting freeze injury will be more likely to have crown gall problems. Grapevines that appear to be crown gall-free for several years may develop the disease when conditions conducive to infection (generally freeze injury) occur.

Purchase pathogen-indexed nursery stock - Nursery stock should be purchased from a reputable nursery. Discard vines with visible galls. Remember, healthy-looking propagation material may already be systemically infected with the crown gall bacterium.

Cultural - Cultural practices that may assist in managing crown gall are multiple trunking, which allows production to continue on gall-free trunks after infected trunk(s) are removed, and hilling-up of soil up around the crown during the dormant period. Avoid cultural practices that may injure the base of the vine. Good sanitation practices are essential to prevent spread of contaminated material on tools and equipment from vineyard to vineyard. Also, contaminated irrigation sources can carry the pathogen from infested areas to noninfested areas. Removal of infected vines and leaving soil fallow or planting a nonsusceptible crop (legumes or grasses) for 2 to 3 years may help to reduce the chance of carryover of the pathogen, depending on the amount of grape debris that is left in the soil and its rate of decomposition.

Chemical/Biological - Several products are used in an attempt to control crown gall, but no commercially available product will eradicate infections once they have occurred. Products painted onto gall tissue will kill galls at the application site, yet due to the systemic nature of the disease, new galls are likely to appear the following year. Biological control products for crown gall made from *Agrobacterium radiobacter* (strains K-84, K1026) are not labeled for grapes and are not active against the strain of the crown gall bacterium that affects grapes.

Grapevine Yellows

Grapevine yellows is a destructive disease of grapevines in many areas of the world, but has only been found Virginia in the Southeast. It is caused by two different strains of a phytoplasma (a bacteria-like organism). The disease is most prevalent on Chardonnay and Riesling, but Sauvignon Blanc and Cabernet Sauvignon are also affected. Initially, yellow patches develop on leaves of one or two shoots. Leaves tend to curl downward and are brittle in texture. Affected shoots fail to harden and may have a weeping appearance. Flowers and bunches may wither and abort before harvest. In Virginia affected vines usually die within 1 to 3 years. The pathogen is spread in the vineyard by leafhoppers, which acquire the bacterium from infected vines in the vineyard or reservoir hosts surrounding the vineyard. Because little is known about the vectors and reservoir hosts of the grapevine yellows phytoplasma, effective control programs have not been developed for the disease in Virginia. Infected vines should be rogued as soon as they are observed to reduce vine-to-vine spread in the vineyard.

Viral and Virus-like Diseases

There are numerous viral diseases, and other graft transmissible diseases believed to be caused by viruses, that affect grapes. However, few of these diseases cause problems due to current nursery certification programs. Leafroll is the only virus disease that has been confirmed in North Carolina. Tomato/tobacco ringspot virus decline has been found in Virginia and has the potential to become a problem in North Carolina.

Leafroll

Vines displaying symptoms of leafroll virus are scattered throughout many vineyards in North Carolina. Symptoms are most obvious in the late summer and early autumn when leaves on affected vines display colors between green veins ranging from red to purple in red varieties to yellow to red in white varieties. Affected leaf margins tend to roll downward, giving the disease its name. Death of vines is not usual, yet yields may be reduced 20 percent and the fruit may ripen later than fruit on noninfected vines. The virus can be transmitted in the vineyard by mealybugs and soft-bodied scale insects.

Management Options

Purchase vines only from nurseries that participate in virus certification programs. Rogue infected vines to prevent vine to vine spreading. There is no information on the use of insecticides to manages the vectors in North Carolina.

Tomato and Tobacco Ringspot Virus Decline

Tomato and tobacco ringspot virus decline have not been reported from North Carolina but occur in Virginia and states to the north. Because tomato ringspot virus and tobacco ringspot virus occur in many wild hosts, it is likely the disease will be found in North Carolina vineyards. However symptoms tend to be more severe in colder growing regions, so the disease may never become very important here. Symptoms caused by the two viruses are the same and tend to vary with variety and region of the country. Interspecific hybrids tend to be more severely affected than varieties of vinifera. Vidal blanc is one of the varieties most severely affected by tomato ringspot virus in Virginia. Initial symptoms on Vidal blanc are sparsely filled fruit clusters or clusters with many small fruit. Shoots on other varieties may have shortened internodes and small chlorotic or distorted leaves. Infected vines may die during the winter or produce mostly stunted basal suckers by the third year after infection. Most infected vines eventually die.

Both tomato ringspot virus and tobacco ringspot virus infect many common wild (reservoir) hosts including chickweed, plantain, dandelion, and red clover and are transmitted by the dagger nematode (*Xiphenema americanum*) to grapes. This nematode is common in most soils in the piedmont and mountains of North Carolina.

Management Options

Purchase vines only from nurseries that participate in a virus certification program. Avoid susceptible varieties, such as Vidal Blanc, and use resistant rootstocks, such as 5C and C-3309 Sample vineyard soil for nematodes before planting. Control broadleaf weeds between rows as they can serve as reservoir hosts for the virus. Preplant soil fumigation may be needed if the population of the dagger nematode is high.

Nematodes

There is very little information about the importance of nematodes on grapes in North Carolina. These roundworms attack the roots causing a decline in vigor and yield, but they rarely kill vines. Nematode damage is usually not uniform throughout the vineyard but is localized in certain areas, often associated with soil type. Nematodes that have the potential to cause problems include the root knot nematode (*Meloidogyne* spp.), the dagger nematode (*Xiphinema* spp.), the lesion nematode (*Pratylenchus* spp.), and the ring nematode (*Mesocriconema xenoplax*). Sample soil prior to planting to determine if there are damaging populations of nematodes present because there are few management options once vines are planted.

Root Knot Nematode

Root knot nematodes are most damaging in sandy soils. Consequently they are not likely to be a problem in most grapes growing regions in the piedmont and mountains. These nematodes feed on the inside of roots. Feeding sites are characterized by swellings (galls) on young feeder roots, and large galls on older roots. High populations result in reduced vine vigor and yield. Symptoms are most pronounced under water stress or where there are nutritional deficiencies.

Dagger Nematode

The dagger nematodes, *Xiphinema* spp., are common in many soils in the piedmont and mountains of North Carolina. These nematodes feed on tips of the fine feeder roots, which become necrotic and stop growing, resulting in small galls or a "witches broom" appearance as new roots appear and are damaged. High populations can result in significant reduction in vine vigor. In addition to causing damage to the roots, the dagger nematode can transmit several virus diseases including grape fanleaf virus (GFLV), tomato ringspot virus (TomRSV), and tobacco ringspot virus (TRSV).

Lesion Nematode

Lesion nematodes are widespread in many piedmont and mountain soils in North Carolina. They feed on the finer roots causing lesions, which result in poor root development and reduced vine vigor.

Ring Nematode

The ring nematode is usually a greater problem in the sandy soils of the coastal plain than the heavier soils in the piedmont and mountains. Above-ground symptoms are similar to those caused by the lesion nematode.

Insects and Mites

Numerous insects and several mite species can attack bunch grapes. Some, such as the grape berry moth, are chronic pests in almost all vineyards. Many others, such as aerial phylloxera, affect a small proportion of vineyards in numbers large enough to require the use of control measures. The insects described in this section are often found in damaging numbers in commercial Virginia and North Carolina vineyards.

Japanese Beetles

Among the most visible feeders of grape foliage are Japanese beetles, which account for the greatest number of insecticide applications in many vineyards. Despite the insect's intensive feeding and the resultant grower concern, vigorous grapevines can tolerate a certain amount of beetle defoliation.

Japanese beetles overwinter as larvae in the soil, where they feed on grass roots in the autumn and spring. Following pupation, adult beetles emerge in late spring and may be present in vineyards until September. The adult beetles are approximately ½ inch long and are green with copper-colored wings. The beetles feed on leaves, often in large numbers, but rarely feed on fruit. Feeding is concentrated on the upper, younger leaves of the canopy. Mating occurs and eggs are deposited in the soil, where the young larvae feed on grass roots and where they overwinter.

A certain amount of defoliation is tolerable with established, vigorous grapevines. As a rule, if vines retain at least 15 healthy leaves per shoot, no delay of fruit maturation should occur. Occasional insecticide sprays may be necessary to keep feeding within tolerable limits. Young or weak vines should be protected more diligently. Broad-spectrum insecticides, such as carbaryl, are effective against Japanese beetles but have the undesirable effect of reducing beneficial insect populations. Indeed, intensive insecticide applications can increase the incidence of certain secondary pests, such as European red mites. Thus, insecticides should be used judiciously.

A bacterial insecticide is commercially available for lawn and turf application to control Japanese beetle larvae feeding. This product (milky spore disease) may reduce injury to turf by larval feeding but it is unlikely to have a measurable impact on the number of adult beetles that fly into a vineyard. Similarly, attractant traps are unlikely to trap enough adults to reduce beetle levels effectively. Traps may actually attract more beetles from afar and result in greater feeding injury than if traps were not used.

Grape Berry Moth

The grape berry moth is widely distributed east of the Rocky Mountains. It overwinters in pupal form. Adults emerge in early to mid-May in Virginia but somewhat earlier in North Carolina. Mating occurs and the first generation eggs are deposited on flower clusters at or before bloom. Newly hatched larvae feed on the blossoms and small berries, webbing clusters together and often destroying the entire cluster. In three to four weeks the larvae become full grown and pupate. Second-generation moths emerge in 10 to 24 days and repeat the mating and egg deposition processes. At least three and possibly four generations of grape berry moths have been observed in Virginia. Second and subsequent generation larvae feed on developing berries. After véraison the infested berries may be prone to fruit-rotting organisms.

Adult moths, which do no direct damage to grapes, have a wing spread of about ½ inch and are drab brown with a gray or blue band across the back. The larvae are greenish or gray-green and may exceed ½ inch in length. Some reduction in damage may be obtained through cultivation of leaf litter under the trellis in early spring before first-generation adults emerge. Pheromone mating disruption has been found effective under certain conditions in Virginia.

Grape Phylloxera

The grape phylloxera is native to the eastern United States. The biology of this plant louse is very complicated. One form of this aphid-like insect feeds on foliage, where it causes gall-like growths. Other forms feed on the roots of the grape. American species of grape, such as *Vitis riparia, V. labrusca,* and *V. rupestris,* are generally tolerant of the root feeding that occurs, although their foliage may be heavily infested with aerial forms. *V. vinifera* varieties are severely injured by phylloxera root feeding and for this reason must be grafted to pest-resistant rootstocks in this region. Several commercially important hybrid grape varieties, including Seyval and Villard blanc, are highly susceptible to aerial phylloxera feeding. Six or more generations occur per year, and galling may be severe enough to warrant an insecticide application. Feeding and galling are most severe on young, recently emerged leaves.

Grape Root Borer

The grape root borer is the larval stage of a clear-wing moth. The adults resemble a wasp. They are dark bronzed brown and yellowish orange and measure about 1 inch in length. The larvae measure 1 inch or more in length and are generally white with brown heads. Eggs are laid on foliage in late summer. One moth may lay as many as 400 eggs during August and September. Eggs hatch promptly; the larvae drop to the soil and bore into the crown and larger roots, where they feed for two or three years. The extensive injury to roots results in loss of vine vigor, reduced yields, and eventual death of the vine. Pupation and emergence usually occur in the summer of the second year. Pupation takes place in cocoons near the soil surface. In Virginia, adults emerge from mid-July to late July, and their shed pupal cases may be observed near the base of affected vines. Adult moths do not feed on grapes, but mating occurs and additional eggs are laid.

Control of this destructive insect is difficult. Registered insecticides for the larval stage are available, but their efficacy is uncertain. One cultural control measure involves mounding soil beneath the vines after the larval stage has pupated in late June. In theory, the adults are then unable to dig to the surface when they exit their cocoons. Timing of mounding is critical and varies with vineyard location: if done too early, the larvae simply tunnel into the mounded soil before pupating; if done too late, the adults may have already emerged.

Climbing Cutworms

Climbing cutworms are a group of related moth species whose larvae can feed on grapevine buds. Cutworm feeding results in lack of shoot development from swollen buds or destruction of recently emerged shoots. Cutworm larvae feed at night and seek shelter in soil and debris during the day. The larvae are smooth, brown or gray, and have stripes running the length of their bodies. A quick search around the base of an affected vine can usually reveal the pest.

Feeding begins in the spring when buds begin to enlarge. The extent of damage depends not only on the cutworm population but also on the duration of the bud-break stage. During cool springs, when the period from bud swell to bud break is delayed, damage can be extensive. Vineyards should be monitored carefully for cutworm feeding in the period leading up to bud break and for a week or two thereafter. Treatment with an insecticide is warranted if feeding affects more than 2 percent of the buds. Cutworm control can be improved by spraying in the late afternoon or early evening to ensure that fresh residues are present when feeding commences.

Bees and Wasps

Bees and wasps usually feed on ripe grapes through injuries caused by other insects, birds, and splits in the skins of overripe berries. Some large wasps are capable of causing direct injury to berries, but honey bees and most wasps are only opportunistic feeders attracted to split or otherwise damaged berries. Insecticides with either zero or very short preharvest interval restrictions may be sprayed to provide some control of bees and wasps. Pickers with severe allergies to bee stings should be advised of sting risks if bees are present at harvest. Latex rubber gloves can provide some protection against stings. Although not extensively tested, some growers have reported limited success at reducing bee populations by locating and destroying nests and by using commercially available bee traps.

European Red Mite

The European red mite is the principal mite pest of grapes in this region. This mite overwinters as tiny brick-red eggs concentrated around the nodes of canes. The eggs hatch in early spring, and nymphal stages begin feeding on young leaves. Adult mites are red and no larger than the period at the end of this sentence. Six or more generations may occur per year, with the peak population often occurring in late August or September. Deposition of winter eggs begins in August and continues into the fall. Mite feeding causes grape leaves to develop a uniform chlorotic or brownish cast, sometimes referred to as mite bronzing. Older leaves show symptoms before younger leaves. With severe infestations, the impaired photosynthesis caused by mites can delay sugar accumulation. Infestation and foliar symptoms usually develop in "hot spots" but will soon spread to entire vineyard blocks if the mite population continues to build unchecked by miticides or natural predators.

If European red mites were numerous in the previous year and overwintering eggs are common, a superior oil spray should be applied at the rate of 2.0 gallons of oil per hundred gallons of water per acre. Apply the oil about the time of bud break. Sprays applied much earlier will have less effect on mite eggs. Superior oil may be applied after green tissue is exposed; however, the oil should not be mixed with other pesticides and should not be applied if a frost is expected within 48 hours. Oil acts by suffocating the eggs and is most effective if applied just before mite eggs hatch. Oil sprays will delay or prevent mites from reaching economically damaging levels. If population development is sufficiently delayed, natural enemies may be able to suppress the buildup.

When miticides are needed, apply well-timed sprays. Apply sprays only to economically important populations. An action threshold for use on grapes has been provisionally set at 5 mites per leaf (10 mites per leaf on labrusca types). Such recommended treatment levels are approximations because of variability among varieties, crop loads, plant stress, weather, and other environmental interactions. When mites exceed these levels, monitor populations closely to determine foliar injury. Heavy bronzing of foliage must be prevented, but minor bronzing is tolerable. In fact, if minor visible injury is tolerated, the likelihood of eventual biological control increases. Most miticides currently available work best on motile (nonegg) stages. Applying such a spray kills the active mites present, but many eggs will survive and hatch. This surviving generation may require a second miticide application 7 to 10 days after the first spray.

Miticides should be used cautiously. Most are relatively expensive, and mites have a tremendous potential to develop resistance to miticides, making control measures ineffective. Mites are secondary pests, rising to economic status after elimination of their natural enemies by sprays for key pests such as Japanese beetle and grape berry moth.

Wildlife

Birds

Many species of birds are fond of ripe grapes and will quickly cause appreciable crop loss if not controlled. Birds are daytime feeders and can be identified if you happen to be in the vineyard when they are present. Otherwise, the clues to bird feeding are peck marks in individual berries, remnants of berry skins retained on the rachis (cluster stem), and selective feeding on individual berries of the cluster, leaving the rachis intact. Birds tend to consume the darkest pigmented berries first, leaving the greener, unripe berries for a later day. Feathers in the vine are an obvious clue. Vines under or close to roosting areas such as a treeline or overhead power lines are the most vulnerable. Dark-fruited, small-berried winegrape varieties are particularly susceptible.

Options to control bird feeding are diverse; few are entirely effective. They include recorded distress calls played on audio equipment in the vineyard; electrical wires mounted in the vineyard to shock birds attempting to land; various reflective materials intended to frighten; gas cannons with loud, frightening reports; various balloons and kites suspended above the vineyard intended to simulate bird predators; shooting; and enclosing the vines in netting to exclude birds. All of these devices have limitations. Most birds will eventually overcome their aversion to the various scare tactics. Bird netting, although laborious to apply and remove as well as expensive, is the choice where total, environmentally benign control is desired.

Deer

The white-tailed deer is remarkably adaptable and can be found in rural as well as suburban settings. Deer depredation may be identified by sighting the deer in the vineyard or by their pattern of feeding.

Deer lack upper incisors and feed by tearing off leaves, shoots, and ripening grapes. Their feeding produces jagged edges that distinguish deer browsing from damage caused by other animals. Look for rachises that are torn or shredded and shoot tips and leaves that have been stripped. Deer may be deterred from vineyard feeding by various scare tactics, repellents, fencing, or regulated shooting. Each method has limitations. Whatever method or methods are used, they should be implemented well before the damage becomes intolerable. Once deer have learned about the source of food, it will be exceedingly difficult to discourage them.

SCARE DEVICES. Scaring deer with noisemakers or visual objects offers, at best, a temporary solution. Scare tactics include propane cannons, electronic acoustic recordings, pyrotechnics, and physically patrolling the vineyard with people or dogs. Noise emitters should be moved every few days so that deer do not become accustomed to the sounds. Their disadvantage is that they often become a nuisance to vineyard owners or neighbors. Permitting domestic dogs to roam the vineyard deters deer to a limited degree.

REPELLENTS. A wide range of taste- or odor-active repellents are available (Table 8.8). Taste repellents are usually sprayed directly onto the plant and are formulated to be distasteful to deer. Because of the potential to leave distasteful residues, some of these products may be restricted to use on nonbearing vines or used only during the period before fruit set. As with nonsystemic fungicides and insecticides, sprayable repellents must be reapplied after heavy rains and as new, unprotected growth develops. Odor repellents deter deer by scent alone. Some products include ingredients that deer associate with humans, such as aromatic constituents of soaps. Depending upon formulation, the odor repellents may be sprayed on or around vines or mounted on the trellis. Here are some keys to using repellents effectively:

- ❑ Apply the repellent before damage occurs. Periods when damage is likely may be predicted by past experience. Do not allow a feeding pattern to become established.

- ❑ Feeding pressure will be greatest when alternative food sources are scarce. Repellents may work well when other food is available but may fail miserably if little else is available for deer. This may partially explain year-to-year variation in repellent effectiveness or mixed results among different vineyards.

Table 8.8. Examples of Commercially Available Deer Repellents for Crop and Noncrop Use

Product	Manufacturer	Mode of Action	Active Ingredients
Hot Sauce Animal Repellent	Miller Chemical and Fertilizer Company	Taste	Capsaicin
Hinder Deer and Rabbit Repellent	Matson LLC	Taste and odor	Ammonia; mixed rosin and fatty acids
Havahart Deer-A-Way	Woodstream Corporation	Taste and odor	Putrescent egg solids

Note: Products in this table may be obtained through pesticide or fertilizer supply companies. Be certain to read the entire label before purchasing and using these or other crop protection chemicals. Some animal repellants are registered by the U.S. Environmental Protection Agency as pesticides, and use of those products in a manner inconsistent with their labels is prohibited by law.

❑ Monitor the effectiveness of the repellents. Reapply them or alternate with other tactics if necessary.

❑ Rotate repellents or implement alternative strategies so that deer do not become accustomed to a specific odor or taste.

Besides sprayable repellents, at least three other odor-active repellents have shown some measure of effectiveness in vineyards and orchards.

1. Human Hair. The odor of humans deters deer. Hair can be obtained from barbershops. Place a handful in a mesh bag and hang it from trellis wires around the perimeter of the vineyard. Replace it yearly before the fruit ripens.

2. Animal Tankage. A mixture of blood and other animal products from slaughterhouses or poultry-processing facilities may be used as a deer repellent. Place ½ to 1 cup of this mixture in mesh bags and hang them from trellis wires around the vineyard perimeter before the fruit attracts deer. Note, however, that this material may attract dogs and other animals.

3. Soap Bars. Purchase small hotel-use soap bars by the case. Leave the wrappers on to slow weathering. Drill a hole in each bar and thread a string through it; then hang the bars from trellis wires around the perimeter of the vineyard. Fragrant soaps are particularly alarming to deer.

FENCING. Fencing is probably the most effective means of excluding deer from vineyards. Although the initial costs may be high, the near-perfect protection afforded makes fencing economical, especially taking into account the fact that a well-constructed fence will last 20 years or more. Fencing may be either electrified or nonelectric. Nonelectric fences are usually made of a woven mesh and may be 8 to 12 feet in height. The advent of high-tensile-strength (HT) fence wire, coupled with high-voltage, low-impedance electric fence chargers, has made electric fencing the preferred option for deer fences. Many designs exist, but the least complicated may be the most effective and easiest to install and maintain. The six-wire vertical design depicted in Figure 8.18 shows an effective, modified version of the Penn State five-wire design. An optional hot (+) wire located about 4 or 5 inches above the ground will provide good deterrence of raccoons and other small animals; however, it is essential that the soil under the fence be kept free of weeds that can reduce the effectiveness of the fence charger if they contact the positive wires. The six-wire fence is only about 5 feet tall, a height that deer have no difficulty in jumping. However, approaching deer will first attempt to crawl through or under the fence before jumping. The high-energy output of the charger modifies deer behavior, training deer to avoid the fence.

Products for HT electric fencing are available from numerous sources, including those listed at the end of this chapter.* Properly charged fences produce an extremely unpleasant but noninjurious shock. Therefore, electric fences should always be posted to alert people to avoid accidental shock.

Electric fences must be kept charged continuously. Upon being questioned, most growers who complain about ineffective electric fence operation confess that the fence was not constantly charged. It is best to erect the fence before the vineyard ever bears a crop; the deer are much less tempted to investigate what is on the other side. Clear at least 10 feet of brush and trees from the outside (deer side) of the fence. This gives uninitiated deer plenty of room to approach the fence, touch it with their moist noses, and receive a shock. Keep vegetation, including weeds, clear of the charged wires. When vegetation touches the wires, it drains off some of the energy, resulting in rapid battery discharge and insufficient shocking energy. A preemergence herbicide can be applied under the fence to keep weeds down.

Depending upon terrain and how much brush clearing is involved, a battery-operated, solar-recharged, six-wire electric fence can be installed around a 5-acre vineyard for $1,500 to $2,000 in material costs

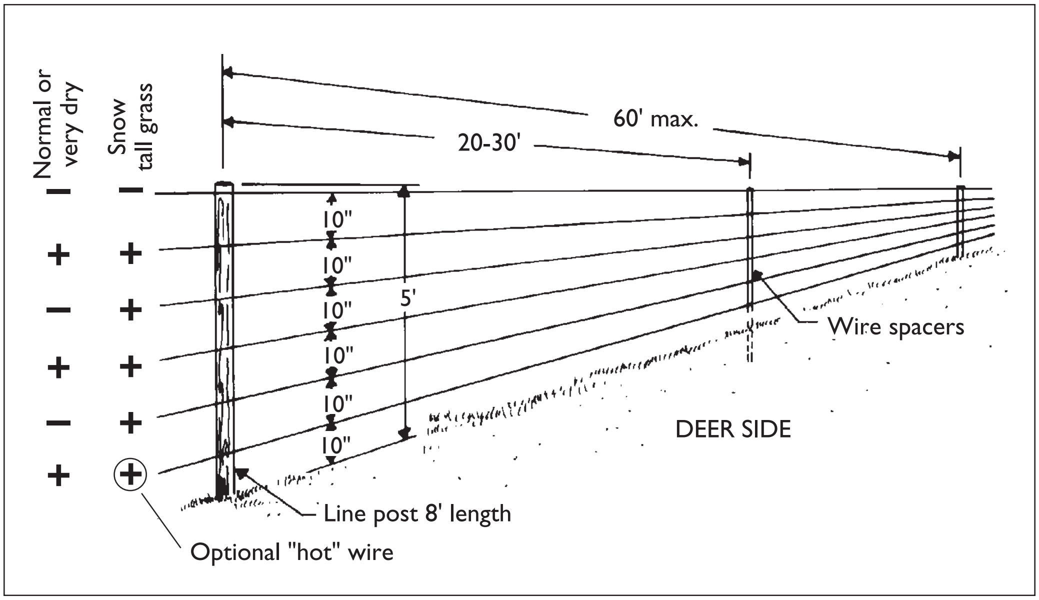


Figure 8.21 An effective design for a six-wire electric fence to exclude deer from the vineyard.

Weeds

Vineyard Floor Management

Pest management in vineyards largely focuses on insect and disease pests due to the direct impact on fruit quality. However, weed and vegetation management impacts a vineyard in numerous ways. A number of weed species have the ability to compete with grapes for nutrients, water, and sunlight. Weeds reduce harvest efficiency, as well. Grasses and broadleaf weeds are the most common, although sedges can be found in vineyards. The most common grass weeds are large crabgrass, fall panicum, and goosegrass, although perennial grasses like bermudagrass or Johnsongrass are sometimes present and can be very competitive. Common broadleaf weeds include dandelion, horsenettle, annual morningglory species, common lambsquarters, and pigweed. The most common sedge is yellow nutsedge. Sedges look similar to grasses, however, their triangular stems distinguish them from grasses.

The Sod/Weed-free Strip

The vineyard floor should be managed to minimize weed competition, prevent erosion, promote worker efficiency, promote integrated approaches to vertebrate (mice and voles) and insect pest management, facilitate equipment movement during wet weather, and maximize the radiant heat benefit. Although asthetics do not directly impact fruit quality, it is important to many managers, especially in vineyards with an adjacent wine-tasting room.

The vineyard floor management system of choice consists of a 6- to 8-foot-wide perennial grass strip between the grape rows. In the grape rows herbicides are directed under the vines to keep a 3- to 4-foot-wide area in the vine row relatively weed-free. (Figure 8.22). The perennial grass strip minimizes competition and supports equipment movement through the vineyard during periods of wet weather.

