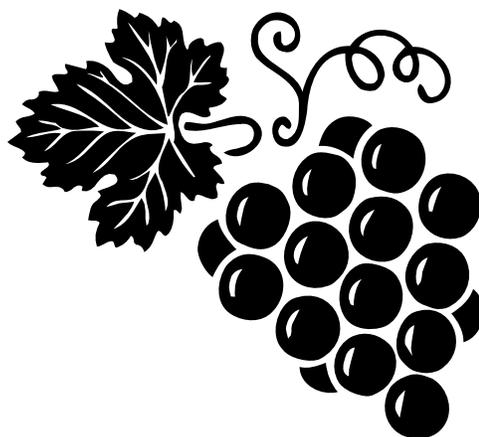


Grapevine Rootstocks: Current Use, Research, and Application

Proceedings

of the

2005 Rootstock Symposium



Edited by
Peter Cousins
R. Keith Striegler

Southwest Missouri State University
Mountain Grove Campus
Mid-America Viticulture and Enology Center

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Evolution, Genetics, and Breeding: Viticultural Applications of the Origins of Our Rootstocks

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We can use information about the natural habitat and environmental adaptation of grape species and about the genetic composition of grape rootstocks to help us determine which rootstocks would be suitable for a particular vineyard.

Key principles:

1. The characteristics of grape species reflect their native environment and adaptations.
2. Just like families of people, families of grape varieties have common characteristics.
3. Characteristics of rootstocks reflect their selection criteria.

Rootstocks were first used for grapes because of phylloxera, a root-feeding aphid. Phylloxera can kill grapevines of the species *Vitis vinifera*, which includes the varieties Cabernet Sauvignon and Chardonnay. Following the accidental introduction of phylloxera to Europe in the 1800s, thousands upon thousands of acres of vineyards were devastated. Scientists recognized that phylloxera came from North America. They reasoned that if the wild grapes of North America grew in areas infested with phylloxera without damage, the roots of these wild vines must be, in some way, resistant to phylloxera. Extensive experimentation followed to identify which selections of North

American grapes were suitable for use as rootstocks in European vineyards. Phylloxera resistance was a critical component of the first rootstocks and remains so today. Other traits were important as well. Nurseries had to be able to easily root dormant cuttings of rootstock selections. Cuttings needed to graft easily with *V. vinifera* scion varieties. Adaptation to calcareous soils is essential in many European viticultural regions.

Many species of North American grapes are resistant to phylloxera. But only a few species were suited for direct use as rootstocks. The wild grapes *Vitis riparia* and *V. rupestris* were an important source of rootstock selections. These two species root easily from dormant cuttings and provide protection against phylloxera. Plants of those species were collected from nature and tested. Those that matched grower criteria were adopted for direct use in the vineyard. Although individual members of grape species share common attributes, the individuals can differ in horticulturally important ways. Not all *V. rupestris* selections are equally easy to root, for example. Characterization of rootstocks based on their parental species is a helpful generalization, but only thorough testing determines the value of a given rootstock variety for particular pest, soil, or other horticultural conditions.

Vitis riparia is North America's most widely distributed wild grape species. It is found across eastern North America from Canada to Florida. Within its range *V. riparia* can be very common. It often grows roadside, up telephone poles and on fences. It's frequently seen draped on the trees and shrubs at the edge of a forest. The name "riparia" means "riverbank" and while *V. riparia* does grow along streams and rivers, it will grow nearly anywhere, as long as there is enough water. Eastern North America tends to be a region of abundant summer rain. You don't have to water your vegetable garden here because there is enough rain. A grape species, like *V. riparia*, that is adapted to this environment doesn't need a deep root system that searches through the soil for water. *Vitis riparia* is native to regions where phylloxera is present and its roots are not susceptible to phylloxera. Some *V. riparia* selections are used directly as rootstocks; Riparia Gloire is the most popular. Growers in the northeast continue to make selections from *V. riparia* vines that are well adapted to their local conditions and to adopt them for rootstock use in their vineyards.

