Wyoming Grape Guide

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Barnyards & Backyards

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Chapter 1 - Introduction to Grape Growing in Wyoming

How would you describe Wyoming to someone who has never seen it? Those visiting parts of our state generally use words like empty, big, dry, and barren. Since before Wyoming became a territory, it has had the reputation of wide-open spaces full of short grass prairie, high plains deserts, and snowcapped mountains only suitable for raising livestock.

Were grape vineyards a part of your description? Wyoming does not have a reputation of producing grapes; however, many people do not know Wyoming has around 30 acres of grape production in the state (Fig. 1.1). That is a far cry from Wyoming's 1.06 million acres of hay production. Nonetheless, in the past several years there has been a lot of interest from hobbyists and niche market entrepreneurs in producing Wyoming grown grapes. Growing grapes comes with challenges in Wyoming. One of these is the harsh climate of Wyoming is not always suitable. In particular, Wyoming's cold winters, late spring, early fall freezes, and short growing seasons can be hard on a vineyard. On the other hand, Wyoming's hot, dry, arid climate provides perfect conditions for growing high quality grapes with little to no disease and pest pressures (Fig. 1.2). This manual has been

Figure 1.1 A grape vineyard in Wyoming

created in response to hobbyist and producer demand for more information to help them grow successful vineyards.

Plant Taxonomy

We humans tend to favor some kind of order and structure to our lives. Over the centuries, biologists have spent their lives understanding the natural world around them and attempting to organize it in a system that identifies all organisms, along with explaining the relationships among them. The first known attempt to classify plants was by Theophrastus, who was a student of Aristotle and Plato, in the 4th century B.C. Theophrastus used leaf characteristics to distinguish plants from each other and was able to classify nearly 500 plants into trees, shrubs, and herbs.

This system evolved over time to become the binomial nomenclature, or a two-name system, first introduced by Linnaeus during the 1700s. In this system, all organisms are identified using Latin names for the genus and species, for example, *Vitis vinifera* is the scientific name for European grapes, whereas *Vitis riparia* is the scientific name for riverbank grapes native to North America. The genus name describes a group of plants similar in morphological, biochemical, and genetic properties, whereas the species name identifies a population of plants within a genus that can be recognized and reproduced. Individuals within a species will interbreed freely in nature but do not usually interbreed well with other species.

Through cultivation of crops and selection of desirable traits, species have been further divided into smaller groups known as cultivars. The word cultivar can be used interchangeably with variety and designates a group of plants similar in appearance. They are propagated for specific characteristics that distinguish them from other individuals within the species. Typically, grapes are referred to by their cultivar names, such as Chardonnay, Merlot, Shiraz, Frontenac, Bluebell, Edelweiss, etc. As species and cultivars are identified, they are placed within the taxonomy of all organisms, which consist of the kingdom, class, order, family, and genus to represent where they fit in relation and lineage to all other organisms. There are over 60 species of grape plants with thousands of cultivars in the world. This amount of diversity gives growers the opportunity to find grape varieties that might successfully grow in their area.

Grape Taxonomy

- Kingdom: Plantae (plants)
  - Subkingdom: Tracheobionta (Vascular plants)
    - Superdivision: Spermatophyta (Seed plants)
      - Division: Magnoliophyta (Flowering plants)
        - Class: Magnoliopsida (Dicotyledons)
          - Subclass: Rosidae
            - Order: Rhamnales
              - Family: Vitaceae (Grape family)
                - Genus: Vitis L.

History of Grapes

Would it be a surprise to learn grapes are the world's number one fruit, based on tons produced? This is because grapes are a very diverse plants, which allows them to be grown in many countries, and they have numerous uses. Grapes are primarily produced for wine production, fresh juice, fresh fruit and dried fruit, but can also be used for concentrated juice, distilled liquors, grapeseed oils, anthocyanin pigments, and ethanol production.

Where did this magical fruit come from? Viticulture, or the culturing of grapes, is generally associated with the age of civilization itself. Archeologists can trace the cultivation of grapes as early as the Neolithic era, around 6500 B.C., from chemical analysis of ancient pottery. By 4000 B.C., grape growing had extended from Transcaucasia, the strip of land between the Black Sea and the Caspian Sea, to the Nile Delta in Egypt. Viticulture continued to expand with the Hittite's westward migration to Crete, Bosporus, and Thrace around 3000 B.C. The Greeks and Phoenicians brought grapes to the areas of Carthage, Sicily, Southern Italy, Spain, and France. In 1700 B.C., King Hammurabi of Babylon enacted one of the world's first liquor laws establishing rules for wine trading.

Figure 1.2 Grape vines growing vigorously

The migration of viticulture grew under the Roman Empire's rise and fall when it was spread throughout Europe and in particular to the valley of the Rhine and into Germany. During the fall of the Roman Empire around 1500 A.D., viticulture and wine making were primarily in monasteries (Fig. 1.3). However, the drinking of wine grew beyond the religious rites and entrenched itself as a social custom in society. Viticulture steadily grew through the 16th to the 20th centuries with wine, dried fruit, and fresh table grapes as the main commodities. The conquistadors brought viticulture to America, where explorers found native grapes thriving in the new lands. Grape production rapidly spread in California as well as in regions along the East Coast where European settlers were experimenting with varieties derived from native American grapes. Viticulture was a thriving industry until the imposition of prohibition in 1914, which almost decimated grape production and wine making in the United States. Grape production flourished

Figure 1.3 An old cellar used for aging wine

again following the repeal of Prohibition in 1933 with major production regions occurring along the West Coast and parts of the East Coast.

Climate has the largest influence on viticulture. Most of today's viticulture is found between 30 degrees and 50 degrees north and between 30 degrees and 50 degrees south latitudes. These latitudes correlate to minimum temperatures of 20 degrees Celsius and 10 degrees Celsius (68°F and 50°F, respectively), during the growing season. This results in the following grape growing regions:

- Europe (Italy, Spain, France, and Germany)
- North America (U.S., Canada, and Mexico)
- South America (Chile and Argentina)
- Australia and New Zealand
- South Asia (China and India)
- Africa (Algeria, Egypt, and South Africa)
- Middle East (Israel, Iran, Iraq, Oman, and Turkey)

Currently, 90 countries commercially produce grapes with 70 percent of production for wine, 28 percent table grapes, and 2 percent dried fruit. Worldwide grape production occurs on approximately 45 million acres with 75 million tons of fruit produced annually. Focusing on North America, there are about 1 million acres with approximately 7 million tons of grapes produced annually. Wine grapes, table grapes, fresh and concentrated juice and raisins are the primary markets in North America. There is a niche market known as ice wine, which is a very sweet dessert wine produced in Northeastern U.S. and Canada. North America is the center for the genetic diversity of the world's viticulture with 70 percent of the world's grape species grown here.

Surprisingly, there is grape production in every state with California, Washington, and New York dominating with 98 percent of the production. Wine is the bulk of the market followed by dried fruit and fresh fruit respectively. Grapes are the tenth most valuable U.S. agriculture crop, are the number one fruit crop, and contribute approximately $162 billion annually to the U.S. economy. Grapes account for 30 percent of the value of all fruit crops produced. The viticulture industry creates approximately 1.1 million jobs for the American workforce.

Chapter 2 - Grape Genetics and Varieties

Why is having some basic knowledge about grape genetics important? The answer is quite simple: it greatly assists in selecting the correct variety for the unique growing conditions in Wyoming. Grapevine production and quality is governed by the complex interaction of the grape variety with prevailing soil and climatic conditions. Since soil and climatic conditions cannot be changed, variety selection is one of the most critical factors for your vineyard's success.

As selecting a suitable variety for your area is critical to success, an understanding of basic grape genetics and taxonomy can help make these selections. The grapevine is a creeping vine that belongs to the **Vitaceae** family. Other notable plants in this family include the Virginia creeper and Boston ivy. Grape belongs to the genus **Vitis**, which contains more than 50 species from which several thousand grape varieties have been developed worldwide. Different species of grapevines have specific characteristics such as high yield and fruit quality, disease resistance, or cold tolerance that make them particularly attractive for the development of new varieties for specific production regions.

Grapes are classified based on their use for wine, table-fresh consumption (Fig. 2.1 and 2.2), processing into raisins, juice jam, jelly, or for use as rootstocks.

Rootstocks are not valued for their fruit characteristics but impart protection after grafting against soil borne insects, disease, and other unfavorable growing conditions such as drought, salinity, and heavy soils. A brief description of the important species and the varieties developed from them is particularly helpful in selecting varieties right for Wyoming production.

Species of Grapes

Vitis vinifera

This species is commonly known as the European bunch grape. It is believed to have originated in the Caucasus Mountains and then spread throughout the world. The species dominates grape production worldwide and is the majority of grape acreage (Fig. 2.3). The varieties from this species are characterized by clusters with several berries (40-200), thin skins, a wide array of aroma and flavors, and high sugar content. They are widely used for wine production, fresh consumption, and processed products such as juice and raisins. Varieties such as Chardonnay, Cabernet Sauvignon, Merlot, Pinot Noir, and Riesling

Figure 2.1 A *Vitis vinifera* white table grape variety

Figure 2.2 A *Vitis vinifera* red table grape variety

are highly valued for their wine, while table grape varieties such as Thompson Seedless, Flame Seedless, Perlette, and Superior Seedless are grown for fresh consumption and raisin production. Varieties from this species exhibit some undesirable characteristics such as susceptibility to fungal and bacterial diseases. Additionally, varieties in this species are very susceptible to cold/freezing temperatures, which is why they generally cannot be grown for production in Wyoming.

Figure 2.3 *Vitis vinifera*

Vitis riparia

This species is commonly known as the riverbank grape (Fig. 2.4). It is widely distributed throughout North America with its range extending from the southwest to the Canadian prairies. *V. riparia* is an extremely cold hardy species surviving to temperatures of -45 degrees Celsius (-49°F). Other desirable characteristics such as its ability to quickly acclimate/adjust to colder temperatures makes this an ideal species for development of cold-hardy grape varieties. *Vitis vinifera* and *Vitis riparia* are frequently used as parents for the development of a number of cold-hardy grape varieties.

Figure 2.4 *Vitis riparia*

Vitis labrusca

This species is native to eastern North America and is commonly known as the fox grape due to its "foxy" or earthy flavored grapes that produce large bunches (Fig. 2.5). An easy way to identify the species is the "slip skin" characteristic of the berries where the skin easily separates from the pulp in fully ripe berries. The species exhibits moderate cold hardiness and has been used as a parent along with *V. vinifera* for development of hybrid varieties valued for juice, jelly, and wine production. Famous examples of *V. labrusca*-derived hybrid varieties include 'Concord', 'Niagara', and 'Delaware' that are widely used for the production of processed products. Although varieties developed from this species can be grown in Wyoming, they might exhibit nutrient deficiency problems in soils with high pH.

Figure 2.5 *Vitis labrusca*

Vitis rotundifolia

This species is commonly known as the muscadine grape and is native to the southeastern United States (Fig. 2.6). An easy way to identify this species is the large berries, sometimes reaching the size of a small plum; however, in contrast to other species, cluster size is small, ranging from 2-10 berries. Varieties developed from this species are extremely drought tolerant, disease resistant, and extremely susceptible to low temperatures, making them difficult to grow in Wyoming.

Figure 2.6 *Vitis rotundifolia* (muscadine)

Vitis aestivalis

This species, commonly known as the summer grape, is widely distributed in the southern United States and is well known for its disease resistance. It has been used as a parent along with *V. vinifera* to produce varieties resistant to Pierce's disease, a plague that infects most *V. vinifera* varieties. Common varieties developed from this species are 'Blanc du Bois', 'Conquistador' and 'Norton'. These varieties cannot be successfully grown in Wyoming due to their lack of cold hardiness.

Grape Varieties Suitable for Production in Wyoming

Intensive breeding efforts in the past 50 years have led to developing several cold-hardy grape varieties, some of which are suitable for production in Wyoming. In general, any grapevine varieties that can be grown in USDA cold hardiness zones of 4b or below are suitable for production in Wyoming. Brief descriptions of some of the important cold-hardy varieties that can be grown in Wyoming are provided in Table 1, page 11. Yield data from cold-hardy grape variety trials at the University of Wyoming's Powell Research and Extension Center can be found in Appendix 1, page 77.

Grapevine Sources

Grapes are a perennial fruit crop, which means that, once planted, they produce fruit for a period of 15-20 years or more. Keeping this in mind, purchasing the best quality planting material available on the market to assure success from the initial planting is essential. Lower quality plant material can be a source of infected grapevines, which could lead to replanting the vineyard a few to several years into production.

A number of diseases can be transmitted during plant propagation from the mother stock vines. Viruses are the most commonly transmitted disease via infected propagation material.

Viruses may remain dormant in infected grapevines for several years. The grower may cultivate the vineyard for 8-10 years without being aware of this infection. After 8-10 years, signs of viral infection such as leaf rolling, incomplete cluster development, low sugar content in berries, and declining yields might be observed. At this point, the only option for the grower is to uproot and burn the vines. This may result in a huge loss of initial investment, time, and production. The transmission of crown gall disease through infected planting material can be another issue during vineyard establishment. Crown gall is caused by the bacterium

Agrobacterium. The bacteria genetically engineers plant cells and cause the cells to produce food and hormones, which results in rapid cell division and the subsequent formation of galls or tumors. Crown gall disease appears when grapevines are weakened due to adverse weather conditions such as a severe freeze event. Crown gall and other propagated diseases can be avoided by purchasing clean planting material certified disease-free. Some sources for purchasing grapevines are listed below:

Double A Vineyard, Fredonia NY
www.doubleavineyards.com

Inland Desert Nursery, Benton City WA
http://inlanddesert.com

North Eastern Vine Supply, West Pawlet, VT
https://nevinesupply.com

St. Francois Vineyard, Park Hills MO
http://www.stfrancoisvineyard.com

Winterhaven Vineyard and Nursery, Janesville MN
http://www.winterhavengrapevines.com

Seaway Cold Hardy grapevines, Evans Mills NY
http://www.seawaycoldhardygrapes.com/

Grafted Grapevine Nursery
http://www.graftedgrapevines.com

Figure 2.7 *Vitis* hybrid 'Frontenac'

Figure 2.8 *Vitis* hybrid 'Alpenglow'

Figure 2.9 *Vitis* hybrid 'Ives'

Figure 2.10 *Vitis* hybrid 'Marquette'

Figure 2.11 *Vitis* hybrid 'Brianna'

Figure 2.12 *Vitis* hybrid 'Osceola Muscat'

Table 1 Varieties Suitable for Production in Wyoming (Fig 2.7-2.12)

Variety name	Use	Cold hardiness zone	Vigor	Season duration	Trellis	Reference
Red Varieties						
Alpenglow	wine	4	medium	early	High-wire	1,2
Beta	juice, jelly, table	3	high	early	High-wire	1,2,3
Bluebell	juice, jelly, table	3	high	early	High-wire	1,2,3
Campbell Early	juice, table	4	medium	early	High-wire	1,2
Frontenac	wine	3	high	late	High-wire	1,2,3
Ives	juice, jelly, wine	4	high	late	High-wire	1
King of the north	jelly, juice, table	3	high	mid-season	High-wire	1,2
Landot	wine	4	medium	early	High-wire/VSP	1
Leon Millot	wine	4	medium	early	High-wire	1
Marachal Foch	wine	4	medium	early	High-wire	1,2
Marquette	wine	4	medium	early	High-wire/VSP	1,3
Reliance	table (seedless)	5	medium	early	High-wire	1
Swenson red	table, wine	4	high	mid-season	High-wire	1,3
Somerset seedless	table (seedless)	4	medium	early	High-wire	1
Valiant	juice, wine, table	3	high	early	High-wire	1
White Varieties						
Brianna	table, wine	3	medium	early	High-wire	1
Elvira	wine	3	high	mid-season	High-wire	1
Edelweiss	jelly, juice, table, wine	4	high	early	High-wire	1,3
Kay Gray	table, wine	3	high	early	High-wire	1
LaCrescent	wine	3	medium	early	High-wire	1,3
LaCrosse	wine	4	high	early	High-wire	1,2
Osceola Muscat	wine	4	medium	early	High-wire	1,2
Swenson White	table, wine	4	medium	mid-season	High-wire	1
Skujins	wine	3	low	early	High-wire	1

1. Double A Vineyards, (www.doubleavineyards.com)
2. *A Review of Cold-Climate Cultivars*, Iowa State University, Extension and Outreach (Hort 3040)
3. University of Minnesota, Grape Breeding Program (https://mnhardy.umn.edu/varieties/fruit/grapes)

Chapter 3 - Site Selection

Site location is the first and foremost decision when planning a vineyard. Selecting a quality site will pay large dividends to the success of the vineyard because once a site is chosen, certain influencing factors, such as wind direction, cannot be easily changed. Having the site location picked out and critical infrastructure installed well before planting grapevines is highly recommended.

How do you select a quality site in Wyoming? Wyoming climatic conditions are characterized by short growing seasons, hot summers, and very cold/freezing winters. Due to wide variations in topography and elevation statewide dividing the state into homogenous climatological zones difficult, so it is not easy to say that this or that area of the state is great for grape growing. Instead, each area should be evaluated for its grape growing characteristics.

Soil type and quality, local climate, topography, microclimate, and land history are the major considerations. These influencing factors are also interconnected and related. Understanding them and how they affect the site will help you select the best possible site, which, in turn will give you the best chances of success.