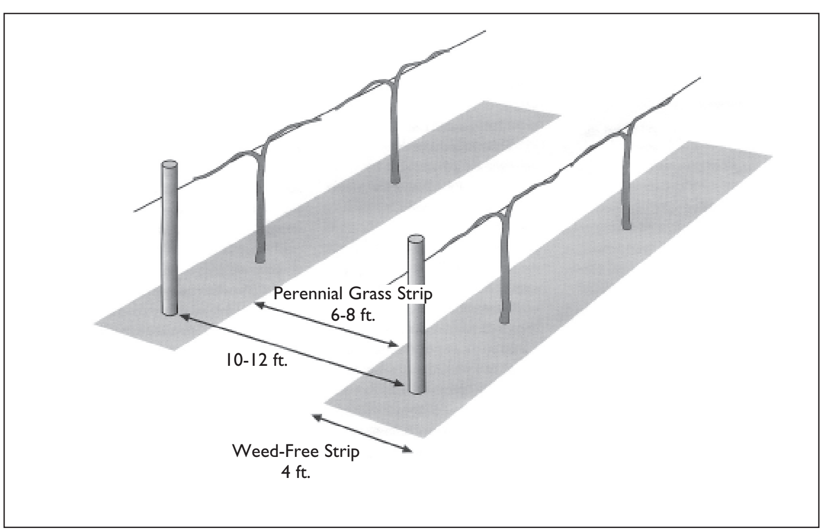
Strip Management

Due to the state's favorable climatic conditions, like a long growing season, good rainfall, and high humidity, weeds thrive in North Carolina. As a result, maintaining a weed-free strip in the vine row is more difficult in North Carolina than other regions of the country. Herbicides offer the most economical means for maintaining a weed-free strip. However, growers interested in organic production, or those preferring to avoid herbicides, other options like tillage, and organic and inorganic mulches are possibilities. All of these options are discussed later in this chapter.

Why a Weed-Free Strip?

Competition Maintaining a weed-free strip in the vine row is especially important in the first and second years of vineyard establishment. Weeds compete with grape vines for water and nutrients, reducing vine growth and yield. Competition for water causes the greatest stress on vines. Although irrigation is common in many vineyards, its efficiency is greatly reduced with the presence of weeds. Research conducted in North Carolina has shown that newly planted vineyards should be maintained weed-free 12 weeks after planting. Herbicide options in newly planted vineyards are relatively limited after spring transplanting. By using grow tubes on newly planted vines, you will have the option of using some very effective herbicides in the first summer season for weed control. Grow tubes are plastic sleeves that create a greenhouse-like environment for the vines to grow in, and also serve to protect new vines from herbicide drift. The number of herbicide options improves for vines in their second growing season, and weed control in the third year and subsequent seasons is achieved with a wide range of preemergence herbicides. In addition, established vineyards shade more of the vineyard floor, minimizing weed emergence and growth.

Figure 8.22 Strip management minimizes erosion, helps with weed and pest management, and maximizes the radient heat benefit.



Radiant Heating – Frost/Freeze Benefit It is well-documented that ground cover management techniques can impact the vineyard microclimate directly impacting vineyard temperature. Research has shown that bare, firm, moist soil has the greatest capacity to absorb heat from sunlight. Heat is reradiated, over a longer time period at night, altering the microclimate by increasing air temperatures in the vineyard and providing additional protection from frost events. In addition, the weed-free surface in the vine row, and closely mown vegetation in the row middle facilitates air drainage, providing additional frost protection.

IPM Benefit Controlling weeds is part of integrated pest management in the vineyard. Weeds provide cover that creates an ideal habitat for voles. Part of vole management includes maintaining a weed-free strip year-round. In addition, weeds under vines provide egg laying sites for grape root borer, and the weeds interfere with soil-applied insecticides used to control grape root borer.

Sod Middle (Species Selection and Management)

As previously discussed, the perennial sod middles are critical for preventing erosion and providing a firm ground cover that allows equipment to move through the vineyard even during periods of wet weather. Ideally, ground cover should be noncompetitive, need minimum mowing, and should be durable. A preferred species is red fescue, but tall fescue has become the most common species used in North Carolina vineyards. Red fescue is not competitive, undesirable for voles, and needs minimal mowing. However, red fescue seed is expensive and can be difficult to establish. Tall fescue seed is readily available and is considerably less expensive than red fescue. Tall fescue can be established easily. If the property was previously used for grazing, it is likely planted in tall fescue. On the other hand, tall fescue is very competitive for water and nutrients and needs mowing more often than red fescue.

Sod can be managed with sublethal rates of glyphosate to minimize the need for mowing. This practice is commonly referred to as "chemical mowing". Chemical mowing can stop growth for 90 to 120 days, therefore eliminating the need for mowing during that time. Specific directions for chemical mowing can be found on glyphosate labels. Grass yellows after chemical mowing with glyphosate.

Herbicide Issues

A number of effective herbicides are registered for use in grape vineyards. Herbicides largely fall into two categories, preemergence (PRE) and postemergence (POST). Preemergence herbicides provide weed control prior to weeds emerging from the soil. Postemergence herbicides control weeds that are emerged from the soil and actively growing. A PRE herbicide is often tank mixed with a POST herbicide in order to control emerged weeds with one application. PRE herbicides have to be activated by rainfall or overhead irrigation in order to work properly. Poor herbicide activation will result in less than desirable herbicide performance. The interval between application and the need for activation varies from one herbicide to another. Some herbicides need activation by rainfall or irrigation within a day while others may wait for 2 or 3 weeks before significant losses in effectiveness occurs. However, the sooner activation occurs from rainfall or irrigation after herbicide application the better.

POST herbicides can be divided into the two categories referred to as contact and systemic. Contact herbicides kill or destroy the area of a plant it contacts. Systemic herbicides move through the leaf surfaces of weeds, into the weed's vascular system where it is able to move through the plant. Herbicides that have POST contact properties include paraquat, and glufosinate (Rely). Examples of herbicides that are systemic include glyphosate, sethoxydim (Poast), and clethodim (Select or Arrow). In order for most POST herbicides to perform properly spray additives may be required. The two most commonly used spray additives are a non-ionic surfactant or a crop oil concentrate. A non-ionic surfactant acts as a spreader to maximize coverage and may aid in penetration. Crop oil concentrates are approximately 15 percent surfactant emulsifier and 85 percent petroleum-based oil. Crop oil concentrates increase herbicide penetration through weed leaf surfaces. POST herbicide labels have specific directions on their label pertaining to spray additives. Always follow label directions.

The effectiveness of POST herbicides can be affected by weed size, growth stage, and soil moisture. In general, small weeds are more easily controlled than large weeds while perennial weeds are more sensitive to glyphosate at specific stages of growth. Ideally, POST herbicides should be applied to non-stressed, actively growing weeds. Weeds stressed from drought can be more difficult to control than non-stressed weeds. However, application timing for POST herbicides should be based primarily on weed size or growth stage when it is most susceptible to the herbicide being applied.

Herbicides – Effective and Economical

Establishment and First Year. Weed control during the initial year of planting and subsequent developmental years is extremely important. The

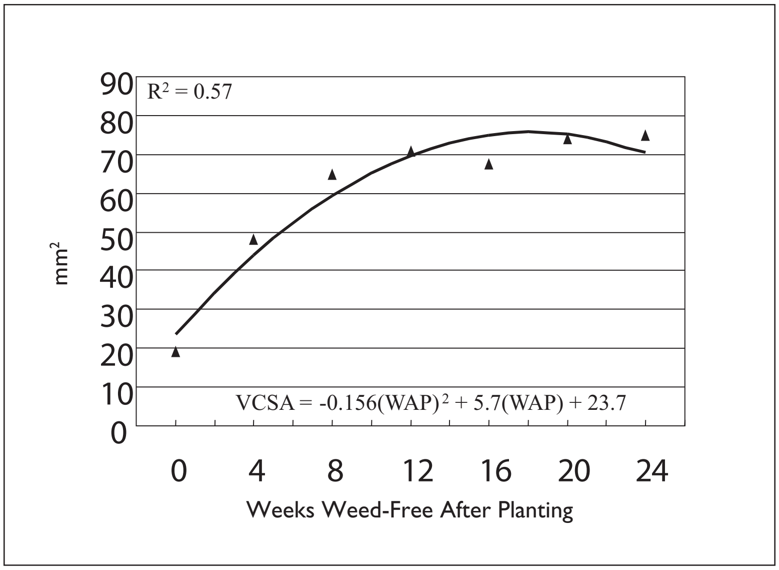
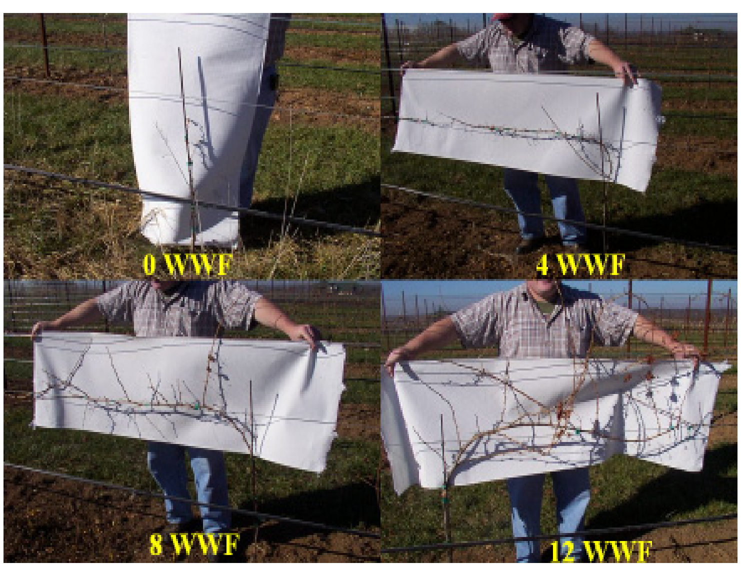


Figure 8.20 Impact of Weed-Free Interval on Vine Cross-Sectional Area

Figure 8.21 Differences in Vine Growth Due to Weed-Free Interval



investment for a vineyard is considerable, and vineyards become fully productive only after several years. In order to maximize the return as soon as possible, optimum vine growth during in the formative years of a vineyard is essential.

In many cases, vineyards are planted into an established, perennial sod. After grape rows have been marked off, and prior to planting, glyphosate can be used to kill vegetation. Usually glyphosate applied 4 weeks prior to planting will control cool-season grasses and perennial weeds common to grape production areas. In order to control most warm-season perennial grasses, apply glyphosate. Prior to planting, sub-soiling or other tillage operations can then be performed. At planting, the use of grow tubes are recommended to protect young vines from herbicide injury. Some herbicide labels require shielding of young vines. Once soil has settled around grape roots after planting, a PRE herbicide should be applied. Flumioxazin (Chateau – shielded vines), oryzalin (Surflan), pendimethalin (Prowl), dichlobenil (Casoron), oxyfluorfen (Goal - if trellis system is used), and napropamide (Devrinol) can be applied to newly planted grapes. POST herbicides will need to be applied to control escaped weeds throughout the summer. However, young grape vines must be shielded from paraquat or injury will occur. Grow tubes offer excellent herbicide protection along with increased growth during the first year. Perennial grasses can be very competitive with grapes. Choose a herbicide like sethoxydim (Poast), fluazifop (Fusilade), and clethodim (Select), which are registered for use in newly established vineyards. They are safe, effective options for POST grass control.

Established Vineyards (2 years or the year after transplanting). In established vineyards, growers have a broader range of herbicide options. There are four programs growers can consider. They include a spring PRE program, which is a traditional approach; the delayed PRE option; the fall/spring split option; and the spring/summer split option.

- ❑ *Spring PRE Program.* Traditionally, a vineyard herbicide program has consisted of a spring PRE herbicide applied with a non-selective POST herbicide like glyphosate or paraquat followed by POST applications of paraquat or glufosinate (Rely) as needed.
- ❑ *Delayed PRE Program* requires a spring glyphosate application. The spring application should be made prior to bud break. Mid to late March is a good application time. Later, when

Table 8.9 Herbicide Program for Grape Vineyards

Crop Age	Fall	Winter	Spring	Summer
Newly Planted			Oryzalin (once soil settles after transplanting)	Oryzalin + paraquat (May or June); Poast or Select (as needed)
			Chateau (once soil settles after transplanting)	Chateau + paraquat (June or July); Fusilade or Poast or Select (as needed)
			Prowl 3.3 or Prowl H2O (vines must be dormant)	paraquat (multiple applications as needed); Fusilade or Poast or Select (as needed)
Vines Established 1 to 2 Years	glyphosate (spot treat for perennial weeds)	glyphosate (mid March)	Oryzalin + paraquat, glyphosate, or Rely (early May)	paraquat or Rely (multiple applications as needed)
	glyphosate (spot treat for perennial weeds)	Chateau + glyphosate, paraquat, or Rely (mid to late March)	Chateau + paraquat, paraquat, or Rely (early June)	Poast (as needed for POST grass control)
	glyphosate (spot treat for perennial weeds)	Solicam (vines est. 2 years) + glyphosate, paraquat, or Rely		Glyphosate, paraquat, Rely, or Poast (as needed)
Vines Established 3 years or more	glyphosate (spot treat for perennial weeds)	glyphosate (mid March)	Simazine + oryzalin + glyphosate, or Karmex + glyphosate	paraquat, Rely, or Poast (as needed)
	glyphosate (spot treat for perennial weeds)	Chateau + glyphosate (mid to late March)	Chateau + paraquat or Rely (early June)	Poast (as needed for POST grass control)
	glyphosate (spot treat for perennial weeds); Simazine + paraquat or Rely (after harvest)		Chateau + paraquat or Rely (mid to late May)	paraquat, Rely, or Poast (as needed)

emerging summer annual weeds reach 2 to 4 inches tall, glyphosate plus a PRE herbicide should be applied. The second application is generally applied the second week of May in western North Carolina. Delaying the PRE herbicide for 6 to 8 weeks extends PRE weed control for 6 to 8 weeks in the summer. The March glyphosate application provides control into early May. Therefore, there is no benefit to applying a PRE herbicide prior to that time.

- *Fall/Spring Split Program.* Grape growers in areas where weeds germinate throughout the winter and summer should consider this program (piedmont). This program begins with a fall PRE application in combination with a nonselective burndown herbicide like paraquat or glufosinate applied after harvest. In late spring a PRE herbicide with glyphosate should be applied for residual summer annual weed control when control from the fall application fails. When a fall PRE herbicide is applied post-harvest, the spring PRE herbicide is applied in late May in western North Carolina.
- *Spring/Summer Split Program* consists of an early spring application of glyphosate with

flumioxazin (Chateau). This application would be applied in late March in western North Carolina. Another application of paraquat or glufosinate with flumioxazin should be applied when control from the initial application fails and emerging weeds are 2 to 4 inches tall. The second application is generally applied in early to mid June in western North Carolina. This program can only be implemented with flumioxazin since other products' labels (like simazine and diuron) do not allow for sequential applications within the same year. Regardless of the PRE herbicide program, perennial weeds like bermudagrass, johnsongrass, brambles, etc., will be troublesome.

Preemergence Herbicides for Newly Planted and Established Vineyards

Dichlobenil (Casoron 4G) at 4 to 6 lb ai/acre (100 to 150 lb/acre) controls many annual and perennial weeds. Apply in January and February for best results. Dichlobenil may be applied in newly planted grapes once soil has settled and plants have recovered from transplanting.

Flumioxazin (Chateau 51 WDG) at 0.19 to 0.38 lb ai/acre (6 to 12 oz/acre) controls annual broadleaf and grass weeds. Sequential applications are most effective. An initial application in March followed by a second application when control from the initial one deteriorates will provide residual control of annual weeds through harvest. Grapes established less than 2 years must be shielded from contact with the herbicide and trellised 3 ft above the soil surface. DO NOT apply within 60 days of harvest and allow a minimum of 30 days between sequential applications. Hooded or shielded application equipment must be used in established vineyards to prevent contact of spray solution with foliage or fruit. Tank mix with glyphosate, paraquat, or glufosinate for postemergence weed control. Applications of flumioxazin after bud break should not be applied with glyphosate.

Isoxaben (Gallery 75 DF) at 0.5 to 1. lb ai/acre (0.66 to 1.33 lb/acre) controls broadleaf weeds including pigweed, lambsquarters, horseweed, ragweed, aster, smartweed, and chickweed. Apply once soil has settled after transplanting. Tank mix with oryzalin, paraquat, glyphosate, or glufosinate.

Napropamide (Devrinol 50 DF) 4 lb ai/acre controls most annual grasses and small seeded broadleaf weeds. Apply prior to weed emergence. Activation from rainfall or overhead irrigation is needed within 24 hours of application for optimum results to prevent napropamide breakdown by sunlight. DO NOT apply within 35 days of harvest. Apply once soil has settled around vines after transplanting.

Oryzalin (Surflan 4 AS, FarmSaver 4 AS) applied at 2 to 4 lb ai/acre (2 to 4 qt/acre) controls most annual grasses and annual sedge. It also controls small seeded broadleaf weeds like chickweed, purslane, carpetweed, lambsquarters, and pigweed. Rate is soil-texture dependent. Oryzalin may be used in newly planted vineyards once soil has settled around plants after transplanting. Oryzalin can be tank mixed with oxyfluorfen, simazine, glyphosate, paraquat, or glufosinate.

Oxyfluorfen (Goal 2 XL, Galligan 2EC, OxiFlo 2EC or GoalTender) 0.5 to 2 lb ai/acre (2 to 8 pt/acre for all 2EC formulations, 1 to 4 pts/acre for GoalTender). Oxyfluorfen provides both PRE and POST broadleaf weed control. It should only be applied prior to vine bud swell while the crop is dormant. DO NOT apply to grapes established less than 3 years unless vines are on a trellis wire, 3 ft above the soil surface. Oxyfluorfen may be tank-mixed with pronamide, nampropamide, simazine, oryzalin, paraquat, glyphosate, or glufosinate.

Pendimethalin (Prowl 3.3 EC or Prowl H2O) at 2 to 4 lb ai/acre (2.4 to 4.8 qt/acre of Prowl 3.3 EC or 2 to 4 qt/acre of Prowl H_2O) controls annual grasses and small seeded broadleaf weeds including chickweed, pigweed, purslane, carpetweed, and lambsquarters. The rate is soil texture dependent. Apply as a directed spray to dormant vines only. DO NOT apply pendimethalin within one year of harvest. Pendimethalin can be tank mixed with paraquat, glyphosate, or glufosinate.

Preemgence Herbicides for Established Vineyards

Diuron (Karmex 80 DF) applied at 1.6 to 2.4 lb ai/acre (2.0 to 3.0 lb/acre) controls annual broadleaf and grass weeds. Susceptible broadleaf weeds include chickweed, dogfennel, jimsonweed, lambsquarters, pigweed, and purslane. DO NOT apply in vineyards established less than 3 years. DO NOT apply to soils with less than 1 percent organic matter. Rate is soil texture dependent. Karmex may be applied in the fall or spring. It can be tank mixed with norflurazon, paraquat, glyphosate, and glufosinate.

Norflurazon (Solicam 80 DF) applied at 1 to 4 lb ai/acre (1.25 to 5 lb/acre) controls annual grasses and some broadleaf weeds. Use only on vines established at least 2 years in the field. Whitening in grape leaf veins may occur if applied within 3 months of bud break when grapes are grown in coarse-textured soils. Solicam may be tank mixed with simazine, diuron, glyphosate, and glufosinate.

Pronamide (Kerb 50W) at 1 to 4 lb ai/acre (2 to 8 lb/acre) provides POST and PRE control of winter annual broadleaf weeds, cool-season perennial grasses, and other grass weeds. DO NOT apply pronamide to vines less than one year old. Pronamide (Kerb 50W) should be applied in late fall or early winter when temperatures do not exceed 55°F.

Simazine (various 90 WDG and 4L formulations) applied 2 to 4 lb ai/acre (2.2 to 4.4 lb/acre or 2 to 4 qt/acre). Generic formulations of simazine are available. Simazine controls some annual grasses, annual sedge, and many broadleaf weeds including ragweed and smartweed. It can be applied in fall or spring. DO NOT apply simazine in vineyards less than 3 years old or to vines planted in gravelly, sand, or loamy sand soils. It can be tank mixed with oryzalin or noflurazon to improve PRE grass control. It may be applied in combination with paraquat, glyphosate, or glufosinate for control of emerged weeds.

Postemergence Herbicides

Bentazon (Basagran) at **0.75 to 1 lb ai/**acre (1.5 to 2 pt/acre) will control some emerged broadleaf weeds like cocklebur, common ragweed, smartweed, spreading dayflower, as well as, yellow nutsedge in **non-bearing** grape vineyards. In order to control yellow nutsedge sequential Basagran applications 7 to 10 days apart must be applied to yellow nutsedge that is 6 to 8 inches. In order to maximize herbicide effectiveness, crop oil concentrate must be included in the spray solution at 1 qt/acre.

Carfentrazone-ethyl (Aim 2EC) at 0.016 to 0.031 lb ai/acre (1 to 2 oz/acre) will control certain broadleaf weeds like cocklebur, pigweed and lambsquarters. DO NOT allow spray solution to contact leaf tissues, flowers, or fruit of the crop. DO NOT use on vines established less than 1 year or apply within 3 days of harvest. Apply in a minimum spray volume of 20 gpa. Apply in combination with crop oil concentrate at 1 % v/v (1 gal per 100 gal. of spray solution) or nonionic surfactant at 0.25% v/v (1 qt/100 gal of spray solution)

Clethodim (Select 2EC or Arrow 2EC) applied at 0.09 to 0.125 lb ai/acre controls annual and most perennial grasses. Clethodim has no soil activity or activity on broadleaf weeds or sedges. The addition of nonionic surfactant at 0.25% v/v (1 qt per 100 gal of spray solution) is necessary for optimum results. Spray solution contact with grape leaves during hot, humid conditions can cause foliar burn or injury. Sequential applications will be necessary for controlling perennial grass weeds like bermudagrass or johnsongrass. DO

NOT apply to weeds stressed from drought. DO NOT apply within one year of harvest. Clethodim is for non-bearing grapes only. Apply in spray volumes of 15 to 20 gal per acre for best results.

Fluazifop (Fusilade DX) at 0.25 to 0.375 lb ai/acre (16 to 24 oz/acre) provides excellent POST control of annual and perennial grasses. Fusilade has no soil activity or activity on broadleaf weeds or sedges. For optimum results add 1 qt of a crop oil concentrate or 8 oz of nonionic surfactant for every 25 gal of spray mix. Spray solution contact with grape leaves during hot, humid conditions can cause foliar burn or injury. Sequential applications will be necessary for controlling perennial grass weeds like bermudagrass or johnsongrass. DO NOT apply to weeds stressed from drought. DO NOT apply within one year of harvest.

Glufosinate (Rely 1L) apply at 0.75 to 1.25 lb ai/acre (3 to 5 qt/acre) for non-selective POST weed control. Apply as a directed spray to the base of plants. DO NOT allow herbicide to contact desirable foliage or green bark or apply within 14 days of harvest. Glufosinate can be used for sucker control. Apply at 4 qt/acre when sucker length does not exceed 12 inches. Two applications, 4 weeks apart are recommended—see label for directions. Glufosinate can be tank mixed with PRE herbicides for residual control.

Glyphosate (Various formulations of 5.5L or 4L) applied at 0.75 to 1 lb ai/acre (16 to 22 oz/acre of 5.5L formulations or 0.75 to 1 qt/acre of 4L formulations) will provide non-selective POST weed contro1. The rates listed above controls most weeds. Some species (woody perennial, etc.) require higher rates for control; refer to label for details. Grapes exhibit excellent tolerance to glyphosate applied in winter, spring and early summer. However, grapes become sensitive to glyphosate applied after June through late fall until grapes become dormant. Applications made in late summer and fall may be injurious. DO NOT spray green bark or foliage. DO NOT apply on first-year plantings. Glyphosate may be used as a spot treatment for controlling perennial weeds like brambles, mugwort, Virginia creeper, and poison ivy. Some glyphosate formulations may require the addition of a surfactant. See label for details. Glyphosate is most effective when applied in spray volumes of 15 to 30 gal per acre. Glyphosate can be tank mixed with PRE herbicides for residual weed control.

Paraquat (Firestorm 3.0L, Gramoxone Inteon 2.0L) applied at 0.66 to 1 lb ai/acre (1.75 to 2.7 pt/acre for 3.0L formulation, 2 to 4 pt/acre for 2.0L formulation) provides POST control of annual weeds and suppresses perennial weeds. Apply when grass and broadleaf weeds are 1 to 4 in high and actively growing for best results. Green bark of grapes must be shielded from contact with spray solution. The addition of a nonionic surfactant at 0.25% v/v (1 qt per 100 gal of spray solution) is necessary. Apply in no less than 20 gal of spray solution per acre. Paraquat can be used to suppress or control suckers, however application must be when sucker length does not exceed 8 in. Paraquat may be tank mixed with PRE herbicides for residual weed control.

Sethoxydim (Poast) applied at 0.28 to 0.47 lb ai/acre (1.5 to 2.5 pt/acre) provides excellent control of annual and some perennial grasses. Sethoxydim has no soil activity or activity on broadleaf weeds or sedges. The addition of crop oil concentrate at 1 qt/acre is recommended. Spray solution contact with grape leaves during hot, humid conditions can cause foliar burn or injury. Sequential applications will be necessary for controlling perennial grass weeds like bermudagrass or johnsongrass. DO NOT apply to weeds stressed from drought. DO NOT apply within 50 days of harvest.

Tillage/Herbicide Program

While specialty tillage equipment can be used in conjunction with herbicides to provide excellent weed control in the herbicide strip, it can result in problems. One system consists of a fall (post-harvest) tillage operation that ridges soil in the vine row. The ridge is knocked down in the spring after vines break dormancy with an in-row tiller. The freshly tilled, flat surface is then treated with a PRE herbicide for residual weed control. The combined tillage operations (fall and spring) delay the need for a spring PRE herbicide several weeks. The delay extends residual weed control into the summer.

Topography and vineyard size limits the utility of this method. Rolling terrain, where erosion is more likely, limits where tillage may be appropriate. Due to the cost associated with specialized tillage equipment, economies of scale have to be considered before purchasing such equipment. It may not be cost-effective for small vineyards.

In general, tillage is not recommended in vineyards. Tillage disrupts soil and in areas prone to erosion promotes washing. Frequent tillage injures grape roots and vines, destroys soil structure, and increases soil compaction. Tillage equipment also can easily spread perennial weeds through the vineyard.

Herbicide Mixing, Application, and Sprayer Calibration

Before applying any pesticide it is the responsibility of the applicator to read the label. The label is a legal document that outlines specific conditions and restrictions for which that particular pesticide is to be used. It contains information on re-entry interval, personal protective equipment needed, and preharvest intervals among other important issues pertaining to proper use of the pesticide in question. Any use of a pesticide inconsistent with label direction is a violation of the law. Any grower who intends to use pesticides should contact his or her local Cooperative Extension Service agent to get information on a private applicator pesticide license.