Vitis rupestris is not a grapevine! It is a grape bush. It grows along the ground as a shrub, not climbing into trees like *Vitis riparia*. It is native to the central United States, from Texas, Oklahoma, Arkansas, and Missouri to Tennessee, Kentucky, Ohio, and West Virginia. It doesn't grow so much streamside (as *V. riparia*) as actually in the river. Its typical habitat is gravel beds and sand bars. This is a precarious place for a plant to grow—when floods come, a plant growing in a river risks being sent downstream. How does *V. rupestris* manage in this environment? It has deep roots that go down into the substrate and hang on. What are the implications of the growth characteristics for the use of *V. rupestris* and its hybrids as rootstocks? The deep rooting habit makes *V. rupestris* types good choices for sites where a vine might need

to go looking for water—hillsides and other well drained sites, for example. Like *V. riparia*, *V. rupestris* is native to a region with phylloxera and when used as a rootstock, *V. rupestris* provides protection against phylloxera. Several selections of *V. rupestris* are used directly as rootstocks; St. George is the most important.

Vitis riparia and *V. rupestris* are very important in the history of rootstock breeding because they provided selections that could be used immediately in vineyards where they were adapted. No additional crossing or selection among seedlings was necessary. Unfortunately, these two species are not very tolerant of calcareous soils. The availability of nutrients in the soil varies with pH. Plants that grow in high pH soils need to be adapted to low availability of iron. Many important viticultural regions in Europe have calcareous, high pH soils. *Vitis vinifera* is very tolerant of these soils and for centuries *V. vinifera* varieties were grown on calcareous soils without rootstocks; this practice was all but ended by phylloxera. Rootstock breeders continued their search for suitable parents that would be a source of adaptation to these soils.

Vitis berlandieri is recognized for its adaptation to calcareous, high pH soils. Some of the places in central Texas where *V. berlandieri* is native have ancient sea shells on top of white, chalky soil. *Vitis berlandieri* is tolerant of calcareous soils and resistant to phylloxera, but this species is very difficult to root from hardwood cuttings. No *V. berlandieri* selections are used directly as rootstocks.

Breeders crossed *V. berlandieri* with *V. rupestris* and *V. riparia* and developed new families of rootstocks that combine adaptation to calcareous soils with ease of propagation. Since all three species provide protection against phylloxera, the hybrids among them

also are recommended for use in phylloxera prone vineyards. The three groups of rootstocks formed by the hybridization of these species are the most important in viticulture today. The attributes of the rootstock varieties reflect the characteristics of their parental species.

The *V. riparia/V. rupestris* hybrid family of rootstocks includes 3309 C, 101-14 Mgt, Schwarzmann, and 3306 C. Like *V. riparia* and *V. rupestris*, these rootstocks tend to be easy to root and graft and they provide excellent protection against phylloxera. They tend to have deeper rooting than pure *V. riparia* rootstocks, which means improved drought tolerance/resistance. Neither *V. riparia* nor *V. rupestris* are known for their tolerance of calcareous soils and their hybrids as a group are not well adapted to such soils either.

Hybrids of *V. berlandieri* and *V. riparia* include important rootstocks such as SO₄, Teleki 5C, Kober 5BB, and 420A Mgt. These rootstocks tend to be of lower to moderate vigor and are adapted to moister vineyard sites. *Vitis berlandieri* contributes adaptation to calcareous soils and both parents contribute to the excellent phylloxera protection provided by these rootstocks.

Crosses between *V. berlandieri* and *V. rupestris* are adapted to deep, well-drained soils, such as hillsides. Like the *V. berlandieri/V. riparia* hybrids, they tolerate calcareous soils well and provide excellent protection against phylloxera. Many are noted for their high vigor. Rootstocks in this family include 110 R, 140 Ru, and 1103 P.

Many thousands of grapevine hybrid seedlings have been examined for their possible use as rootstocks. Rootstocks are like people—the ones which are closely related tend to share more characteristics than those which are

distantly related. Like people, rootstocks typically show characteristics from both of their parents. And while families of people or rootstocks show similarity to one another, the members of one family are not identical. Knowing the characteristics of the important parental species used in rootstock development helps us to understand the viticultural attributes of the rootstock families.