Determine the purpose of growing grapes and/or a vineyard to begin the site assessment process. Why do you want to grow grapes? What are the grapes going to be used for? The purpose ultimately determines the amount of space needed. For example, growing three or four grapevines to cover an arbor for aesthetic reasons is going to take significantly less space, cost, and effort to maintain than a vineyard (acre or larger) of grapes grown for production for wine, juice, or other uses. No matter the purpose, the same influencing factors affect the grapevines. How important is berry quality to your purpose? Is the vineyard going to be a hobby or a full-fledged business? To clarify your thoughts, try writing down the purpose of your vineyard with as much detail as possible.

Understanding the purpose will provide the parameters to use for further planning. It can also reduce the odds the vineyard will need to be moved or modified once it has been established. Planning and establishing a vineyard correctly the first time increases the chance of success while eliminating additional labor and costs in correcting a vineyard site later. This does not mean a vineyard cannot be expanded or built in stages. Sites can be chosen where future expansion would be feasible.

Soil Texture and Quality

Now that the purpose and a rough size of the future vineyard is known, start assessing site locations. Soil type and quality are the first influencing factors to understand. Although high quality soil conditions are sometimes considered vital for production of fine wine, grapes are grown over a wide variety of soils and wide range of soil conditions. Vineyards can often be established on sites considered unsuitable for most other crops. However, soils are an incredibly complex system and can be critical to the quality of the end product. The following is a brief summary of soils and how they relate to grape growing.

Soil type is the amount of sand, silt, and clay found in the soil. Two different methods can be used to determine soil type. The first is to submit a soil sample to a laboratory for analysis. This is a great option if samples are being submitted for fertility analysis anyway or if an individual does not feel confident to assess their own soil with the second method – texture-by-feel method.

This method is not as accurate as a laboratory test but can be done by the landowner for free and is accurate enough to make decisions about soil type. Both methods compare results to the soil triangle (Fig. 3.1) to classify the soil as a clay, loam, sand, silt, or another classification in between. Generally speaking, most grapevine roots grow within the top 3 feet of the soil. This rooting zone is where soil sampling and texturing efforts need to focus.

So what is the ideal soil for growing grapes? The most desirable soils for grape cultivation are well-drained soils. Well-drained soils provide a balance of good drainage while still having adequate moisture holding capacity. This type of soil is important because grapes perform poorly or do not survive when their roots are constantly saturated

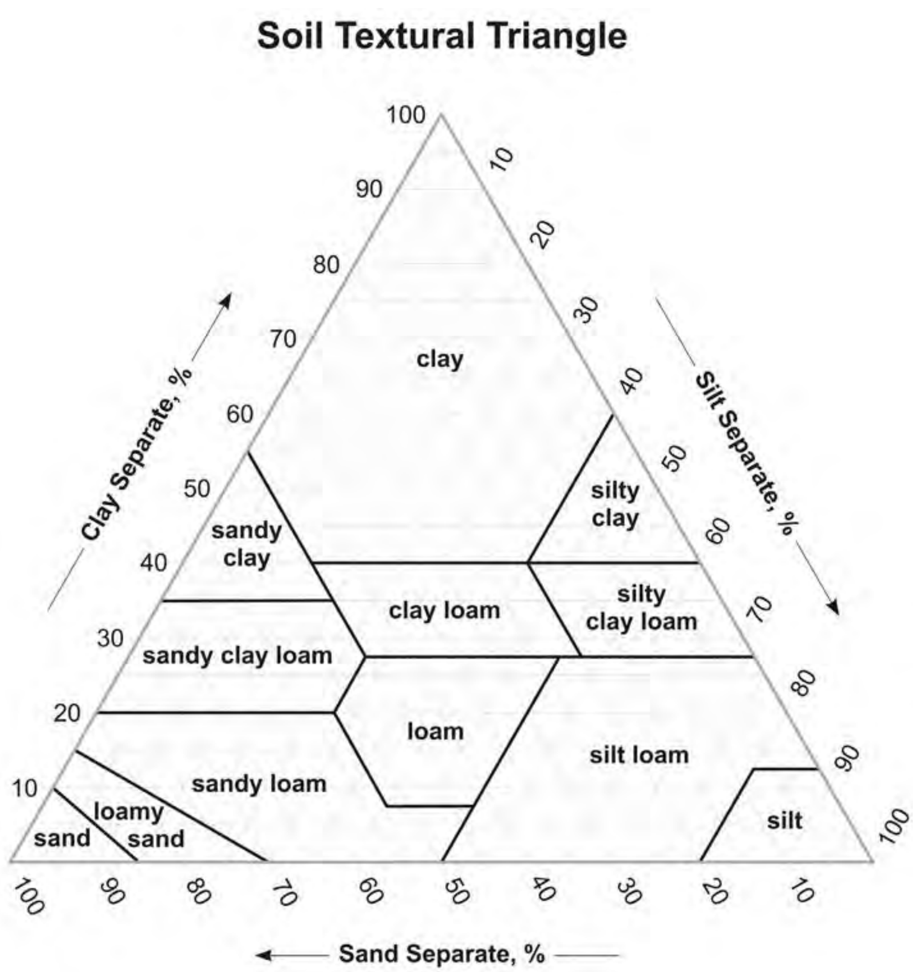


Figure 3.1 Soil triangle is used to determine soil texture Image: NRCS

with water. Grape roots need adequate oxygen to survive, which well-drained soils provide.

The reason grapes can be grown in a wide variety of soil types is that a majority of soils provide good drainage and moisture holding capacity, except for heavy clay soils. Higher clay content in a soil results in a decrease in drainage ability; however, there is also an increase in water and nutrient holding capacity. There are concerns that clay-type soils can also restrict root growth, which would inhibit plant vigor and growth. Adding organic matter can help manage this issue, though it will not completely eliminate it. More sand content in the soil means drainage ability increases while water and nutrient holding capacity decreases (Fig. 3.2). Of the two, drainage is considered to be the most critical attribute because water holding capacity can be managed with irrigation scheduling (more frequent irrigation on sandier soils will maintain adequate moisture levels). Loam soil types (clay loam, sandy loam, loam and sandy clay loam) are generally considered the happy medium of soils and is a balance of sand, silt, and clay.

Soil textures are unchangeable, meaning the soil type you have is the soil type you need to work with. Adding sand or clay to the soil to improve its characteristics will most likely result in creating a natural cement and cost the vineyard more money with no benefit. However, unlike soil texture, certain characteristics of soil quality can be improved.

Figure 3.2 A vineyard established in sandy soil

Soil quality is the characteristics of soil that maintain plant and animal productivity. Soil organic matter, fertility, salinity, and pH aid in the determination of soil quality. Fortunately, grapes do not require extremely fertile soils to be productive. Grapes perform in a wide range of soil qualities meaning there is really no standard for soil quality, especially for organic matter, fertility, and pH. Nonetheless, higher soil quality lends itself to growing healthier and more productive plants. A higher quality soil would be a soil with an organic matter level of 2 percent or higher and a pH level between 6 to 7. One soil quality factor that is of greater concern is salinity. At this point, grapes can only tolerate moderate to low salinity levels, although this can be alleviated to a certain extent by choice of rootstocks. However, it appears grape breeders will be able to offer more saline tolerant varieties/rootstocks in the near future.

Soil quality can be determined by laboratory analysis or do-it-yourself analysis kits. Laboratory results are more accurate and provide more detailed answers, whereas do-it-yourself kits are cheaper and provide general information, but the results are not always reliable.

So where do Wyoming soils fit in the scheme of grape production? Wyoming has a wide range of soil types, from sandy soils in the southeast (Cheyenne) to the clay soils in the north (Sheridan), and the bentonite hills in the Big Horn Basin (Lovell). Wyoming's native soils are typically considered underdeveloped, young soils with a poorly developed topsoil layer, are low in organic matter and nitrogen, and tend to show a close relationship to their parent material. These soils can range in pH slightly below neutral to high alkalinity and can have varying degrees of salinity.

Most soils found within Wyoming are created by alluvial wash, debris-laden waters at the mouth of canyons or ravines or by glacial deposit, which is soil deposited from receding glaciers. This means Wyoming soils are a jumble of generally well-drained material and can be potentially suitable for growing grapes. The low organic matter can be managed by utilizing compost during planting, while fertility can be managed through adding fertilizers and increasing soil organic matter. Some places within Wyoming that have extremely heavy clay soils and/or high salinity, such as alkali spots, may not be suitable for grapes.

Local Climate

The climate for your area is the second influencing factor. Climate is the generally prevailing weather conditions of a region monitored as temperature, air pressure, humidity, precipitation, sunshine, cloudiness, and winds averaged over multiple years. The following is a brief summary of Wyoming's climate and factors affecting it.

The basin and range geography found throughout the state are some of the most important factors affecting Wyoming's climate. Wyoming has several mountain ranges (the "range" in "basin and range geography") generally running north and south, with large, high plains deserts (basins) in between the mountain ranges. The High Plains desert covers more land surface in Wyoming than the mountain ranges. The mountain ranges are physical barriers to the westerly prevailing winds, which brings moisture from the Pacific Ocean. The

Wyoming Geography Facts

The state of Wyoming covers 97,914 ft^2 of land.

Water covers 714 ft^2.

The average elevation is 6,700 ft.

The lowest point is 3,125 ft. in the Northwest corner along the South Dakota border.

The highest point is 13,785 ft., Gannett Peak in the Wind River Range.

mountains force air currents up in elevation to clear the mountains, resulting in a majority of the moisture falling out on the western slopes and creating a rain shadow effect for the eastern sides. This rain shadow effect, having little precipitation, is the reason for the majority of Wyoming's semiarid climate east of the mountains.

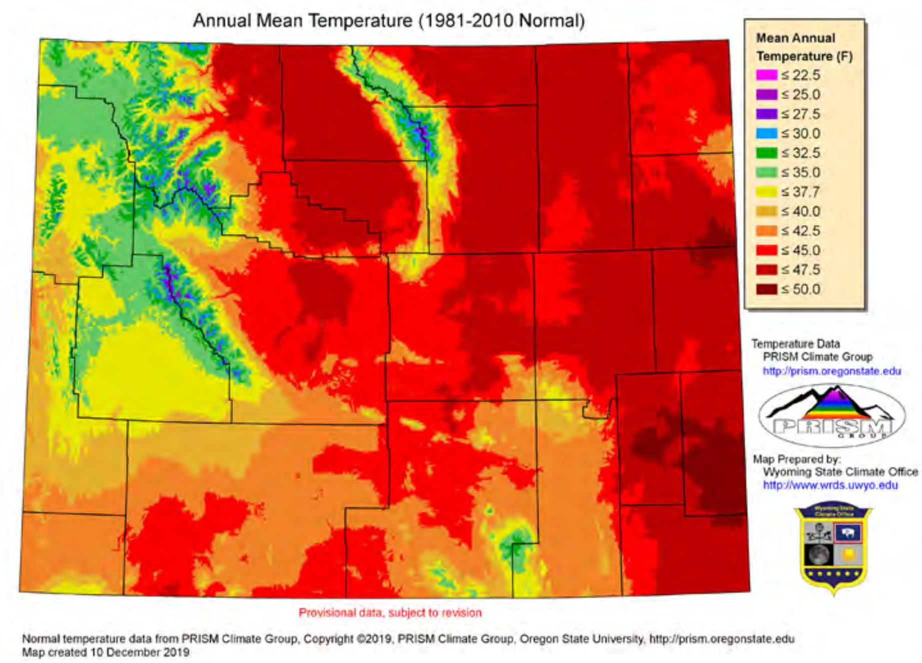


Figure 3.3 Annual mean temperature for the state of Wyoming

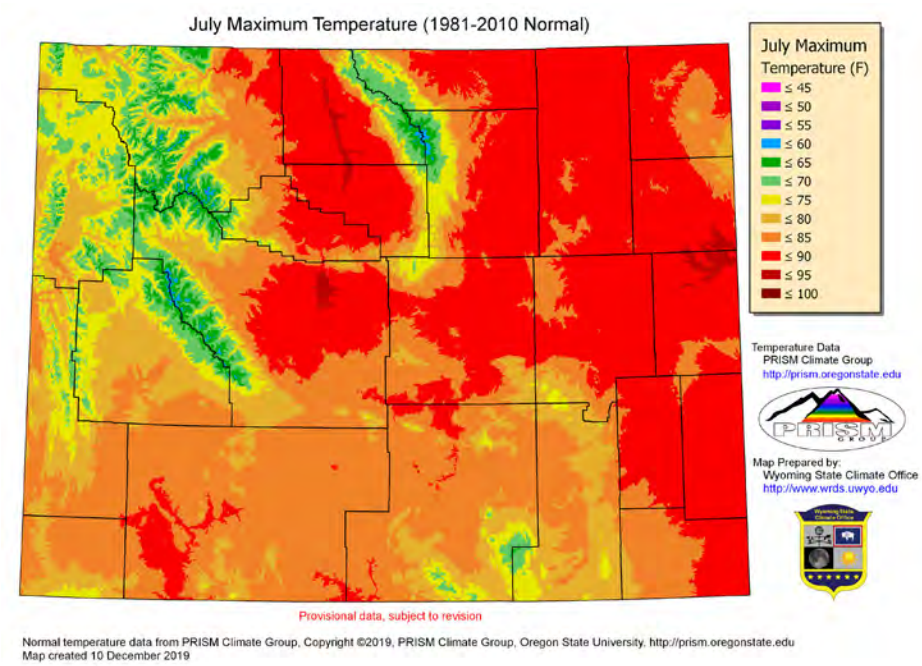


Figure 3.4 July average maximum temperature for the state of Wyoming

Wyoming's climate is considered relatively cool mainly because of elevation. Wyoming has an annual average temperature of 45.6 degrees Fahrenheit, with an average maximum temperature in July ranging between 85-95 degrees Fahrenheit (Fig. 3.3 and 3.4). The warmest parts of the state are in the Bighorn Basin and the lower elevations of the central and northeastern parts of the states. The winter season experiences rapid and frequent changes between mild weather and cold spells. January is typically the coldest month with minimum temperature range mostly from 5-10 degrees Fahrenheit. The coldest areas in the state are the western valleys, Big Piney being one of these locations. Wyoming also sees temperature fluctuations from daytime highs and nighttime lows throughout all seasons. Late freezes in the spring and early freezes in the fall are very common, resulting in rather long winters and short growing seasons. The average growing season, or the freeze-free period, is approximately 125 days for the principle agriculture areas. This number can be misleading because there is a large variance in growing seasons around the state. For example, Star Valley and Jackson Hole have very short growing seasons since there is always a threat of a freeze.

Wyoming's temperatures are a result of sunshine the state receives. On an annual average, Wyoming experiences sunshine 64 percent of the year, with a majority of those days during the summer (75 percent of summer days and 60 percent of days in the winter). Summer days in many locations in the state characteristically begin with clear sunny mornings which then develop into afternoons with a chance of scattered showers. Because of Wyoming's elevation and very small amounts of fog, haze, and smoke, the intensity of sunshine is unusually high. This large amount of intense sunshine drives Wyoming's temperatures and creates the very low relative humidity experienced in the state. During the hot summer days, humidity can be about 25 percent and then climb to around 65 or 75 percent late in the night. However, in the winter, humidity levels can be well below 10 percent.

Wyoming Temperature Facts

Highest recorded temperature is 116°F
Lowest recorded temperature is -66°F
This is a 182°F span between its all-time highest and lowest reading.

Wind is another factor influencing humidity. There is no denying it, Wyoming is windy, especially during the winter. The typical prevailing wind direction varies from west to southwest to northwest and can be determined by local terrain. These prevailing winds are responsible for bringing Wyoming its moisture from the West Coast.

Wyoming is considered a semiarid climate; however, this does not depict the variation in precipitation from one location to another. Generally speaking, the mountain ranges and higher elevations usually get more rainfall. A snapshot of annual precipitation around the state would look as follows: the driest part of the state can be found in portions of the Bighorn Basin with 5 to 8 inches, the southwest portion receives around 7 to 10 inches, the northeast corner of the state getting 12 to 16 inches and the southeast receiving 13 to 18 inches. Understand that a good portion of Wyoming's precipitation occurs in spring and early summer. The rather low precipitation throughout a majority of the state is the main reason Wyoming's crop production relies heavily on the snow melt-fed streams and rivers for adequate irrigation water.

How does Wyoming climate fit for growing grapes? Wyoming's climate is not the most favorable for growing grapes. The cold, harsh winters, short growing season, late springs, and early fall freezes, and the dry periods during summers are the biggest concerns. Planting only cold hardy varieties gives the vineyard the best chance of surviving the winters and being able to produce fruit in the short growing season; however, even these varieties can succumb to the extremely cold and harsh winters that hit Wyoming once every 30 years or more. A constant supply of water supports healthy grapevines that in turn increases the vines' chance of surviving the winter. Reliable irrigation water is the best way to guarantee a constant water supply for the vineyard. Unfortunately, there is little management that can protect against late spring or early fall freezes. These unfortunate events occur at the most vulnerable growth stages for the plant. Grapevines lose their ability to withstand freezing temperatures once they break dormancy.

Local Topography and Microclimates

Local topography and the microclimate of the actual vineyard area is the third influencing factor to understand. Topography and surrounding structures, such as buildings, shelter belts, trees, or fences near or adjacent to the vineyard influence the microclimate (Fig. 3.5). A microclimate is the climate in the surrounding area of the grapevine canopy and soil. Microclimates can have a positive or negative impact on vine health, growth, and development resulting in differing berry quality and yield. Topography and other surrounding structures influence the air currents and wind, length of direct sunlight, humidity, temperature, and other microclimate factors in the vineyard.