Herbicides are often tank mixed to broaden the control spectrum. There could be as many as three to four products included in a single tank. To ensure proper mixing follow the mixing order given below.

1. Wettable powders (W) or water dispersable granules (WDG or DG) or dry flowables (DF)
2. Flowables (F)
3. Emulsifiable Concentrates (EC)
4. Oils
5. Surfactants (fill tank before adding to avoid foaming)

Herbicides are applied using water as a carrier, although there are circumstances in certain crops when herbicides are applied using liquid fertilizer as carrier. The amount of carrier containing the herbicide applied on acre is known as the spray volume. The optimum spray volume for applying herbicides can vary from one herbicide to another but most herbicides generally perform very well when applied in a spray volume ranging from 20 to 25 gallons per acre (GPM). In order to correctly and safely apply herbicides, the sprayer must be calibrated properly. Over- as well as under-application can be costly. Procedures for herbicide calibration are given at the end of this chapter.

Herbicide Alternatives

Tillage can effectively reduce weed competition in the weed-free strip. A grower choosing to use tillage must be timely. Waiting until weeds are large will limit the effectiveness of the tillage operation. Furthermore, specialty tillage equipment used in vineyards is designed to control small, seedling weeds. Large weeds with well-developed root systems are very difficult to remove by tillage. Growers must also be aware of soil moisture conditions when using tillage equipment in the vineyard. Tillage when soil is wet will result in clod development and lead to poor soil structure. Tilling has negative effects on organic matter because it increases

Table 8.10 Herbicide Efficacy Table[1]

Weeds	Aim	Basagran	Casoron	Chateau	Clethodim	Devrinol	Diuron	Fusilade	Gramoxone	Glyphosate	Kerb	Oryzalin	Oxyflruorfen	Poast	Prowl	Rely	Simazine
Barnyardgrass	N	N	E	E	E	G	G	G	G	E	E	G	E	E	G	G	E
Large Crabgrass	N	N	E	E	E	E	G	G	G	E	E	E	E	E	E	G	E
Crowfootgrass	N	N	E	-	E	E	G	G	G	E	E	E	F	E	E	G	G
Fall Panicum	N	N	N	G	E	G	F	G	G	E	E	E	F	E	G	G	E
Foxtail species	N	N	E	G	E	E	G	G	G	E	E	E	F	E	E	G	G
Goosegrass	N	N	E	E	E	E	G	G	G	E	E	E	E	G	E	G	G
Johnsongrass(es)	N	N	E	-	E	P	P	G	F-G	E	P	G	F	E	G	G	P
Signalgrass	N	N	G	G	E	G	P	G	G	E	G	G	F	E	G	G	P
Texas Panicum	N	N	E	G	E	P	F	G	G	E	P	G	F	E	G	G	P
Carpetweed	E	-	E	E	N	G	-	N	E	E	G	G	E	N	G	E	E
Chickweed	P	-	E	E	N	E	G	N	E	E	E	G	E	N	G	E	E
Cocklebur	E	E	-	G	N	P	F	N	E	E	P	P	-	N	N	E	F
Dodder	-	-	N	-	N	-	-	N	E	E	E	N	-	N	N	-	N
Dogfennel	-	-	E	-	N	-	E	N	-	E	-	N	-	N	N	-	N
Eveningprimrose	F	-	E	G	N	G	-	N	G	F	G	P	-	N	G	-	G
Galinsoga	-	F	-	G	N	E	-	N	G	E	F	P	F	N	P	E	G
Horseweed	-	-	E	G	N	-	E	N	F	E	-	N	G	N	N	G	-
Jimsonweed	G	E	-	G	N	P	G	N	E	E	P	P	G	N	P	E	E
Lambsquarters	E	F-G	E	E	N	G	E	N	E	E	E	G	E	N	G	E	E
Morningglory	E	F-G	G	E	N	P	F	N	E	G	G	P	P	N	P	E	G
Pigweed	E	P	E	E	N	F	E	N	E	E	E	G	E	N	G	G	G
Prickly Sida	-	-	-	E	N	P	F	N	E	E	-	P	E	N	P	G	G
Common Ragweed	-	F	E	G	N	G	G	N	E	E	E	F	E	N	P	G	E
Smartweed	-	G	E	E	N	G	F	N	G	G	G	F	E	N	P	G	E
Velvetleaf	E	G	-	G	N	P	F	N	E	E	P	F	G	N	E	G	-
Bermudagrass	N	N	P	N	E	P	N	E	F	G	P	P	N	G	N	F	N
Bramble	N	N	N	N	N	N	N	N	P	G	N	N	N	N	N	F	N
Greenbriar	N	N	P	N	N	N	N	N	P	G	N	N	N	N	N	P	N
Johnsongrass	N	N	F	N	E	N	N	E	F	G	P	N	N	E	P	F	N
Yellow Nutsedge	N	G	E	N	N	N	N	N	F	F-G	N	N	N	N	N	F	N
Virginia Creeper	N	N	P	N	N	N	N	N	P	G	N	N	N	N	N	P	N

E = Excellent; G = Good; F = Fair; P = Poor, N = No effect

[1]Weed response to herbicide is based upon proper herbicide activation for preemergence herbicides and timely application for postemergence herbicides.

decomposition. It may also be destructive to grape roots.

Organic and inorganic mulches can be used to reduce weed competition in vineyards. Sources of organic mulch include wood chips, pine straw, straw, hay, grass clippings, or leaves. In order to be effective, organic mulches need to be 4" thick and have to be replenished annually as decomposition occurs. Mulches should not be used in vineyards with poorly drained soils. Plastic mulches (like that used in annual strawberry production) can be used as a barrier to weeds, but rodents tend to be more problematic where plastic mulches are used. The use of mulch largely depends on the sources that are readily available near your vineyard. Application of mulch is labor intensive and use of organic mulches can introduce additional weeds into a vineyard if the mulch has not been composted.

Another nonchemical means of managing weeds in a vineyard is flame cultivation. Specialized equipment is required to flame weeds. Young vines must be shielded from the heat from the flame cultivator's burners. Mature vines can also be injured if too much heat contacts the vine bark. For optimum control, flaming must be done when weeds are small.

References

Pearson, R. C., and A. C. Goheen. 1988. Compendium of Grape Diseases. St. Paul, MN: APS Press. 93 p.

West Virginia University (WVU) Cooperative Extension offers a series of excellent publications on deer and deer control strategies, including electric fence design and construction. Information on these publications can be obtained by contacting WVU Cooperative Extension in Morgantown, West Virginia.

Consult your county Cooperative Extension Service agent for current pesticide recommendations.

Supplies and Services

Suppliers of fencing and electric fence charging materials include:

Gallagher Power Fence, Inc.
18940 Redland Road
PO Box 708900
San Antonio, TX 78270
(512) 494-5211

West Virginia Fence Corp.
U.S. Rt. 219
Lindside, WV 24591
(304) 753-4387

Kiwi Fence Systems, Inc.
RD 2 Box 51A
Waynesburg, PA 15370
(412) 627-8158

Kencove Farm Fence
111 Kendall Lane
Blairsville, PA 15717
(800) 536-2683

Laboratories offering disease testing services for viruses and Pierce's Disease:

AgDia
30380 County Rd. 6
Elkhart, IN 46514
(219) 264-2014

Agri-Analysis Associates
45133 County Rd. 32-B
Davis, CA 95616
(916) 757-4656

Chapter 9

Vine Nutrition

Grapevines require 16 essential nutrients for normal growth and development (Table 9.1). Carbon, hydrogen, and oxygen are obtained as the roots take in water and as the leaves absorb gases. The remaining nutrients are obtained primarily from the soil. Macronutrients are those used in relatively large quantities by vines; natural macronutrients are often supplemented with applied fertilizers. The micronutrients, although no less essential, are needed in very small quantities. When one or more of these elements is deficient, vines may exhibit foliar deficiency symptoms, reduced growth or crop yield, and greater susceptiblity to winter injury or death. The availability of essential nutrients is therefore critical for optimum vine performance and profitable grape production.

Ensuring adequate vine nutrition begins in the preplant phase of vineyard establishment. Soil samples should be collected at that time to determine whether lime or other fertilizers are needed. Soil depth, texture, and internal drainage must also be evaluated before the vineyard is established because deficiencies in those factors can lead to poor root growth and reduced nutrient absorption.

Grapevines typically grow very slowly during the first few months after planting. That slow growth is due to a small root system and minimal carbohydrate reserves in the rooted cutting or grafted vine. Trying to stimulate growth with fertilizer application is tempting. Unfortunately, young vines are occasionally injured more than benefited by fertilizer applied during the first season. Under most conditions, if the vineyard soil was well prepared and the soil pH was adjusted before planting, vines will require very little if any fertilizer in the first few years of growth.

Poor growth of young vines is more often due to lack of water, competition by weeds, overcropping, or poor disease control than to inadequate soil fertility. Fertilizer will not compensate for those stresses. Besides possible root burning, excessive nutrient availability can lead to poor wood maturation in the fall and subsequent cold injury during the winter. Applying soil fertilizer in the year of planting is therefore recommended only if the soil is inherently infertile. In that case, a 4-ounce-per-vine application of a 10-10-10 fertilizer (or one having an equivalent nitrogen analysis) is generally sufficient. The fertilizer should be applied in a ring 12 to 18 inches from the base of the vine after planting or just before bud break for vines set the previous fall.

Table 9.1. Nutrients Essential for Normal Grapevine Growth and Development

Obtained from	Obtained from Soil	
Air and Water	**Macronutrients**	**Micronutrients**
Carbon (C)	Nitrogen (N)	Iron (Fe)
Hydrogen (H)	Phosphorus (P)	Manganese (Mn)
Oxygen (O)	Potassium (K)	Copper (Cu)
	Calcium (Ca)	Zinc (Zn)
	Magnesium (Mg)	Boron (B)
	Sulfur (S)	Molybdenum (Mo)
		Chlorine (Cl)

As an alternative to soil application, a foliar fertilizer can be used on young vines. The foliar fertilizer provides a rapid but temporary response. Sprayable 20-20-20 fertilizer or materials of a similar analysis are suitable, but read the fertilizer directions for rates of application and precautions.

Assessing Nutrient Needs of Mature Vines

As vines mature and crops are harvested, many vineyards require periodic application of one or more nutrients and adjustment of pH with lime. Vineyards are sometimes fertilized on the basis of speculation, habit, or wishful thinking. At the other extreme, some growers avoid any fertilizer for fear of overstimulating growth. In other cases, entire vineyard blocks might be fertilized when only specific areas of the block require fertilizer. Inappropriate vineyard fertilization can result in inadequate or excessive vine vigor, poor fruit set, impaired leaf photosynthetic ability, and reduced fruit quality. In some cases, such as with boron, excess availability can cause vine injury more severe than the deficiency symptoms. Therefore, it is important that growers have a sound basis for determining the fertilizer needs of their vines.

No single method exists for accurately assessing vine nutrient needs. Instead, a combination of soil analysis, plant tissue analysis, and visual symptoms should be used. These methods are discussed in detail in the following sections of this chapter.

Soil Analysis

Physical soil features should be evaluated in the site selection process. (See chapter 4.) The soil must meet minimum standards of depth and internal water drainage. Soil survey maps should be consulted to determine the agricultural suitability of any proposed site. The history of crop production at the site or in nearby vineyards can provide some indication of grape production potential. Sites that have been in recent cultivation are usually in better condition than pasture or abandoned farmland.

Detailed soil analyses must be made before the vineyard is established, primarily to determine pH but also soil fertility. Soil test kits are available from either county Cooperative Extension centers or regional agronomists with the NCDA&CS. (See the listing of soil and plant tissue testing services at the end of this chapter.) Soil samples can be collected either with a shovel or a cylindrical soil probe. In either case, samples must be representative of the area to be planted. Sites larger than 2 or 3 acres should be subdivided and each section sampled separately if there are differences in topography or soil classification. Collect samples when the soil is moist and not frozen; fall is an excellent time. Each sample should consist of 10 to 20 subsamples that are thoroughly mixed. Exclude surface litter, sod, large pebbles, and stones, and retain about a pound of the mixed soil for testing. The top few inches of soil are usually quite different from deeper soil with respect to pH and nutrient availability. For this reason, it is best to divide each soil probe into two samples: one from the 0- to 8-inch depth and a second from the 8- to 16-inch depth. Grape roots can grow much deeper than 16 inches in loose, well-aerated soil. Because the ability to alter soil characteristics significantly below that depth is very limited, there is little point in collecting deeper samples.

Soil test results will indicate whether adjustments to pH and macronutrients are necessary. Soil test data are not customarily used to assess the need for nitrogen or trace elements for vineyards, although tests for those nutrients can be included if there are reasons to suspect a deficiency. The test results are accompanied by specific recommendations for correcting soil deficiencies.

Perhaps the most important information provided by the soil test is the pH value. Soil pH is a measure of acidity or alkalinity on a scale from 0 to 14. A value of 7 is neutral. Values less than 7 reflect acidity, whereas numbers above 7 indicate alkaline conditions. The pH scale is logarithmic; a pH of 5.0 is 10 times more acidic than a pH of 6.0 and 100 times more acidic than a pH of 7.0. Soil pH is determined by many factors, including the parent material, the amount of organic matter, the degree of soil leaching by precipitation, and previous additions of lime or acidifying fertilizers.

Grape species differ substantially in the optimum pH for growth. Varieties of *Vitis vinifera* generally grow best at a pH between 6.0 and 7.0, whereas the native American grapes (such as Concord and Niagara) and the hybrids tolerate lower pH values (5.5 to 6.0).

Adjusting Soil pH

Soil pH adjustments in eastern U.S. vineyards, with few exceptions, are made to increase rather than decrease pH. The pH of acid soils can be raised by applying lime. That simple statement unfortunately oversimplifies the complexity of soil acidity problems, particularly in established vineyards. It is very difficult to increase the pH below the top few inches of soil once vines have been planted. This is particularly true once a permanent cover crop has been planted and cultivation is no longer desirable. For that reason it is extremely important to determine soil pH and raise it if necessary before the vineyard is established.

The applied lime should be incorporated as thoroughly and as deeply as possible. Common agricultural-grade liming materials (for example, ground limestone) have very low solubilities and will move very little, if at all, below the first few inches when applied to the soil surface. Even with cultivation, lime incorporation beyond about 12 inches is unlikely with conventional tillage equipment. Subsoil pH can be raised somewhat by applying lime and cultivating deeply (12 to 18 inches) with a chisel plow or subsoiler.

Most vineyard soils tend to become acidic even if they are limed to a pH of 6.5 at the time of establishment. Acidification occurs through leaching of basic ions from the soil profile, through microbial activity, and by the addition of acidifying fertilizers such as ammonium sulfate. Fungicidal sulfur applications can also be expected to reduce soil pH. Soil pH should therefore be monitored every two to three years after vineyard establishment.

The materials commonly used for agricultural liming are the oxides, hydroxides, carbonates, and silicates of calcium or mixtures of calcium and magnesium. Commercial bulk application of lime typically involves spreading ground limestone, which contains calcium carbonate or mixtures of calcium and magnesium carbonate. Limestone containing a high proportion of magnesium carbonate is termed *dolomitic limestone.* Calcitic limestone is more reactive than dolomitic limestone; however, dolomitic limestone can be useful in situations where available magnesium is low. The oxides and hydroxides (hydrated lime is calcium hydroxide) are more reactive and have a greater neutralizing value than the carbonates. These materials are, however, unpleasant to handle. They absorb moisture and can cake, and they can irritate skin and injure tissues of the eyes, nose, and mouth. Oxides and hydroxides are also more expensive than carbonates. In addition to dry materials, liquid lime formulations are available from some distributors.

The choice of liming material is often determined by what is locally available. Most of the cost of liming is due to transportation and spreading. The amount of lime needed for a particular acidity problem is affected by a number of factors including soil pH, texture, and organic matter content; the grape species to be planted; and the type and particle size of lime used. Obviously, recommendations cannot be provided here for all situations. Table 9.2, however, provides some guidelines for liming based on initial pH and soil type. In practice, individual rates of lime application should not exceed 4 tons per acre. Where soils are strongly acidic, several applications of 2 to 3 tons per acre each over a period of several years will likely be more effective than a single, massive dose.

Plant Tissue Analysis

Analyzing plant tissue provides an objective means of determining the nutrient status of grapevines.

Table 9.2. Estimated Quantity of Lime (Ground Limestone) in Tons Per Acre Required to Increase pH Values in Three Different Soil Types

	Soil Type		
pH of Unlimed Soil	**Sandy**	**Loamy**	**Clayey**
		pH desired: 6.8	
4.8	4.25	5.75	7.0
5.0	4.0	5.25	6.25
5.5	3.0	4.0	4.75
6.0	2.0	2.75	3.25
6.5	1.25	1.5	2.0
		pH desired: 6.5	
4.0	3.5	4.5	5.0
5.0	3.0	3.75	4.25
5.5	1.75	2.5	3.0
6.0	1.25	1.5	2.0

Tissue analysis reveals the concentration of essential nutrients or elements absorbed by or within vine tissues. In most respects, tissue analysis is superior to soil analysis, which indicates only the relative availability of nutrients. A high availability of a particular nutrient in the soil does not necessarily mean that the plant can extract enough of that nutrient to meet its needs.

To be meaningful, tissue analysis must entail (1) a standardized tissue sampling procedure; (2) accurate and precise analytical methods for determining the elemental concentrations of tissue samples; (3) standard references with which to compare diagnostic sample values; and (4) a means of interpreting diagnostic data and making sound fertilizer recommendations to the grower.

In practice, a grower collects the tissue sample and submits it to a laboratory for analysis. The laboratory technician follows standardized procedures for determining the mineral nutrient concentration of the tissue. Elemental concentrations of the diagnostic sample are compared with standard grapevine tissue references from healthy vines. Based on those standards, elements or nutrients in the diagnostic sample are classified as being adequate, high, or low (deficient). Fertilizer recommendations to increase the concentration of nutrients that are low or deficient can be made either by laboratory personnel or a grape specialist. The NCDA&CS Agronomic Division can provide further information on submission procedures. (http://agronomy.agr.state.nc.us/)

Specific recommendations for tissue sample collection depend on the grower's objectives. There are basically two reasons to conduct plant tissue analyses. One is for the routine evaluation of nutrient status. The other is to diagnose a particular visible disorder for which a nutrient deficiency is the suspected cause.

ROUTINE NUTRIENT STATUS EVALUATION. The general nutrient status of vines should be evaluated annually or every other year to gauge the vineyard's need for or response to applied fertilizer. These tests will usually detect deficiencies before symptoms become visible. Corrective fertilizer applications are then usually unnecessary because minor deficiencies can be corrected by adjusting the fertilizer used in routine maintenance applications.

The concentration of most essential nutrients varies in the plant throughout the growing season. For example, the concentration of nitrogen in grape leaves is higher at bloom than at véraison (onset of rapid fruit maturation) or near harvest. For other nutrients, such as potassium, research has shown that foliar concentrations in late summer (70 to 100 days after bloom) are better correlated with vine performance than are concentrations diagnosed at bloom. Sample vines at different times of the season to evaluate different nutrients. The NCDA&CS Plant Analysis Laboratory has very reasonable charges for plant analysis. If you take only one plant tissue sample each season, collect that sample at full bloom, which is when about two-thirds of the flower caps have been shed. Because the tissue concentrations of many of the essential elements change rapidly in the early part of the growing season, it is important to sample as close to full bloom as possible.

Sample each variety separately because nutrient concentrations may vary somewhat among varieties. Collect a total of 100 petioles from leaves located opposite the first or second flower cluster from the bottom of the shoot. Petioles are the slender stems that attach the leaf blade to the shoot (Figure 9.1). Collect petioles systematically throughout the vineyard block to ensure that the entire block is represented. If different portions of the vineyard (for example, hills versus low-lying areas) exhibit differences in vine growth, collect separate samples from each of those areas. Collect no more than one or two petioles per vine. Choose leaves from shoots that are well exposed to sunlight and that are free of physical injury or disease. Immediately separate the petioles from leaf blades and place the petioles in a small, labeled paper bag or envelope.

Sufficiency ranges for nutrients from bloom-sampled vines are presented in Table 9.3. Concentrations that exceed the sufficiency range do not necessarily indicate a problem. For example, recent applications of fungicides that contain manganese, copper, or iron can elevate the test results for those elements.

Certain elements, notably potassium, are best evaluated in late summer when their concentrations become more stable. Where bloom-time samples indicate questionable nutrient levels, particularly of potassium, collect a second set of samples 70 to 100 days after bloom. These late-summer samples should consist of 100 petioles collected from the youngest fully expanded leaves of well-exposed shoots. The youngest fully expanded leaves will usually be located from five to seven leaves back from the shoot tip. Separate the petioles from leaf blades and submit only the petioles as described above.

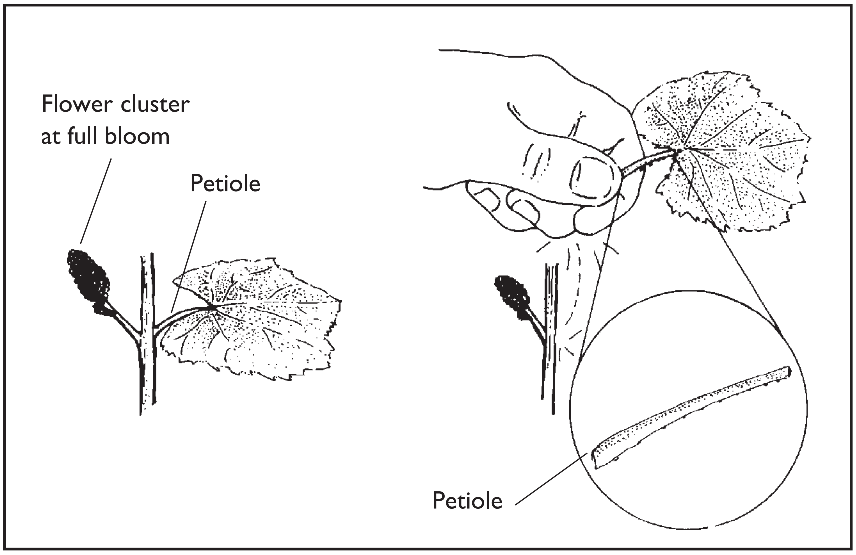


Figure 9.1. Remove and retain only the leaf petiole for tissue analysis. Collect petioles from leaves located opposite the bottom flower cluster at full bloom.

Table 9.3. Sufficiency Ranges of Essential Elements Based on Bloom-Time Sampling of Leaf Petioles

Nutrient[a]	Sufficiency Range	
Nitrogen	1.20 – 2.20	%
Phosphorus[a]	0.15 – ?	%
Potassium	1.50 – 2.50	%
Magnesium	0.30 – 0.50	%
Iron[a]	40 – ?	ppm
Manganese	25 – 1,000	ppm
Copper	7 – 15	ppm
Zinc	35 – 50	ppm
Boron	30 – 100	ppm

[a] Nutrients of Table 9.1 that are not shown here are those that are unimportant from a nutrient management perspective or those for which reliable standards have not been established for North Carolina vineyards.

DIAGNOSING VISIBLE VINE DISORDERS.

For trouble-shooting suspected nutrient deficiencies, sample anytime during the season that symptoms become apparent. Collect 100 petioles from symptomatic leaves regardless of their shoot position. In addition, collect an equal number of petioles from nonsymptomatic or healthy leaves in the same relative shoot position from which affected leaves were collected. Label and submit the two independent samples so that their elemental concentrations can be compared.

Visual Observations

Inspections of foliage for symptoms of nutrient deficiencies and observations of vine vigor and crop size provide important clues as to whether vines are suffering nutrient stress. However, it is possible to be misled by foliar disorders because some are not nutritional in origin. For example, some herbicide toxicity symptoms are similar to those of certain nutrient deficiencies. And, to the inexperienced person, European red mite feeding injury may be misinterpreted as a nutrient deficiency. The correct interpretation of foliar disorders requires a certain amount of experience and understanding of pattern expression. In general, there are three different patterns of symptoms to examine: patterns within the vineyard; patterns on a given vine; and patterns on a particular leaf.

Variation in symptoms within the vineyard can provide useful clues as to whether a nutrient deficiency is the cause of observed symptoms. With undulating or hilly topography, nutrient deficiency symptoms are usually first observed on the higher sites, especially where soil erosion has occurred. In particular, nitrogen, potassium, magnesium, and boron deficiencies may be expected to occur first at higher sites because of thinner topsoil and reduced moisture. Soil moisture aids movement of nutrients to the root-soil interface, and under drought conditions, nutrient deficiencies can develop.

Vine-to-vine variation in symptoms also provides meaningful clues. Generally, a nutrient deficiency will affect sizable portions of a vineyard and rarely only one or two vines at random. Peculiar symptoms that appear on only a few vines throughout the vineyard, or where healthy vines alternate with symptomatic vines, suggest a biological pest. Leafroll virus, for example, will produce distinct foliar symptoms on some red-fruited varieties (for example, Cabernet franc), and affected vines may be directly adjacent to healthy vines.

The position or age of symptomatic leaves on a given vine also provides information about which nutrient might be causing the deficiency symptoms. Generally, deficiencies of the mobile elements such as nitrogen, potassium, and magnesium appear on older or midshoot leaves. Deficiency symptoms of some of the less mobile trace elements, notably iron and zinc, first appear on the youngest leaves of the shoot.

Finally, the particular pattern of symptoms on individual leaves can also yield information. Specific patterns for individual elements are described in the following section and are summarized in Table 9.4 for three commonly deficient macronutrients.

In addition to foliar symptoms, observations of vine vigor and fruit set and yield can be used to further diagnose a suspected nutrient deficiency. Uniformly weak vine growth, for example, may point to a need for added nitrogen. However, first consider that water stress, overcropping, and disease can also constrain growth. Poor fruit set, straggly clusters, and uneven berry size and shape could suggest a boron deficiency. Remember that similar symptoms might point to a tomato ringspot virus infection.

It should be obvious, then, that the diagnosis of nutrient deficiencies depends on experience and should be confirmed with a combination of visual examination and laboratory tests.