A few other North American grape species have been used in grape rootstock breeding. The same principles of understanding their native habitat and adaptations help explain the characteristics of their hybrids that are used as rootstocks.

Vitis cordifolia and *V. monticola* provide excellent phylloxera protection, but are very difficult to root. These two species were used as parents in hybrid combinations with easier to root species such as *V. riparia* and *V. rupestris* to develop the rootstocks 44-53 M and 106-8 Mgt (*V. cordifolia*) and 188-15 C (*V. monticola*). *Vitis cordifolia* is found throughout much of eastern North America and like *V. riparia* is adapted to moist sites; it is poorly suited to high pH soils. *V. monticola* is restricted in nature to central Texas and is adapted to drought and calcareous soils.

Vitis x champinii is a source of root-knot nematode resistance in several rootstocks. This wild grape is found in central Texas in rugged terrain where a vine needs to be tough in order to survive drought, poor soils, and other harsh conditions. When *V. x champinii* vines are pampered (relatively speaking) in a vineyard where they are irrigated and fertilized, they can be overly vigorous and take up excess mineral nutrients, especially potassium. Dog Ridge and Ramsey are selections of *V. x champinii* and Freedom and Harmony are complex interspecific hybrids with *V. x champinii* parentage; as a group the rootstocks are recognized for their high vigor.

The muscadine grape, *V. rotundifolia*, is native to the southeastern United States. It is so different genetically from other grape species that many of the pests and diseases that attack other grapevines apparently do not recognize *V. rotundifolia* as a suitable host. It is highly resistant to several important grape pests and diseases, including phylloxera, many nematodes, fanleaf degeneration, and downy and powdery mildew. Coming from the warm and humid south, it is not very cold hardy or drought tolerant. *Vitis rotundifolia* does not tolerate calcareous soils and its cuttings are among the most difficult to root of all species. O39-16 is the most important *V. rotundifolia* hybrid rootstock in use today and is recommended specifically for sites with the dagger nematode *Xiphinema index*, the vector of grapevine fanleaf virus. Breeders continue to make crosses with this species in an attempt to use its excellent pest and disease resistance in developing new rootstocks.

Vitis labrusca is a minor player in the history of rootstock breeding. Also a component of American hybrid scion varieties such as Concord and Catawba, *V. labrusca* is an easy to root species suited to lower pH acid soils. Its phylloxera resistance is classified as moderate to poor and it is not well adapted to calcareous sites. No *V. labrusca* selections are used directly as rootstocks. The *V. labrusca* hybrids Violla and Sonoma are in very limited use as rootstocks.

Vitis vinifera is best known as a fruit producer—the most important scion varieties are *V. vinifera* or *V. vinifera* hybrids, including Cabernet Sauvignon, Thompson Seedless, Seyval, and so forth. Humanity's association with this species stretches back thousands of years. The exact primordial distribution of *V. silvestris*, the wild progenitor of cultivated *V. vinifera*, cannot be known with certainty. Historical reports, archaeological findings, and remnant populations suggest that *V. silvestris*

once was found across southern and eastern Europe, northern Africa, the Middle East, the Black Sea basin, and across southwestern and central Asia as far as Afghanistan and Kazakhstan. This is a diverse region that is a challenge to ecogeographically summarize, but the adaptations of *V. vinifera* are reflective of its native environment. *Vitis vinifera* varieties are among the most tolerant of drought, salinity, and calcareous soils of all grape species. *Vitis vinifera* shows resistance or tolerance to several virus diseases thought to be originally found within its native range. Since *V. vinifera* evolved in the absence of phylloxera, however, it is highly susceptible to this pest.