Figure 3.5 A vineyard established on a steep slope

Figure 3.6 A vineyard established with terracing to prevent soil erosion

Will the vineyard be on a hill or flat ground? Mountains, hills, or slopes in the topography channel the air flow and winds of the area. Air flowing up and down a slope changes with temperature. Typically in the morning, air is flowing downhill because cold air sinks. Then as the day warms, the air warms up and begins to flow uphill because warm air rises. This process then reverses in the evening as air temperature drops. If a vineyard is established parallel to the slope (Fig. 3.6), then air currents can push the cold air through the vineyard to lower areas leaving slightly warmer air within the vineyard resulting in increased winter survival of grapevines. During the summer, this type of air flow can decrease the humidity and temperature and increase the evaporation in the vineyard. This can be beneficial because low humidity inhibits disease establishment and growth and also offer a cooling effect to the summer's heat. This can also result in drying a vineyard out further in Wyoming's arid climate. However if a vineyard is established on contour with the hill, this can block air flow through the vineyard resulting in potential higher temperatures, higher humidity, and wetter conditions. Slight subtleties in where and how a vineyard is established can have big impacts to vineyard microclimates in positive or negative ways.

A vineyard at the bottom of topography or slope can be affected by the cold air settling into the vineyard. If the vineyard is on flat ground, not directly adjacent to topography, then there will be no up or down air currents that will affect the microclimate. If the vineyard is at the bottom of a slope, then the coldest air will sink and settle into the vineyard, potentially increasing the likelihood of cold damage and/or decreasing winter survival of grapevines (Fig. 3.7).

If the vineyard is on flat ground with no significant topography around it, then air currents are directed by wind and other structures, such as buildings, trees, fences, etc., which determine the effects of air currents on the microclimate. As a general rule of thumb, air movement (air currents and wind) in a vineyard decreases warm temperatures and humidity and dries out the vines while also driving out cold air during winter. If a vineyard is protected from air movement, then the reverse happens; increase in warm temperatures and humidity, vines do not dry out as fast, and cold air is not moved out of the vineyard during winter. Of course, the amount of impact an air current has on the microclimate is dependent on how fast it moves, frequency, and duration of the event. The vineyard's individual situation determines the significance of impact and if changes can be made to improve the microclimate of the vineyard.

Would the planned vineyard be on a north, south, east, or west aspect? Aspect is the position of an object in terms of direction to others. The vineyard's aspect to large structures and hills is important to evaluate because this can significantly affect the microclimate. Objects can affect the duration and intensity of sunshine on the vineyard resulting in drier or wetter conditions. A northern aspect on a hill or side of a large structure (building, trees, fence, etc.) will create a cooler and wetter microclimate because of the shading of direct sunshine. A southern aspect on a hill or side of a large structure will create a warmer, drier microclimate because of the direct intense sunshine that hits the area.

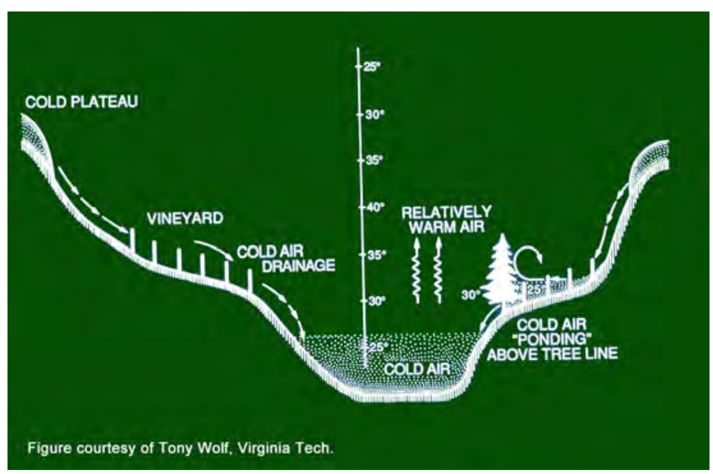


Figure 3.7 Diagram showing how air flows and temperatures change based on topography

An eastern or western aspect on a hill or side of a large structure will create a moderate microclimate between the southern and northern aspect microclimates because it receives half direct sunshine and half shading.

Another factor that effects microclimates would be waterbodies, in the form of lakes and rivers (Fig. 3.8). Water bodies buffer temperatures and temperature fluctuations to the land surrounding it. The closer a vineyard is to a water body, the more influence a water body has on the microclimate. Also, the larger the body of water, the more land surface is affected. Generally speaking, water bodies reduce the risk of winter cold hazard, late spring and early fall frosts, moderate summer and winter temperatures, and decrease temperature fluctuations.

Figure 3.8 A vineyard established near a large water body

So how does local topography and microclimates affect grapevines in Wyoming? The cold, harsh winters, short growing seasons, late spring and early fall freezes (Fig. 3.9), and the dry periods during summers are the biggest concerns. Microclimates are a potential management tool for minimizing these factors. Recommendations in Wyoming usually are that vineyards be planted on a southern aspect to capture the direct, intense sunshine to maximize the short growing season and decrease the potential for cold damage to vines. Vineyards can also benefit from blocking the predominant winds, which creates a little wetter/more humid microclimate for summer and potentially warmer conditions during winter. Again, most predominant winds are west or northwest; however, this could be different for individual locations in the state.

Figure 3.9 Cold damage in grapevines from an unseasonal freeze event

Land Knowledge

The fourth and final influencing factor to understand would be detailed knowledge of the specific spot of the vineyard. Useful information would be crop history of the land, past pesticide use, disease and pest (including wildlife) history, zoning laws, local restrictions, and proximity to markets and labor forces. Understanding the land history prior to establishing a vineyard prevents possible failures due to poor soil conditions, potential disease issues, and carryover of selected pesticides that would kill grapevines before they were able to get established (Fig. 3.10). Zoning laws and local restrictions along with proximity to markets and labor forces are fairly self-explanatory. We do not want to incur the expense of establishing a vineyard to find out it is illegal and needs removed or that we are not able to sell the produce or manage the vineyard.

As for Wyoming, the biggest concerns for this influencing factor would be wildlife damage, small markets, and low labor force. Wyoming is known for its abundance of wildlife: deer, antelope, elk, bears,

Figure 3.10 Herbicide damage in grapevines

raccoons, mice, rabbits, and birds to name a few. Most of the large mammals such as deer, elk, bears, etc., can be managed by installing a strong fence. Typically, fences need to be a minimum of 6 feet tall and made of woven wire or other solid material. Unfortunately, a fence of this type is expensive to construct and maintain. Traps, pesticides, and other control means are typically needed for animals such as raccoons, rabbits, mice, voles, and others. Plastic fencing that is commercially sold as game fence can be cheaper than metal fencing, but rodents are able to chew through the plastic. As for birds, netting or scare tactics such as fake owls, eyes, and scarecrows can be used to deter them. Always check local wildlife regulations to understand legal methods for handling wildlife.

The current markets in Wyoming for grapes would be two wineries and niche market sales such as farmers markets or value-added products (jelly). Unfortunately, a potential concern is the distance to commercial markets, which can significantly decrease the profitability of a vineyard. Wyoming's high labor cost and low labor force could also have a negative impact on the feasibility of making a viable business from the vineyard. This should all be assessed prior to investing heavily into a vineyard as a business.

Chapter 4 - Vineyard Establishment and Planting

You've identified the site and the grape varieties. Now is the exciting time of installing and establishing the vineyard (Fig. 4.1). Grapes are perennial vines. Any modifications to the site location and microclimate should be done prior to planting. A strong support structure should be established to help them grow. Modifications to the site location may include things like installing waterlines for the irrigation system, removing trees, bushes, and other vegetation, amending the soil, controlling weeds, installing a trellis system, and fencing. Grapevines are the last thing installed in a vineyard. This will prevent poor establishment or death of vines due to physical damage during installation of the vineyard or by being accidentally sprayed by a harmful pesticide.

For most situations, especially large vineyards, creating a detailed plan of the needed work to prepare and plant the vineyard and prioritizing the order of this work can make for more efficient efforts and keep different parts from overstepping each other. Below is an example of a work plan; this can be modified to fit your specific vineyard.

1. Mow all vegetation at the site.
2. Auger holes for the trellis posts and for grapevines.
3. Install trellis posts.
4. Install landscaping fabric the length of the trellis row.
5. Install trellis wire.
6. Trench in the irrigation trunk line and laterals for all trellis rows.
7. Install the perimeter fence and gate.
8. Burn holes in landscaping fabric for planting the grapevines.
9. Install one drip emitter off of the lateral line for each grapevine.
10. Test irrigation system and hydrate the ground to a moist condition, if needed, prior to planting.
11. Pull or spray weeds.
12. Plant grapevines and irrigate immediately.

Trellis Systems

Traditionally, commercial vineyards are grown on trellises. Trellises are recommended for managing a large number of vines (more than 10); however, traditional trellises may not always work for everyone's situation, especially hobbyists who only have room for a few vines. If a trellis is not feasible or desired in your situation, then the support system needs to be stable and strong enough to support heavy, mature grapevines that exert a lot of force on the structure. Forces such as wind, rain, and snow can put additional stress on support structures.

Figure 4.1 A newly planted vineyard on a vertical shoot positioning (VSP) trellis system

Figure 4.2 A mature table grape vineyard on a VSP trellis system

Figure 4.3 A mature wine grape vineyard on a VSP trellis system

Trellis systems are a large portion of the expense of establishing a vineyard. Today, trellising alone can cost from $2,000 to $8,000 per acre. The cost depends on trellis type, local material costs, and additional supports put in the trellis. Do not cut corners or costs on building the trellis. It will usually cost more money and time to fix it than to build it correctly the first time. Trellises should be built to last. Paying for quality materials and installation will pay off over the life of the trellis.

What type of trellis should be installed? There are many different trellis types: Vertical-Shoot-Position (VSP), Two Wire Vertical, High Wire Cordon, Smart Dyson, Smart Henry, and some even divide the canopy. Each trellis system is structured differently to accommodate different types of training methods and varieties (Fig. 4.2-4.4). The main differences among trellis systems is the height, number, and location of the wires, along with the use of wire spreaders, support of wires, end posts, and anchorage for end posts.

How to decide which system is best? The grape varieties grown influence the type of trellis needed. In Wyoming, the varieties that can be grown do the best on the High Cordon or the Geneva Double systems because of their drooping/downward growth habit.

Other trellis systems can be used or modified as needed to train grapes as long as they allow for the downward growth habit of the vine. Plan on the top wire, which is the fruit bearing wire, being 5 to 6 feet tall (Fig. 4.5) and 12-gauge wire. This type of trellis system gets the grapevines off the ground and away from the coldest air, which can reduce cold damage to the vine. Install the trellis wire on the wind side of the post. Training the vines to the wind side of the wire can also be beneficial. This reduces wear and tear on the trellis and damage to the vines because the vines are being blown into the support system of the trellis and not pulled away from it.

Let's discuss the difference between the High Wire Cordon and the Geneva Double Curtain systems. The High Wire Cordon system (Fig. 4.6) is one of the simplest and cheapest trellis systems because there are typically two wires (one wire at 18 inches and one wire at the top) attached directly to the posts, and no additional arms or supports need to be mounted like in the Geneva Double Curtain. End posts anchor the trellis systems and line posts within the trellis support the wire. Posts are 6 feet high with the fruit bearing wire secured to the tops of the posts, while a second wire is mounted on the side of the post at 18 inches, mainly supporting a drip irrigation lateral. A third wire can also be mounted 4 feet high, if more support is desired. For this training system, the head of the grapevine is established at the top wire, in this case also called the fruit bearing wire, and a cordon is trained down each direction

Figure 4.4 A wine grape vineyard on a four arm kniffin trellis system

Figure 4.5 A young grapevine trained on a high wire cordon training system

Figure 4.6 A dormant grapevine on a high wire cordon training system

Figure 4.7 A view down the length of a Geneva Double Curtain (GDC) training system

Figure 4.8 An end view of a GDC training system

Figure 4.9 Line post installation in a vineyard

of the wire. The canes then hang vertically to the ground in a single curtain of vegetation. The spacing between trellis rows is 10 to 12 feet apart, post spacing within the row is 20 feet, and vine spacing is between 6 to 8 feet.

The **Geneva Double Curtain** system is more elaborate and expensive because more materials are needed to create the double curtain system (Fig. 4.7). However, this system can produce higher yields than the High Wire Cordon or other single curtain systems because more leaves and clusters are exposed to sunlight resulting in the higher yield bump. The Geneva Double Curtain system uses three wires: two fruit bearing and one trunk support. There are end posts that anchor the trellis system and line posts within the trellis that support the wire. Posts should be 6 feet high, and the trunk support wire is attached directly to the posts at 4½ feet. Use wire-spreading arms, either metal or wood, to hold a fruit bearing wire to each side of the posts at 6 feet and with 3½ to 4 feet separation between the two fruit bearing wires (Fig. 4.8). A fourth wire is mounted on the side of the post at 18 inches, mainly to support a drip irrigation lateral. This keeps the lateral out of reach from mechanical weeding and rodents. Grape vines are trained up the center of the trellis with the trunk loosely secured to the trunk wire and the head ending on one fruit bearing wire. The cordon is trained down each direction of the wire. Grapevines are trained to the alternate fruit bearing wire as one progresses down the trellis. The canes of one individual grapevine hang vertically to the ground on one fruit bearing wire. The spacing between trellis rows is 11 to 12 feet apart, post spacing within the row is 20 feet, and vine spacing is 6 to 8 feet.

How long should a trellis be? Trellises can be any length that is desired with the most confining factor being the physical space of the land. As for commercial vineyards, the minimum trellis size is around 120 feet with the maximum 600 feet long. A trellis should not exceed 600 feet because the weight on the trellis exerts enough force to pull the end posts and anchors out of the ground, ruining the trellis system (Fig. 4.9).

If done correctly, trellises should create a long wall of vegetation, and this results in a shadow. The ideal spacing should be a 1:1 ratio between trellis height and row width, such as a trellis 6 feet high and 6 feet between rows. Because of these shadows, does the orientation of the trellises matter? The simple answer is yes! The complex answer is it depends. This topic does not have a straight answer because local climate, microclimate, and topography all are deciding factors. In terms of maximizing sunlight (because this is directly correlated to yield), some argue a north and south orientation provides the most exposure because the vines receive sunlight on both sides of the canopy. While others argue an east and west orientation receives no less sunlight because plants grow toward sunlight and have full exposure throughout the day. The purpose of row spacing, the space between trellises, is to space rows far enough apart they do not shadow the next trellis, while also making best use of the land space available. Again, since cold damage and short growing seasons are the biggest concerns for growing grapes in Wyoming, selecting the orientation of the rows should be made by first considering the effects of row orientation on the microclimate in the vineyard and choosing one that will reduce the effects of cold damage. Maximizing the growing season should be the second consideration.

The time to get a materials list compiled is when the trellis type, number of rows, and length of rows has been determined. What items are needed to install a trellis? This depends on the type of trellis constructed, cost of materials, preference on strength, and how end posts will be anchored. Trellises are not always a cookie cutter system because people have their own preferences on how to build them cheaper, stronger, and incorporate other inventive ideas. The following explains individual items and anchor options used in trellis construction.

Figure 4.10 Line post installation in a vineyard

Figure 4.11 Wire tightener

Figure 4.12 Side view of an end post and anchor wire

Posts

There are two options generally used for posts, **wood** and **T-posts** (metal), with wood posts generally costing more (Fig. 4.10). Large-diameter wood posts, 6 inches or bigger, are extremely useful for end posts and anchoring, while smaller diameter wood posts, minimum 4 inches, and T-posts can be used for line posts. Wood posts should be buried into the ground at least 2 feet, while end posts should be buried deeper or cemented in place in addition to being anchored.

Wire

Use **high tensile, aluminum or galvanized-coated, 12.5-gauge wire** because of their high strength and non-corrosive properties, especially for any double curtain trellis (Fig. 4.7). Other types of wires, especially non-coated types, will sag with time and eventually need replaced on a regular basis, resulting in vine damage.

Wire tightener

This is an item used in fencing to put tension on a wire. One end of the wire is secured to the wire tightener (Figure 4.11) and the other end of the wire is put in the roller and rolled until the desired tension is established. These are handy for retightening wires annually as they sag over time, although not necessary. The wire is wrapped around posts and tightened with fence stretchers before wire tighteners are used.

Cable

Anchor cable can be a unique system available through vineyard supply stores or just smooth wire from a fencing supply store (Fig. 4.12). The unique cable system comes with cable and a device called a gripple. The specialized gripple tool is needed to tighten the wire through the gripple and when released, the gripple does not let the cable slide back through. Smooth wire and tighteners are other options.

Anchors

There are traditionally two anchor systems used in vineyards. The first is a **metal earth anchor** driven into the ground or anchored in cement (Fig. 4.13 and 4.14). The second is using a **wood post** to anchor the end of the wire.

Straight post with anchor (Fig. 4.15) – A large-diameter wood post is put vertically level in the ground and attached with a cable system to an anchor (metal or wood) at a 45 degree angle on the opposite side of the post than the trellis.

Inclined post with anchor (Fig. 4.16) – A large-diameter wood post is put at an angle away from the trellis at roughly a 60 degree angle and attached with a cable system to an earth anchor at a 45 or 60 degree angle on the opposite side of the post than the trellis.