Table 9.4. Characteristics of Foliar Symptoms of Nitrogen, Potassium, and Magnesium Deficiencies

	Leaf Injury Pattern		Location of the Most
Nutrient	**Mild Symptoms**	**Severe Symptoms**	**Severely Affected Leaves**
Nitrogen	General fading of green leaf color	Pronounced leaf yellowing or chlorosis	Basal to midshoot leaves
Potassium	Interveinal and marginal chlorosis	Necrosis or scorching of leaves from margins inward	Midshoot leaves
Magnesium	Interveinal chlorosis that does not extend to leaf margin on at least some leaves	Necrotic spots and leaf chlorosis, including chlorosis of leaf margins	Basal to midshoot leaves

Specific Nutrient Deficiencies and Their Correction

Fortunately, of the 16 essential elements required by grapevines, only nitrogen, potassium, magnesium, and boron are commonly deficient in North Carolina. This section provides an overview of the role of these nurtients, the symptoms of deficiencies, and options for correcting the deficiencies.

Nitrogen

ROLE OF NITROGEN. Vines use nitrogen to build many compounds essential for growth and development. Among these are amino acids, nucleic acids, proteins (including all enzymes), and pigments, including the green chlorophyll of leaves and the darkly colored anthocyanins of fruit.

SYMPTOMS AND EFFECTS OF NITROGEN DEFICIENCY. Nitrogen deficiency is not as easily recognized as are deficiencies of certain other elements such as magnesium or potassium. The classic symptom is a uniform light green color of leaves (Figure 9.2), as compared to the dark green of vines that receive adequate nitrogen. Nitrogen deficiency is considered severe if leaves show this uniform light green color. Other clues pointing to nitrogen deficiency are slow shoot growth, short internodal length, and small leaves. Insufficient nitrogen can also reduce crop yield through a reduction in clusters, berries, or berry

Figure 9.2. Nitrogen deficiency symptoms.

set. Thus, nitrogen deficiency might be observed as a reduction in yield over several years. It is important to remember, however, that other factors such as drought, insect and mite pests, and overcropping can also cause similar symptoms.

EXCESSIVE NITROGEN. Nitrogen stimulates vegetative growth. If excess nitrogen is available to vines, excessive vine growth may occur. Shoots of such vines can grow late into the fall and may attain a length of 8 to 10 feet. Conventional trellis and training systems do not accommodate such extensive growth, and some form of summer pruning might be needed to create an acceptable canopy microclimate for fruit and wood maturation. The percentage of shoot nodes that mature (become woody) can also be decreased when excessive nitrogen causes growth to continue late in the season.

Yields can also suffer from excessive nitrogen uptake. Yield reductions can result from reduced bud fruitfulness caused by shading of buds in the previous year. Yields can also be reduced by inadequate fruit set in the current year. In the latter situation, vigorous shoot tips can provide a stronger "sink" than the flower clusters for carbohydrates, nitrogenous compounds, and hormones necessary for good fruit set.

Some growers believe that any added nitrogen will reduce the cold hardiness of vines. This is an unfortunate misconception. If vines exhibit poor vigor and are not producing good crops as a result of nitrogen deficiency, the addition of moderate amounts of nitrogen (30 to 60 pounds of actual nitrogen per acre) will not reduce their cold hardiness and will undoubtedly improve their overall performance.

CAUSES OF NITROGEN DEFICIENCY. Nitrogen is the essential element used in greatest amounts by vines. In older vineyards, nitrogen is the nutrient that most commonly must be added routinely. Once absorbed by the vine, nitrogen can be lost through fruit harvest and the annual pruning of vegetation. Considering that grape berries contain approximately 0.18 percent nitrogen, a 5-ton crop removes approximately 18 pounds of nitrogen per acre from the vineyard. The reduction in nitrogen is even greater if cane prunings (about 0.25 percent nitrogen) are removed from the vineyard.

Given a removal of nitrogen in the crop and prunings with no input (fertilizer), most soils will eventually be depleted of readily available nitrogen. Nitrogen depletion occurs most rapidly in soils having a low organic matter content. Much of the nitrogen in soils is associated with organic matter. Through a series of reactions involving soil organisms, the pool of organic nitrogen is converted to other forms (ammonia and nitrate-nitrogen) capable of being absorbed by vines and other plants. When soil nitrogen reserves are exhausted, nitrogen must be applied to satisfy the vines' needs.

Vines grafted to pest-resistant rootstocks (for example, *Vitis vinifera* varieties) are often more vigorous than nongrafted vines, and their requirements for nitrogen fertilizer may be substantially less than that for own-rooted vines. However, grafted grapevines are not immune to nitrogen deficiency. The robust root system of grafted vines is capable of exploring a large volume of soil. Even so, continued cropping or soil mismanagement will eventually exhaust available soil nitrogen.

ASSESSING THE NEED FOR NITROGEN FERTILIZER. No single index serves well as a guide in assessing the vine's need for nitrogen fertilizer. Instead, a number of observations should be made over several consecutive years to determine the vine's nitrogen status. Vines can be grouped into three general categories with respect to their nitrogen status: deficient, adequate, and excessive.

Nitrogen deficient vines commonly exhibit these symptoms:

- ❑ Vines consistently fail to fill the available trellis with foliage by the first of August.
- ❑ Crop yield is chronically low.
- ❑ Cane pruning weights are consistently less than ¼ pound per foot of row or per foot of canopy for divided-canopy training systems (for example, less than 1.75 pounds for vines spaced 7 feet apart in the row).
- ❑ Mature leaves are uniformly small and light green or yellow.
- ❑ Shoots grow slowly and have short internodes.
- ❑ Shoot elongation ceases in midsummer.
- ❑ Fruit quality may be poor, including poor pigmentation of red-fruited varieties.
- ❑ Bloom-time petiole nitrogen concentration is less than 1 percent.

If the nitrogen status is adequate, vines typically exhibit these characteristics:

- ❑ Vines fill the trellis with foliage by the first of August.

- ❑ Yields are acceptable.
- ❑ Cane pruning weights average 0.3 to 0.4 pound per foot of row.
- ❑ Mature leaves are of a size characteristic for the variety and are uniformly green.
- ❑ Shoots grow rapidly and have internodes 4 to 6 inches long.
- ❑ Shoot growth ceases in early fall.
- ❑ Fruit quality and the maturation period are normal for the variety.
- ❑ Bloom-time petiole nitrogen concentration is between 1.2 and 2.2 percent.

With excessive nitrogen, vines may present these symptoms:

- ❑ Shoots fill trellis with an excess of foliage: shoots are 8 to 10 feet long by mid-July.
- ❑ Fruit yields are low because there are few clusters, poor fruit set, or both.
- ❑ Cane pruning weights consistently exceed 0.4 pound per foot of row (for example, 3 or more pounds of cane prunings for vines spaced 7 feet apart in the row).
- ❑ Mature leaves are exceptionally large and very deep green.
- ❑ Shoot growth is rapid; internodes are long (6 inches or more) and possibly flattened.
- ❑ Shoot growth does not cease until very late in the fall.
- ❑ Fruit maturation is delayed.
- ❑ Bloom-time petiole nitrogen is greater than 2.5 percent.

Again, the occurrence of symptoms listed as typical of nitrogen-deficient vines does not prove that nitrogen is limiting growth. Drought, in particular, can cause similar symptoms. Nitrogen fertilizer will not overcome problems arising from the lack of water or other growth-limiting factors.

CORRECTING NITROGEN DEFICIENCY. It is far better to prevent nitrogen deficiency than to wait until correction of a deficiency is necessary. Maintaining an appropriate nitrogen status is based on experience, observations of vine performance, and supplemental use of bloom-time petiole analysis of nitrogen concentration. Once nitrogen deficiency symptoms are visually detected, yield or quality losses have already been sustained and the deficiency will require time to correct.

If application of nitrogen fertilizer is warranted, a prudent starting point is to apply it at a rate of 30 to 50 pounds of actual nitrogen per acre. Do not be surprised if an initial application of nitrogen has no pronounced effect in the year of application. It sometimes takes two years for added nitrogen to have an impact on vine performance because much of a vine's early-season nitrogen needs are met by nitrogen stored in the vine from the previous growing season. Thus, nitrogen applied to vines in the current year may have its greatest benefit in the following season.

Several forms of nitrogen fertilizer are commercially available. All will satisfy the vines' needs (Table 9.5). Urea or ammonium nitrate are commonly the most economical forms in this region. Ammonium-based fertilizers such as urea and ammonium nitrate should be incorporated into the soil to minimize volatilization (and hence loss) of ammonia. Rain within one or two days of application is a convenient but unpredictable means of incorporation. As an alternative, soil cultivation, as by dehilling of grafted vines, is acceptable. Recommendations for application of actual nitrogen must be translated into rates based on commercial formulations. A recommended application rate of 40 pounds of actual nitrogen per acre, for example, would require 87 pounds of urea, 114 pounds of ammonium nitrate, or 190 pounds of ammonium sulfate per acre.

Nitrogen fertilizer should be applied only during periods of active uptake to minimize loss through soil leaching. These times include the period from bud break to véraison and immedi-

Table 9.5. Common Nitrogen-Containing Fertilizers

Nitrogen Source	Percentage of Actual Nitrogen	Price Per 50-pound Bag[a]	Cost Per Pound of Actual Nitrogen
Urea	46	$11.25	$0.49
Ammonium nitrate	35	$9.00	$0.51
Ammonium sulfate	21	$6.75	$0.64
Di-ammonium phosphate	18	$9.40	$1.04
Calcium nitrate	16	$9.50	$1.19

Note: To this list could be added liquid nitrogen, anhydrous ammonia, and "complete" fertilizers such as 10-10-10. However, specialized equipment for application or greater cost per unit of nitrogen may need to be considered with those forms.
[a] Prices quoted are those for piedmont North Carolina in 2005. Prices are significantly lower if the product is purchased in bulk. However, the quantities of nitrogen needed in most North Carolina vineyards do not warrant the inconvenience of bulk handling.

ately after fruit harvest. Generally, routine maintenance applications should be made at or immediately after bud break. This timing coincides with normal precipitation patterns that increase the likelihood of soil incorporation. Where applications of more than 75 pounds of actual nitrogen per acre are required, a split application should be used, applying 50 to 75 percent of the total nitrogen at bud break and the balance immediately after bloom. This method ensures that some nitrogen is absorbed with spring rains, but it also extends the absorption into the most efficient phase of nutrient uptake. The disadvantage of this approach is the extra labor involved.

Apply nitrogen in a band under the trellis rather than broadcasting it over the entire vineyard floor. Under-trellis application can be done either by placing the fertilizer in a ring around individual vines or by banding it with a modified tractor-mounted fertilizer spreader. The quantities of nitrogen used are so small that ringing individual vines — at 12 to 18 inches from the trunks — is a practical alternative for small vineyards. Regardless of the method used, apply nitrogen only where it is needed.

Potassium

ROLE OF POTASSIUM. Potassium functions in a number of regulatory roles in plant biochemical processes, including carbohydrate production, protein synthesis, solute transport, and maintenance of plant water status. Although potassium can account for up to 5 percent of tissue dry weight, it is not normally a component of structural compounds.

SYMPTOMS AND EFFECTS OF POTASSIUM DEFICIENCY. Foliar symptoms of potassium deficiency become apparent in mid- to late summer as a chlorosis or fading of the leaf's green color. This yellowing commences at the leaf margin and advances toward the center of the leaf. Leaf tissue adjacent to the main veins remains darker green, at least when the potassium deficiency is mild (Figure 9.3). Midshoot leaves are the first to express these symptoms.

With advanced or more severe potassium deficiency, affected leaves will have a scorched appearance where the chlorotic zones progress to brown necrotic tissue. Leaf margins will curl either upward or downward. Severe potassium deficiency also reduces shoot growth, vine vigor, berry set, and crop yield. Fruit quality suffers from reduced accumulation of soluble solids and poor coloration.

The symptoms described can also appear under conditions of extreme drought or extreme moisture. Furthermore, leaf scorching can also occur under some conditions from pesticide phytotoxicity. Phytotoxicity is generally most acute on the younger leaves, and shoots soon develop newer, unaffected leaves.

CAUSES OF POTASSIUM DEFICIENCY. Vines grown in soils that are very high in exchangeable calcium and magnesium and low in exchangeable potassium may require periodic potassium application. Potassium absorption may also be limited when the soil pH is very basic (greater than 7.0) or acidic (less than 4.0). Experience and tissue analysis results from Virginia vineyards have rarely shown a need for added potassium. Indeed, excessive absorption, as evidenced by very high tissue potassium levels (3 to 5 percent of dry weight), is more often the case. There is some evidence that high foliar concentrations of potassium are associated with elevated potassium levels in maturing fruit, and under some conditions the fruit may have an undesirably high pH, which can negatively affect wine quality. Thus, aside from the cost, there is good reason not to apply potassium unless it is needed.

ASSESSING THE NEED FOR POTASSIUM FERTILIZER. Visual observation of vine performance and foliar symptoms should be coupled with routine leaf petiole sampling to determine the potassium status of vines. Research in New York indicated that late-summer tissue sampling (70 to 100 days after bloom) was superior to bloom-time sampling for accurately gauging the vines' potassium status. Thus if visual observations (Table 9.4) or the bloom-time tissue analysis used for other nutrients indicate a marginal potassium level (Table 9.3), additional tissue samples should be tested in late summer to confirm the need for added potassium. Petioles of recently matured leaves (about the fifth to seventh back from the shoot tip of non-hedged shoots) are collected for late-summer samples. As in sampling for other nutrients, separate samples should be collected from regions of different topography or soil type.

CORRECTING POTASSIUM DEFICIENCY. Potassium deficiency is corrected by applying potash fertilizer. Short-term correction can be made with foliar-applied potassium fertilizer; however, the less-costly and longer-lasting remedy is soil application. Two commonly used potash fertilizers are potassium sulfate and potassium chloride (also called muriate of potash). Potassium chloride is generally much less expensive. Potassium may also be applied as potassium nitrate, but this fertilizer is usually very expensive. Application rates vary with the severity of potassium deficiency (see Table 9.6).

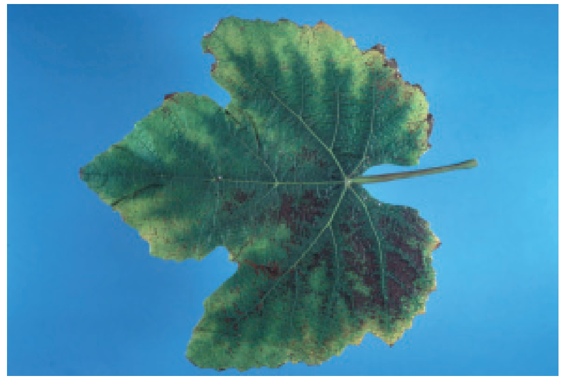


Figure 9.3. Potassium deficiency symptoms. (Photo courtesy of T.J. Zabadal.)

Potassium fertilizers should be banded under the trellis rather than broadcast over the vineyard floor. Banding assures that a major portion of the fertilizer will be available for root uptake and will minimize the amount fixed by soil colloids. Potassium can be applied anytime, but maximal uptake will probably occur between bud break and véraison and again immediately after fruit harvest.

Table 9.6. Guidelines for Application of Potassium Chloride (KCl) or Potassium Sulfate (K_2SO_4) to Correct Potassium Deficiency

	Per Vine (lb)		Per-Acre Equivalent (lb)[a]	
Vine Deficiency	**KCl**	**K_2SO_4**	**KCl**	**K_2SO_4**
Severe	1.5	2.0	900	1,200
Moderate	1.0	1.3	600	800
Mild	0.5	0.7	300	400

[a] Based on approximately 600 vines per acre.

Magnesium

ROLE OF MAGNESIUM IN THE PLANT. Magnesium has several functions in the plant. It is the central component of the chlorophyll molecule — the green pigment responsible for photosynthesis in green plants. Magnesium also serves as an enzyme activator of a number of carbohydrate metabolism reactions. In addition, the element has both structural and regulatory roles in protein synthesis.

SYMPTOMS AND EFFECTS OF MAGNESIUM DEFICIENCY. Deficiency is usually expressed in mid- to late summer when basal (older) leaves develop interveinal (between the veins) chlorosis or yellowing. The nature of the chlorosis depends upon the grape variety, but generally the central portion of the leaf blade loses green color to a greater extent than the leaf margins (Figure 9.4). Tissue near the primary leaf veins remains a darker green. As symptoms progress, the yellow chlorosis can become necrotic and brown. Magnesium deficiency of red-fruited varieties can cause leaves to turn reddish rather than chlorotic. Because magnesium is mobile within the vine, younger leaves are supplied with magnesium at the expense of older leaves. Magnesium symptoms are therefore usually confined to the older leaves except in cases of severe deficiency.

Figure 9.4. Magnesium deficiency symptoms.

CAUSES OF MAGNESIUM DEFICIENCY. Grapevines express magnesium deficiency symptoms because they are not obtaining sufficient magnesium from the soil. Magnesium accounts for approximately 0.25 to 0.75 percent of the dry weight of nondeficient, bloom-sampled grape petioles. Research shows that vines having petiole magnesium concentrations of less than 0.25 percent at bloom will typically develop magnesium deficiency symptoms by mid- to late summer. Magnesium deficiency is often observed where vines are grown in soils of low pH (less than 5.5) and where potassium is abundantly available. The likelihood of magnesium deficiency appears to increase when petiole potassium-to-magnesium ratios exceed 5 to 1. Plants grown on soil high in available potassium often express magnesium deficiency even though soil magnesium levels test relatively high.

ASSESSING THE NEED FOR MAGNESIUM FERTILIZER. As with most other nutrients, leaf petiole sampling at bloom time can be used to determine the vines' magnesium status. Tissue analysis results (Table 9.3) coupled with visual observations should indicate whether to apply magnesium.

CORRECTING MAGNESIUM DEFICIENCY. Magnesium deficiencies can be corrected with either foliar or soil applications of magnesium fertilizers. Foliar application is appropriate to correct a mild deficiency or for short-term correction, but soil application offers a more long-term remedy.

If foliar application is chosen, spray the foliage with 5 to 10 pounds of magnesium sulfate ($MgSO_4$) in 100 gallons of water per acre. This measurement will assure uniform coverage of leaves. Apply the $MgSO_4$ three times at two-week intervals in the post-bloom period. This approach is significantly more effective than waiting until deficiency symptoms are evident in mid- to late summer. Magnesium sulfate can be purchased in a sprayable formulation from fertilizer dealers in 50-pound bags or it can be purchased at drug stores as Epsom salts in smaller quantities. The magnesium sulfate can be mixed with most fungicide or insecticide sprays unless the pesticide label cautions against this combination.

Long-term correction of magnesium deficiencies is achieved by periodic soil application of magnesium-containing nutrients. If the soil pH is also low (less than 5.5), high-magnesium-content limestone (dolomitic lime containing 20 percent magnesium) is the preferred magnesium source and should be applied at 1 or 2 tons per acre. If dolomitic lime is not readily available, then fertilizer-grade magnesium sulfate or other fertilizers containing some percentage of magnesium oxide (MgO) are generally available and sold either in bulk or in bags. Magnesium sulfate is applied at 300 to 600 pounds per acre (50 to 100 pounds of magnesium oxide per acre). To be most effective, magnesium sulfate or magnesium oxide should be banded under the trellis rather than broadcast over the vineyard floor. In small plantings, the fertilizer can be placed in rings 12 to 18 inches from the trunks of individual vines.

Boron

ROLE OF BORON. Boron is an essential micronutrient; very small quantities are required for normal growth and development. Boron has regulatory roles in carbohydrate synthesis and cell division. A deficiency can disrupt or kill cells in meristematic regions of plants (regions of active cell division such as shoot tips). Boron deficiency also reduces pollen development and pollen fertility. Reduced fruit set is thus a common occurrence with boron-deficient vines.

SYMPTOMS AND EFFECTS OF BORON DEFICIENCY. Boron deficiency symptoms can be easily confused with other vine disorders and must be confirmed by tissue analysis before attempting corrective measures. California literature distinguishes early-season boron deficiency symptoms from symptoms that develop later in the spring or summer. The early-season symptoms appear soon after bud break as retarded shoot growth and, in some cases, death of shoot tips. Shoots can also exhibit a zig-zag growth pattern, have shortened internodes, and produce numerous, dwarfed lateral shoots (Figure 9.5). Those early-season symptoms are thought to be more severe following a dry fall or when vines are grown on shallow, droughty soils; either situation reduces boron uptake.

A second category of boron deficiency develops later in the spring and is marked primarily by reduced fruit set. The nature of the reduced set can range from the presence of a few normal-sized berries per cluster to a condition in which numerous BB-sized berries are also present. The "shot" berries lack seeds and often have a somewhat flattened shape, as opposed to the normal spherical to oval shape. A note of caution: poor fruit set is not necessarily due to boron deficiency. Other factors, such as tomato ringspot virus and poor weather during bloom, can reduce fruit set. Furthermore, the application of boron can lead to phytotoxicity if the boron concentration is already sufficient (Figure 9.6).

Foliar boron deficiency symptoms may accompany the reduced fruit set if boron deficiency is severe. Foliar symptoms begin as a yellowing between leaf veins and can progress to browning and death of these areas of the leaf. Boron is not readily translocated throughout the vine. Thus, the foliar symptoms develop first on the younger, more terminal leaves of the shoot. As with early-season deficiency symptoms, primary shoot tips may stop growing, resulting in a proliferation of small lateral shoots.

CAUSES OF BORON DEFICIENCY. Grapevines are considered to have higher boron requirements (on a dry weight basis) than many other crops. For bloom-sampled vines, petioles containing less than 30 parts per million (ppm) are considered marginally deficient, although clear boron deficiency symptoms may not appear until the boron level drops to 20 ppm or lower. Soil

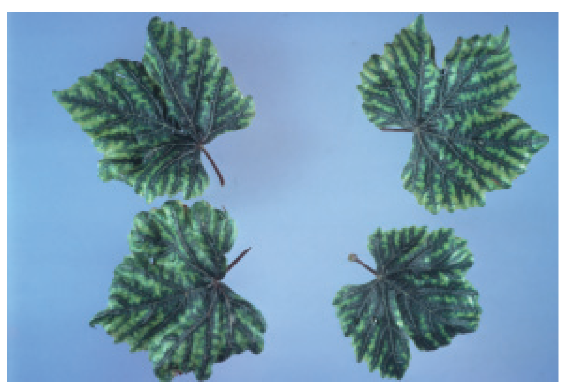


Figure 9.5. Boron deficiency symptoms. (Photo courtesy of T.J. Zabadal.)

pH, leachability of the soil, frequency of rainfall, and the amount of organic matter in soil affect the availability of boron.

A soil pH of less than 5.0 or greater than 7.0 reduces the availability of boron. Boron is actually very soluble at low soil pH, but in sandy soils the increased solubility, if coupled with frequent rainfall, can lead to leaching of boron from the root zone. Vines grown on sandy, low-pH soils subjected to frequent rainfall are therefore prime candidates to express boron deficiency symptoms.

Figure 9.6. A boron toxicity problem.

Topsoils, which generally contain more organic matter than do subsoils, provide vines with the bulk of their boron needs. If the topsoil of the vineyard is eroded, the availability of boron may to be reduced. Furthermore, droughts intensify boron deficiency, probably because the topsoil dries sooner than the subsoil. This drying pattern reduces the vines' ability to extract nutrients from the topsoil even though moisture and some nutrients can be obtained from the relatively moist subsoil.

ASSESSING THE NEED FOR BORON FERTILIZER. The foremost consideration in correcting boron deficiency is to determine whether the vines are actually deficient. Excess boron uptake leads to pronounced leaf burning and leaf cupping (Figure 9.6). Therefore, it is imperative not to apply boron unless it is needed. Routine bloom-time petiole sampling should be used to determine the vines' boron status.

CORRECTING BORON DEFICIENCY. If plant boron levels are low, corrective measures can be made in the following season. Confirmed deficiencies are corrected by spraying soluble boron fertilizer on the foliage. Recommendations developed in New York appear appropriate for this region and consist of two consecutive foliar sprays. The first application is made about two weeks before bloom. The second is made at the start of bloom but no earlier than 10 days after the first application was made. Apply ½ pound of actual boron per acre in each spray using enough water to thoroughly cover the flower clusters. It is important not to exceed this rate of application nor to reduce the 10-day interval between consecutive applications. Solubor 20 is a borate fertilizer containing about 20 percent actual boron. Thus, 2.5 pounds of this material should be applied per acre to provide the ½ pound of actual boron needed.

The water-soluble packaging of certain fungicide and insecticide formulations reacts with boron to produce an insoluble product. Therefore, boron should not be tank mixed with pesticides packaged in that manner nor with any pesticide that cautions against boron incompatibility. Foliar application of boron is a temporary solution but has the advantage of avoiding a possibly excessive soil application. With proper calibration, boron can be applied in soluble form to the soil with irrigation equipment, with an herbicide sprayer, or with an airblast sprayer before bud break or after defoliation in the fall. Soil applications can be made at any time of the season, but their effect will be delayed until the boron reaches the root zone. Dry formulations of boron, such as borax, are difficult to apply uniformly to the soil because very small quantities are used.

Other Nutrients

Other essential elements are generally found at or above sufficiency levels in North Carolina vineyards and are currently of minor concern. Occasionally, tissue analyses will show excessive levels of certain micronutrients such as iron, zinc, or copper. Those elevated levels are usually due to residues of fungicides containing those elements, not to excessive root absorption.

Achieving and maintaining adequate vine nutrition is but one component of sound vineyard management. If a nutrient is deficient, vines will not achieve optimal yields and fruit quality, and maximum returns on the vineyard investment will not be realized. Good vine nutrition starts in the preplanting phase and extends through the productive years of the vineyard. It requires recognition of visual deficiency symptoms and the use of specialized soil and plant tissue analysis techniques. Ideally, fertilizers should be applied when needed on a maintenance schedule rather than waiting until a nutrient deficiency is observed. The producer must also be willing to apply lime and other fertilizers efficiently where they are needed. Considering the low cost-to-benefit ratio of most fertilizers, that should not be a difficult management decision.

Additional Reading

Christensen, L. P., A. N. Kasimatis, and F. L. Jensen. 1978. Grapevine Nutrition and Fertilization in the San Joaquin Valley. University of California Division of Agricultural Sciences, Publication No. 4087. 40 pp.

Winkler, A. J., J. A. Cook, W. M. Kliewer, and L. A. Lider. 1974. General Viticulture. University of California Press. Berkeley, California. 710 pp.

Soil and Plant Tissue Testing Services

Call the laboratory or visit www.agr.state.nc.us/agronomi/index.htm to determine current pricing and submission information.