Many *V. vinifera* hybrid rootstocks have been produced. Like other rootstock families, hybrids with *V. vinifera* show characteristics of their parental species. *Vitis vinifera* is easy to root and graft and is very tolerant of calcareous soils. Those are desirable characteristics in a rootstock. However, *V. vinifera* is susceptible to phylloxera and so *V. vinifera* hybrid rootstocks must be used only with great caution. Rootstocks that are half *V. vinifera* include AxR#1, 143A, and 1202 C. AxR#1 once was widely planted in California. In many ways AxR#1 is a good rootstock; it is easy to root and graft and it is tolerant of many virus infections. But it fails in one essential aspect component: it is not resistant to phylloxera. AxR#1 is a *V. vinifera* x *V. rupestris* hybrid, and its *V. rupestris* parent is phylloxera resistant. It is not known what genes from *V. vinifera* cause susceptibility to phylloxera. Therefore, it is difficult to predict how a rootstock containing *V. vinifera* will react to phylloxera over the long term in the vineyard. For example, the closely related rootstocks Harmony and Freedom both contain *V. vinifera* in their parentage. Harmony is reported to have collapsed to phylloxera in the field and yet Freedom has so far demonstrated satisfactory phylloxera resistance. Few *V.*

vinifera hybrids are in broad use as rootstocks today because of the question of durable phylloxera protection. Hybrids developed to combine *V. vinifera*'s rooting ability with *V. berlandieri*'s phylloxera resistance, such as 41B and Fercal, are well adapted to calcareous soils and present one of the few exceptions to the strong trend away from *V. vinifera* hybrid rootstocks.

There are many other species of grapes that are being used in rootstock breeding. New selections from the University of California, Davis and USDA rootstock breeding programs derive resistance against specific pests, especially nematodes, from species not previously used extensively in rootstock breeding. The species now being used in rootstock breeding include:

- members of the *V. aestivalis* species complex, which includes *V. rufotomentosa* and *V. x slavinii*; this broadly distributed complex ranges from Canada into the Southeast
- *V. arizonica*, native to the American Southwest
- *V. nesbittiana*, native to the mountains of eastern Mexico
- *V. mustangensis*, native to eastern Texas and adjacent Oklahoma, Arkansas, and Louisiana

What characteristics might we expect from these species as they are used in rootstock breeding? A grape species coming from eastern Mexico might not be very cold hardy—rootstocks with that parentage might be better for use in warmer regions. *Vitis mustangensis* is a giant beast of a highly vigorous vine in many cases—its hybrids might be quite vigorous as well. As we learn more about the genetic resources, more species will be used in breeding to introduce specific traits, such as adaptation to particular soils or resistance against pests and diseases not addressed by today's rootstocks. Like our current

rootstocks, new rootstocks probably will have *V. riparia* and or *V. rupestris* parentage to improve rooting and grafting ability.

The criteria used by the breeders to select specific rootstocks help guide rootstock selections. Rootstock users should be aware of the conditions under which a rootstock was selected and why it was chosen and should try to match their expectations with the known attributes of a particular rootstock. For example, the rootstock Harmony was selected because of its easy rooting and nematode resistance. However, this rootstock was not selected in an area known for heavy phylloxera pressure. Should we chose Harmony for a site where phylloxera is expected to be a problem? No—in fact, Harmony turns out to be not very resistant to phylloxera, consistent with the selection criteria of the breeders when it was identified. When seeking a rootstock for a particular condition in your vineyard, look for rootstocks selected or successfully tested under those conditions. A rootstock selected in one environment may perform well in many environments, but don't assume that wide applicability is the rule either for pest resistance or adaptation to particular soils.

Paulsen and Ruggeri were rootstock breeders in Sicily. We know their names from their rootstocks—1103 P for Paulsen and 140 Ru for Ruggeri. What kind of place is Sicily? It is a dry, hilly Mediterranean island. There isn't a lot of rain. It is not an easy place to be a grapevine. You have to be tough to make it as a rootstock in Sicily. If we plant 1103 P or 140 Ru in a nice flat vineyard with moist, deep, fertile soil, what should we expect? These tough as nails rootstocks that can survive under the harshest conditions have the potential to grow very vigorously under optimal conditions. Suppose we took a *V. riparia* selection from the northeastern U.S., growing on moist, deep, fertile soil, and sent it to Sicily to grow on a dry hillside. What should we expect in that case? We should not

expect high vigor potential—the *V. riparia* is poorly adapted for such growth under such conditions. We can approximately predict this scenario by knowing the species backgrounds of our rootstocks, understanding the conditions under which the rootstocks were selected, and appreciating the native environments to which the wild grape species are adapted.