Double end post – Also called an H-brace in fencing, this buries two large-diameter wood posts, both posts are similar in diameter, at least 6 feet from each other with a 3-inch brace rail nailed between them approximately a foot from the top of the post. Smooth wire is then wrapped from the bottom of the outside post to above the brace rail on the inside post. This smooth wire is twisted with a metal rod or stick, 1 to 2 inches in diameter, to tighten the brace. The twister bar is then secured to the brace rail where it naturally rests because of the twist.

Figure 4.13 An uninstalled earth anchor

Figure 4.14 Installed earth anchor

Figure 4.15 Straight end post with anchor

Figure 4.16 Inclined end post with anchor

Staples

There are special staples sold by vineyard supply stores that have a loop in the staple that allows the wire to rest within, preventing the staple from pinching or cutting the wire. This staple also allows the wire to slide freely when the wire is retightened. Normal fencing staples can be used, although they can cut the wire and do not allow the wire to slide when tightening, if installed too tightly.

Wire vises

A wire vise is a conical-shaped piece that has a spring-loaded pincher inside that grabs the wire and holds it in place. A hole must be drilled into a wood post for the wire to go through and also to anchor this wire vise. The wire is then passed through the hole of the post, through the wire vise, and pulled until the wire is tight and the vise is against the post.

Figure 4.17 Installation of a drip irrigation main line in the vineyard

Figure 4.18 Eight feet high fencing to prevent animal damage

Wire spreading arms

Wire spreading arms can be purchased from vineyard supply stores or made with home construction (Fig. 4.8). These are usually made of wood, 2x4s, or metal. These arms bear the support of the double curtain and should be robust and well supported to carry the weight of mature grapevines and environmental factors that exert forces on this support system.

Irrigation and Fencing

During or after trellis installation is a great time to install a **drip irrigation** system. The main line of the irrigation can be trenched in from the water source and then lateral lines connected to the trunk line and installed to the bottom wire, which is 18 inches off the ground (Fig. 4.17). In Wyoming, it is a toss-up if these lateral lines should be installed on the ground or on the trellis wire. Lines placed on the ground surface are exposed to more damage by animals (rabbits, voles, moles, mice, etc.), which chew holes into the hoses. However, laterals, which are installed on the trellis wire, (the tubing distributing water to the plants), can be blown around by strong winds resulting in improper placement of irrigation and resulting in dry vines.

Fencing to keep out wildlife should be done after equipment is no longer needed for the installation of the trellises or irrigation systems and prior to planting. The distance from the fence to the edge of the trellis should be no less than 20 feet; however, it would need to be wider to allow for equipment such as trucks, utility vehicles, or harvesting equipment. Wyoming's harsh conditions, such as our temperature fluctuations and snow loads, put a lot of stress on fences. Because of this it is important to build the fences out of strong materials that will last. Cutting corners on smaller or cheaper materials can result in replacing the fence more frequently and reduced performance as a physical barrier to wildlife (Fig. 4.18).

Planting

Time to plant our vines (Fig. 4.19 and 4.20). Grapevines typically come as bare root plants. Bare root plants are a complete plant with already established roots and usually a single trunk with live buds. Bare root plants are usually 1 to 1½ years old. They should be kept cold (around 40°F) if the vines arrive/are purchased with many days (more than two weeks) left until planting to keep them dormant until the planting date.

Figure 4.19 A newly planted vine in the vineyard

Figure 4.20 A newly planted vineyard

Vines can also be potted and grown in a greenhouse for months prior to planting, if that is an option. As with most plants, starting them in a greenhouse allows the plant to grow longer, which results in a larger and more robust plant with a better chance of survival.

New grapevines should be planted when there is a low chance of a late frost, which in Wyoming is typically late spring to early summer depending on the location. For example, this would be around the end of May to the middle part of June for Sheridan. Planting during this time period gives the vines all season to grow and establish, which gives them the best chance of surviving the winter.

The bare root plants should be soaked in water for a day or two prior to planting in a vineyard or potting in a greenhouse. This fully hydrates the plants. A bucket should be filled with room temperature water and the plants submerged an inch past the crown of the plant. The soaking plants should be stored in a warm room that is above 50°F; exposure to sunlight is not necessary. If the grape plants have been cultivated in a greenhouse for several months, then break the root ball and repot the plant a month prior to planting in a field to stimulate vigorous, straight-growing roots.

Measure and mark out the desired spacing for the new grapevines to be planted, which is usually determined by the variety. Dig a hole large enough to accept all the roots, meaning a hole that is slightly deeper and wider than the roots naturally extend, without bending or curling the roots. If adding compost, mix with the soil that will refill the hole and used as backfill. Planting grapevines too shallowly or deeply affects a plant's chance of survival. The proper planting depth is with the crown of the plant at the soil surface. While holding the plant in place, gently backfill the hole. Water the vine with a garden hose, bucket, or by other means once the hole is completely backfilled.

Chapter 5 - Grapevine Growth and Development

Grapevines are perennial plants that live and produce fruit for many years after establishment. Some vines are known to live for more than 100 years and produce a huge amount of fruit every year. Knowing the parts of a grapevine and how they grow and develop will help you understand how to best grow, train, and prune vines to get the results you are interested in. Some of the practices based on this knowledge (such as pinching flowers as they emerge for the first 2 to 4 years to channel vine resources into the growth and development of healthy roots and trunks rather than fruit production) are critical to successful long-term grape production.

True to its name, the grapevine grows by the creeping growth habit of a vine, which needs support from other plants or structures to grow toward open sunlight to capture energy for photosynthesis. The parts of a mature grapevine can be classified into above-ground and below-ground structures.

Below-ground Structures

Below-ground structures include the **crown** of a plant and root system. The crown is the union between the above-ground and below-ground structures and is found just below the soil surface. This structure is directly above the root flare (where the roots flare away from the trunk) and is responsible for the production of shoots and roots. New shoots grow from the crown when grapevines die back to the ground.

The grapevine has an extensive root system that consists of woody primary roots and smaller fibrous lateral roots with rootlets. The primary root anchors the vine in the ground and provides mechanical support, while the fibrous roots are responsible for the absorption of water and nutrients from the soil. Grapevine roots can go several feet deep and spread over a large area depending on the soil type and availability of nutrients and moisture. Adverse growing conditions such as a hard soil pan, salt accumulation in the soil, or poorly drained soils can restrict root growth and development, which in turn affects overall vine growth. Certain plant hormones responsible for different aspects of growth and development, such as cytokinins, are also produced by the roots.

Above-ground Structures

Above-ground structures include the **trunk, cordons, arms, and shoots** (Fig. 5.1). A young vine, whether propagated from seeds or cuttings, produces a shoot that continues to grow indefinitely and eventually becoming the trunk of the plant. In commercial vineyards, shoots of young vines are allowed to grow to 3-5 feet long (depending on grape variety and trellis type) where they are cut back to form the head of the plant. Producing the head of the grape plant at the top of the trellis promotes horizontal growth of the shoot on either side of the vine forming the cordons. The **cordons** may be considered as horizontal extensions of the shoot. During the first few years (2 to 4 years) of vine growth and development, all flowers are removed to keep the vine from expending energy in berry production and conserving that energy for strong root, trunk, and shoot development that increases the vine's cold hardiness for the coming winters. After several years of growth, the **shoot** matures to form a trunk that thickens in diameter over time. The **trunk** is the connection between the canopy of the vine and the root system. The trunk and cordons are mainly comprised of tissues (xylem and phloem) that help in the movement of water, nutrients, sugars, and other solutes. The xylem tissues transport water and dissolved nutrients from the roots to various plant parts. The phloem tissues are responsible for translocating sugars and other compounds produced by the leaves to various parts of the vine.

Cordons may be permanent or replaced every few years depending on the pruning system used in production. Please see the section on

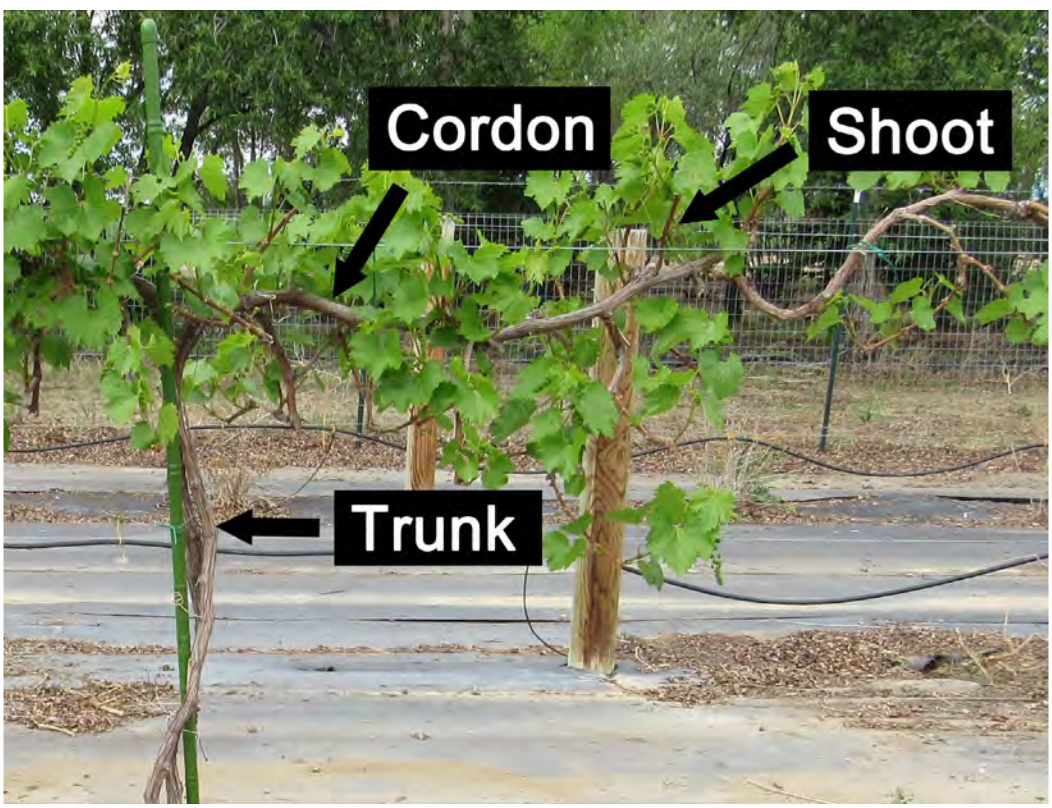


Figure 5.1 Structure of a mature grapevine showing the trunk, cordons/arms, and shoots

pruning for more information on pruning systems. Cordons contain buds that produce shoots and leaves during the spring and summer season and bear fruit for the current season. Shoots begin to harden and turn brown in color following the bearing of fruit and its harvesting. This is accompanied by certain biochemical changes in the canes including the accumulation and storage of certain kinds of sugars to ensure cold hardiness during freezing temperatures. This process is known as **acclimation**. The canes begin to shed leaves and begin entering dormancy during the onset of decreasing daylength and temperatures. Eventually, the canes shed their leaves entirely and are completely dormant. Since acclimation is a gradual process, vines growing in regions that have a gradual and mild fall acclimate better and are more cold hardy during a harsh winter than vines that may be exposed to rapid fluctuations in temperatures during fall. Some cold hardy grape hybrids that go through acclimation can survive temperatures up to -35°F during winter.

A grapevine shoot, cordons, and canes may be several feet in length and contain 20 or more **nodes**, with each node bearing **buds** (Fig. 5.2). Buds produce the growth in the subsequent season. There are different kinds of buds on grapevine shoots – compound and lateral – and are named for the location on the vine. The compound bud is found at the growing tip of each shoot. The lateral bud is produced in the axil of each leaf. The lateral bud produces a **lateral shoot** (also known as a summer lateral), which grows and dies the same season.

Figure 5.2 Cane formation showing nodes. Buds are located at these nodes where the leaf petiole attaches to the cane.

Compound buds are also found at the base of each lateral shoot along with the ones at the growing tips of the shoots. The compound bud is comprised of three buds. The three buds are known as the **primary**, **secondary**, and **tertiary** buds. Under normal conditions, the primary bud develops faster than the secondary and tertiary buds and will produce the subsequent season's growth. The primary bud is found in the center and is the largest of the three buds. The primary bud produces shoots, leaves, and flowers. The secondary bud produces shoots, leaves, and, depending on variety, may produce flowers; however, if secondary buds flower, they only produce 20-30 percent of yield generally obtained from primary bud growth (Fig. 5.3). The tertiary bud only produces shoots and leaves. The compound bud will develop rudimentary shoots and

Figure 5.3 Simultaneous shoot expansion from both the primary and secondary buds

flower clusters during the current growing season. These rudimentary structures will remain dormant in the current season and begin growth in the next season when they will produce shoots that bear the fruit.

The primary bud develops faster than the other buds and is more susceptible to freeze damage. If the primary bud is damaged, such as by a severe freeze, the secondary bud will produce growth. If both the primary and secondary buds are killed due to a freeze, the tertiary bud develops. The subsequent year's development, shoots, leaves, and especially flowers occurs a year in advance. **Management decisions and cultivation practices completed in one year can have a large impact on next year's growth and fruit production**.

During the winter season, the compound buds are covered with scales and hairs along with a waxy coating, which protect them from freezing temperatures, and are completely **dormant**. Following the onset of the spring season, as temperatures increase, the dormant compound buds go through successive phases of development to the **scale crack** stage (Fig. 5.4) where the scales on the bud are cracked open. As warm conditions prevail, compound buds begin to **swell** and finally **break** to produce that season's shoots, leaves, and flowers (Fig. 5.5 – 5.7).

Calculating Bud Break

Grapevines initiate growth and developmental activities above 10 degrees Celsius (50 F). This temperature is the threshold temperature (Threshold T). This temperature along with the maximum and minimum temperature can be used as a reference to calculate the amount of heat accumulated each day measured in terms of **growing degree days** (**GDD**). Under normal conditions, compound buds break and produce growth after a heat accumulation of 40 GDD. The approximate date when bud break will occur can be estimated by measuring the GDD accumulation for each day when temperatures cross the threshold temperature. This can be achieved using a simple formula:

$$GDD = [(Tmax + Tmin)]/2 - Threshold\ T$$

where Tmax is the maximum temperature for the day, Tmin is the minimum temperature for the day, and Threshold T is the threshold temperature (which is 50°F or 10°C).

For example, if the maximum temperature on April 15, 2017, was 70°F and the minimum temperature was 40°F, the GDD accumulation for April 15 would be

$$[70+40/2) - 50 = 5$$

Figure 5.4 Dormant grapevine buds, Left – still totally dormant. Right – At the scale crack stage.

Figure 5.5 A grapevine bud at the full swell stage

Figure 5.6 Primary and secondary bud break in grapevine

Figure 5.7 Grapevine exhibiting primary bud break

Figure 5.8 Shoot elongation from a primary bud

Figure 5.9 Inflorescence emergence in a grapevine primary bud

Figure 5.10 Inflorescence initiation in a grapevine shoot

Figure 5.11 Inflorescence elongation in a grapevine shoot

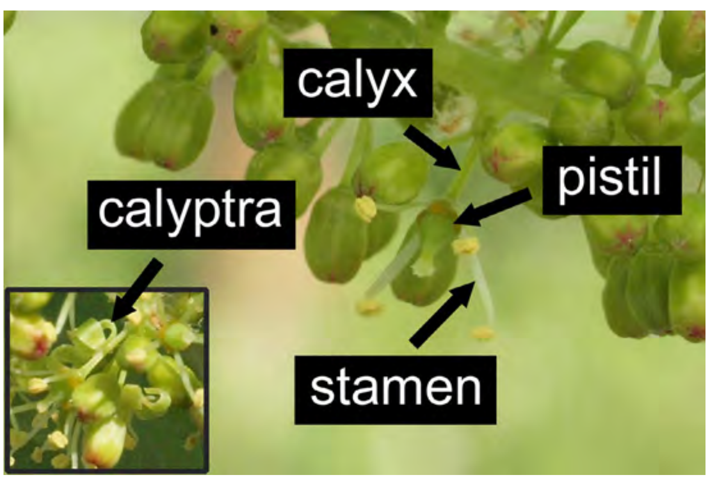


Figure 5.12 Parts of a flower in a grapevine inflorescence

The GDD for April 15 is 5. Information on GDD accumulation along with historic weather data, which provides information on the date(s) of the last killing spring frost for the region, can help predict the possibility of damage occurring to developing compound buds. Additionally, the total GDD/heat accumulation during the growing season (generally calculated from April 1 to October 31) can be estimated to determine whether early, mid-season, or late cultivars can be grown in the region.

For example: Total growing degree days of 1,595 for a season that begins April 1 and ends on September 20 means the early season varieties such as Frontenac and Brianna would work best.

Following bud break and increasing spring temperatures, rapid vegetative growth is observed in grapevines leading to the production of long shoots (Fig. 5.8). The shoots are quite tender at this stage and highly susceptible to wind damage. Following shoot growth, flower buds can be observed growing on the third and fourth node of each shoot (Fig. 5.9). Flower clusters continue to grow and elongate under conditions of favorable temperature, light, and soil moisture (Fig. 5.10 and 5.11).