Plant Analysis Laboratory
NCDA&CS
Mailing address:
1040 Mail Service Center
Raleigh, NC 27699-1040
Physical address for samples via UPS or FedEx:
4300 Reedy Creek Rd.
Raleigh, 27607-6465
phone: 919-733-2655
fax: 919-733-2837

Soil Analysis
Agronomic Division
Soil Testing Section
1040 Mail Service Center
Raleigh, NC 27699-1040

Physical address for samples via UPS or FedEx:
NCDA&CS Agronomic Division
Soil Testing Section
4300 Reedy Creek Rd.
Raleigh, 27607-6465
phone: 919-733-2655

Grapevine Water Relations and Vineyard Irrigation

Like other perennial plants, mature grapevines have extensive root systems and therefore, unlike shallow-rooted annual plants, they are fairly tolerant of mild droughts. Nevertheless, a certain amount of moisture is necessary to support growth and development. Lacking sufficient moisture, vines will suffer water stress, which can reduce productivity as well as fruit quality. Supplemental moisture can be provided by permanent (solid-set) or temporary irrigation systems. Drip irrigation has become the standard water delivery system for North Carolina vineyards in recent years. Drip irrigation can represent a substantial investment (see chapter 2 for details), but the benefits can far outweigh the costs in many vineyards. In 2005, it was estimated that drip irrigation would cost $22,743 to purchase and install the equipment required for a 10-acre drip system, or $2,274 per acre. Drip irrigation can be as effective on steep slopes as on rolling and flat surfaces.

The Vineyard Hydrologic Cycle

Water enters the vineyard as rainfall (Figure 10.1) or through irrigation. Some of this moisture drains out of the root zone into deeper soil layers and some runs off the soil surface. Water that remains in the root zone is available for absorption by the vine roots. A vineyard soil at field capacity (the amount of water that the soil can hold after gravitational drainage occurs) will lose moisture in two principal ways: through direct evaporation into the atmosphere and by transpiration from the leaves of the vines and any ground cover (Figure 10.1). Water moves out of the leaves through stomata, the small pores that admit carbon dioxide and release water vapor and oxygen. Collectively, transpiration and evaporation are referred to as *evapotranspiration.*

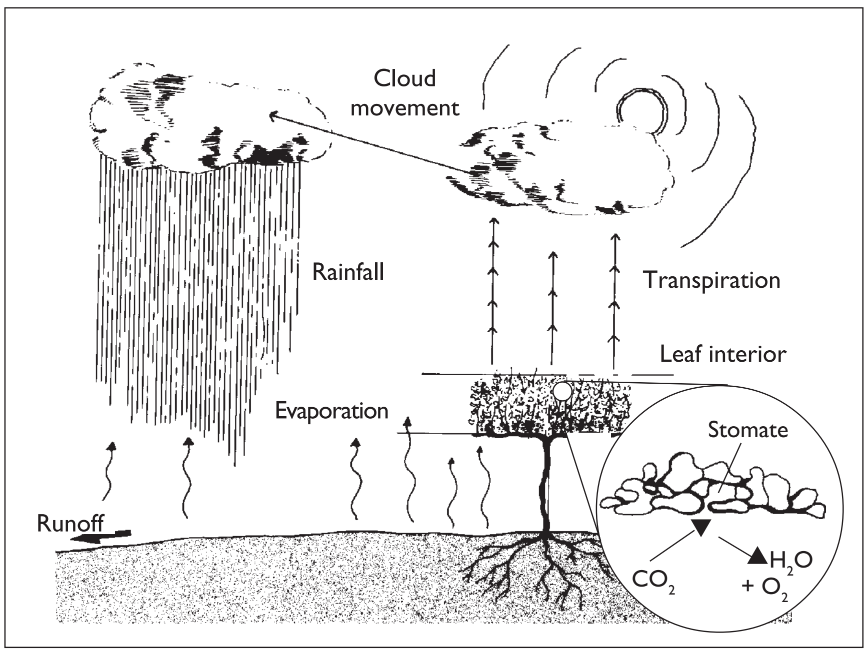


Figure 10.1 The vineyard hydrologic cycle. Water enters the vineyard as rainfall or irrigation and is removed through gravity, runoff, evaporation, and transpiration through plant leaves.

Summer Climate and the Potential for Drought

Agricultural meteorologists and climatologists use the expression *potential evapotranspiration,* or *PET,* to compare the water loss potential of different regions. PET, expressed in inches of water per unit of time, is a measure of how much evapotranspiration should occur from a moist surface. Evapotranspiration rates for vineyards vary according to the development of the vine canopy, presence or absence of ground cover, cultivation, and atmospheric conditions. Monthly precipitation is less than PET losses during summer months for

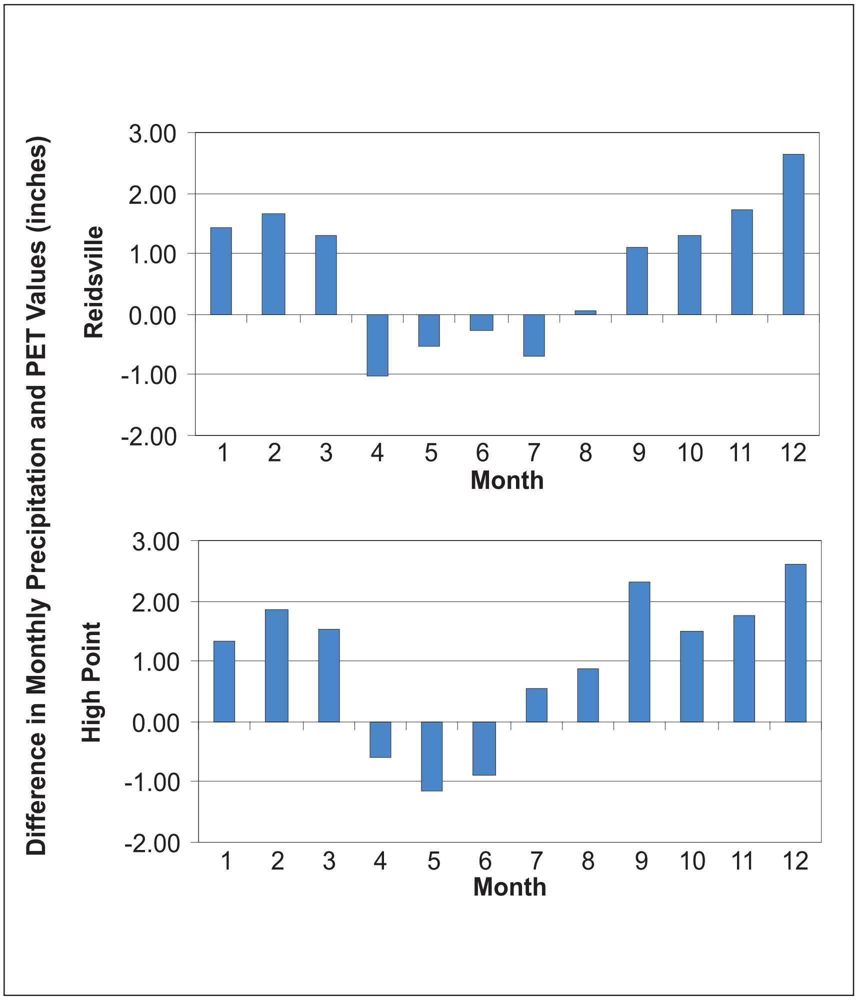


Figure 10.2 The imbalance between precipitation and potential evapo-transpiration (PET) for two North Carolina locations.

most North Carolina locations. Figure 10.2 illustrates the imbalance between precipitation and PET values for two North Carolina locations. Note the water deficits that occur at those stations during the summer months. Averaged across all of North Carolina's State Climatic Weather stations, PET values exceed rainfall by an average of 1.5 inches during July.

Precipitation records indicate that most North Carolina weather stations record between 40 and 60 inches of precipitation per year. However, those annual averages do not reflect the frequency of rainfall. Even monthly precipitation averages can give a misleading impression of moisture availability. Summer precipitation in this region often results from thunderstorms. Those storms are usually restricted to small areas, and significant precipitation might cover only a 10- to 50-square-mile area. Furthermore, because rainfall during thunderstorms is intense, less water is absorbed by the soil than if an equal amount of precipitation fell over a longer period. Thus, infrequent summer downpours may not satisfy the vines' critical need for moisture that would develop during extended hot, dry periods. Given high PET rates and the spotty nature of summer precipitation, summer droughts are not uncommon in this region. Consequently, irrigation may be of benefit at certain times during every growing season.

The Role of Water in the Vine

To an extent, all physiological processes in the plant are dependent upon water. In the larger scheme of plant processes, water plays a pivotal role in driving growth. The cells of adequately watered vines exert an outward pressure, which is termed *turgor pressure.* This pressure causes cell enlargement, which in turn leads to an increase in tissue and organ size, such as the lengthening of shoots. The lack of cell turgor pressure results in a flaccid or wilted appearance. Wilting occurs when the transpiration rates of leaves exceeds the ability of the vine to absorb water from the soil and conduct it to the leaves.

Symptoms of Water Stress

One of the first signs of drought is a change in the appearance of the vines. Rapidly growing shoot tips of well-watered vines appear soft and yellowish or reddish green. If large portions of the soil become dry, the rate of shoot growth slows and the shoot tips gradually become more grayish green, like the mature leaves. Tendril drying and abscission is also a useful early indicator of vine water stress. As water stress continues, leaves appear wilted, particularly during midday heat. Under prolonged and severe stress, leaves curl, brown, and eventually drop. Vines that suffer severe water stress begin to defoliate, exposing more of the fruit that had been shaded by foliage. Depending on the time and severity of water shortage, berries of stressed vines may not attain their full size. Water-stressed fruit exposed to the sun can sunburn and shrivel, much like a raisin. Water shortages also reduce the vine's ability to absorb nutrients from the soil. Symptoms of nutrient deficiencies are therefore more apparent during prolonged dry periods.

In addition to visual indicators, vine water stress can be measured with special instruments. Some instruments measure the water status of vines, whereas others measure the moisture status of the soil. Hand-held infrared thermometers can measure the temperature of vine canopies. The leaves of water-stressed vines are often warmer than the surrounding air because of reduced transpirational cooling. Leaves of well-watered vines are generally cooler than the air, even during the hottest period of the day. The moisture status of the soil can be determined with instruments that range from simple tensiometers to sophisticated neutron probes. The use and merit of various soil moisture sensors are reviewed by Coggan (2002) and Selker and Baer (2002).

The water status of vines can also be measured by determining how much pressure is required to force water from a detached leaf. A wilted leaf will hold its remaining moisture with more tension (negative pressure) than will a fully hydrated leaf. The tension with which a leaf holds water is expressed in units of negative pressure called *milliPascals* (mPa). Figure 10.3 shows the changes in leaf water potential throughout the course of a day. The more negative the value, the more stressed the leaf is.

Leaf water potentials become more negative throughout the course of a day as the leaves lose moisture. The leaf water potential is generally most negative during the hottest part of the day and then decreases (becomes less negative) as vines regain their hydrated status in the cool of the night (Figure 10.3). When leaf water potentials reach about -1.2 mPa, stomata close. This closure conserves the remaining water in the leaf, but the "cost" of this water conservation is decreased sugar production. With stomata closed, carbon dioxide cannot enter the leaf and the photosynthetic conversion of carbon dioxide into sugars will not occur.

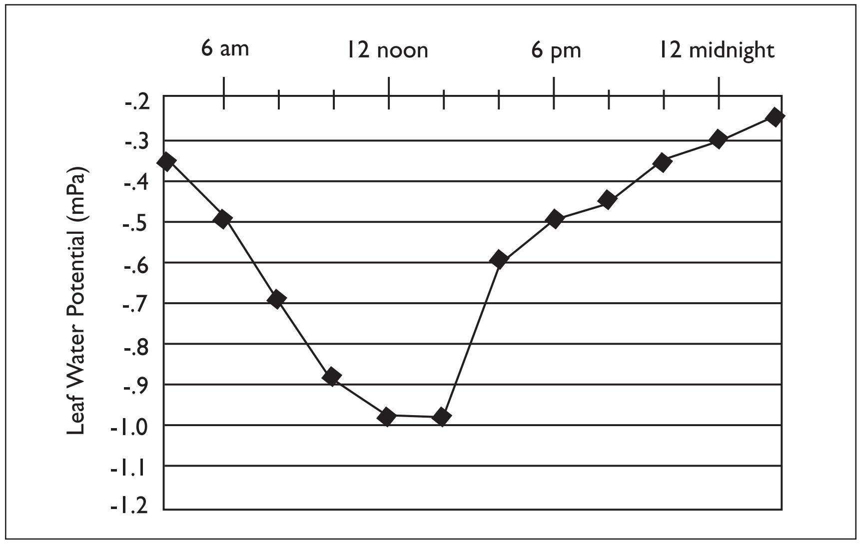


Figure 10.3. The leaf water potential is the most negative during the hottest part of the day.

Extended periods of drought prevent the vine from regaining its hydrated status. Dehydrated leaves remain at or below -1.2 mPa for much of the day, and consequently photosynthesis is greatly reduced. The impairment of the photosynthetic processes will generally occur before leaves are visibly wilted. Reduced photosynthesis can explain why fruit fails to increase in soluble solids during periods of water shortage; little or no sugar is being manufactured. A point will be reached at which the daily stress of insufficient water will have an irreversible impact on the vine's performance. By the time leaf wilting occurs, vines are severely stressed.

Many processes are disturbed or impaired by water stress. The impairment of those processes depends on the severity of stress and can be characterized as either reversible or irreversible. Reversible effects include

- ❑ decreased cell turgor pressure
- ❑ reduced stomatal conductance (that is, less carbon dioxide enters the leaf)
- ❑ reduced photosynthesis (sugar production)
- ❑ decreased shoot growth rate
- ❑ reduced berry size.

These events are "normal" occurrences in the day-to-day cycle of growth and development even of adequately watered vines. As water stress intensifies, however, irreversible effects become apparent. These effects, in order of increasing water stress and severity, include

- ❑ irreversible reduction in berry size
- ❑ decreased fruit set
- ❑ delayed sugar accumulation in fruit
- ❑ reduced bud fruitfulness in the subsequent year
- ❑ reduced fruit coloration
- ❑ leaf chlorosis (yellowing) and eventual burning
- ❑ berry shriveling
- ❑ reduced wood maturation and possibly reduced vine cold hardiness
- ❑ defoliation
- ❑ vine death

Delayed sugar accumulation and reduced bud fruitulness are of special interest because their occurrence is variable. Slight water stress can actually hasten sugar accumulation and increase bud fruitfulness by causing a somewhat more open or light-porous canopy. Exposed fruit tends to accumulate sugar at a faster rate than does shaded fruit. Furthermore, slowed vegetative growth reduces the "sink" strength of shoots and roots. Thus, more of the vine's carbohydrates are directed to fruit "sinks." Slight water stress, therefore, might result in hastened fruit maturation.

However, excessive water stress can impair photosynthesis and fruit sugar accumulation. Buds exposed to sunlight during their development are more fruitful than those that are shaded. However, severe water stress reduces the fruitfulness of developing buds and thus reduces crop yields in the subsequent season. Thus, irrigation should supply no more water than is needed to maintain adequate vegetative growth and berry development.

Water use increases in proportion to the leaf area of the vine. Large vines require more water than do small vines. However, water stress is usually more severe in a young vineyard because the young vines have less-well-developed root systems and cannot draw moisture from as large a volume of soil as can large vines. Thus, the best time to install an irrigation system in the vineyard is at or before the time it is established.

Finally, the presence or absence of weeds and cover crops also affects the vines' need for supplemental water. Cover crops compete with the vines for water. This competition can be minimized by keeping the cover crop mowed short or by using cover crops that become dormant during hot, dry weather. Weeds also compete with vines for critical moisture. Weeds should be excluded from the area under the trellis by mechanical or chemical means. Irrigation should *never* be used as a remedy for poor weed control. The elimination of weeds might go far towards alleviating the vines' water stress, as discussed in the chapter 8 section on vineyard floor management.

Irrigation Systems

A properly functioning irrigation system ensures that vines have adequate moisture. As stated earlier, the objective of irrigation is to supplement natural precipitation so that vines achieve adequate vegetative growth and berry development. Vineyards can be equipped with a sprinkler, drip, or trickle irrigation system; each has its particular advantages and disadvantages. A drip irrigation system uses lightweight plastic tubing and fittings to make frequent applications of small amounts of water directly to the plant root zone. Drip irrigation is generally preferred over sprinkler irrigation for these reasons:

- ❑ less water is used (1/3 to 1/2 less with proper management)
- ❑ less energy is required because less water is delivered at lower operating pressures

- leaves remain dry during irrigation, reducing the incidence of disease
- the solid-set nature of the drip system results in lower labor and operating costs
- field operations can continue while irrigating
- the need to control weeds or to cultivate and mow between rows is reduced
- less fertilizer is needed if it is injected directly into the irrigation water
- less runoff occurs on hilly terrain, reducing soil erosion
- no wind interference occurs
- the system can be easily automated.

Drip irrigation systems also have several disadvantages:

- system components can be damaged by insects, rodents, and laborers
- the small emission orifices may be easily clogged
- the system offers no frost protection

Drip irrigation systems are similar to sprinkler irrigation systems in that they require a pumping station to deliver water, a main line to move water from the source to the vineyard, submains to distribute water throughout the vineyard, and laterals with emitters, which replace the sprinklers. The lateral tubing and emitters may be suspended from a trellis wire, laid directly on the ground, or buried in the root zone of the vines.

Water Supplies

The primary difference between drip irrigation and sprinkler irrigation systems is the consideration that must be given to water quality with drip irrigation. Particulate matter such as sand, silt, and algae can easily clog the small orifices of emitters. Therefore, a water filtration system must be installed between the pumping station and the vineyard. For groundwater supplies such as wells and protected springs, an inexpensive screen filter is usually adequate. When streams or ponds are used, sand media filters are recommended. Sand filtration systems designed for drip irrigation are relatively expensive. For small systems, however, standard swimming pool filters may be substituted. The use of self-flushing emitters is highly recommended if the water quality is questionable. When water is of extremely low quality, microsprinklers, another form of low-volume, low-pressure irrigation, should be considered. The water quality of the potential water source should be analyzed before any substantial expenditures are made for an irrigation system. Contact your county Extension agent or regional agronomist for further information on water testing services available from the Agronomic Division of the NCDA & CS. Additional tests should be requested if specific contaminants are suspected. Water sources with little or no recharge should contain from 6 to 9 acre-inches of water for each acre to be irrigated during the season (1 acre inch equals 27,152 gallons). Sources such as streams or wells will need to yield 5 to 10 gallons per minute for each acre irrigated at a time. Zones smaller than 1 acre might be possible for smaller systems, thereby requiring even lower flow rates.

Soils

Any soil suitable for vineyard establishment can accommodate a drip irrigation system. Since water is applied slowly, even soils with very limited infiltration properties are not a deterrent to the use of drip irrigation. The major soil consideration is that of lateral water movement. Generally, in a light-textured, sandy soil water will move primarily downward, whereas in heavy-textured, clayey soils water will tend to move laterally outward from the emitter. In the former case, more emitters per vine may be required to thoroughly wet the root zone.

Terrain

The terrain, or topography, of the vineyard must also be considered. If designed properly, drip irrigation systems can be used on relatively steep slopes. In such applications, the use of pressure-compensating emitters are recommended. Whenever practical, vineyard rows should be laid out along the contour to minimize elevation changes along drip irrigation laterals and to minimize erosion associated with rain.

Pumps

Pumps for drip irrigation systems are considerably smaller than those for comparable sprinkler systems because the required flow rates and pressures are lower. Because the pressure is low, it is sometimes possible to use gravity feed from an elevated tank or reservoir. The major advantage of the smaller pumping unit requirement is that single-phase electric motors (under 7.5 horsepower) may be used to drive the pump in many cases. Electric pumping units are widely preferred for irrigation systems of this size and are well-suited to automatic control.

Injection Systems

Provision should be made for injection of fertilizer and chemicals into the irrigation water. Fertilizer efficiency can be greatly enhanced if the fertilizer is applied in this manner. In drip irrigation systems, an injection system is particularly helpful for introducing chlorine for algae control or acid for removal of bacterial slime or precipitated materials such as iron. Care must be taken to prevent environmental damage from accidental spills. It is required in North Carolina that safety equipment installed to prevent backflow of chemicals into the water source or chemical storage tank include some or all of the following, depending upon the method of injection: check valve, backflow preventer, vacuum breaker, low-pressure drain, and a power supply interconnected between irrigation pump and injector. In addition, proper installation calls for the use of corrosion-resistant components and injection away from water sources.

Water Management

Good water management is critical for proper drip irrigation operation. Tensiometers or electrical resistance blocks can be placed directly in the row to monitor the soil moisture conditions in the root zone of the vines. These “sensors” can be used to control pumping stations for fully automatic control of the irrigation system.

System Design

Because of the complexity of drip irrigation systems and the number of variables involved, consultation with an irrigation design professional is highly recommended. If you are interested in drip irrigation, discuss your needs with reputable companies that specialize in irrigation system design, installation, and maintenance. These companies often advertise in trade publications and exhibit their systems at trade shows. For more information, contact your county Cooperative Extension agent.

Drip Irrigation Suppliers

Some full-service drip irrigation dealers serving the region are:

Berry Hill Irrigation
3744 Hwy 58
Buffalo Junction, VA 24529
1-800-345-3747
sales@berryhilldrip.com
www.berryhilldrip.com

Gra-Mac Irrigation
2310 NC Hwy 801 N.
Mocksville, NC 27028
1-800-422-35600
gramacirr@yadtel.net

Johnsons & Company
PO Box 122
Advance, NC 276006
1-800-222-2691
henry.johnson@johnsonandcompanyirrigation.com
www.johnsonandcompanyirrigation.com

Mid-Atlantic Irrigation Company
PO Box L, Farmville, VA 23901
434-392-3141
mairrigation@cstone.net
www.irrigationparts.com

References

Coggan, M. 2002. Water measurement in soil and vines, Vineyard and Winery Management. May/June, 43-53.

Fereres, E. (Ed.). 1981. Drip Irrigation Management. University of California Division of Agricultural Sciences, Leaflet No. 21,259. 39 pp.

Neja, R. A. 1982. How to Appraise Soil Physical Factors for Irrigated Vineyards. University of California Division of Agricultural Sciences, Leaflet No. 2,946. 20 pp.

Kasimatis, A. N. 1981. Vineyard Irrigation. University of California Division of Agricultural Sciences, Leaflet No. 2,823. 9 pp.

Selker, J., and E. Baer. 2002. An engineer's approach to irrigation management in Oregon Pinot noir. Oregon Wine Advisory Board, OSU Winegrape Research Progress Reports 2001-2002. Oregon State University Agricultural Experiment Station, Corvallis.

Chapter 11

Spring Frost Control

To grow more consistent crops and improve your cash flow in years with damaging frost events, this chapter will show you how you can:

1) *identify an active protection system to protect your vineyard during budbreak and early shoot development,*
2) *use the basic principles of frost and frost/freeze protection to deal with complex cold protection scenarios, so that you use your active protection system(s) efficiently, and*
3) *operate the equipment correctly.*

As the North Carolina winegrape industry continues to grow, much of the recent expansion in *vinifera* and hybrid plantings has occurred in the central and western piedmont. Careful site selection as described in Chapter 4 can help you avoid completely unsuitable sites, but even the best vineyard sites in the piedmont and mountains are not completely frost-free. If the economic analysis of the cost of spring frost has you considering an active system of frost protection, this chapter will help you understand the benefits and limitations of wind machines, heaters, over-vine sprinklers, foggers, sprays that inhibit frost, and even the occasional use of a helicopter.

Choosing a Frost Protection System

While people use the terms frost and freeze interchangeably, you need to learn the key differences between a freeze, a frost/freeze, and two types of frost. You must match your frost protection system to the prevailing types of cold events that occur in your vineyard following budbreak. This basic information will help you select the most effective type of active protection system for your vineyard and will be the key to operating that system effectively. Some forms of active frost protection that are highly effective in

Active frost control differs from passive control *strategies and methods* discussed in chapter 4, *Site Selection*, in several important ways:

1) Energy Use. Active control *methods* include energy intensive practices (vineyard heating with fuel, over-vine sprinkling with water, etc.) that are used during the cold event to replace natural energy, or heat losses from the vine (Snyder, 2001).

2) Direct vs. Indirect Method. Active control *strategies* rely on *direct* frost protection methods (e.g. wind machines, heaters, over-vine sprinkling), and involve active control against a cold event (Westwood, 1978). Passive control or protection involves *indirect* practices (e.g. site selection, variety selection, and cultural practices like double pruning), that cause the plant to be less susceptible to cold injury, or decrease the probability or severity of radiation frosts (Evans, 2000).

3) Time of Implementation. Active control strategies and methods must be implemented *just prior to and/or during* the cold event to counteract an immediate threat of a radiation frost or frost/freeze. Passive protection includes strategies and practices that are generally done well ahead of cold events.

certain types of frost can actually damage the vines when used in other types of frost.

Remember, there is no perfect method of active frost control that will be able to counter all of the different types of cold events that may be encountered, especially a freeze when the winds are greater than 10 miles an hour.

FREEZE *(also called advective* or *wind-borne freeze)*

- ❑ Temperature below freezing.
- ❑ Wind usually greater than 10 miles per hour.
- ❑ Little if any stratification of air temperature occurs with changes in elevation.
- ❑ More common in late winter (February or early March) in North Carolina, well before new shoots have emerged.

All mechanical methods of conventional spring cold protection discussed in this chapter (wind machines, heaters, over-vine sprinklers and helicopters) are of very limited value, or no value, under true *freeze* conditions. Do not use active methods for frost control when winds are greater than 10 miles per hour; you can damage the vines (Trought et. al, 1999).

Even good site selection, the basic method of frost protection, can work against a vineyardist in a freeze. Lower lying river-bottom-type areas that are protected from the winds would be the best choice in a freeze, but these areas are not recommended for vineyards because they are highly subject to radiational frost events. Fortunately, freezes are rare after budbreak.

Wind machines and over-vine sprinkler irrigation systems must **not** be used in a freeze. The winds can damage equipment and the vines. Sprinkler irrigation is also risky due to a phenomenon known as *evaporative cooling* under freezes.

Perry (2001) has indicated that heaters may provide some protection under windborne freeze conditions due to radiant energy, which is not affected by wind and will reach any solid object not blocked by another solid object. However, the cost of fuel presently rules out the use of heaters (see chapter 4).

FROST/FREEZE

- ❑ Temperature below freezing.
- ❑ Persistent winds in the range of 5 to 10 miles per hour will prevent the formation of an inversion, so wind machines and helicopters will not provide sufficient protection.
- ❑ A well-designed over-vine sprinkling system can be effective, but you risk extensive crop losses if sprinkling is inadequate, or the irrigation system fails during the night.
- ❑ Vineyard heaters provide some protection, but the cost of fuel may make their use cost-prohibitive.