Understanding how grape flowers develop and berries form and ripen will aid in knowing what development stage the vine is at and if there is a developmental issue. A grape flower consists of the calyx, the calyptra, the stamen, and the pistil (Fig. 5.12). The **calyx** is the attachment between the flower and the main stalk, whereas the **calyptra** is a cap-shaped cover. The **stamen** is the male reproductive parts comprised of the **filament** and the **anther**, which produces **pollen grains** or **sperm cells** of the plant. The **pistil** is the female reproductive part, comprised of the **stigma**, **style**, and **ovary**. The **ovules** or **egg cells** are produced in the ovary.

Flowers open and are ready for pollination approximately 5-10 weeks after bud break. Grape flowers open by shedding off the **calyptra.** They then release pollen grains from the **anthers**. This process is known as **anthesis**. The time required for flower development and anthesis varies by cultivar and prevailing weather conditions.

There are three types of grape flowers: perfect flowers, female flowers, and male flowers, found within the different species and cultivars in the world. Most commercial grape cultivars have flowers with functional male and female parts, known as **perfect flowers**. Self-pollination occurs in perfect flowers in grapes, which eliminates the need for depending on external agents such as wind and insects to pollinate the flowers.

Figure 5.13 Insect pollination in a grapevine inflorescence

Figure 5.14 Fruit set in grapevine following pollination

Figure 5.15 Fruit development in grapevine. Note increase in size of fruit.

Figure 5.16 Veraison (change in berry color) in a developing fruit cluster

Alternatively, some commercial cultivars and wild species may have either female flowers or male flowers. Such flowers depend on external agents for pollination and fertilization to cross the female plant with the male plant. Pollen released by the anthers either lands on the stigma or are carried to the stigma by wind or insects (Fig. 5.13).

After pollination, the pollen then germinates on the stigma, travels down through the style and reaches the ovary. It penetrates the ovule after which the sperm unites with the egg cell to achieve fertilization. Once fertilization takes place, the ovary begins to enlarge and eventually develops into a **berry**. A few days after fertilization, several berries the size of pinheads can be seen developing in a single grape bunch, also known as a **cluster**. The cluster is made up of the peduncle, rachis, and berries. The **peduncle** holds the cluster to the shoot. The **rachis** is the main stem of the cluster that attaches the peduncle to the **pedicels**. The pedicels attach the rachis to individual berries.

A mature berry is made up of the **skin**, the **flesh**, and the **seeds**. Berry development and ripening can be roughly divided into three phases. The first phase (growth phase 1) of development occurs for 7-8 weeks. During the first phase, the berry undergoes rapid cell division and increases in size (Fig. 5.14 and 5.15). This is accompanied by the accumulation of a number of biochemical compounds. The berry is predominantly composed of **tartaric** and **malic acids**, which impart a sour taste during this phase of development. The berry also accumulates **tannins**, which impart a bitter and astringent flavor to the wine, minerals, amino acids, and other chemicals that provide a specific aroma to discourage foraging by birds and animals. The second phase is a lag phase where berry growth pauses while the seed embryos form.

During the third phase (growth stage 2) in red cultivars, ripening is initiated by the physical change in berry color, which is known as **veraison** (Fig. 5.16). During the second phase of growth stage 2 of berry development, which lasts for another 6-8 weeks, berries double in size resulting in the dilution of compounds, such as tartaric acid, during the first phase of development. Aroma compounds produced during the second phase decrease with exposure to sunlight. **Sugars** produced by the vine canopy during photosynthesis are transported to the berries through the phloem system resulting in increased sweetness of berries. Berries accumulate high amounts of sugar, which are measured in the form of **total soluble solids** (**TSS**). A refractometer is a hand-held device used to measure TSS. Berry sweetening is also accompanied by the accumulation of **anthocyanin** pigments, which impart the dark color to berries (in case of colored grapes), and other aroma compounds that create the sweet smell in berries of several cultivars. Color development is more prominent in red/black grapes compared to

Figure 5.17 A fully ripe cluster ready for harvest

white grapes where berries turn from a dark green to a yellowish color. Ripening is also accompanied by a significant softening of berries (Fig. 5.17). The relative levels of sugars, acids, color pigments, and other volatile/aroma compounds are critical to the winemaker and ultimately determine the quality of wine that can be produced from such fruit.

Chapter 6 – Grapevine Pruning Systems

Pruning grapevines sparks production of higher quality grapes, which is accomplished by balancing the vegetative growth and the fruiting wood. A non-pruned mature grapevine can have over 400 buds. That many buds, if allowed to grow, creates over cropping, which results in smaller berries, reduced sugar accumulations, reduced pigmentation in the berry, and increased susceptibility to cold damage. Pruning decreases the number of buds by more than 90 percent. Grapevine flowering occurs on 1-year-old canes that have matured the previous season. Since first-year wood is the only portion of a vine that produces fruit, there is little benefit to keeping all canes past the first year. Annual pruning removes older (nonproductive) wood, diseased or damaged vines, encourages new growth, opens the canopy to sunlight and air flow, and keeps the vine size to a manageable level. These features result in higher quality berry production and larger yields.

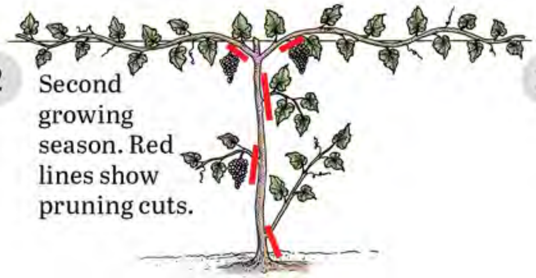
There are two pruning techniques: cane pruning and spur pruning. **Cane pruning** is followed in grapevine varieties that are not fruitful from the basal buds/nodes – table grapes for example. **Spur pruning** is followed in grapevine varieties that are more fruitful from basal buds – wine grapes for example. Spur pruning is the most common technique because it is considered less labor intensive than cane pruning; however, research has demonstrated vine training systems are more important for productivity and reducing cold damage than pruning techniques in northern climates.

Cane Pruning

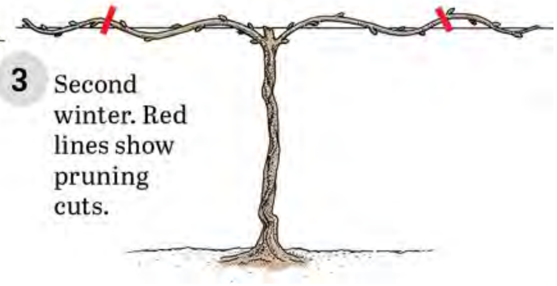
1. Train and tie the grapevine to the top wire of the training system. In Wyoming, this step can take a few years, because enough root reserves need to be developed to keep the above-ground growth alive through winter. It is recommend to pinch all flowers throughout the growing season.
2. After step one, the following growing season's canes that emerge from the head of the vine are trained/tied to the trellis to form the cordons. Trunks are trained to heavy stakes so they do not sag or curve. It is recommend to pinch all flowers throughout the growing season.
3. The next winter and prior to bud break, prune back the canes to 15-20 buds and prune all other canes from the head of the vine. It is recommend to pinch all flowers throughout the growing season.
4. Allow as much growth as possible the subsequent growing season.

Cane Pruning

1 Training the vine. First winter (This step may take more than one year after planting.)

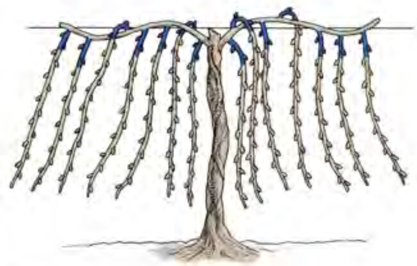


2 Second growing season. Red lines show pruning cuts.



3 Second winter. Red lines show pruning cuts.

4 Third growing season

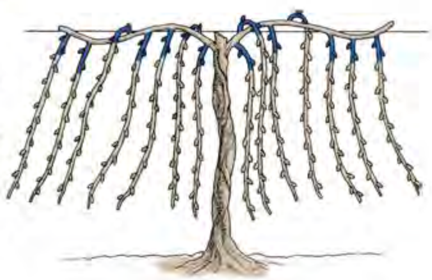


5 Third winter before pruning. Blue canes will be retained for next season's fruiting wood.

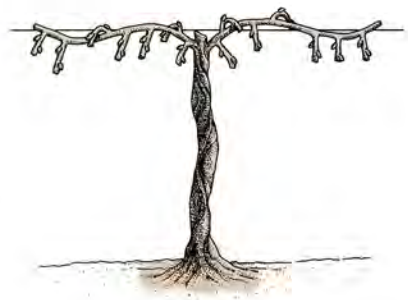
6 Third winter after pruning.

Spur Pruning

The beginning training of the vin for spur pruning is identical to cane pruning. Follow steps 1 through 3 before switching t the spur pruning steps.

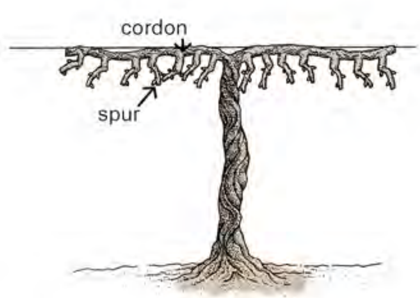


Third winter before pruning (blue indicates fruiting spurs that will be retained for next season).



Third winter after pruning.

Fourth winter before pruning (blue indicates fruiting spurs that will be retained for next season).



Fourth winter after pruning.

Images reprinted with permission from Strik, B. (2011). Growing table grapes (EC 1639). Oregon State University Extension Service. https://catalog.extension.oregonstate.edu/ec1639

5. The following winter prior to bud break, select four canes that have a good diameter near the head of the vine. These will be retained for next year's canes and renewal spurs. Remove all other canes.
6. After pruning, from the four canes chosen, select the two healthiest canes on either side of the head and prune to 15-20 buds and tie to the trellis for next year's cordons. Prune the remaining two canes to 2-4 buds for renewal spurs.
7. Repeat steps 4-6 every calendar year for the life of the grapevine.

Spur Pruning

1. Train and tie the grapevine to the top wire of the training system. In Wyoming, this step can take a few years, because enough root reserves need to be developed to keep the aboveground growth alive through the winter.
2. After step one, the following growing season's canes that emerge from the head of the vine are trained/tied to the trellis to form the cordons. Trunks are trained to heavy stakes so they do not sag or curve.
3. The next winter and prior to bud break, prune back the cordons to 15-20 buds and prune all other canes from the trunk of the vine.
4. Allow as much growth as possible the subsequent growing season.
5. After step four and prior to the next bud break, prune back the canes to 2-6 buds, which is called a spur.
6. Every winter prior to bud break prune back the canes to a spur of 2-6 buds.

Making comparisons between the two pruning systems can be useful to understand the differences between cane and spur pruning. Cane pruning consists of laying new canes every year whereas spur pruning doesn't involve laying new canes every year. Cane pruning involves greater manual labor while spur pruning can involve some degree of mechanization. Disease and insect pressure is relatively low in cane pruned grapevines compared to spur pruned grapevines because more plant material is removed, which removes the vector for certain diseases and insects.

Assessment of Cold Damage Prior to Pruning Grapevines

Vines are exposed to extremely low temperatures during the winter season. In colder regions of the United States, including Wyoming, when temperatures fall below the cold hardiness tolerance of the grapevine, there can be damage to buds, canes, cordons, and trunks

Figure 6.1 Cold damage to entire grapevine in Wyoming

Figure 6.2 Sucker production in a grapevine following vine death due to cold damage

(Fig. 6.1 and 6.2). In worst-case scenarios the roots are killed resulting in complete vine death. Pruning grapevines is necessary for getting a growing season off to a great start, preparing the plant for a bountiful year, and for vigorous growth. But if pruned incorrectly, yield can be significantly reduced or even cause the vine to not bear fruit. Damage to compound buds must be assessed and taken into account prior to determining how to prune grapevines. This can help get an estimate of grapevine growth and yield to expect following freeze-induced damage to canes. Failure to estimate the amount of cold damage can result in low yields and a strain on the health of the vines trying to bounce back following a hard freeze. You can avoid these situations by determining the correct amount of pruning, which should be done while the vines are still dormant. Since cold damage is such a major factor in vineyard health in Wyoming, assessing it will help plan appropriate pruning for that year.

A cold damage assessment of a vineyard determines the percentage of dead or damaged buds in the vineyard. As mentioned previously, a bud is the point of growth for new shoots, leaves, and flowers. Damage or death to these buds significantly influences next year's yield.

To recap

A grapevine bud is a compound bud, meaning there are multiple buds within the one bud. In grapevines, there are three small buds (primary bud, secondary bud, and tertiary bud (Fig. 6.3). The **primary bud** is the largest of the three buds, located in the center of the compound bud, and produces a majority of the flowers, which equates to fruit, seen through

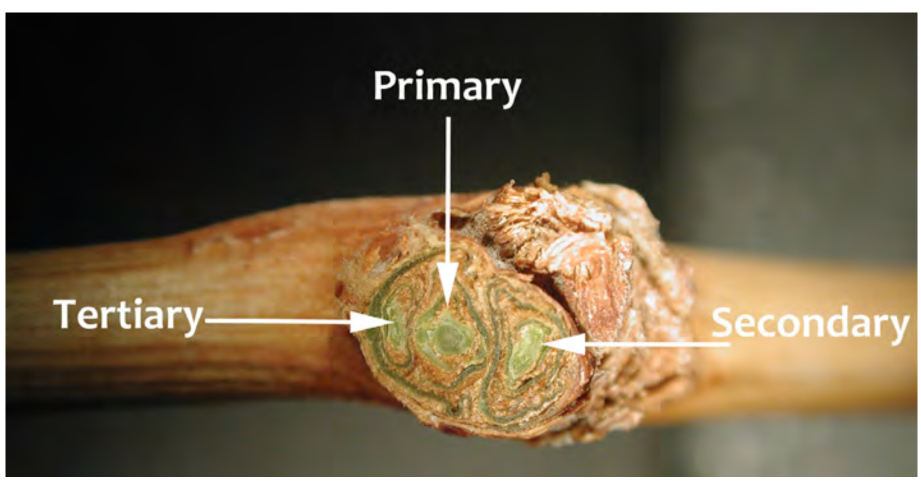


Figure 6.3 Structure of a grapevine compound bud showing the primary, secondary, and tertiary bud

the growing season. The **secondary bud** is less developed and may or may not produce flowers (depending on variety), although the bud does produce shoots and leaves. Production from secondary buds can be up to 30 percent of what can be expected from primary buds. The **tertiary bud** is the smallest of the three and only produces shoots and leaves. The secondary bud usually only grows if the primary bud is damaged, and the tertiary bud usually only grows if the primary and secondary buds are damaged. Cold damage typically kills the primary bud first followed by the secondary and then tertiary bud.

Assessing a vineyard for cold damage can be laborious, especially in large vineyards (or backyards). Sampling every vine is usually unfeasible, so to effectively assess a vineyard, focus on the grape varieties and landscape characteristics to determine various zones within a vineyard. To determine zones, be mindful of where the different grape varieties are in the vineyard, elevation changes throughout the vineyard, structures inhibiting airflow, soil variation, and vineyard size.

Since cold damage is being assessed, the zones should be representative of the different temperature regions found within the vineyard. Remember, cold air sinks, meaning that cold damage usually occurs on portions of the vine closest to the ground, vines that are lower in elevation, and low spots in the topography. Uniform damage can be seen in small vineyards or relatively level topography. Focus a good portion of the assessment if there is a zone that always has cold damage.

Assess the vineyard while buds are still dormant – after the lowest winter temperatures have occurred and prior to bud break, approximately March through April. As a general rule, sampling 100 buds per zone is a good representation and makes the math simple. Collect entire-length canes from random vines throughout the entire zone. If the vineyard is small enough to sample each vine, then remove one entire length cane from each vine. Samples should be bundled and labeled with the zone and variety from which they were collected. Once samples are collected, use a sharp razor blade to cut open the buds to assess the interior color. Using a magnifying glass or loupe may be helpful in seeing the three different buds. Hold the cane horizontally with the bud pointing straight up, then make three cuts horizontally through the bud as described below:

1. First cut should be approximately two-thirds up the bud. If done correctly, the primary bud is exposed. (Fig. 6.4)
2. Second cut should be slightly lower down on the bud. If done correctly, the second and primary bud is exposed. (Fig. 6.5)

3. The third cut should be slightly lower still. If done correctly, all three buds should be exposed. (Fig. 6.6)
4. Three small cuts are preferred to one large cut, to avoid cutting too deep and removing the bud altogether. (Fig. 6.7)

Green color in the bud indicates live and healthy tissue, whereas a brownish/black color indicates bud damage or a dead bud. Begin with the first bud on the cane (which is the closest to the base where the cane was cut from the cordon) and work toward the tip of the cane. Record the variety, zone, bud number, and the status of the three buds (primary, secondary, and tertiary) in sequence as you work down the cane. After all the buds are assessed per zone,

Figure 6.4 The first cut exposing the primary bud

Figure 6.5 The second cut exposing the secondary bud

Figure 6.6 The third cut exposing the tertiary bud

Figure 6.7 A compound bud that was cut too deep

calculate the percentage of live primary, secondary, and tertiary buds with the equation below.

(# of live buds / total buds) * 100 = percent of alive buds

Example: (64 / 95) * 100 = 67 percent of primary buds are alive

Knowing the number of live buds, especially primary buds, determines how many buds should be left on the vine during pruning to produce the most bountiful yield. Most pruning adjustments are based off the survivability of the primary buds. Some calculations use the primary and secondary bud to determine crop potential and to adjust bud number for pruning. The information of tertiary buds is only used when most or all primary buds are dead and canopy recovery is a concern.

Use the percentage of live primary and secondary buds for each zone and variety to adjust pruning practices as recommended in Tables 1 and 2.

Analyze the information you have just created on your vineyard after estimating the adjustments for pruning. Are there any patterns? For

Table 1 Pruning recommendation based on primary bud damage

If you have...	Then...
Under 25% primary bud damage	Prune as normal
25-75% primary bud damage	Use the adjustment calculation in Table 2.
Over 75% primary bud damage	Prune after bud break or not at all

Table 2 Bud adjustment calculation

Step 1:	
Crop potential =	$\frac{(\% \text{ alive primary buds}) + (0.25 \times [\% \text{ alive secondary buds}])}{100}$
Step 2:	
Adjusted bud number =	$\frac{\text{The number of buds you normally leave}}{\text{Crop potential}}$

Example			
Step 1: After assessment, you found only 30% of your primary and 60% of your secondary buds are alive.	Crop potential =	$\frac{30 + (0.25 \times 60)}{100} = \frac{30 + 15}{100} = 0.45$	
Step 2: In most years, you would leave 24 buds/vine at this particular site.	Adjusted bud number =	$\frac{24}{0.45}$	= 53 buds this year

Wolfe, W. 2000. Vine and Vineyard Management Following Low Temperature Injury. Proceedings of the American Society for Enology and Viticulture 50th Anniversary Annual Meeting. Seattle, WA. June 19-23.

Figure 6.8 Cold damage in grapevine shoots following a late season freeze

example, has one variety received more cold damage than others? Has a certain zone received more cold damage than others? Is there a pattern of which buds on the cane received the most damage? For example, you noticed that, after the eighth bud on the cane, all other buds were dead. This management technique will aid understanding the vineyard's dynamics and help maximize future crops.

Cold damage can also occur with a late freeze after the vines has broken dormancy in the spring or early freeze in the fall before vines go dormant (Fig. 6.8 – 6.10). The best management for protecting vineyards from cold damage is correct variety selection, vineyard site selection, and managing for strong healthy vines. In large vineyards, circulation fans keep air movement within the vineyard to prevent temperature inversions; however, this has no effect on freezing temperatures (Fig. 6.11).

Figure 6.9 Cold damage to a grapevine following an early season freeze

Figure 6.10 Vine death in a Wyoming vineyard following an early fall freeze

Figure 6.11 A wind machine being used to mix cool and warm air layers to prevent temperature inversions

Chapter 7 - Grapevine Pest Management

A number of pests including insects, nematodes, diseases, animals, and weeds, can severely affect grapevines. This heavy pest pressure makes grapes among the most heavily sprayed crops (Fig. 7.1). A pest is considered to be of economic importance when the damage justifies the use of various control measures. Effective pest management in grapevines requires growers to have adequate knowledge of the lifecycle of insects and diseases, their spread, environmental effects on pest development, and techniques used for integrated pest management. Effective pest management on grapevines is highly dependent on the accurate identification of what is causing the damage symptoms – insect, animals, disease, drought, nutritional, or physiological disorders. Misidentification will cause growers to spend money and time on ineffective control measures. Learning to identify potential issues should be a priority.

Figure 7.1 Pesticide application in a grape vineyard

Figure 7.2 Grapevine leaves exhibiting insect damage

Photo: Geoffrey Budsea, shutterstock.com

Figure 7.3 A lady bird beetle (aka ladybug) larva. The larvae look quite different than the adults.

Figure 7.4 Leaf hopper infestation in a Wyoming grape vineyard

Figure 7.5 Spider mite infestation in greenhouse-grown grapevines

Insects

A number of insects that feed by sucking and chewing infest grapevines and cause damage to foliage, flowers and fruit (Fig. 7.2). Insect pests cause damage to grapevines starting around bud break and can continue through flowering and fruiting. Additionally, some insect pests may not cause damage by themselves but are vectors for the transmission and spread of bacterial and viral pathogens. Information on taxonomy and life cycle of various insect pests can help identify the developmental stage causing damage and feeding habit of the insect pest. This can aid in adopting the proper control measures. It is also important to identify pests of economic importance versus those whose damage will not significantly impact the operation.

The life cycle of insects includes direct or indirect metamorphosis. In case of direct metamorphosis, insects pass through the **egg**, **nymph**, and **adult** stages. During indirect metamorphosis, they pass through the **egg**, **larva**, **pupa**, and **adult** stages of development. Feeding habits of insect pests depend on the development stages, which can help determine the use of control measures, which typically depend on systemic or contact insecticides.

Phylloxera

Phylloxera is an insect pest with great historic and economic importance. Phylloxera is a tiny insect that resembles aphids and feeds on roots. Nymphs and adults have sucking mouthparts allowing them to feed on grapevine roots and weaken the plants. The accidental spread of Phylloxera from the United States to Europe occurred with a shipment of native American grape planting material in the 19th century and almost led to the decimation of the European grape industry. While native American grapes are tolerant to the pest, European bunch grapes are especially susceptible. The only solution for controlling damage from Phylloxera is to graft European bunch grapes onto native American species used as rootstocks. There is also a form of Phylloxera that feeds on the foliage resulting in damaged leaves but is not considered to be a serious pest. Phylloxera does not occur in Wyoming due to the freezing conditions during winter.

Mealy bug

Another insect pest causing major damage in vineyards is the **mealy bug**. The mealy bug that infests grapevines is also a pest in other fruits and ornamentals. It can be easily identified by its white powdery covering. The nymph and adult stages have a sucking feeding habit that weakens grapevines by extracting vital plant fluids. Adults also lay eggs beneath the bark tissues of vines, which hatch into nymphs. Mealy bugs also excrete a sugary substance that supports the growth of black sooty mold that can sometimes cover leaves completely, thereby interfering with photosynthesis. Another concern of mealy bug infestations is the ability of this pest to transmit viral pathogens. Mealy bugs can be controlled using systemic insecticides as well as biological predators such as lady bird beetles larvae (Fig. 7.3).

Sucking pests

Other sucking pests affecting grapevines are **grape leafhoppers**, **mites,** and **sharpshooters** (Fig. 7.4–7.6). **Leaf hoppers** are frequently observed in Wyoming vineyards. Adults can survive through the winter on vine debris in the vineyard. During the spring, they lay eggs on the lower surface of the leaves. Both nymphs and adults cause damage to leaves by feeding on leaf cells giving the leaves a reddish-brown appearance. In cases of severe infestation, leaves exhibit a marble white appearance (Fig. 7.7) and complete defoliation of vines may be seen.

The **red spider** and **two-spotted mites** have needle-like piercing/sucking mouthparts and are known to infest grapevines causing damage like leaf hoppers. Mite damage can be identified by extensive webbing on infested plant parts (Fig. 7.8). In cases of severe infestation, leaves turn reddish-brown and may fall off.

Unlike mites, **grape sharpshooters** have sucking mouthparts with both nymphs and adults feeding on vines. While the insect does not cause significant damage, it is responsible for the spread of a bacterial pathogen, which causes Pierce's disease in grapes. The pest assumes economic importance in California due to its ability to spread Pierce's disease but has not been observed in Wyoming vineyards. Systemic insecticides can control leafhoppers, mites, and sharpshooters.

Chewing pests

Grapevines are also damaged by insects with chewing mouthparts and habits. These include the **grape berry moth**, **Japanese beetle**, and the **flea beetle**.

The larval stage of the **grape berry moth** damages shoots, flowers, and developing berries. Adults lay eggs in developing flower clusters. Larvae formed from the eggs upon hatching feed on vegetative and reproductive growth, causing damage to foliage and berry clusters. Pupation occurs in the vineyard on debris material. Following pupation, adults emerge and lay eggs to continue the insect life cycle.

Flea beetles have a similar life cycle; however, in this case, the larvae and adults cause damage to young buds, developing shoots, and leaves. The insect has a chewing feeding habit and can be easily identified by the "shot" holes they make on leaves and shoots. The

Photo: Sarah2, shutterstock.com

Figure 7.6 A blue-green sharpshooter, a vector for transmission of Pierce's disease

Figure 7.7 Extensive foliage damage caused by leaf hopper infestation in a Wyoming vineyard

Figure 7.8 Formation of webs from spider mite infestation on greenhouse-grown grapevines

Figure 7.9 Larval stage of tobacco horn worm feeding on foliage in a Wyoming vineyard

Figure 7.10 Fruit damage caused by wasps in a Wyoming vineyard

Figure 7.11 Sticky traps used for monitoring insect threshold levels in a vineyard

Figure 7.12 An insect trap showing insect populations in a vineyard

adult is the damaging stage. It feeds on foliage tissue and can be identified by the presence of "skeleton leaves" on vines.

Japanese beetle larvae feed on grasses and weeds in the vineyard and are not a damaging stage. Pupation for both flea and Japanese beetles occurs in vineyard debris. Upon emergence, adults continue the life cycle.

The life cycle of the above insects can be disrupted by timely removal of debris, including pruned material, old hanging grape clusters, and other material from the vineyard, which provides a habitat for pupation. Similarly, removal of weeds and maintaining a weed-free vineyard provides less habitat for Japanese beetle larvae. The insects can also be controlled by contact insecticides.

Tobacco hornworms

Tobacco hornworms are occasionally observed in Wyoming vineyards (Fig. 7.9). The larvae are voracious feeders of leaf tissues, but damage rarely reaches levels that justifies using insecticides.

Nematodes

Nematodes are unsegmented microscopic worms that feed mainly on the grapevine roots. They may be ectoparasitic (causing external damage) or endoparasitic (living inside the plant tissues). Grapevines damaged by nematodes typically exhibit symptoms of stunting, loss in vigor, and a reduction in yield. Some nematode species may also be vectors for the spread of viral pathogens. Nematodes can be controlled by using grapevines grafted onto resistant rootstocks and growing cover crops that discourage nematode growth. **Nematodes are generally not observed in Wyoming vineyards due to the heavy soil types that grapes are grown in**.

Spotted wing drosophila

Spotted wing drosophila is a fruit fly new to Wyoming. This fruit fly, unlike other fruit flies, lays eggs on undamaged and ripened fruit. The host range of this fly is very wide and includes all fruits including tomatoes; however, it tends to favor soft flesh berries. Specifically for grapes, female drosophila flies cannot penetrate grape berries that have intact skins; however, as the berry ages, the skins become thinner making it more susceptible to splitting, allowing the drosophila fly to lay eggs with ease. Damage from hail, birds or diseases also provides opportunities for the fly to lay eggs on berries. Maggots hatch from the eggs and feed within the berries resulting in reduced yields and quality. There are two control options available for drosophila control in grapes. The first and most effective is management practices that minimize fruit splitting and damage. This includes utilizing bird deterrents such as netting and scare tactics, removing damaged or deteriorating berries, and harvesting fruit as soon as it has ripened. Pesticides is the second control option. There are no insecticides for the control of maggots in the fruit, so applications need to be applied to eliminate adult flies before they mate and lay eggs. Well-timed applications can effectively manage this pest. Utilizing monitoring traps aids in timing these sprays. Treatment is usually begun when one individual is detected in these traps.

Other insect pests

Other insect pests such as **aphids**, **whiteflies**, **thrips**, and **wasps** can occasionally cause damage in vineyards. Wasps may attack fruit during the ripening stages (Fig. 7.10). This results in open wounds to berries, which may be a source of infection for fruit-borne diseases such as sour bunch rot. Other insects such as **ants** may be a nuisance factor during the growing season. The combined use of cultural methods such as clean vineyard practices, insect traps to monitor pest populations (Fig. 7.11 and 7.12), predators that may occur naturally or can be purchased and released in the vineyard, use of oils and other insecticides, can help in effective control of insect pests.

Weeds

Weeds are frequently problematic. Weeds compete with vines for water, nutrients, and sunlight and can be especially damaging in young vineyards (Fig. 7.13 and 7.14). Weeds can serve as an alternate host for a number of insects and diseases and help them complete their life cycles during periods of dormant vine growth. Weeds also provide habitat for rodents in addition to being a fire hazard. Weeds are mainly controlled by mechanical and chemical means (Fig. 7.15). Both pre- and post-emergent herbicides can be used to effectively control weeds in the vineyard. **Grapevines are extremely sensitive to herbicides and extreme caution should be followed when applying herbicides to control weeds in or near the vineyard** (Fig. 7.16).

Diseases

A number of bacterial, fungal, and viral pathogens can infect grapevines and reduce yields and quality, while compromising the overall health of the vineyard.

Agrobacterium vitis

A major bacterial pathogen of grapevine is ***Agrobacterium vitis***, which causes crown gall disease. The pathogen gains entry into vines through damaged tissues that may occur from a freeze or mechanical damage during cultural operations. *Agrobacterium* is known as nature's genetic engineer. The bacterium transfers a piece of cellular DNA into the grape plant's nucleus. The transferred DNA sequence

Figure 7.13 Weed infestation in a vineyard from poor weed management

Figure 7.14 A clean vineyard with proper weed management

Figure 7.15 Mechanical weeding in the vineyard using a tractor mounted implement

Figure 7.16 Foliar damage caused by improper herbicide application in a vineyard

Figure 7.17 Leaf scorching symptoms exhibited by vines infected with Pierce's disease

Figure 7.18 Early symptoms of downy mildew on the lower side of foliage in a vineyard

Figure 7.19 Foliage heavily infected with downy mildew in a vineyard

Figure 7.20 Berries exhibiting symptoms of powdery mildew infection

codes for the production of certain proteins that serve as food for the parasitic bacteria along with certain hormones that cause excessive cell multiplication and gives the infected site a gall-like appearance. Grapevines weakened by a natural event such as a hard freeze may be especially susceptible to attack by *Agrobacterium*.

Pierce's disease

Pierce's disease is an important bacterial disease that is spread by sharpshooter insects (Fig. 7.17). The pathogen was first discovered in the 19th century and is still a major threat to the California viticulture industry. The pathogen is known to live and proliferate in the xylem (water conducting tissues) system of grapevines. As a result, the xylem vessels become clogged and unable to transport water and dissolved nutrients to different vine parts. As a result, grapevines exhibit symptoms typical of drought such as leaf scorching, islands of brown tissues on shoots, and poor berry set. Grapevines severely infected with Pierce's disease eventually die to the ground leaving the roots alive, which leads to severe suckering and new shoot production from the crown.

Grapevines infected with crown gall and Pierce's disease need to be uprooted from the vineyard and burnt. Since the bacterial pathogens can be spread when infected grapevines are used as a source to propagate new plants, make sure that planting stock is purchased from nurseries that sell certified disease-free vines. This can help minimize damage caused by Pierce's disease and crown gall.

Fungal diseases

Grapevines are also affected by several fungal diseases that, if unchecked, can cause anywhere from 20-100 percent reduction in yield. Fungal pathogens are known to infect above- as well as below-ground parts of the vine. Most fungal pathogens thrive in hot and humid conditions that are not frequently observed in Wyoming during the growing season. Fungal pathogens that may be seen in Wyoming are downy and powdery mildew, anthracnose, black rot, and botrytis.

Downy mildew appears as a fluffy white growth on the lower side of leaves (Fig. 7.18 and 7.19). The fungus also infects developing flower and berry clusters. Infected tissues turn black and complete defoliation is observed in severe cases. The fungus remains dormant during the winter on dead tissues and in vineyard debris and infects vines when conditions are favorable.

Powdery mildew is one of the most devastating fungal pathogens infecting grapes worldwide. The fungus produces a powdery growth on leaf tissues, flowers, and developing berries (Fig. 7.20). Infected leaves turn yellow and eventually fall off. Berry clusters affected prior to veraison will develop poor color, uneven ripening, and are not suitable for consumption or wine production.

Anthracnose, also known as bird's eye spot disease, infects grapevines under warm and humid conditions (Fig. 7.21 and 7.22). The fungus affects foliage, flowers and fruits, and severe infection results in tissue death and defoliation. The fungus remains dormant in vineyard debris and infects vines when conditions are suitable.

Black rot occurs during high humidity conditions. These conditions generally only occur in Wyoming after unusually large amounts of rainfall (Fig. 7.23). The fungus produces brown lesions on leaves, shoots, and developing berries, and carries over to the next season by over-wintering on vineyard debris.

Botrytis, commonly known as soft rot/storage rot disease, infects young shoots, flowers, and developing berries (Fig. 7.24). The fungus may remain dormant until harvest and then infects ripe berry clusters in storage and transit, producing a grayish fluffy growth. Berries that are damaged from insect attack may become infected and serve as an inoculum for spreading the pathogen to healthy berries. The fungus remains dormant in berry clusters left hanging in the vineyard following harvest and becomes active during favorable conditions.

A group of fungal pathogens infect grapevines causing a complex known as "trunk diseases." These include ***Eutypa***, ***Phomopsis,*** and ***Botryosphaeria***. These pathogens affect the vascular system and can result in the death of spurs, cordons, and trunks. The disease symptoms typically appear as wedge-shaped discolorations in a cross-section of the infected vine (trunk, cordons, and canes). Trunk diseases may be spread during pruning of infected vines.

Fungal pathogens can be effectively managed by a combination of cultural techniques such as maintaining clean vineyards, removing weeds that may serve as alternate hosts for fungi, and monitoring the climate to predict conditions that are favorable for buildup of fungal pathogens. Chemical control measures using fungicides are effective at preventing the infection process when used at the right concentrations and following appropriate chemical rotations to prevent development of fungicide resistance in vineyards.