Frost Warning

The National Weather Service may issue a “Frost Warning,” for temperatures *above* 32°F, but this is simply a *warning* of a possible frost event. It does not mean that a radiation frost event has temperatures above 32°F. In fact, Perry (2001) defines a ***radiation frost*** as having temperatures near the surface ***below freezing*** **(32 F).**

Table 11.1 Definition of Frost/freeze Warnings Issued by National Weather Service.

Frost Event	Wind Speed (miles per hour)	Air Temperature (°F)
Frost	Below 10	Above 32
Frost/freeze	Below 10	Below 32
Freeze	Above 10	Below 32

RADIATIONAL FROST

- ❑ Caused by rapid radiational loss of heat.
- ❑ North Carolina has two types of radiational frosts: hoar frost and black frost.
  - *Hoar frost* results when atmospheric water vapor freezes in small crystals on solid surfaces; also called a white frost.
  - *Black frost* has few or no ice crystals because the air in the lower atmosphere is too dry; sometimes called a dry freeze even though it is not technically a freeze.
- ❑ Either type of radiational frost may occur after grapevines have broken bud and commenced spring shoot growth.
- ❑ A black frost is always going to be a killing frost; a hoar frost may or may not damage the crop.
- ❑ Active frost protection can protect the crop under certain conditions, as explained below.

Types of Active Frost Protection

Use Table 11.2 to help you assess the potential effectiveness of different methods of active cold protection under hoar frost, black frost and frost/freeze conditions. As the first column in Table 11.2 shows, wind machines, heaters, over-vine sprinklers, and helicopters *all* may protect against hoar (white) frost conditions. However, as you can see, the method of active frost protection you select matters a great deal when it comes to either a black frost or frost/freeze condition. For example, in a black frost condition (second column) with temperature minimums below 28°F, a wind machine may require supplemental heaters, or possibly even a helicopter (which can adjust to the height of the inversion), to add extra heat to the vineyard when minimum temperatures are going to be too low for a wind machine. Generally, wind machines are not found to be

Table 11.2 Relative Effectiveness of Passive, Active Frost, and Active Frost/freeze Protection Methods Under Different Cold Event Scenarios. [1]

Method	Radiational Hoar Frost; Temperature 28 to 36°F	Radiational Black Frostand/ or Weak Inversion; Temperature- Below 28°F	Frost/freeze (winds 5 to 10 mph)	Comments
Good site selection (passive)	***	**	*	Locations with good air drainage; visualize air flow/and evaluate frost climatology.
Wind machine	***	*	x	**Do not use** if winds are greater than 5 miles per hour.
Wind machine- plus heaters	na	**	*	Can be effective in black frost, weak inversion, and merits further attention. Heaters not needed in a hoar frost.
Wind machine- plus helicopter	na	***	0	Useful when inversion ceiling is high. Not needed in a hoar frost.
Over-vine sprinkling	***	***	**	Incorrect use can cause greater damage.
Helicopter	***	**	x	Very high costs per hour, greater than $825 in 2006.
Heaters	***	**	*	Very limited use in NC vineyards due to high cost of fuel.

[1]*highly effective = ***; effective = **; limited effectiveness = *; ineffective = 0; and, potentially damaging = " x "; not applicable = "na"*

practical when you need to raise the temperature more than 1 to 3 degrees. Keep in mind that wind machines require an inversion to be effective. Also, they are not effective if winds are greater than 5 miles per hour. Wind machines are not an appropriate choice for sites subject to frost/freeze conditions following bud break. Wind machines will provide no protection in freeze conditions, and their use may increase injury to vines and damage the equipment as well.

For vineyards subject to black frosts and/or frost/freeze conditions, over-vine sprinkling can be very effective. Over-vine sprinkling can be designed to provide enough heating capacity to protect vines in cold events with minimums in the low 20s. But, you must be aware of the greater complexity of operation of sprinkler irrigation, especially under winds in the 8- to 10-mile an hour range.

Ultimately, the proper choice of protection equipment will depend on many factors. A detailed economic analysis of each frost protection system is beyond the scope of this chapter, as is a full consideration of the environmental impacts of the various protection systems. Here are some general points regarding the general utility, relative cost effectiveness, and environmental impacts of these systems outside the area being treated.

WIND MACHINES may prove profitable on sites where there is a 20 percent or higher probability of spring frost during early stages of new shoot growth (see investment analysis in Chapter 4). Wind machines use the inversion that develops in a radiation frost. Seven to 10 acres is the minimum size vineyard for a wind machine.

The experiences of several commercial vineyards in North Carolina's over the last decade have affirmed the value of wind machines on piedmont sites with chronic radiational frost problems. In some instances, the sites helped are near valley floors or creek bottoms that are very prone to frost. Although wind machines do not provide more than 1 to 3°F of warming, they are particularly well suited for managing the dominant kinds of cold weather events that occur in North Carolina vineyards after bud break–radiational frosts.

Although hourly operating costs are higher than for over-vine sprinkling, these costs are still substantially below operating costs for return-stack oil heaters and standard propane heaters. In 2005, the initial cost of a fully installed wind machine was approximately $2,800 per acre in North Carolina.

Other benefits not widely reported have to do with using them for moisture control during harvest in August and September, when heavy dews in lower lying areas can cause significant delays in harvest and increase fruit rot pressure. Wind machines started at 6 a.m. can have the grape canopy dry and ready for harvest by as early as 9 a.m.

Wind machines may also be appropriate for use to protect a grape crop from fall frosts in higher elevation areas with shorter growing seasons, and they may also be useful for protecting the vineyard canopy from frost damage shortly after harvest. Leaf damage from fall frost may delay cane hardening and render the vines more susceptible to winter damage (Sugar et al., 2003).

Wind machines produce a very loud noise, and you should be conscious that any nearby neighbors may strongly object to their use!

HEATERS may be the sole source of protection for radiation frosts, but the rising cost of fuel may make the use of 40 to 50 heaters per acre prohibitively expensive. No heaters are being used in North Carolina vineyards at this time, but a limited number of heaters arrayed near the perimeter of the vineyard and in portions of the vineyard farthest from the wind machines may merit consideration under colder radiational frost conditions. Air pollution by smoke can be a significant problem, and the use of oil-fired heaters is banned in many areas.

OVER-VINE SPRINKLING – Sprinkling for frost and frost/freeze protection has been very successful in North Carolina for years on low-growing crops like strawberries, but it has not been very popular with vineyard operators in the state for a number of reasons, including:

- ❑ the cost of materials, installation, and development (usually including a pond);
- ❑ not having enough water resources to safely provide three consecutive frost/freeze nights of protection (about 150,000 gallons of water for each acre of vineyard),
- ❑ complexity of operation and high risk of vine damage if the system fails in the middle of the night, and
- ❑ even though sprinkler irrigation offers the highest level of protection of any single frost control system, their fixed-rate design delivers more protection than generally necessary (Perry, 1998). They can only be turned on or off, so you can't vary the irrigation rate.This contributes to over-watering, which can waterlog soils, leach fertilizers, and may increase disease pressures.

If your vineyard is highly prone to frosts and frost/freezes, one of the real advantages of over-vine sprinkling is its very reasonable cost for operating. Evans (2000) has reported that over-vine sprinkling was about 12 percent of the cost per hour of wind machines (requiring fuel), and only about 4 percent of the hourly cost to operate a return-stack oil heater system (40 per acre).

If you decide to invest in over-vine sprinklers for frost/freeze control in the vineyard, it is much more convenient to install the system before the vineyard is planted than it is to add it to an existing vineyard.

HELICOPTERS are another option that may be economically justified under special circumstances, despite the fact that charges started at $825 an hour in 2006. Currently, helicopter services are used in Virginia vineyards, but not in North Carolina.

FOGGERS – When the dew point temperature is close to the air temperature, the fog that can form can act as a barrier to radiative heat losses from plants at night. Fog lines that use high pressure lines and nozzles to make fog droplets have been reported to provide excellent protection under calm conditions. Little water is deposited, minimizing the potential for ice-load damage (a concern with over-vine sprinkling). However, containing and/or controlling the drift of fogs and potential safety/liability problems (if fogs cross a road), are factors that may seriously limit the usefulness of fogging systems (Evans, 2000). Dew point temperature is discussed in Principles of Cold Protection.

ICE NUCLEATION BACTERIAL INHIBITORS – A few vineyards in North Carolina are using special foliar nutrient sprays to change the freezing point of the plant tissue, but more research on this technique is needed. In trials conducted in Oregon (Sugar et al., 2003), little or no frost protection was obtained from treating vines with substances that are supposed to depress the freezing point or inhibit bacteria that can serve as nucleators for ice formation.

Principles of Cold Protection

With a clear understanding of the frost and frost/freeze management principles in this section, you will be better able to deal with complex cold protection scenarios. You will also know when active protection is likely to have success as well as understand when it can lead to greater crop damage. Since there is very little that you can do to protect against a freeze, this section focuses on frost and frost/freeze events.

1. Cold Damage Mechanisms

If the plant tissue in developing shoots spend just 30 minutes at 31°F, or lower, significant damage can occur (Sugar, 2003). On thawing, cold damaged grape shoots lose turgor, completely darken and become water soaked–completely limp grape tissues may be observed within a few hours following the cold event (Sugar et al., 2003). Thus, one very important goal of *active frost protection* is to provide enough supplemental heating to keep tender shoots above 31°F. As *a general rule*, start your frost protection system to keep plant tissues safely in the range of 31.5 to 32°F (Sugar et al., 2003).

Obviously, you must begin countermeasures before the critical temperature is reached and an irreversible freezing strain has occurred, but there is one very serious catch: you cannot rely on air temperature alone. When atmospheric conditions are relatively dry, you need to monitor *both* vineyard air temperature and humidity using dew point (DP)[1] temperature.

2. Monitoring Atmospheric Moisture Using Dew Point Temperature

To protect your crop, you need to know the dew point (DP) temperature. The DP temperature is unquestionably one of the most valuable pieces of information you get as a subscriber to and advance weather forecast service. A relatively low DP temperature indicates drier air, and thus the potential for a killing *black* frost. Conversely, a relatively high DP indicates the potential for a *hoar frost,* which may or may not injure succulent grape tissues.

[1] The dew point (DP) is also defined as the temperature at which water vapor in the air becomes saturated, and then condenses as dew, fog or frost (Westwood, 1978).

MOIST ATMOSPHERIC CONDITIONS AND ICE CRYSTALS. Dew point temperature is an excellent indicator of whether the lower atmosphere is moist enough for ice crystals to form on plants. Essentially, a forecast for DP temperatures near or above the freezing point (in the upper 20s and low 30s), indicates that the lower atmosphere is relatively moist, and you need to pay very close attention to the start of ice crystal formation on plant tissues. *Your goal is to prevent ice crystals from forming on young grape shoots.*

Although DP temperature is an excellent indicator of the potential for a hoar frost, you should also be aware of other important conditions, including calm winds and clear skies. Natural factors that will help keep ice crystals from forming include winds greater than 5 miles per hour, cloud cover, and potentially drier soil conditions (Table 11.3). Thus, in cloudy, breezy

Table 11.3 Natural Factors That Favor and Counteract Frost

Favor	Counteract
Calm winds	Winds greater than 5 miles per hour (slows radiative cooling of solid objects)
Clear skies	Cloud cover (acts as a blanket; the thicker the cloud cover, the slower the cooling rate)[1]
Surface air temperature at 32°F, or below	Surface air temperature above freezing
Dew point temperature in upper 20s and lower 30’s	Dew point temperature in mid 20s and lower (atmosphere is too dry)
Soils containing abundant water	Drier soil conditions

[1] Since heat loss from the ground and plants at night is in the form of long wave radiation that does not pass through clouds, clouds act as a blanket over the earth, and in most cases hoar frost will not occur on cloudy nights (Sugar et al, 2003).

weather, frost will not occur and observed low temperatures will likely be very close to forecast values. But under clear calm conditions with DP temperatures in the upper 20s to lower 30s, there is potential for heavy frost.

Researchers have found that a hoar frost sometimes actually helps protect the plant from frost damage. In practical terms, it is much too difficult to determine if a hoar frost will injure grape tissues. Be proactive and *start frost protection at the first appearance of frost (ice crystals) forming on young grape shoots.* Use wind machines or any other frost protection method (over-vine sprinklers, heaters, and helicopters) to prevent ice crystal formation on plant surfaces. A potential *hoar frost scenario* in North Carolina would be:

- ❑ air temperature forecast in the mid- to low 30s
- ❑ dew-point temperature forecast in the low to mid-30s
- ❑ calm wind forecast of less than 3 miles per hour
- ❑ clear to mostly clear skies (no cloud cover)

DRY ATMOSPHERIC CONDITIONS AND BLACK FROST. When speaking with growers across North Carolina, we have found that many are unfamiliar with *black frosts.* Few or no ice crystals form on plant surfaces in a black frost. The crystals do not form because the lower atmosphere is too dry. If the DP is in the mid-20s (relatively low), for example, you will not be able to see (or feel) any ice crystals forming on the plant surface until the air temperature drops into the mid-20s–this is the frost point.[1]

[1] The frost point is the temperature to which the air must be cooled to cause atmospheric moisture to change from a gas to solid (Perry, 1998).

Table 11.4 Characteristics of the Two Types of Radiational Frosts[1]

Hoar (White) Frost	Black Frost
Calm winds	Calm winds
Clear skies	Clear skies
Temperature drop is gradual through the night due to high relative humidity	Temperature drop can be rapid after sunset (more than 2°F per hour) due to relatively dry atmosphere
Dew point may be above the critical temperature for buds and shoots, and hoar frost is not necessarily injurious to plant tissues	Relatively dry air (low dew point); dew point temperature is below critical temperature of sensitive plant tissues, and black frosts are always *killing frosts*
Ice crystals form on surface of solid object from water vapor (not dew)	Development of ice crystals depends on dew point, or frost point of air
Frost formation may trigger ice nucleation and possibly plant freezing	Plant freeze injury may occur in absence of ice crystals forming on plant surface
Initiate frost protection at first sign of ice crystal formation on plant tissues	Frost protection is more complicated as plant tissue temperatures may be several degrees colder than air temperature under low humidity atmospheric conditions; use the dew point temperature to determine when to begin frost protection

[1] Perry (2001) defines a *radiation frost* as having temperatures near the surface below freezing (32°F), and winds of less than 5 miles per hour.

By the time you see crystals on blades of grass, your pickup truck hood, or tender grape shoots, the damage has been done. Grape tissue temperatures will have already dipped below their critical point, and irreversible crop injury will be the outcome. *You cannot wait until you see frost if the DP is low.*

Another confusing characteristic is that plant tissues radiate their own heat back into space under dry atmospheric conditions. So the plant becomes progressively colder than the surrounding air, **and air temperatures may be several degrees *warmer* than the actual crop temperature** (Evans, 2000). To keep tender shoots above 31°F, frost protection procedures using wind machines, heaters, or helicopters must begin at air temperatures that are 1 to 6 degrees higher than the expanding grape shoot's critical temperature. The exact start-up temperature for cold protection will depend on the dryness of the lower atmosphere, as indicated by dew point temperature.

If the DP is in the

- ❑ teens, start frost equipment when the air temperature is around 35 to 37°F.
- ❑ low- to mid-20s, start frost protection equipment when the air temperature is around 34°F.
- ❑ upper 20s, start frost equipment when the air temperature is around 32 to 33°F.

If you do not use dew point temperatures, you are simply guessing at when to start cold protection on radiational frost nights with low atmospheric humidity.

Use Table 11.4 to distinguish hoar frost from black frost events. You will note that both types of radiational frost events occur under calm winds. Under the next principle of cold protection, we consider your cold protection options when winds are sustained and exceed 5 miles per hour, but are less than 10 miles per hour.

3. Cold Protection Principles Under Windy Conditions (Frost/freeze)

Advance weather forecasts will often contain information on **wind speed,** which can be especially helpful information. Persistent winds of 5 to 10 miles per hour prevent an inversion, so there would be no warmer air for a wind machine or helicopter to return to the plants. Heaters work in *frost/freeze* conditions, but the cost of fuel may make them prohibitive. Over-vine sprinkling systems offer a high degree of cold protection relative to other systems of cold protection and are relatively cost-effective (Sugar et al, 2003), but they are risky when sustained winds are greater than 7 miles per hour. Damaging evaporative cooling effects are promoted by winds and low humidity.

Adequate over-vine sprinkling rates in windy conditions. The success of over-vine irrigation for frost/freeze protection is critically dependent on having adequate delivery rates to keep grape shoots safely at 31.5 to 32°F (Sugar et. al, 2003); the grower should not attempt sprinkling unless he or she is sure that their system can provide adequate sprinkling to offset wind-related, evaporative cooling demand.

A final point about cold protection under windy conditions: if the atmosphere is dry (DP is low), swollen buds and grape shoots may not be injured until the air temperatures are several degrees below the temperature thresholds that are normally considered critical for cold protection activities. Under very dry atmospheric conditions in the vineyard, Wolf and Boyer (2003) report that injury to grape shoots may not occur until air temperatures reach 25 to 26°F, which is several degrees colder than the critical temperature points reported for young shoots (30°F). When the humidity is low and cooling is gradual, newly developing grape shoots have the ability to supercool (drop below their normal freezing points) and may not freeze at 30°F. Thus, the best strategy may be to take no action at all in a number of *frost/freeze* situations. Fortunately, frost/freeze events are more likely to occur before spring budburst, and they are *not* considered a "prevailing condition" for most winegrape growing areas in North Carolina. However, be sure to consult a qualified climatologist if you are unsure about the potential for frost/freeze events in your general area and vineyard location, especially in colder sections of the mountains (see chapter 4).

4. Cold Protection Principles—Be Proactive in Planning Your Strategy!

As stated in the milestone extension bulletin, *Frost and Frost Control in Washington Orchards* (J.K. Ballard, 1981), the grower, "… must know the kind of frost confronting him each time the frost alarm rings," and today's advance weather forecast allows the modern day vineyard producer to make an educated guess about what can potentially happen several days, or more, before the cold event occurs. You can then revise control options and strategies as more information becomes known about the event in 48-hour and 24-hour updates.

If you decide to use a commercial provider for specialized weather forecasts, be sure to use one of the more farm-specific services. They may provide twice daily reports on the Web or send you reports via e-mail or fax. Weather forecasts for your vineyard should provide the following information:

- ❑ When a cold event is coming.
- ❑ How cold it will get (minimum air temperature at the weather shelter level of 5 feet).
- ❑ How long the cold may last (duration).
- ❑ Wind speeds and direction.
- ❑ Whether the humidity will be low or high and specifically the dew point temperature.

Unfortunately, the current methods for predicting wind speeds coupled with widely varying terrain for mountain zones of North Carolina, greatly limit the capability of various weather forecast services to provide meaningful wind forecast products for this region of the state.

Know Your Vineyard

Conditions specific to your growing site can affect temperature, humidity, wind speed, and inversion strength during radiational cooling. Knowing what has happened in the past when the forecast was similar can help you to predict what is likely to happen in your vineyard during a cold event.

Keep a Weather Journal

Organizing a journal can help you develop a successful cold protection strategy. A weather journal should include the following information for each cold event:

- ❑ Date of the event and type of event (freeze, frost/freeze, or frost).
- ❑ The minimum dry bulb temperature (at 5 feet) and at the canopy level.
- ❑ Wind speeds and directions.
- ❑ Amount and type of cloud cover.
- ❑ Dewpoint temperature (frost point)
- ❑ Inversion strength

In summary, take full advantage of regional and localized weather forecast products, and key information on *wind speeds*, *dew point temperatures* and *minimum temperatures.* Then use your personal knowledge of your vineyard site's microclimate, and past experiences and "lessons" in frost and frost/freeze protection, to determine a strategy that will give you the best chance of success.

Operating Frost Protection Systems

This section provides in-depth information on the actual operation of several conventional frost control systems (wind machines, over-vine irrigation, and heaters), and also explores scenarios where combination approaches may be a better choice, such as the use of both wind machines and heaters. Information is also provided on helicopters, which are another option that may be economically justified under special circumstances, despite their high hourly charges (starting at $825 per hour).

Wind Machines

Choose this method for your vineyard when:
1) most spring cold events during grape budbreak and early shoot development are likely to be radiational;
2) there is a 20 percent probability, or higher, that you will lose 50 percent of your yield an average of twice every 10 years; and
3) the frequency and strength of low-level inversions during the budbreak and early shoot development will make over-vine wind machines effective.

INSTALLATION. Typically, an 18-ton crane is required for installation, but a 14-ton truck crane can often suffice, as long as the boom-out is at least 60 feet. The heaviest part of the wind machine is the steel tower, which weighs about 4,000 pounds. Also, the ground-mounted unit requires a concrete pad (about 7.5 yards of concrete gravel mix with no fly ash). There are well-qualified wind machine vendors serving North Carolina. Your county Extension agent can provide you contact information. Wind machine suppliers typically have a great deal of field experience, and they will be able to help you with the appropriate placement of the wind machines in your vineyard.

PRINCIPLES OF OPERATION. Ground-mounted wind machines with heavy-duty industrial engines, combined with high-strength 18-foot fan blade mounted approximately 30 feet from the ground, can move large volumes of air through the vineyard. *These machines rely on the principle that a large, slow moving cone of air can produce the greatest temperature modification around the vines by mixing warmer air above the vineyard with cooler air around the vines.* The propeller revolves at approximately 590 revolutions per minute and rotates 360 degrees about its vertical axis every 4½ minutes. The motor should be strong enough to drive the air turbulence into the vineyard 300 to 400 feet under windless conditions. You will notice in Figure 11.1 that the protected area is usually an oval pattern. This is because the machines are located to take best advantage of natural patterns of air movement in the vineyard during frosty nights. In Figure 11.1, you can see that a single wind machine may drive the air 500 to 600 feet with the air drift, but that the effective turbulence is only 250 to 300 feet on the upwind side. *The effectiveness of a wind machine depends on a temperature inversion so that there is a source of warm air for mixing* (Sugar et al. 2003). One Davidson County vineyard, where a wind machine has been recently installed, quite commonly experiences inversions of 7°F from the ground level to 50 feet in elevation. (This would be considered a strong inversion with 1.4°F per 10 feet). The general rule is that with a typical inversion layer at 40 to 50 feet, wind machines can be expected to increase the temperature around the vines by one-fourth to one-half of the difference in temperatures between air around the vines and the warmest air in the range of the wind machine.

Operation

1. A reliable **weather prediction system** will allow you to decide in advance of the cold event if frost protection with a wind machine will be adequate. Start checking weather forecasts at least 48 to 72 hours in advance of the event. Once you know what type of cold event is coming, you can start making plans to use your wind machine or to add a backup system if supplemental heating may be needed. On the night of the cold event, make sure your frost alarm is correctly set (usually at 37°F).

2. **Calculate the strength of the inversion.** Wind machines work well under hoar frost (white frost) conditions, but you may need to use

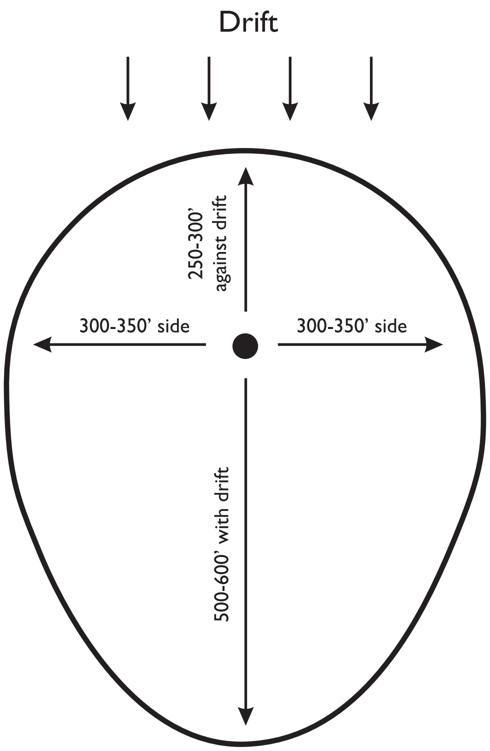


Figure 11.1. Oval pattern of protection provided by wind machines.

an additional method in *black frost* conditions when more than 2 or 3°F is needed to keep developing new shoots above their critical temperature. Remember that wind machines bring in warmer air from the thermal inversion, but these machines are not very effective when the inversion strength is small. Calculate the strength of the inversion by multiplying the difference in air temperature at 50 feet and the vine level by a factor of ¼ to ½ (e.g., if the difference in temperature is 4°F, then the inversion will only provide about 1 to 2°F of warming of the air around the vines). Advance information about the likely strength of the inversion may be obtained from your weather forecast service.

3. **The critical temperature** will vary with the stage of plant tissue development and environmental conditions. For the most part, an air temperature of 31°F or lower for 30 minutes or longer, may be considered critical beyond budbreak (Sugar et al. 2003) for frost and frost/freeze protection.

4. **Air temperature measurment.** By definition, the critical temperature of 31°F is the *air temperature* as read on a properly sheltered, correctly calibrated vineyard thermometer. A well-managed frost protection system depends on accurate temperature readings and also on having thermometers properly distributed. At least one is needed in the coldest location in the vineyard, and the number of other thermometers required will be a function vineyard size. The idea is to have enough to keep you posted on the temperature behavior throughout the protected area (Ballard, 1981). The thermometers must be sheltered and not exposed to the sun during the day or sky during the night (Fig.11.2).

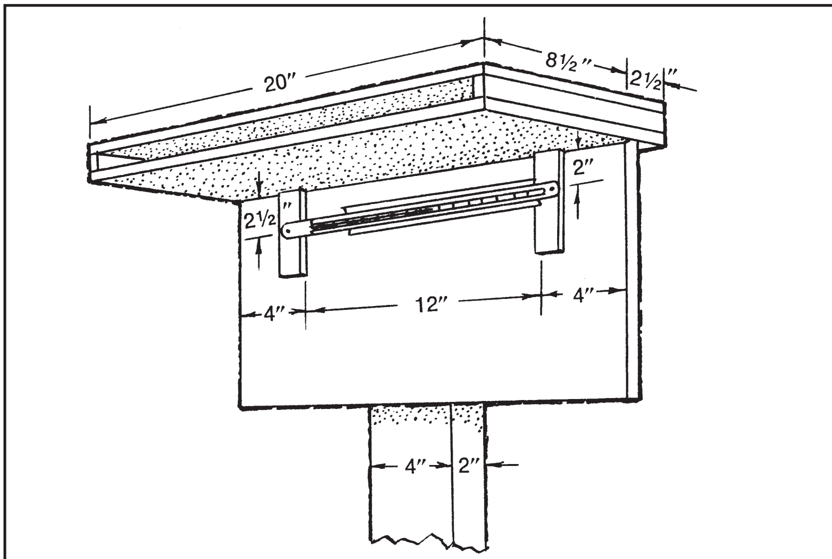


Figure 11.2 Properly sheltered air temperature thermometer. (Illustration courtesy of Washington State Cooperative Extension)

5. **Know your dew point temperature!** When your frost alarm clock has awakened you, begin checking temperatures in the vineyard. Many growers will automatically turn on the wind machines at about 32°F (based on the temperature of the thermometer in the coldest vineyard location), but this may or may not be a good decision. A better strategy takes into account

both air temperature *and* dew point temperature.[1] When the dew point is low, temperature can drop very rapidly, and it is not unusual to see the air temperature drop more than several degrees in the first hour. The U.S. Weather Service reports that dew points of 30°F are considered **high** and those of less than 20°F are considered **low** (Ballard, 1981). Evans (2000) recommends that if the weather forecast is for subfreezing temperatures accompanied by low dew points (less than 20°F), that you should turn on the wind machine(s) at 35 to 37°F to start moving the warmer air through the vineyard even with weak inversions. This will at least partially replace radiative losses and strip cold air layers away from the buds and shoots. If the dew point is in the low- to mid-20s and air temperatures are dropping at an average of 2°F per hour, turn on the wind machine when the temperature is around 34°F. If the dew point is in the upper 20s, 32 to 33°F should be satisfactory.