Figure 7.21 Anthracnose symptoms on grapevine shoots and foliage

Figure 7.22 Grape berries exhibiting "bird's eye spot" symptoms from anthracnose infection

Figure 7.23 Grapevine foliage exhibiting symptoms of black rot in a vineyard

Figure 7.24 A grapevine exhibiting symptoms of Botrytis

Detailed information on integrated pest management for grapevines, including pesticides and associated restrictions, can be found at the University of California Integrated Pest Management program website http://bit.ly/GrapePests.

Viral pathogens

Viral pathogens are a serious threat to the grape industry in the United States. More than 60 viral pathogens are known to infect grape vineyards worldwide. Among the important viruses, **leafroll associated virus**, **grape fanleaf virus,** and **red blotch** are important pathogens. An exhaustive list of viral pathogens can be found at http://bit.ly/GrapevineTesting. Viral pathogens are most commonly spread when infected mother vines in a nursery are used as a source material for propagating new vines. Some viruses can also be spread by mealy bugs and nematodes. Viruses may remain latent in infected vines for a long period of time before they express themselves. Infected grapevines exhibit poor vigor and ultimately reduced yields. Additionally, fruit produced from infected vines may not accumulate the usual amount of sugars and pigments thereby lowering the quality of the fruit. The National Clean Plants Network is an association involving federal agencies and other organizations that was mandated by Congress for the production of clean propagation materials. Stock planting material for several grapevine cultivars have been cleaned of viral pathogens and maintained under clean conditions at the Foundation Plant Services of the University of California, Davis. Clean material is then distributed to commercial nurseries for further propagation and distribution to retailers for eventual sale to grape growers. There are no control measures for grapevines infected with viruses. Infected vines are uprooted and destroyed. The use of clean planting material from nurseries producing certified virus-free grapevines is the best way to maintain a healthy vineyard free of viruses. A list of nurseries from where planting material can be obtained is provided in Chapter 4. **Prior to purchasing vines, please check with the nursery to determine if the planting material is certified disease-free**.

Figure 7.25 Deer in a vineyard

Animals

Additional pests affecting grape production in Wyoming include animals such as bears, raccoons, deer, rodents, and birds (Fig. 7.25).

Establishing a **high fence** (6 feet tall) is absolutely necessary to avoid predation of foliage and fruit by most animals, such as deer, rabbits, and bears, which can be a problem, especially during the latter part of the season.

Fruit damage and losses from birds are a major problem facing grape production in Wyoming. If left unchecked, birds can destroy 100 percent of the crop during a single day of feeding. Bird damage is observed mainly from veraison to harvest (Fig. 7.26). A number of bird species such as robins, starlings, and doves, can feed on grapes causing total loss of produce. **Bird netting** is the most effective way for minimizing feeding (Fig. 7.27 and 7.28). Netting can be obtained in different sizes from several vendors. Care should be taken to ensure the netting is adequately secured. Any gaps left in the netting might be exploited by birds to gain access to the fruit. Netting can be removed just prior to harvest and reused in the subsequent seasons.

Figure 7.26 Fruit damage from bird predation in a vineyard

Figure 7.27 Bird netting ready to be installed in a vineyard

Figure 7.28 Bird netting installed for protecting fruit from bird predation

Chapter 8 - Grapevine Nutrient Management and Fertilization

Grapevines remove large quantities of nutrients from the soil every year for growth, development, and fruit production. Balanced nutrition is very important for maintaining healthy and productive vines, obtaining high yields and fruit/wine quality, improved cold hardiness, and long-term sustainability of the vineyard. Balanced nutrition is also essential to make sure the vines do not receive excessive fertilizer, which can result in uncontrolled growth of the canopy, increased disease, and poor fruit quality. Excess fertilizer also wastes money and increases potential for water contamination. Under-fertilization can result in weak vines with poor production capacity and increased susceptibility to cold damage. The presence and availability of nutrients to grapevines depends on the climate (temperature and rainfall during the growing season), the soil's physical and chemical characteristics including soil structure, texture, organic matter, and pH, the type of grape cultivar being grown, rootstocks, and irrigation system. Knowing the levels and availability of nutrients in the vineyard site is important to effectively create fertilizer regimes. This can be done through detailed soil nutrient analysis and testing.

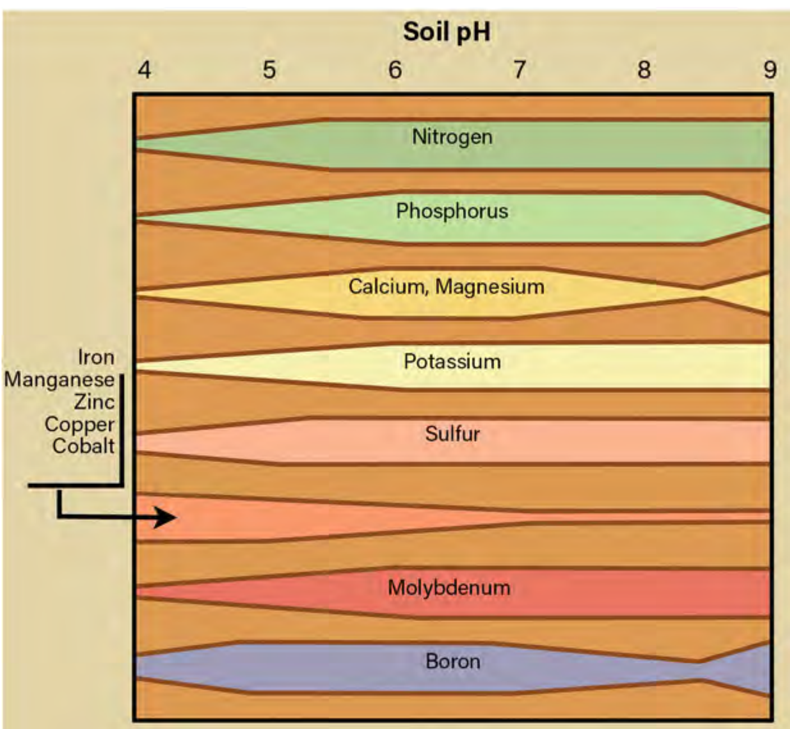


Figure 8.1 Effect of soil pH on availability of macro- and micro-nutrients (Source: eXtension)

Essential elements required for plant growth and development are broadly classified into **macronutrients** and **micronutrients** based on the uptake and use of these nutrients by the plant. Primary macronutrients utilized in high quantities include nitrogen (N), phosphorus (P), and potassium (K), secondary macronutrients include calcium (Ca), magnesium (Mg) and sulfur (S), while micronutrients include boron (B), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn). Although these essential elements may be present in adequate quantities in the soil, their availability to the plants depends on factors such as **soil pH** and the interaction among these elements. Soil pH is a measure of the hydrogen ion concentration and provides information on acidic and alkaline soil conditions. A pH of 7 is considered to be neutral;

lower than 7 pH indicates acidic conditions while higher pH indicates alkaline conditions. At low soil pH, elements such as Ca, Mg, and P may be present in adequate quantities, but plants cannot extract them from the soil. Conversely, plants find it difficult to extract micronutrients from the soil at high pH. Wyoming soils are often alkaline (having a high soil pH); micronutrient deficiencies are often seen in Wyoming vineyards (Fig. 8.1).

Macronutrients

Nitrogen

Nitrogen (N) is used most heavily by grapevines. It is important for the production of nucleic acids, proteins, and pigments in grapevines. Nitrogen is removed annually from the vineyard in large quantities via fruit harvest and pruning. The demand for nitrogen is high following bud break and throughout the periods of vegetative growth. Nitrogen deficiency symptoms can be easily identified by yellowing of leaves and shoots with symptoms appearing earlier in the older leaves (Fig. 8.2). Severe deficiency can result in poor shoot/cane production, smaller leaves, berries, and clusters and weak vines. On the other hand, excessive nitrogen can cause vigorous growth resulting in an unmanageable canopy, increased disease incidence, poor fruit quality, and wood maturation (increasing the susceptibility of vines to cold damage). Nitrogen should be applied early in the season for effective utilization by vines. Nitrogen can be lost by leaching with excessive irrigation. Late application of nitrogen can lead to tender vegetative growth in the fall and susceptibility to cold damage.

Figure 8.2 Nitrogen deficiency in grapevine

Phosphorus

Phosphorus (P) is required for energy, root, and fruit development for grapevines. Phosphorus deficiency symptoms appear as reddening of leaves, which starts at the margin and progresses between the veins. Other symptoms include reduction in vine vigor, flower and fruit set, along with delayed maturity of the fruit. Unlike nitrogen, phosphorus is a stable element and once applied can be used for an extensive period of time by vines. Deficiency in phosphorus may be observed at low soil pH and when high levels of iron and aluminum are present in the soil (Fig. 8.3). Different forms of phosphorus fertilizer are available (rock phosphate, ammonium phosphate, etc.). Which types are used mainly depends on the soil pH.

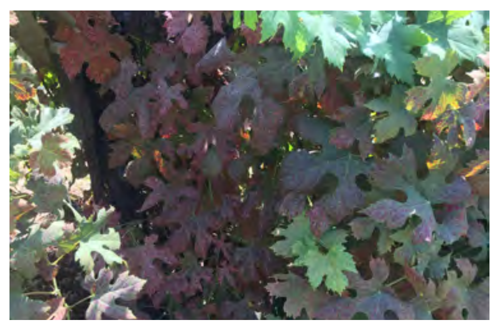


Figure 8.3 Phosphorus deficiency in grapevine

Potassium

Potassium (K) is actively involved in maintaining plant turgidity, food production, imparting disease resistance, and fruit ripening. Berry juice contains high levels of potassium. Deficiency symptoms appear during the latter part of the season as leaf yellowing and burning along

Figure 8.4 Potassium deficiency in grapevine

Figure 8.5 Magnesium deficiency in a red grape cultivar

Figure 8.6 Magnesium deficiency in a white grape cultivar

Figure 8.7 Iron deficiency in grapevine

Figure 8.8 Boron deficiency in grapevine leading to symptoms of shot berries in the cluster

the leaf margins, reduction in vine vigor, poor fruit set and color, and decreases in yield (Fig. 8.4). Potassium, like phosphorus, is a stable element and can be applied early during the season.

Calcium

Calcium (Ca) is an important secondary macroelement involved in cell wall formation, transport of sugars, and imparting cold hardiness to vines. Calcium deficiency symptoms are mainly observed on fast-growing plant parts (shoots, inflorescences, etc.) that turn black/ necrotic.

Magnesium

Magnesium (Mg) is needed in plant tissues for carrying out photosynthesis, respiration, and the production of nucleic acids. Magnesium deficiency symptoms are observed as yellowing of leaves between the veins (interveinal), which gets worse with severe deficiency in white grape cultivars. Leaf reddening is observed in magnesium deficient red grape cultivars (Fig. 8.5 and 8.6).

Sulfur

Sulfur (S) is part of a number of proteins and flavor and aroma compounds. Sulfur deficiency is generally not observed in vineyards due to the frequent use of sulfur fungicides. Calcium, magnesium, and sulfur can be applied as foliar sprays or can be included in the combination of fertilizers applied through the soil.

Micronutrients

Micronutrients are required by grapevines in minor quantities for a number of essential metabolic processes such as sugar and lipid production, photosynthesis, respiration, as well as imparting chilling and cold tolerance. Among the various micronutrients used by grapevines, **iron (Fe)** and **boron (B)** deficiency are frequently observed in Wyoming vineyards. Iron deficiency symptoms are observed as severe yellowing of young leaves between the veins (Fig. 8.7). Boron deficiency symptoms are observed as the production of short/stunted shoots, poor berry set (also known as berry shot), and abnormal size and shapes of the berries (Fig. 8.8). **Zinc (Zn)** deficiency symptoms are similar to those seen in boron deficiency with incomplete cluster formation and stunted shoots and small leaves.

Testing and Analysis

The amount and kind of fertilizer to apply mainly depends on the current levels of these nutrients in the soil. A detailed **soil analysis test** that provides information on current nutrient levels can help you decide on the kind and rate of nutrients to apply. If sending a sample(s) in for analysis, soil samples should be collected from different parts of the vineyard that represent various soil types and topography and pooled together to create one sample to be sent for analysis. Individual samples of different areas in the vineyard can also be sent in for more site-specific recommendations. Soil testing and analyses is recommended every five to seven years to stay up-to-date on the nutrient levels.

Petiole analysis can be utilized to assess and diagnose nutrient problems during the growing season. Growers are then able to make adjustments at critical times that will protect or increase yield. Petiole analyses are conducted by collecting leaf petioles at random from the vineyard two times during the growing season, typically once during flowering and once at veraison. The process of collecting leaf petiole samples involves selecting leaves opposite to the flower/fruit cluster. The leaves along with the petiole are cut with a sharp scalpel. A sample of 20-50 leaves can be collected depending on the size of the vineyard. The samples are then brought indoors, and the petioles (leaf stalk) cut off from the leaf using a sharp scalpel. The petioles can be dried overnight in an oven (100°F) and then shipped off to a laboratory for nutrient analysis. A few labs that carry out petiole nutrient analysis are listed below:

A & L Great Lakes Lab Inc.
https://algreatlakes.com/

University of Minnesota Research Analytical Lab
http://ral.cfans.umn.edu/

Pennsylvania State University, Agricultural Analytical Services
http://agsci.psu.edu/aasl

Chapter 9 - Grapevine Irrigation Management

Grapes are considered to be relatively drought tolerant and thrive well in well-drained soils; however, severe water stress during the growing season can result in a substantial decrease in yield and fruit quality while adversely affecting vine health. Grapevines experiencing drought conditions exhibit symptoms such as dying/browning of tendrils, drooping of leaves and shoots, and leaf scorching in severe cases. Prolonged drought can result in shoot death and a decrease in the amount of canopy.

Irrigation management of vineyards is a very important aspect of grape production for obtaining sustainable yields of high-quality fruit. Effective grapevine irrigation management provides several benefits such as better control of the growth and vigor of vines, reducing fertilizer loss via leaching, better fruit size for table grapes, a dramatic improvement in fruit quality parameters for wine grapes, and reductions in energy and water used for irrigation, which leads to a decrease in the cost of production. Additionally, irrigation scheduling in cold climate regions helps maintain a healthy vineyard with an improvement in cold hardiness of grapevines. Excessive and deficit levels of irrigation can cause adverse effects on grape production. Excessive soil moisture can result in very vigorous vines that make

Figure 9.1 A vineyard irrigated with flood irrigation

managing the canopy difficult. It also results in decreased fruit quality including poor color development, low sugar accumulation, and decreased shelf life following harvest. Too little irrigation on the other hand can reduce canopy growth and decrease berry set and size resulting in poor yields.

Vineyards are irrigated using a variety of techniques such as **flooding**, **sprinkler**, **drip irrigation**, or can be **rainfed** in regions that have a uniform distribution of rainfall during the growing season (Fig. 9.1 and 9.2). Drip irrigation combined with the application of fertilizers through the system (known as **fertigation**), is the most effective management technique for vineyards. The average water requirement for a mature vineyard ranges from 22-28 inches during the growing season. However, grapevine water requirements depend on several factors including the grape cultivar, the purpose of production (fresh fruit, wine, or other products), age of the vines, climatic factors such as temperature, humidity, rainfall distribution during the growing season, soil type, and topography.

Water Requirement of Table Grapes

The water requirements and irrigation scheduling of table grapes varies widely from wine grapes. Table grape production largely focuses on seedless cultivars that exhibit characteristics such as high yields and large sweet berries with thin skins. The water requirement for table grapes is around 2.5-4 inches of water from bud break to bloom stage.

Figure 9.2 Sprinkler irrigation in a vineyard

In most regions, available soil moisture might be sufficient to meet vine water requirements. However, supplemental irrigation may be necessary in dry regions or in vineyards with sandy soils or soils with a cover crop growing between the rows. Water requirement of vines is around 7-9 inches as the crop progresses from bloom to veraison, when individual berries are rapidly increasing in size. Irrigation scheduling at this stage is critical to ensure vines do not experience drought stress, which can result in decreased berry size and yields. During the ripening phase, water requirement is around 8-10 inches to support the increased berry size. Maintaining adequate soil moisture during the ripening phase is important to maintain and improve the crop's yield. However, excessive irrigation at this stage can lead to delayed maturity and ripening, and a reduction in color of berries.

Following harvest, water requirement is generally low to support existing canopy growth and discourage any new growth late in the season. A moderate water stress at this stage will promote the maturation of the vines into setting wood and aid in the acclimation process. One heavy irrigation at the end of the season is beneficial in ensuring vines are hydrated going into the winter season while also helping in leaching any salts that accumulate in the soil. Excessive drought at this time of the year may stress vines too much resulting in poor bud break in the subsequent season.

Water Requirement of Wine Grapes

As previously mentioned, water requirements and irrigation scheduling of wine grapes is quite different from that of table grapes. Wine grape production lays a strong emphasis on fruit quality including color/pigments, flavors, and other metabolites accumulating in the berries that will ultimately influence wine quality. A strategy known as **regulated deficit of irrigation (RDI)** is adopted for wine grapes and focuses on stressing the vines by providing less water than the vines actually need. The amount of water stress depends on the growth and fruit development stages. Regulated deficit of irrigation balances vegetative and fruit growth and greatly enhances fruit quality. The timing and amount of water stress imposed on vines is extremely critical to ensure the desired results. The success of implementing RDI in the vineyard depends on several factors including vine age, soil type, and rainfall distribution during the growing season. For instance, if the vineyard site receives heavy rainfall during a particular part of the season, imposing RDI might be very difficult. If the soil at the site is heavy and has a high water holding capacity, imposing RDI becomes challenging. In general, moderate RDI, which consists of providing the vines irrigation at 50-60 percent of their actual needs, gives the best results in controlling canopy growth and improving fruit quality. Regulated deficient irrigation seems to have a greater beneficial effect on red grape cultivars compared to white grape cultivars.