If the dew point is near or above the critical temperature for grape tissue (around 31°F), it is important to be aware that the heat released at the dew point may provide sufficient heat to avoid reaching damaging temperatures, or at least may delay the temperature fall and postpone the need to turn the wind machine on (Sugar et al. 2003). HOWEVER, as soon as you detect any frost forming on exposed grape plant tissues, TURN THE WIND MACHINE ON! By stirring up the air, wind machines can interfere with ice crystal formation. As discussed in Principles of Cold Protection, the formation of ice crystals on succulent grape shoots can be very damaging.

6. **Heaters** may be lit to supplement the wind machines on nights when temperatures are expected to go below 27 to 28°F. See the section on *Heaters* for additional information.

7. **Using a helicopter service as back-up.** In colder radiational frost conditions, some Virginia vineyards will use both wind machines and also have helicopters on standby in case temperatures may fall below the capacity of wind machines. This can be relatively expensive, but growers faced with devastating black frost losses find them very effective. Information about helicopters is provided in a later section.

8. **Shut-down of wind machine.** *Monitor air temperatures after sunrise, and continue to run the wind machine until the temperature is above 32°F in the lowest area of the vineyard.* Technically, you could safely turn off the wind machine before an air temperature of 32°F is reached, as the air temperatures will warm more slowly in the morning than the grape shoot tissues. If you own a device for monitoring actual tissue temperatures (e.g. digital thermometer with thermocouple inserted in grape shoot tissue), you will see that as the crop tissues receive direct rays from the sun in the morning and they will warm up more rapidly than the surrounding air. You would need an instrument for monitoring this, and since few grape growers own these devices, it is recommended that you continue to run the wind machine until the air temperature is safely above 32°F in the lowest area of the vineyard.

Over-vine Sprinkling Systems

This is the most complicated method of active frost protection and should only be chosen if you have established that your vineyard site is highly prone to frost and frost/freezes and that you have enough water to provide three consecutive frost/freeze nights of protection (about 155,000 gallons of water per acre).

[1] Dew point is predictable from the difference between the wet- and dry-bulb thermometer readings. Grape growers who do not have a weather forecast service that provides hourly dew points may find it to their advantage to determine their own dew points with a sling psychrometer. Your Extension agent can tell you where you can purchase a sling psychrometer and obtain a copy of psychrometric tables for obtaining the dew point.

PRINCIPLES OF OPERATION. The overhead sprinkler irrigation system relies on two key principles: *heat of fusion* and *heat of vaporization***.** As water freezes, heat is released by the freezing process (heat of fusion). The amount of heat generated when water freezes is 1,200 British thermal units (btu) per gallon or 80 calories per gram of water frozen. This heat keeps plant temperatures safely at 31.5 to 32°F (Sugar et al. 2003) when air temperatures are colder. Evans (2000) indicates that the ice and water mixture is at about 30.9°F.

As long as an *adequate layer of freezing water* covers the buds and shoots, the temperature will stay above the critical damaging temperature.

With very low air temperatures, greater rates of water are required for adequate protection. Also, the presence of wind while sprinkling over the vines can lead to extensive crop loss if sprinkling rates do not offset evaporative cooling heat losses. Since the heat taken up by evaporation at 32°F is about 7.5 times as much as the heat released by freezing, at least 7.5 times as much water must freeze as is evaporated. Thus, relatively high sprinkling rates are required under windy compared to calm wind conditions (see Table 11.5), and this is needed to both supply heat to warm the vineyard as well as to satisfy heat losses through evaporation. Keep in mind that under cold conditions evaporation is happening all the time from the liquid and frozen water, and if the system should fail at anytime during the night, it goes *immediately* from a heating system to a very good refrigeration system, and damage can be much worse than if no protection has been used at all (Evans, 2000).

Furthermore, there may be what is called an "evaporative dip," or "cold jolt," due to evaporative cooling of the sprinkler drops when the system is first turned on. This 15- or 20-minute dip can push temperatures of the grape tissues below their critical point and cause serious cold injury at the outset of the sprinkling operation. Under conditions favoring evaporative cooling (winds and low humidity), it is very important to **turn on the sprinklers** on the basis of **wet bulb temperatures,**[1] and **not ambient temperatures**.

Operation

1. Start-up. Under low dew point and/or windy conditions, ***start watering <u>before</u> the wet-bulb temperature reaches the critical grape shoot temperature of 31°F***. The wet-bulb temperature governs the turn-on time, not ambient temperature. Except when the air is saturated with moisture, the wet-bulb temperature is normally lower than the air temperature but higher than the dew-point temperature. For example, when the air temp is 33°F and the wet-bulb is 30°F, the dew point is 25°F (Ballard, 1981). But, by waiting to turn on the irrigation system until the wet-bulb temperature is below 31°F, you are running some risk of plant tissue injury due to the 'cold jolt' phenomenon. It is far better to waste 30 or so minutes of irrigating early in the evening than to risk damaging grape shoots. Under higher dew-point conditions and winds, it will still be important to monitor wet-bulb temperatures and turn on sprinkling before the wet-bulb temperature reaches the critical grape shoot temperature of 31°F. Under low wind speeds (less than 2 miles per hour) and/or no winds, along with relatively high dew points (upper 20s and low 30s), *start frost protection procedures at the first sign of ice crystals forming on the plant surfaces under hoar frost conditions.*

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[1] Knowing wet bulb temperature is especially important to growers who use over-vine sprinkler irrigation for frost/freeze protection of grapes. (It is not critical to know wet bulb temperatures when using other types of frost protection, such as wind machines, heaters, or helicopters). The wet bulb temperature determines when you turn the irrigation system on and off. Wet bulb temperature is a measurement of the evaporative cooling power of the air and can be measured using a sling psychrometer, an instrument comprised of two thermometers. The wet bulb temperature has a gauze wick attached to the bulb end; and to measure wet bulb temperature, the gauze wick is immersed in water, and the instrument is swung in a circular motion for a few minutes. (The above information on wet bulb temperature and how to take a wet bulb temperature reading is taken from *Priniciples of Freeze Protection for Fruit Crops,* ANR-1057A, March 2000, Arlie A. Powell and David G. Himelrick.)

2. **Once sprinkling starts** and an ice coat has built up, the system must operate continuously through the night until the vines are free of ice the next morning, or at least until the wet-bulb temperature of 32°F, or above, has been reached. Be especially cautious about stopping the application of water during the night if the temperature rises because of a light breeze or a few clouds. Once the breeze falls or the clouds disappear, the temperature will probably drop rapidly again. With sprinkler irrigation for frost protection in vineyards, the system must be designed for worst-case conditions.There are several excellent irrigation suppliers in North Carolina who can design a vineyard sprinkler system to provide protection down to a target temperature of 20 to 22°F. In Oregon, it is reported that an application rate of 0.19 inch per hour can protect grape buds and shoots down to 22°F (Sugar et al., 2003). However, it should be noted that under relatively high wind conditions and with temperatures approaching 22°F, you may need to apply more than 0.19 inch per hour (see Table 11.5). In North Carolina it would be better to design a vineyard sprinkler irrigation system that can deliver precipitation rates of up to 0.25 inch per hour to take into account evaporative cooling heat losses when winds are in excess of 5 miles per hour at an air temperature of 22°F. Less water is required for protection to 26°F, and in Oregon it is recommended that an application rate of 0.12 inch per hour will be sufficient at this temperature (Sugar et al., 2003). Water should slowly but continuously drip from the vine when the sprinkling system is working properly (Evans, 2000). The application rate is not sufficient if the ice has a milky color (from occlusion); ice should be clear at all times.

Large amounts of water are required for over-vine irrigation, so you should size your pond(s) to provide for three continuous nights of protection at 10 hours per night. You would need 5.7 acre-inches of water (27,152 gallons equal 1 acre-inch) for sprinkling at the rate of 0.19 inch per hour (for control down to 22°F), for 10 continuous hours each night over 3 nights. Or, 1.9 inch/night (10 hours x 0.19 inch) x 3 nights = 5.7 acre-inches. An irrigation pond would need to hold about 155,000 gallons of water for each acre of vineyard production under these conditions (5.7 inch x 27,152 gal per acre inch = 154,766 gallons).

3. **Shut-down of irrigation system.** Operate continuously after sun-up until you can see free water running between the ice and the grape buds and shoots, or until ice falls easily from the

Table 11.5. Required Irrigation Rates (Inches per Hour) in Fruit Crops to Maintain a Temperature of 28°F and Relative Humidity of 70 Percent [1]

	Wind Speed			
Minimum Temperature (°F)	0 to 1 mile per hour, apply	2 to 4 miles per hour, apply	5 to 8 miles per hour, apply	9 to 14 miles per hour, apply
27	0.10	0.11	0.14	0.16
26	0.10	0.13	0.16	0.17
25	0.10	0.14	0.18	0.21
22	0.10	0.18	0.24	0.29
20	0.11	0.21	0.28	0.34
18	0.12	0.23	0.31	0.38
16	0.13	0.26	0.35	0.43

[1] This table illustrates the affect of wind speed on precipitation rates in fruit crops; it is not specific to grapes.
Source: Perry, Katherine (1998, Feb.). Guide to deciding when to start and stop irrigation frost protection of fruit crops, *Hort. Information Leaflet 713*

vine structures (spurs, cordons). It is not necessary to run until all the ice has melted after the warm sunlight "takes over" (Ballard, 1971). But, if the morning should turn cloudy after sunrise and/or if there are chilly winds, CONTINUE TO RUN THE IRRIGATION UNTIL THE **WET BULB** TEMPERATURE IS **ABOVE 32°F** IN THE COLDEST PORTION OF THE VINEYARD.

Heaters as a Supplement to Wind Machines[1]

For years the principal method of frost protection in fruit crops was by burning fuel to create heat. But burning these fuels (e.g. diesel, propane) as the sole means of frost protection is prohibitively expensive. Burning 40 heaters per acre with a diesel price of $2.50 per gallon would cost $100 per hour. There is the additional cost for labor to light the heaters and put them out in the vineyard, as well labor to refill them with oil for the next night of frost protection. *However, in North Carolina, heaters can be considered as an effective method of adding extra heat during nights when temperatures may fall below the capacity of wind machines wind machine protection*.

PRINCIPLES OF OPERATION. The hot gases emitted from the top of the heater initiate convective mixing in the crop area, tapping the important warm air source above in the inversion. About 75 percent of a heater's energy is released as hot gases. The remaining 25 percent of the total energy radiates from the hot metal stack. Radiated heat is not affected by wind and will reach any solid object not blocked by another solid object. *Heaters may thus provide some protection under windborne freeze conditions.* A relatively insignificant amount of heat is also conducted from the heater to the soil.

[1]This section is partially adapted from Horticultural Information Leaflet 705, *Frost/freeze Protection for Horticultural Crops* by K.B. Perry, North Carolina Cooperative Extension Service, 2001.

Operation With Wind Machines

Using heaters with wind machines is more energy efficient than relying on heaters alone. The number of heaters is reduced by at least 50 percent by dispersing them into the peripheral areas of the wind machine's protection area (Evans, 2000). In Oregon vineyards, when heaters are the sole source of protection, 40 to 50 heaters burning at the rate of 0.5 gallons per hour per acre is recommended (Sugar et al., 2003). There do not seem to be any absolute formulas to follow on this, but by lighting 20 to 25 heaters per acre you may expect approximately 3°F protection (Sugar et al., 2003). The lightest heater concentration should be nearest the wind machine tower to minimize vertical current interference with the fan blast (Ballard, 1981). Grower testimony in North Carolina has further revealed that heaters are not usually necessary within a 150- to 200-foot radius from the base of the wind machine. Heaters give you the option of delaying protection measures if the temperature unexpectedly levels off or drops more slowly than predicted. There is no added risk to the crop if the burn rate is inadequate; whatever heat is provided will be beneficial (Perry, 2001).

Helicopters

Because of the great expense, helicopter use for frost protection is limited to special cases and emergencies, such as when a black frost in the mid-20s is forecasted at a critical growth stage and only a wind machine is available for protection, which is not likely to be adequate under such conditions. (Wind machines usually provide 1 to 3°F protection. In this scenario, at least 5 or 6°F protection is required.) Helicopters are generally hired for particular events, and will remain on standby either in the vineyard or close by. This is a relatively expensive operation, with hourly costs ranging from $825 to $1,600 per hour (depending on the size of the helicopter, and availability). The grower is also asked to guarantee at least 3 hours of work.

PRINCIPLES OF OPERATION. Helicopters are an expensive variation of wind machines (Evans, 2000), but they can be considerably more effective than a wind machine since they can adjust to the height of an inversion. A single large helicopter can protect more than 50 acres under the right conditions (Evans, 2000).

Operation

Contact the helicopter service well in advance of any serious frost/freeze event to make appropriate arrangements. The only company servicing our region in 2006 already has many long-standing commitments with vineyards in Virginia. (See Resources at the end of this chapter.) Since frost/freeze protection on some nights will last 6 hours or more, it is usually also necessary for the company to dispatch a jet fuel truck to the vineyard for refueling. Typically, you will be given a two-way radio so that you can talk with the helicopter. You and your workers must walk the vineyard during the cold event, checking vineyard thermometers with flashlights, so you can give the helicopter operator information on cold spots in the vineyard. A rapid response thermometer in the helicopter helps the pilot adjust the flying height for the best heating effect (Evans, 2000).

Summary

The cost effectiveness of active frost control depends on how prone a particular vineyard site is to radiation frosts (and possibly frost/freezes) in the spring from budbreak through early shoot development. Good site selection is still the best method of passive cold protection, but as more winegrape vineyards are planted in frost-prone areas of North Carolina, growers need to consider active methods of frost control. A number of growers in the piedmont and mountains are using wind machines to control radiation frost events in their vineyards. Radiation frosts occur on clear nights with calm winds (less than 5 miles per hour) and temperatures near the surface below freezing. When either a hoar frost or black frost threatens, they turn on the wind machines to break up the temperature inversion (warm air above the cold air close to the ground) by mixing warmer air with cold air.

Once ice forms in the plant tissue, there will be damage. Growers are advised to be proactive in their use of wind machines or any other frost protection method (over-vine sprinklers, heaters, and helicopters) in preventing ice crystal formation associated with a *hoar (white) frost.* In a *black frost* few or no ice crystals form because the air in the lower atmosphere is too dry, and the grower cannot wait for "evidence" of ice crystals to start up frost protection measures in these conditions. Advance weather forecasts from a subscription service can provide information on *dew-point temperatures* (DP), which can help the grower assess whether he or she may be dealing with a *hoar frost* (DP in the upper 20s and low 30s), or *black frost* (DP in the mid 20s or lower). If the DP is in the low to mid-20s, for example, turn on the wind machines when the air temperature is around 34°F. When the dew point (DP) is below the critical temperature of 31°F, expect that plant tissue temperatures will fall more rapidly than the surrounding air temperature, and the amount of *upward adjustment* in the start-up air temperature is going to be related to the dryness of the lower atmosphere, as indicated by dew point temperature. In dry atmospheric radiation frost conditions, be conscious of the need to monitor *both* vineyard air temperature and humidity (*using dew point temperature*).

On a *frost/freeze* night, the best strategy may be to take no action at all. Five- to 10-mile-per-hour winds will prevent the formation of an inversion, so wind machines and helicopters will not be effective. Over-vine sprinkling can be designed to provide enough heating capacity to protect vines exposed to *frost/freeze* conditions. The system must be carefully engineered specifically for use under windy conditions that promote evaporative cooling. If the grower has any doubt about the capacity of the irrigation system to provide adequate heating in *frost/freeze* conditions, the best strategy may be to take no action at all as an ice-covered vine will cool below the temperature of a comparable dry vine if freezing stops and evaporation begins.

Use the details for operating several conventional frost control systems (wind machines, over-vine irrigation, and heaters), and the discussion of some cold event scenarios to help you determine which system(s) might be best for your vineyard. Regardless of the system(s) you use, remember that successful cold protection must be approached with a sound understanding of frost and frost/freeze management principles, a good knowledge of your vineyard site's microclimate and weather conditions that are favorable for the operation of your cold protection system, and careful attention to the details contained in specialized weather forecasts on air temperature minimums, dew point temperatures, wind speeds, cloud cover, and inversion strength.

References

Ballard, J.K. & Proebsting, E.L. 1981. Frost and frost control in Washington orchards, Washington State University Cooperative Extension, Pullman WA, Extension Bulletin 634, 27pp

Evans, R. G. 2000. The art of protecting grapevines from low temperature injury. Proc. Of ASEV 50th Anniversary Annual Meeting, Seattle WA, June 19-23, pp. 60-72.

Perry, K.B. 1998. Basics of frost and freeze protection for horticultural crops. HortTechnology, 8(1) 10-15.

Perry, K.B. 2001. Frost/freeze protection for horticultural crops. Horticultural Information Leaflet 705, North Carolina Cooperative Extension Service, NC State University, Raleigh, NC

Snyder, R. L. 2001. Principles of frost protection. University of California, Atmospheric Science, Davis, CA, http://biomet.ucdavis.edu/frostprotection/Principles%20of%20Frost%20Protection/FP005.html

Sugar, D., R. Gold, P. Lombard and A. Gardea. 2003. In: Oregon Viticulture, Strategies for frost protection, Editor, E.W. Hellman, Oregon State University, pp. 213-217.

Trought, M.C.T, G.S.Howell and N. Cherry. 1999. Practical considerations for reducing frost damage in vineyards, Lincoln University, New Zealand, 43 pp.

Westwood, M.N. 1978. Temperate-zone Pomology. W. H. Freeman and Company, San Francisco, CA., p. 319.

Wolf, T. K., and J.D. Boyer. 2003. Vineyard Site Selection. Publication Number 463-020, Virginia Polytechnic Institute and State University, Blacksburg, VA. http://www.ext.vt.edu/pubs/viticulture/463-020/463-020.html

Resources

Climate Information

Ryan Boyles, Associate State Climatologist
State Climate Office of North Carolina
1005 Capability Drive, Suite 240
Research III Building, Centennial Campus
Box 7236, North Carolina State University
Raleigh, North Carolina 27695-7236
ryan_boyles@ncsu.edu
919-515-3056, 877-718-5544
Fax: 919-515-1441
http://www.nc-climate.ncsu.edu

Jan Curtis, Applied Climatologist
NRCS - National Water & Climate Center
1201 NE Lloyd Blvd, Suite 802
Portland, OR 97232-1274
jan.curtis@por.usda.gov
503-414-3017, (503) 956-4609 (cell)
FAX: 503/414-3101
http://www.wcc.nrcs.usda.gov/

County Extension Agent
http://www.ces.ncsu.edu/
index.php?page=countycenters

Heaters (HY-LO Return Stack Heater and similar heaters)

Plummer Supply
Agricultural Irrigation & Orchard Supply Co.
2875 Plummer Park Place
Bradley, MI 49311
269-792-2215, 800-632-7731
http://www.accn.org/~plummer

Helicopter Frost Control Service

HeloAir, Inc.
5733 Huntsman Road
Richmond International Airport, VA 23250
804-226-3400, 888-FLY-HELO
www.heloair.com

Over-vine Irrigation System Suppliers

B.B. Hobbs
PO Box 437
Darlington, SC 29540
843-395-2120
sales@bbhobbs.com
http://www.bbhobbs.com

Berry Hill Irrigation
3744 Hwy 58
Buffalo Junction, VA 24529
434-374-5555, 800-345-3747
sales@berryhilldrip.com
http://www.berryhilldrip.com

Gra-Mac Irrigation
2310 NC Hwy 801 N.
Mocksville, NC 27028
336-998-3232, 800-422-35600
gramacirr@yadtel.net

Johnsons & Company
PO Box 122
Advance, NC 276006
800-222-2691, 336-998-5621
henry.johnson@johnsonandcompanyirrigation.com
http://www.johnsonandcompanyirrigation.com

Mid-Atlantic Irrigation Co.
PO Box L, Farmville, VA 23901
434-392-3141
mairrigation@cstone.net
http://www.irrigationparts.com

W.P. Law Co.
Sales: Brad Scease, Tom Plumlee
303 Riverchase Way
Lexington SC 29072
803-461-0599
Fax: (803) 461-0598
http://www.wplawinc.com/

Weather Forecasting Services

AcuWeather.Com
Online subscription weather forecasting service
State College, PA
http:// wwwa.accuweather.com/

AWIS Inc
Agricultural Weather Information Service Inc.
PO Box 3267
Auburn, AL 36831
888-798-9955, ext 1 or 334-826-2149
info@awis.com
http://www.awis.com

SkyBit, Inc.
369 Rolling Ridge Drive
Bellefont, PA 16823
800-454-2266
info@skybit.com
http://www.skybit.com

Weather Instruments (thermometers, sling psychrometers, frost alarms, digital thermometers, portable weather stations)

B.B. Hobbs
PO Box 437
Darlington, SC 29540
843-395-2120
sales@bbhobbs.com
http://www.bbhobbs.com

Berry Hill Irrigation
3744 Hwy 58
Buffalo Junction, VA 24529
434-374-5555, 800-345-3747
sales@berryhilldrip.com
http://www.berryhilldrip.com

Forestry Suppliers (http://www.forestry-suppliers.com/)

Gempler's
PO Box 44993
Madison, WI
800-382-8473
http://www.gemplers.com/

Omega Engineering
PO Box 4047
Stamford, CT 06907
800-848-4286, 203-359-1660
sales@omega.com
http://www.omega.com

Spectrum Technologies, Inc.
12360 South Industrial Dr., East
Plainfield, IL 60585
800-248-8873, 813-436-4440
info@specmeters.com
http://www.specmeters.com

Wind Machine Suppliers

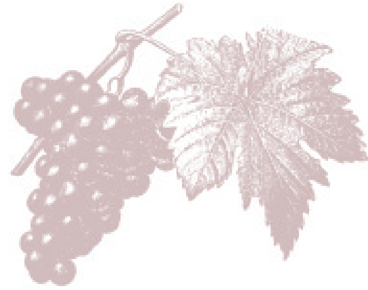
Orchard-Rite Ltd.
Contact: Rod Robert
PO Box 9308
Yakima WA 98909
509-457-9196
Fax: 509-457-9186
sales@orchard-rite.com

Plummer Supply (distributor for Orchard-Rite Ltd.)
Sales: Lee Deleeuw
PO Box 117
2875 Plummer Park Lane
Bradley MI 49311
800-632-7731
Fax: 269-792-6637
plummer@accn.org

W.P. Law Co. (distributor for Orchard-Rite Ltd.)
Sales: Brad Scease, Tom Plumlee
303 Riverchase Way
Lexington SC 29072
803-461-0599
Fax: 803-461-0598

Chapter 12

Crop Prediction



Crop prediction or estimation is the process of projecting as accurately as possible the quantity of crop that will be harvested. Why estimate the crop? The most obvious reason is to know how much crop will be present for sale or utilization. Beyond that fundamental reason, it is also important to know whether vines are undercropped or overcropped. In the absence of methodical crop estimations, the experienced grower can rely on past vineyard performance. This approach is subject to error, however, especially in grape regions subject to spring frosts or winter injury, which can greatly affect a vineyard's productivity from year to year.

Basic Components of Crop Yield

Crop estimation is based on several pieces of critical information: (1) a good historical record of average cluster weights at harvest; (2) an accurate count of current bearing vines per acre or block; and (3) an accurate determination of the average number of clusters per vine at the time of the crop estimate. Of these variables, average cluster weight is most subject to variation from year to year.

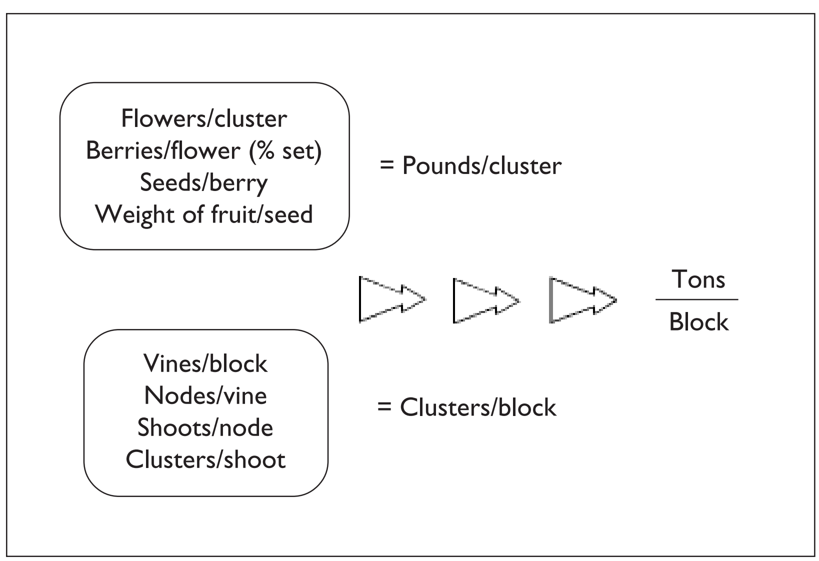
The theory of crop estimation is also based on an understanding of the components of vineyard yield. Those components are shown in Figure 12.1.

As this diagram illustrates, we can differentiate between yield components that contribute to the number of fruit clusters per block and those yield components that determine the average cluster weight. Variability in yield per acre can be traced back to variation in one or more of the many components that collectively determine yield.

Looking specifically at cluster weights (pounds per cluster in the diagram,) it is common to see yearly variation in the percentage of flowers that set fruit. Reductions in set may be due to poor weather during or immediately after bloom, poor vine nutrient condition, and possibly other factors such as pesticide phytotoxicity. Regardless of the cause, average cluster weight data from several years is more meaningful than a single year's data.

The number of clusters per block also varies from year to year. The number of (bearing) vines per block tends to decline through attrition as a vineyard ages unless the vineyardist is conscientious about vine replacement. The number of nodes per vine is a function of dormant pruning severity. The number of shoots per node varies with variety, vine vigor, and the use of shoot thinning as a canopy management practice. The

Figure 12.1. Basic components of crop yield.



number of clusters per shoot is affected by variety, the proportion of bud injury, and the growing conditions of the vine during the previous season. Compared to well-exposed shoots, shoots that develop in dense shade are more likely to have nodes with less fruitful shoots the following year.

Although the relationships shown in Figure 11.1 are helpful in understanding crop variation, it is not essential to consider each component of yield to estimate a crop. In practice, the following equation can be used to estimate crop with reasonable accuracy.

As previously stated, the key elements needed to estimate the crop are: (1) the number of

Equation 12.1

$$\text{Estimated Yield (tons/acre)} = \frac{1}{2{,}000 \text{ lb}} \times \frac{\text{Vines}}{\text{Acre}} \times \left[\frac{\text{Shoots}}{\text{Vine}} \times \frac{\text{Cluster}}{\text{Shoot}}\right] \times \text{Average Cluster Weight (lb)}$$

$$\text{or } \left[\frac{\text{Clusters}}{\text{Vine}}\right]$$

bearing vines per acre; (2) the average number of clusters per vine; and (3) average cluster weight at harvest. The 1/2,000 fraction converts pounds (used in expressing average cluster weight) to tons. There are more sophisticated procedures for estimating crop, but this equation provides a reasonably accurate prediction. The following sections present specific recommendations for determining the values of the three critical elements of the equation.

Number of Bearing Vines Per Acre

The maximum number of vines per acre is determined by the row and vine spacing. A full planted acre of vines spaced 8 feet apart in rows 10 feet apart will have about 545 vines. However, the actual number of bearing vines in most vineyards is somewhat less than the maximum possible. In poorly maintained vineyards, the actual number of vines may be less than 70 percent of the available vine spaces. Yield estimates can err significantly if estimates do not account for missing vines. To use an example, an estimate based on 545 bearing vines per acre might predict 4.9 tons of crop. Using the same average cluster weight (0.6 pound) and number of clusters per vine (30), the actual yield would be only 4.4 tons per acre if 10 percent of the vines were missing or were nonbearing. Unfortunately, it is not uncommon for 10 percent of the vines to be missing. Therefore, it is important to ensure that crop estimates are based on the actual number of bearing vines.

In some vineyards, the trellis spaces created by missing vines are filled in by extending cordons from adjacent vines. While this is a good practice to maintain vineyard productivity, it makes it more difficult to determine the number of vines per acre accurately and to estimate the crop successfully. An alternative is to count the number of panels (the distance between two consecutive posts in a row) per acre and to make counts of clusters per panel rather than clusters per vine.

Number of Clusters Per Vine

The average number of fruit clusters per vine is determined by counting clusters on representative vines and deriving an average figure from those counts. Crop can be estimated any time after all the flower clusters are exposed on the developing shoots. One advantage in waiting until after fruit set, however, is that the percentage of berry set can also be gauged. The vines on which clusters are counted should be selected methodically. One possibility is to sample on a grid — for example, inspecting every twentieth vine in every third row. The number of vines on which to count clusters depends on vineyard size and the uniformity of vines within the vineyard. In a 1- to 2-acre vineyard with vines of a uniform age, size, and training system, it might be necessary to sample only 10 or 15 vines. In larger, nonuniform vineyards, sampling should be stratified to account for variation between distinct areas of the vineyard. Bear in mind that the purpose of sampling is to determine the average number of clusters per vine for the entire vineyard. The larger the sample, the greater the likelihood that the sample average will be close to the vineyard average.

Average Cluster Weight

Cluster weights for each variety should be obtained annually at harvest and averaged. The results should then be averaged over all years for which data are available and used in making crop estimates. Clusters can be collected from picking bins after harvest, but the tendency in that sampling process is to select larger-than-average clusters. For each vine, record the total number of clusters picked, weigh them, and divide the weight by the number of clusters to obtain the average cluster weight. Subtract the weight of the empty picking bins from the total fruit weight. Picking all clusters from vines will ensure that you take into consideration the extremes in cluster size. Again, sampling 10 to 15 vines may be sufficient for a small, uniform vineyard.

Sources of Variation

After the number of bearing vines per acre (or block) and the average number of clusters per vine have been determined, these data can be combined with the average cluster weight to predict the crop yield per acre (or block). Unfortunately, the above discussion oversimplifies the crop prediction process somewhat. Even with thorough sampling, accurate vine counts, and many years' average cluster weight data, the actual crop tonnage at harvest can vary significantly from that which is predicted only two months before harvest. Many experienced producers are satisfied if the difference between predicted and actual yields is less than 15 percent. The most uncertain component of the crop prediction equation presented in this chapter is the average cluster weight. That uncertainty results from variation in the cluster weight components listed in Figure 12.1. Furthermore, environmental conditions, diseases, and insect pests affect cluster weights. A dry summer, for example, tends to reduce berry size and thus decrease average cluster weight. As Table 12.1 illustrates, a 1/10-pound difference in average cluster weight can result in a yield difference of nearly 1 ton per acre. Furthermore, the predicted yield does not account for fruit lost to bunch rots, birds, deer, or other unpredictable factors.

The crop prediction model can be refined to provide a more accurate estimate of actual crop yield if the grower is willing to invest extra time. The process involves repeated measures of cluster weight during the growing season. Those measures are then used to adjust the average harvest cluster weight predicted at harvest. Seasonal cluster weight data can be fitted to a regression model and that model can then be used to predict the harvest cluster weight. Regression analysis is a tool used to describe how a unit change in one variable (for example, number of days after bloom) affects another dependent variable (for example, average cluster weight). However, to derive a meaningful model (one in which the regression model accounts for a significant proportion of variation in cluster weight), it is necessary to sample cluster weight on a number of days during the growing season. This process is somewhat tedious and destructive.

An alternative approach, suggested by researchers at Oregon State University (Price, 1992), involves determining the average cluster weight at the "lag phase" of cluster development and using that single measure to adjust the average harvest cluster weight. For this method, a historical average lag-phase cluster weight must

Table 12.1. Variation in Yield Estimate with a 1/10-Pound Change in Average Cluster Weight

Number of Vines per Acre	Number of Clusters per Vine	Average Cluster Weight (lb)	Yield (tons/acre)
545	30	0.60	4.91
545	30	0.50	4.10

be developed for the vines in a vineyard. The lag phase of cluster growth corresponds to the lag phase of berry expansion that occurs with seed hardening. It can be measured as a temporary slowing of the otherwise linear increase in cluster weight throughout the season. The lag phase occurs about midway between bloom and harvest. Much, but not all, of the variation in harvest cluster weight is determined by this stage. Collect about 300 clusters during the lag phase, weigh them, and derive an average lag-phase cluster weight in the same manner used in determining the average harvest cluster weight. The crop prediction model is then modified to use both a historical average lag-phase cluster weight as well as the average lag-phase cluster weight for the current season to adjust the average harvest cluster weight as follows:
where:

S = lag-phase cluster weight for current season

A = historical average lag-phase cluster weight (several years' data)

H = average harvest cluster weight (several years' data)

Equation 12.2

$$\text{Estimated Yield (tons/acre)} = \frac{\text{Vines}}{\text{Block}} \times \frac{\text{Clusters}}{\text{Vine}} \times \frac{S}{A} \times H$$

Fitting some hypothetical numbers into this refined model will illustrate how a small change in the cluster weight during the lag phase will correspond to a change in the average harvest cluster weight.

Timing the lag phase of berry development is a potential source of variation with this technique. In Oregon, the cluster lag phase occurred about 55 days after first bloom, a period when the seeds of developing berries could no longer be cleanly cut with a sharp knife without the seed crushing the adjacent tissue of the berry.

Even using lag-phase cluster weights, it is necessary to take into account seasonal changes in water surpluses or deficits that can measurably affect cluster weights very close to harvest.

In conclusion, consider the following points:

- ❑ Good average cluster weight data are essential to predict the crop accurately. Do not rely on average cluster weight data from other vineyards. Long-term data will be more meaningful than a single year's data.
- ❑ Cluster-to-cluster variability is thought to be greater than vine-to-vine variability. Sample entire vines to develop the average cluster weights.
- ❑ Nonuniform vineyard blocks (for example, those where variations in soil, topography, vine age, or vine training occur) should be divided into uniform subblocks.
- ❑ The accuracy of yield estimates depends on representative sampling.
- ❑ Sampler variation can be significant. Use the same person each year to estimate crop.

Do not be discouraged if first attempts at crop estimation are inaccurate. The more experience and data acquired, the more accurate the estimates will become. Using crop prediction methods, you may determine that you have more than the desired amount of fruit per vine, and the extent of thinning required to achieve the target yield desired for the vineyard (Hellman and Casteel, 2003).

References

Hellman, E. W. and Ted Casteel. 2003. Crop estimation and thinning. In E.W. Hellman (ed.), *Oregon Viticulture,* 1st ed. Oregon Winegrowers' Association.

Price, S. 1992. Predicting yield in Oregon vineyards. In T. Casteel (ed.), Oregon Winegrape Grower's Guide, 4th ed. Oregon Winegrowers' Association.

Appendix A
Contact Information

Chapter 1. Introduction

E. Barclay Poling, Professor and Small Fruit Specialist, Department of Horticultural Science, North Carolina State University, Box 7609, Raleigh, NC 27695-7609
Barclay_Poling@ncsu.edu
919-515-1195

Chapter 2. Cost and Investment Analysis of Chardonnay (*Vitis vinifera*) Winegrapes in North Carolina

Charles D. Safley, Professor and Extension Economist, Department of Agricultural and Resource Economics, North Carolina State University, Box 8109, Raleigh, NC 27695-8109
Charles_Safley@ncsu.edu
919-515-4538

Carlos E. Carpio, Assistant Professor, Department of Agricultural and Applied Economics, 283 Barre Hall, Clemson University, Clemson, SC 29634
ccarpio@clemson.edu
864-656-2439

E. Barclay Poling, Professor and Small Fruit Specialist, Department of Horticultural Science, North Carolina State University, Box 7609, Raleigh, NC 27695-7609
Barclay_Poling@ncsu.edu
919-515-1195

Chapter 3. Choice of Varieties

R. Andy, Allen, Extension Viticulturist, Institute for Continental Climate Viticulture and Enology, 125 Eckles Hall, University of Missouri, Columbia, MO
allenra@missouri.edu
573-882-6752

E. Barclay Poling, Professor and Small Fruit Specialist, Department of Horticultural Science, North Carolina State University, Box 7609, Raleigh, NC 27695-7609
Barclay_Poling@ncsu.edu
919-515-1195

Amy-Lynn Albertson, Extension Horticulture Agent, North Carolina Cooperative Extension Service, Davidson County Center, Lexington, NC 27292
Amy_Albertson@ncsu.edu
336-249-7300

Chapter 4. Vineyard Site Selection

E. Barclay Poling, Professor and Small Fruit Specialist, Department of Horticultural Science, North Carolina State University, Box 7609, Raleigh, NC 27695-7609
Barclay_Poling@ncsu.edu
919-515-1195

Ryan Boyles, State Climatologist and Director, State Climate Office of North Carolina, 1005 Capability Drive, Suite 240, Research Building III, Centennial Campus, Box 7236, North Carolina State University, Raleigh, NC 27695-7236
Ryan_Boyles@ncsu.edu
919-513-2816

Carlos E. Carpio, Assistant Professor, Department of Agricultural and Applied Economics, 283 Barre Hall, Clemson University, Clemson, SC 29634
ccarpio@clemson.edu
864-656-2439

Chapter 5. Vineyard Establishment

Tony K. Wolf, Director, Alson H. Smith Jr. Agricultural Research and Extension Center, 595 Laurel Grove Road, Winchester, VA 22602
vitis@vt.edu
540-869-2560

Chapter 6. Pruning and Training

Tony K. Wolf, Director, Alson H. Smith Jr. Agricultural Research and Extension Center, 595 Laurel Grove Road, Winchester, VA 22602
vitis@vt.edu
540-869-2560

Chapter 7. Canopy Management

Tony K. Wolf, Director, Alson H. Smith Jr. Agricultural Research and Extension Center, 595 Laurel Grove Road, Winchester, VA 22602
vitis@vt.edu
540-869-2560

Chapter 8. Pest Management

Diseases

Dr. Turner B. Sutton, Professor, Department of Plant Pathology, North Carolina State University, 201 Don E. Ellis Building, Box 7405, Raleigh, NC 27695-7405
Turner_Sutton@ncsu.edu
919-515-6823

Jean Harrison, Extension Horticulture Agent, North Carolina Cooperative Extension Service, Yancey County Center, 10 Orchard Drive, Burnsville, NC 28714
Jean_Harrison@ncsu.edu
828-682-6186

Weeds

Wayne E. Mitchem, Extension Associate, Department of Horticultural Science, North Carolina State University, 455 Research Drive, Fletcher, NC 28732
Wayne_Mitchem@ncsu.edu
828-684-3562

Chapter 9. Vine Nutrition

Tony K. Wolf, Director, Alson H. Smith Jr. AREC, 595 Laurel Grove Road, Winchester, VA 22602
vitis@vt.edu
540-869-2560

Chapter 10. Grapevine Water Relations and Vineyard Irrigation

Tony K. Wolf, Director, Alson H. Smith Jr. Agricultural Research and Extension Center, 595 Laurel Grove Road, Winchester, VA 22602
vitis@vt.edu
540-869-2560

Chapter 11. Spring Frost Control

E. Barclay Poling, Professor and Small Fruit Specialist, Department of Horticultural Science, North Carolina State University, Box 7609, Raleigh, NC 27695-7609
Barclay_Poling@ncsu.edu
919-515-1195

Chapter 12. Crop Prediction

Tony K. Wolf, Director, Alson H. Smith Jr. Agricultural Research and Extension Center, 595 Laurel Grove Road, Winchester, VA 22602
vitis@vt.edu
540-869-2560

acclimation — phase during late summer when shoots stop growing and become brown and woody, and tissues acquire increased cold hardiness.

advective freeze — temperatures below 32°F, caused by the passage of large frontal systems of cold air. Little stratification of air temperature occurs with changes in elevation.

American hybrid — varieties that have resulted from crosses made by North American breeders by crossing American grape species or varieties with *V. vinifera* in an effort to develop varieties that have the hardiness and disease resistance of the American parent and fruit quality more like that of *V. vinifera.*

anthesis — time of full bloom in the flower just after the calyptra has fallen.

apical dominance — ability of shoots near the distal end of the cane to produce hormones that retard development of more basal shoots.

aspect — compass direction toward which the slope faces.

AVA — stands for *American Viticultural Area*, and is used to represent a winegrowing region in the United States. These regional designations are controlled by the Federal Tax and Trade Bureau (TTB). Unlike most European appellations, an AVA specifies only a location. It does not limit the type of grapes grown, the method of vinification, or the yield, for example. Some of those factors may, however, be used by the petitioner who wants to define an AVA's boundaries.

balanced pruning — pruning system that determines the number of nodes to retain based on weight of one-year-old canes removed at dormant pruning.

basal — in the direction of the roots or base of vine; see distal.

blends — of wines; typically a blend includes wines from two or more varieties of grapes, or a wine from one grape variety grown in different locations, or possibly a wine from two or more vintages. A large portion of the world's wines are blended, and the possibilities are almost endless.(Jackisch, 1985).

bud — usually consists of three partially developed shoots with rudimentary leaves or with both rudimentary leaves and flower clusters. A base bud is not borne at clearly defined nodes of canes. Compound buds have several growing points.

bud fruitfulness — ability of the bud to produce fruit; usually the most fruitful are located toward the exterior of the canopy.

budbreak (or budburst) —time when the dormant buds open and newly formed leaves are seen; occurs after vines have received adequate heat in the spring.

cane — a woody, mature shoot after defoliation.

calyptra —petals of the grape flower which stay together and are shed as a "cap" when the flower blooms (anthesis).

canopy — shoots of a vine and their leaves. Canopy management entails decisions regarding row and vine spacing, choice of rootstock, training and pruning practices, irrigation, fertilization, and summer activities.

cliestothecia — overwintering sexually produced structures of some fungi.

climate — how weather acts over many years; refers to the average or normal weather of a particular location or region for a specified period of time, usually 30 years.

clone — one or more vines that originated from an individual vine, which was in some way unique from other vines of the same variety.

continentality — refers to the effect of a continuous mass of land on climate; is inversely related to the degree of water moderation. Mean daily range (MDR - the difference between the mean maximum and the mean minimum temperatures) estimates continentality. Temperatures in continental sites like North Carolina are more variable and extreme.

cordon — long, horizontal extension or two-year-old or older wood.

critical temperature — the temperature, as read on a properly exposed thermometer, that buds, blossoms and berries can endure for 30 minutes or less without injury (Ballard, 1981).

crop load — the ratio of crop weight to cane pruning weight for a given year.

cultivar — a named, cultivated variety.

dewpoint — or dew-point temperature is a measure of atmospheric moisture. It is the temperature to which air must be cooled in order to reach saturation (assuming air pressure and moisture content are constant).

distal — end of the stem towards the growing tip; see basal

dormancy — time between leaf-fall in autumn and bud break in the spring; absence of visible growth.

dormant pruning — annual removal of wood during the vine's dormant period.

double pruning — one pruning cut in late winter or early spring followed by a second pruning cut after the threat of frost is past but before appreciable shoot growth has occurred. Practiced where spring frosts are common.

evapotranspiration — the combined transpiration, or loss of water through stomata, and evaporation of water from the soil surface.

flower — the grape flower does not have conspicuous petals but instead the petals are fused into a green structure termed the *calyptra* but commonly referred to as the *cap*. The cap encloses a single *pistil* (female organ) and five *stamens,* each tipped with an *anther* (male organ). The anthers produce pollen grains. The broad base of the pistil is the ovary, which consists of two internal compartments; each compartment has two ovules with a single egg—there are four ovules per flower and a maximum potential of four seeds per berry (Hellman, 2003).

flower clusters (inflorescences) — a fruitful grape shoot usually produces one to three flower clusters, or inflorescences, depending on variety (Hellman, 2003). Inflorescences are borne opposite the leaves on new shoots arising from buds on one-year canes. Depending on variety, the flower clusters are typically at the third to sixth nodes from the base of the shoot. Botanically, the grape inflorescence is classified as a racemose panicle (Westwood, 1978).

French hybrid — varieties resulting from crosses of *vinifera* and native American species made by French breeders.

fruit — the fruit of grape is a *true berry* with two to four seeds; berry size is related to the number of seeds within the berry but is also influenced by growing conditions and cultural factors, particularly water management.

graft union — where the rootstock is joined to the scion.

head — upper portion of vine consisting of the top of the trunk(s) and junction of the arms.

headland — area at the end of the rows used for vehicle turning.

hedging — pruning during the growing season, ususally removing only shoot tops and retaining only the nodes and leaves needed for adequate fruit and wood maturation.

hilling — protecting the graft union and a portion of the trunk with mounded soil in the fall.

internode — the portion of the stem between nodes.

inversion — generally, a departure from the usual increase or decrease in an atmospheric property with altitude. Specifically, it almost always refers to a temperature inversion, i.e., an increase in temperature with height, or to the layer within which such an increase occurs.

leaves — consist of the *blade,* the broad, flat part of the leaf, and the *petiole*, which is the stem-like structure that connects the leaf to the shoot (Hellman, 2003).

leeward — situated away from the wind; downwind; opposite of windward.

macroclimate — climate of a large geographical region, such as a continent.

mesoclimate — climatic conditions within 10 feet of the ground and peculiar to a local site.

microclimate — environment within a specific small area, such as a grapevine canopy.

necrosis — death.

node — conspicuous joints of shoots and canes. Count nodes have clearly defined internodes in both directions on the cane.

panicle — branching raceme.

pedicel — stem of an individual berry or flower.

periderm — bark.

pH — measure of hydrogen ion (H^+) content; expressed on a scale of 0-14. The pH scale is a logarithmic expression of an exponential function, which means that a change of one pH unit represents a tenfold change in concentration of hydrogen ions. Many of the effects of acids in wines depends on the concentration of hydrogen ion, and pH is a measure of the intensity of the acidity rather than the quantity of acids present as measured by titration (Watson, 2003).

phenology — branch of science dealing with the relations between climatic and periodic biological phenomena; grape phenological stages are described by Meir (2001). Early spring growth stages include budburst, first flat leaf, second flat leaf, and fourth flat leaf; each phenological stages has an associated critical temperature (Gardea, 1987).

phloem — food-conducting tissue. (Material generally flows from the shoots to the roots.)

pith — central part of a shoot or cane.

point quadrats — canopy transects or multiple transectional probes of the vine canopy.

pollinator — vine planted to supply pollen.

primordia — growing points of a bud.

pycnidia — fruiting structures of some fungi; pycnidia produce and release spores.

raceme — simple indeterminate inflorescence in which the flowers are borne on short stalks along a common axis (Westwood, 1978).

radiational frost — Temperatures below 32°F that occur during calm, clear weather. Cooling ground cools the air immediately next to the ground. Lower spots will have lower temperatures.

renewal region (of canopy) — part of the canopy where buds for next year's crop develop (usually the fruiting region).

rootstock — variety used to supply roots to the vine.

scion — above-graft part of a grafted vine, including leaf- and fruit-bearing parts.

self-fruitful — able to set fruit with pollen of the same variety.

shoot — succulent growth arising from a bud, including stem, leaves, and fruit.

soluble solids — measure of the maturity of grapes. It is also used to estimate the final alcohol levels in the wine, since over 90 percent of the T.S.S. in juice is composed of fermentable sugars (Carroll et al, 1991). The units customarily used in the United States to express soluble solids are ° Brix, where each degree is equal to 1 gram of sucrose per 100 grams of solution (Jackish, 1985).

sporangia — specialized spores of certain disease-causing fungi.

spur — cane that has been pruned to 1 to 4 nodes.

stomata — leaf pores that allow gas exchange between leaves and the environment.

suckers — unwanted shoots that grow from the crown area of the trunk (Hellman, 2003).

summer pruning — hedging or removing vegetation during the growing season.

temperature stratification (zonation) — important phenomenon related to radiational cooling and temperature inversions. Temperature stratification can occur if the air is cooled near the ground by contact with a cold earth's surface, and the air aloft will either not be affected, or an inversion will be established. By contrast, when the earth's surface is warmer (during the day) than the air, the air in contact with it will be warmed, while the air aloft will remain cool, which is why the temperature drops rapidly with increase in height.

tendril — stringlike, twining organs of shoots, located opposite leaves at nodes, that can coil around objects and provide shoot support.

terroir — English has no exact translation for the French word *terroir,* but it is a complex notion that deals with the influence of vineyard conditions on wines and their distinctiveness; *terroir* integrates several factors of the natural environment (soil, climate, topography), biological (variety, rootstock), and human (wine-making). Scientists cannot express quantitatively the relationship between a particular *terroir* and the characteristics of the wine produced from that *terroir,* but the concept of *terroir* is used to underpin the geographical demarcation of French viticultural areas (White, 2003).

total acidity — of a must or wine is expressed in the United States as though all the acid were tartaric acid and is reported either as a percentage or in grams per liter. Acidity is measured by a procedure known as titration (Jackish, 1985). Acids in the juice help prevent spoilage during fermentation, development of abnormal color, and flat taste of finished product (Carroll et al, 1991).

trunk — vertical support structure that connects the root system with the fruit-bearing wood of the vine.

unfortified wine — product is fermented naturally or with sugar, and does not exceed 17% alcohol.

vascular cambium — tissue of canes and older wood that generates new xylem and phloem cells annually.

véraison — the period or stage at which fruit begins a third stage of ripening characterized by softening, color change, and perceptible increases in sugar and decreases in acidity.

vine vigor — rate of shoot growth.

watersprouts — undesirable shoots arising from the upper regions of the trunk or from cordons (Hellman, 2003).

weather — state of the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness. Also, weather is the meteorological day-to-day variations of the atmosphere and their effects on life and human activity. It includes temperature, pressure, humidity, clouds, wind, precipitation and fog.

wet bulb — temperature is a measurement of the evaporative cooling power of the air and is the temperature air will cool to when water is evaporated into unsaturated air; wet bulb can be measured using a sling psychrometer.

windward — upwind, or the direction from which the wind is blowing; opposite of leeward.

wine labeling — labeling rules of the Federal Tax and Trade Bureau (TTB) require that: 1) *American wine* may not be labeled a vintage; 2) *Varietal wine* must be 75% by content made from that grape variety (except labrusca which must be at least 51%); 3) *North Carolina Wine* must be 75% North Carolina grapes; 4) *AVA* (American Viticultural Area Designation) must be 85% grapes from that AVA; 5) *Vintage wine* must be 95% grapes from that year; and 6) *Estate bottled wine* must be 100% grapes from winery-owned vineyards.

xylem — water-conducting tissue of wood. (Fluids generally flow from the roots to the shoots.)

zonation — see temperature stratification.

References

Ballard, J.K. and Proebsting, E.L. 1981. Frost and Frost Control in Washington Orchards, Washington State University Cooperative Extension, Pullman WA, Extension Bulletin 634, 27pp

Carroll, D. E., E. B. Poling, and R.G. Goldy. 1991. Wine-Grape Reference for North Carolina. N.C. Agricultural Research Service Bulletin. 480, North Carolina State University, p. 4.

Gardea, A.A. 1987 Freeze damage of 'Pinot noir' (*Vitis vinifera* L.) as affected by bud development, INA bacteria, and bacterial inhibitor. M.S. Thesis, Oregon State University, Corvallis.

Hellman, E.W. 2003. In: Oregon Viticulture, Grapevine Structure and Function, Editor, E.W. Hellman, Oregon State University, pp 5-19.

Jackisch, Phillip. 1985. Modern Winemaking. Cornell University Press, Ithaca and London, p. 46.

Meir, U. 2001. Grapevine. In: Growth stages of mono-and dicotylednous plants. BBCH Monograph. Federal Biological Research Centre for Agriculture and Forestry, Berlin, Germany.

Watson, Barney. 2003. In: Oregon Viticulture, Evaluation of Winegrape Maturity, Editor, E.W. Hellman, Oregon State University, p. 241.

Westwood, M.N. 1978. Temperate-zone Pomology. W. H. Freeman and Company, San Francisco, p. 375

White, Robert. 2003. Soils for Fine Wines. Oxford University Press, New York, pp 3-4.