Imposing water stress during periods of active vegetative growth results in the closing of the stomata, the pores on the leaves that allow gas and water exchange between the plant and the environment. This is a physiological mechanism in response to water stress and helps the plant conserve moisture. However, this also results in a decrease in CO_2 uptake by the plant, decreased photosynthesis, and a reduction in vegetative growth. RDI imposed during the middle of the growing season prior to veraison is useful in controlling vigor of grapevines and managing the canopy to ensure better penetration of sunlight and adequate exposure of fruit to light. Moderate RDI imposed following veraison is extremely important to improve fruit quality. Water stress during this stage will cause a decrease in the expansion of the berry (reduce berry size) and result in the pigments, flavor, sugars, and aroma compounds becoming more concentrated in the berries, leading to fruit with a good quality profile. Avoid excessive irrigation stress at any time during the growing season as this might have adverse effects on canopy growth, fruit yield, and quality. A mild water stress imposed following harvest can help control late season growth while encouraging maturity of wood and vine acclimation. Make sure vines do not face extreme water stress at this time to avoid problems like decreased cold hardiness and poor bud break in the subsequent season.

In commercial vineyards, the “hydration/water status” of grapevines can be estimated using a machine called the pressure chamber. The pressure chamber provides a reading called **leaf water potential (LWP)**, which indicates the water status and subsequent stress imposed by drought on the vine. Leaf water potential is estimated by selecting fully expanded leaves at random in the vineyard either before sunrise (known as pre-dawn LWP) or at noon (known as mid-day LWP). The leaf is obtained by making a sharp cut at the base of the petiole, placed in a plastic bag to avoid any water loss and then inserted in the pressure chamber with the cut end facing outside. The chamber is then made airtight and pressure is applied to push the moisture outside the petiole. Following application of the required pressure, a water bubble emerges at the cut end of the petiole and the pressure required is proportional to the amount of water in the leaf. If the leaf is well hydrated, less pressure is required; however, greater pressure is required when the leaf is drought stressed and contains less moisture. The pressure, expressed in bars, is equivalent to the water potential of the leaf. The leaf water potential of vines can vary from -10 bars (no stress) to -16 bars and above (severe stress), and can help the vineyard manager make a decision on the irrigation strategy to adopt for managing vine growth and fruit quality. Important things to consider when designing an RDI strategy includes age of the vineyard, the soil type, and its water holding capacity, soil depth, any rootstocks being used for production, amount and distribution of rainfall during the growing season, and any potential effects of salinity buildup in the vineyard.

Chapter 10 – Grape Harvesting and Processing

Fruit ripening is a complex process that involves changes in fruit size and chemical composition including sugars, acids, pigments, flavors, and aroma compounds. At the genetic level, a number of genes are switched on while others are switched off in response to the ripening process. The plant hormone ethylene plays an important role in fruit ripening. Ethylene, a gas, is produced by several fruits after maturity but prior to ripening. Ethylene activates a number of genes involved in various aspects of ripening such as sugar accumulation, color development, and softening of the fruit. Plant species in which a burst of ethylene production occurs prior to ripening are known as climacteric fruits. Such fruits can be harvested at physiological maturity and then exposed to ethylene gas, which finishes ripening the fruit. Examples of climacteric fruits include mangos, bananas, apples, and tomatoes. On the other hand, some fruits such as grapes, oranges, and strawberries do not produce a significant amount of ethylene prior to ripening. These fruits belong to the non-climacteric group and cannot be harvested at physiological maturity then exposed to ethylene gas for ripening. They have to be harvested after ripening.

Figure 10.1 Uneven color development in fruit cluster in table grapes

Grapes need to completely ripen on the vine before harvested. Harvesting parameters can vary between table and wine grapes. In case of table grapes, higher sugar levels are desirable at the time of harvest. Sugar content of berries can be measured using an instrument known as a refractometer. Samples of berries are obtained from the vineyard prior to harvest. A drop of juice is squeezed from the berry and placed on the panel of the refractometer. Digital and analog versions of the refractometer are available that will provide a reading known as **total soluble solids (TSS)**. Total soluble solids in fruit juice predominantly consists of sugars along with acids and other compounds. The readings are expressed in degree Brix. Table grapes are generally harvested at TSS levels of 20 Brix and upward (berries of some cultivars accumulate up to 25 Brix). Other important considerations for harvesting table grapes include uniform color development and change in the color of the rachis (Fig. 10.1). In case of white cultivars, berry color changes from green to different shades of yellow-green and yellow (Fig. 10.2). In dark-colored varieties, uniform red or dark black color is observed in berries following ripening (Fig. 10.3).

Figure 10.2 Uniform color development in a white table grape cultivar

Figure 10.3 Uniform color development in a red table grape cultivar

In commercial table grape vineyards, great care is taken during harvest and post-harvest handling of clusters to maintain their attractiveness and luster. Any shriveled, diseased, and insect damaged berries are removed from the cluster prior to packing and cooling. Early morning harvesting helps keep the fruit at a lower temperature and ensures better quality and post-harvest storage.

In case of wine grapes, factors such as the development of aroma compounds in addition to sugars, acids, and color need to be considered during the harvesting process. While the sugar-acid ratio is an important consideration during the harvesting process, some hybrid grape cultivars may be harvested at lower TSS values (17-19 Brix) to avoid development of the foxy/grassy aroma profiles observed during the process of sugar accumulation. This helps in the production of high-quality wine with good flavor and aroma compounds. Berry color is another crucial factor to take into consideration during harvesting. Anthocyanins are pigment compounds responsible for berry and wine color. Anthocyanin accumulation occurs after veraison and peaks during the ripening process. In red cultivars, uniform anthocyanin accumulation is essential prior to harvesting the berries. In major wine producing regions, the decision to harvest may be made by the winemaker after evaluating the quality and chemical profile of ripe berries. Berry qualities are evaluated by measuring characteristics as described in the paragraphs above. Aroma and flavor characteristics are based on personal judgment and the product desired. Following harvesting of wine grapes, check clusters for the presence of any

Figure 10.4 Wine being fermented in large fermentation tanks followed by aging in barrels

extraneous materials such as insects to avoid any off-flavors being imparted to wine during the crushing process. If grapes are not being processed immediately, they can be stored at 4 degrees Celsius (40°F) for a few days prior to use for further post-harvest processing.

Grapes can be processed into a number of value-added products including wine, juice, jelly, and jams (Fig. 10.4). Wine grape cultivars are destemmed and crushed and then fermented in the presence of yeast. The yeast is a fungus that converts the sugars in the juice to alcohol with CO_2 being released as a by-product. Wine making is a labor-intensive process that requires skill and experience. A number of kits are available that can be used by homeowners and hobby growers to make wine from fruit grown in their gardens.

Wine or table grapes can also be harvested for producing jelly and jams. Wine grapes at the Sheridan and Powell Research and Extension Centers have been successfully processed into low-sugar variety jellies and mixed variety jellies. These colorful jellies can accent any table, especially making the holiday season festive. A recipe for low-sugar grape jelly can be found in Appendix 2, page 79.

Glossary

A

Acclimation – Physiological adjustments in growth to changing environment

Advective frost – Frost caused by movement of cold air into the area

Appellation – A unique name linked to a specific grape growing region

Asexual propagation – Process where plants are generated from cuttings of the parent plant

B

Binomial nomenclature – Scientific name for an organism composed of two parts

Bloom – Waxy coating on grape berries, also refers to flowering

Bloom stage – Estimated by determining the total number of open flowers in an inflorescence

C

Canes – Completely matured (hardened and lignified) stems

Canopy – Includes all vegetative and reproductive plant parts aboveground (trunk, cordons, canes, spurs, shoots, fruit, leaves)

Canopy management – Manipulation of the various canopy components to achieve a balance between vegetative and reproductive growth for optimum quality

Canopy microclimate – Climate surrounding and within the canopy (similar to vineyard microclimate)

Chromosomes – Thread-like structures inside the nucleus that carry genes, which are transmitted to the offspring

Climacteric fruit – Fruits where ripening is preceded by a sudden burst in ethylene gas

Cordons – Horizontal extension of trunks (horizontal trunks)

Crop load – Ratio of yield to the pruning weight or leaf area

D

DDC/DDF/GDD – Degree Days in Celsius/ Degree Days in Fahrenheit/Growing Degree Days, summarizes heat accumulation for each day and is used to compute days available for active vine growth

Deficit irrigation – Providing irrigation water at levels much below normal vine use

Deficit threshold irrigation – Type of Regulated Deficit Irrigation (RDI, see page 69) where irrigation is withheld until a level of vine water stress is attained and then irrigated with a specific volume to allow sugar accumulation and preserve canopy cover

Dioecious flowers – Unisexual flowers present on different plants

Diploid – Two chromosome sets

Dormancy – Period of inactive plant growth (paradormancy, endodormancy, ecodormancy)

E

Ecodormancy – Dormancy induced by environmental factors

Endodormancy – Dormancy induced by internal physiological factors (growth inhibitors)

Enology (Oenology) **–** Science of wine production

F

Family, Genus, Species – Taxonomic ranks/levels in biological classification

H

Haploid – One chromosome set

I

Integrated pest management – Effective and environmentally sensitive approach to controlling pests using a combination of chemical, biological, physical, and cultural methods

K

Kicker canes/renewal canes – Spurs that produce back-up canes in case of frost damage

L

Light quantity – Amount of light produced on a particular day (measured in micromoles of photons)

LT50 value – Lethal temperature at which 50 percent buds on a cane are killed. LT50 values are used to estimate compound bud survival during winter

M

Macroclimate – Climate of a particular region

Meristems – Specialized tissues involved in growth (shoots, roots, flowers, cambium)

Mesoclimate – Climate of the vineyard site

Metamorphosis – Developmental stages an insect passes through from hatching of egg to an adult

Microclimate – Climate of the grapevine canopy and soil

Micropropagation – In vitro propagation of plants (propagation through tissue culture)

Monoecious flowers – Unisexual flowers present at different locations on the same plant (e.g., corn has tassels and silks)

N

Non-climacteric fruit – Fruits where ripening is not proceeded by a sudden burst in ethylene gas (e.g., grapes, raspberries, cherries)

P

PAR (light quality) – Photosynthetically active radiation is measured in light wavelength

Paradormancy – Dormancy induced by external physiological factors (apical dominance)

Perfect/bisexual/hermaphrodite flowers – Male and female parts are present in the same flower on the same plant

Pesticide resistance – Repeated exposure of an organism to a chemical can cause selections in the genetic material of the organism, which enables it to resist a chemical

Phenology – Study of a developmental event (e.g., leaf, flower emergence)

Phloem – Tissues that translocate products of photosynthesis from leaves to other parts of the vine

Phytomere – Repeated initiation units consisting of a leaf, node, internode, and meristem produced by a plant

Ploidy – Number of chromosome sets in a cell

Polyploid – Multiple chromosome sets

Primordium – An organ at the earliest stage of development (rudimentary stage of development); plural – primordia

Pruning (dormant pruning) – Annual removal of wood (during the vine's dormant period)

Pruning weight – Amount of wood pruned off a vine in a single season (one year growth)

R

Radiation frost – Radiation loss from soil leading to cold air above it

Regulated Deficit Irrigation (RDI) – Restricting or regulating the application of irrigation that limits vine water use to below that of a fully watered vine

Renewal zone – Area of the vine from which fruiting canes (buds for next year's crop) originate

Respiration – Breakdown of organic compounds to release energy for cellular functions

Rootstock – Lower portion of a grafted plant that consists of the root system

S

Scion – Upper portion of a grafted plant that consists of the shoot system

Sexual incompatibility – Failure of two species to produce offspring following sexual reproduction/propagation

Sexual propagation – Process in which pollen (male) and ovule (female) unite to form a seed (and plant)

Shoot positioning – Arranging shoots of a vine in a manner that upper shoots do not shade lower shoots

Source and sink – Source is the origin of food production (leaves), while sink is the final destination or storage place for the food products (berries, roots, trunk etc.)

Spurs – Canes cut back to 1-3 nodes are known as spurs

Suckers – Shoots that grow from below ground or near the ground on trunks

T

Terroir – Interaction of variety, climate, and soil to produce a specific wine quality (pronounced as "Tehrwahr")

Threshold temperature (T) – Base temperature above which active vine growth begins (10°C or 50°F)

Tissues – Organized group of cells that have a specialized function

Transpiration – Loss of water from plants

Trellis – Structure that supports vine growth

U

Unisexual flowers – Flowers that have either only male (stamens) or only female (pistils) reproductive parts

V

Vascular system – Transportation system of a plant (cambium, xylem, phloem, etc.)

Veraison – Initiation of color change in berries

Vine balance – Appropriate balance between vegetative and reproductive growth

Vine capacity – Maximum amount of shoots that a vine can support and fruit that will ripen

Vine vigor – Describes the rate of shoot growth

Vine water potential – Used to indicate the amount of water in the vine in relation to the environment (leaf water potential, stem water potential)

Viniculture – Process of growing grapes and making wine

Viticulture – Science of grape production

W

Wine – Drink made from fermentation of grapes

X

Xylem – Tissues that transport water (and dissolved nutrients) absorbed by roots to various parts of the vine

Appendix 1: University of Wyoming's Powell Research and Extension Center Grape Vineyard Harvest Data

Variety	# of Vines	Yield Range (Pounds)	Average Yield (Pounds/ Vine)	Total Yield (Pounds)	Comments
2019 Harvest Harvest date: 9/12/19 6-year-old vines 3rd harvest					
Brianna	4	15.2 - 33.8	23.85	95.4	
Elvira	3	9.8 - 27.8	20.4	61.2	2 vines were not ripe, thus not harvested.
Frontenac	4	16 - 37	27.25	109	
Frontenac Gris	4	19 - 26.8	22.15	88.6	
LaCrescent	5	9 - 17.9	12.26	61.3	
Marchal Foch	3	0.4 - 8.2	4.33	13	
Marquette	2	7.2 - 24	15.6	31.2	
Osceola Muscat	5	16.4 - 45	27.52	137.6	
Total Vineyard Yield	**30**		**19.17**	**597.30**	
2018 Harvest Harvest date: 9/20/18 5-year-old vines 2nd harvest					
Brianna	4	20 - 25.6	22.85	91.40	No bird damage
Elvira	3	23.6 - 37.4	32.67	98.00	Not ripe, needs two more weeks
Frontenac	4	6.6 - 23.4	11.45	45.80	50% bird damage
Frontenac Gris	4	6.8 - 12.4	10.50	42.00	25% to 50% bird damage
LaCrescent	2	6.6 - 10.8	8.70	17.40	No bird damage
Marchal Foch	4	7.6 - 17.4	12.30	49.20	minimal bird damage
Marquette	3	3.6 - 16	8.07	24.20	50 to 75% bird damage
Osceola Muscat	5	1.8 - 24.8	12.72	63.60	No bird damage
Total Vineyard Yield	**29**		**14.88**	**431.60**	**Vineyard netted at verasion**

Variety	# of Vines	Yield Range (Pounds)	Average Yield (Pounds/ Vine)	Total Yield (Pounds)	Comments
2017 Harvest Harvest date: 9/22/17 4-year-old vines 1st harvest					
Brianna	4	1.07 - 9.08	5.91	23.62	
Elvira	3	1.26 - 4.12	2.83	8.50	
Frontenac	2	4.12 - 5.43	4.78	9.55	
Frontenac Gris	2	6.22 - 7.71	6.97	13.93	
LaCrescent	2	0.72 - 2.92	1.82	3.64	
Marchal Foch	3	.11 - 1.07	0.55	1.64	
Marquette	4	.75 - 3.43	1.46	5.84	
Osceola Muscat	4	1.69 - 14.7	7.08	28.33	
Total Vineyard Yield	**24**	**.11 - 14.7**	**3.96**	**95.05**	

Appendix 2: Low-Sugar Grape Jelly

Yields 7 half-pint jars of jelly.

1. Measure 5½ cups juice into a large saucepan, and 3¼ cups sugar in a separate bowl.

2. In a small bowl, mix 1 box (3 Tbsp) low-sugar pectin with another ¼ cup sugar.

3. Stir pectin-sugar mixture into juice. Bring mixture to a full rolling boil on high heat, stirring constantly.

4. Quickly stir in remaining sugar. Return to a full boil and boil exactly 1 minute, stirring constantly. Remove from heat and skim off foam.

5. Ladle immediately into hot jars, leaving ¼ inch headspace.

6. Adjust lids and process in a boiling water canner according to the following table:

Altitude	0 - 6,000 ft	6,000 ft - 10,000 ft
Minutes of processing time	10 minutes	15 minutes

Additional resources at http://www.uwyo.edu/foods/food-preservation.html

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University of Nebraska, Grape Research Program, https://viticulture.unl.edu/

University of Vermont, Grape Production Information, http://www.uvm.edu/~fruit/?Page=grapes/gr_home.html&SM=gr_submenu.html

Vitis vinifera L. wine grape map https://plants.usda.gov/core/profile?symbol=VIVI5

Visit barnyardsandbackyards.com and select "Gardening" for more information on growing grapes and other fruits and vegetables in Wyoming.

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