Not all environmental adaptations of a grape species are important in determining its utility as a rootstock. Cold hardiness of a rootstock and its parental species does not directly translate to improving cold hardiness of the scion grafted to it. Consider a rootstock vine growing ungrafted. Some rootstock varieties can handle more cold than other rootstock varieties. This is just like scion varieties; we recognize that some varieties (Frontenac) are more cold hardy than others (Thompson Seedless). With rootstocks, direct cold hardiness is associated with *V. riparia* parentage; those rootstocks with *V. riparia* parentage, in general, are on the more cold hardy side (think about the native range of *V. riparia*—it includes Canada and the northern United States). Direct cold hardiness should be considered when making your rootstock choice because you don't want the rootstock to be winter killed; it would be tragic to have your scion survive the winter, but not the rootstock. Which rootstocks might be questionably cold hardy? Rootstocks with species parentage from warm regions should be used with caution and only after careful preliminary testing in your site. O39-16, a *V. rotundifolia* hybrid, and Dog Ridge, a *V. x champinii* selection, should be considered on the more tender side, especially in comparison with rootstocks such as 3309 C and 5BB.

Will grafting a vine on a cold hardy rootstock improve the cold hardiness? It might, but only through the rootstock's effect on vine size, not through the movement of a "cold hardiness factor" from the rootstock to the scion. The

rootstock does indirectly influence the cold hardiness of the scion, inasmuch as the rootstock influences vine size. A giant vine growing very vigorously towards the end of the season tends to be less cold hardy than a moderately sized vine that matures its wood and dormant buds and is prepared for the winter. Rootstocks influence vine size and vigor, so a rootstock that induces excess vigor can reduce cold hardiness, while a rootstock that provides appropriate vigor promotes cold hardiness.

The genetic composition of our rootstocks is strongly driven by the inclusion of easy to root species. Most rootstocks are at least half *V. rupestris* or *V. riparia*. The rootstocks without *V. rupestris* or *V. riparia* parentage are nearly all *V. vinifera* hybrids. How important it to know the rooting ability of rootstock cuttings? In the history of rootstock breeding and selection, rooting ability has always been a key goal, along with phylloxera protection. For the production and sale of rooted vines, rooting ability is very important. Some growers do produce their own nursery stock or purchase unrooted cuttings. However, most growers simply purchase vines from a nursery and so rooting ability is not important to the grower. *Vitis berlandieri* is not used directly as a rootstock because it is very difficult to root from hardwood cuttings. It is used as a parent in hybrids with easier to root species, especially *V. riparia* and *V. rupestris*. If you propagate your own vines, it is important to recognize that some species root more easily than others. O39-16, for example, is considered difficult to root, which is consistent with its *V. rotundifolia* parentage.

Rootstock breeding and selection is taking place at universities, research stations, and nurseries around the world and more and more new rootstocks are becoming available. We should know the species background and adaptation and testing history of a rootstock

before we choose it for the vineyard and long before we plant it. This contributes to the selection of the appropriate rootstock and the

development and maintenance of a healthy, productive vineyard. Important characteristics of rootstocks are summarized in Table 1.

Table 1. Characteristics of commonly used rootstocks for grape:

Rootstock	Parentage	Relative scion vigor	Phylloxera protection	Root-knot nematode resistance	Dagger nematode resistance	Calcareous soil adaptation
St. George	<i>V. rupestris</i>	high	high	low	low	Low
Riparia	<i>V. riparia</i>	low	high	low	medium	low
Gloire						
1616C	<i>V. riparia</i> x <i>V. solonis</i>	low	high	high	medium	low
101-14 Mgt	<i>V. riparia</i> x <i>V. rupestris</i>	medium	high	medium	medium	low
3309C	<i>V. riparia</i> x <i>V. rupestris</i>	Low to medium	high	low	low	low
Schwarzmann	<i>V. riparia</i> x <i>V. rupestris</i>	medium	high	high	high	medium
Freedom	<i>V. x champinii</i> , <i>V. riparia</i> , <i>V. labrusca</i> , <i>V. vinifera</i> , <i>V. solonis</i> complex hybrid	high	medium to high	high	high	medium
Ramsey	<i>V. x champinii</i>	high	high	high	low	medium
5C	<i>V. berlandieri</i> x <i>V. riparia</i>	medium	high	medium	medium	medium
5BB	<i>V. berlandieri</i> x <i>V. riparia</i>	medium	high	medium	low	medium
SO ₄	<i>V. berlandieri</i> x <i>V. riparia</i>	medium	high	medium	medium	medium
420A	<i>V. berlandieri</i> x <i>V. riparia</i>	low	high	medium	low	medium
110R	<i>V. berlandieri</i> x <i>V. rupestris</i>	medium	high	low	low	medium
1103P	<i>V. berlandieri</i> x <i>V. rupestris</i>	high	high	medium	low	medium
Boerner	<i>V. cinerea</i> x <i>V. riparia</i>	medium	high	high	high	low
Gravesac	<i>V. riparia</i> , <i>V. rupestris</i> , <i>V. berlandieri</i> complex hybrid	low	high	low	(information not available)	low
41 Millardet	<i>V. vinifera</i> x <i>V. berlandieri</i>	medium	medium	low	low	very high
Fercal	<i>V. vinifera</i> , <i>V. berlandieri</i> complex hybrid	medium to high	medium	medium	(information not available)	very high
O39-16	<i>V. vinifera</i> x <i>V. rotundifolia</i>	high	high	low	high	Low

The Meaning of Vine Size

Viticulturists and grape growers measure vegetative growth through dormant cane pruning weight, typically recorded as pounds of pruning per vine or per foot of row (Winkler et al., 1974; Jordan et al., 1980). Although 'pruning weight' or 'vine size' is measured in the winter, it is an indicator of vegetative growth during the previous growing season and a predictor of crop potential for the next growing season. A vine averaging low pruning weight has less leaf area and intercepts less sunlight than a larger vine with more leaf area and higher pruning weight. Therefore, greater vine size leads to higher total canopy photosynthesis and greater potential fruit production. However, when vine size is too large for the allotted trellis space, excessive leaf area increases internal canopy shading and decreases quality production (Shaulis et al., 1966).

So what is optimum vine size? In NY, own-rooted Concord vineyards are typically planted at a 9 foot row and 8 foot vine spacing and producers shoot for 2.5 to 3.0 pound vines, which translates to 0.31 to 0.38 pounds of dormant cane prunings per foot of row. For vineyards at different vine spacing and/or divided canopies, this rule of thumb carries over to a typical recommendation of 0.35 pounds of dormant cane prunings per foot of canopy.

Vine Size and Root Management: The West Tier Experiment

Vine size impacts the potential leaf area to fruit ratio which influences carbon assimilation and partitioning in the grapevine. What does any of this have to do with grapevine root biology and vineyard root management? Roots take up water and mineral nutrients for the vine during the growing season and act as the major storage organ for carbohydrate and

nutrient reserves during the dormant season. As a result, root growth and activity can play a large role in controlling vine size.

In the late 1950's, Dr. Nelson Shaulis planted a factorial experiment at the Cornell Vineyard Lab in Fredonia known as the "West Tier" experiment. The treatments in the trial include pruning severity, training, shoot positioning, floor management, nitrogen fertilization, and rootstocks -- 96 treatment combinations in all (Shaulis and Steel, 1969). On the subject of root biology, the results show that viticultural practices that stimulate root growth and activity increase vine size and productivity, while inhibiting root activity can be a management tool for controlling excessive vigor. Just about every vineyard management decision directly or indirectly impacts grape roots. Pre-plant decisions such as soil type, depth, and drainage establish rooting potential. Vineyard activities such as weed control, fertilization, and irrigation have direct effects on grapevine roots through water and nutrient availability. Furthermore, canopy and crop management have indirect impacts on root growth and function through carbohydrate assimilation and partitioning.

Results from the west tier factorial are shown in Figure 2. A significant increase in vine size and a 3 to 4 ton/acre yield increase were measured through simple weed control (light cultivation) and fertilization (50 pounds actual nitrogen per year). However, most commercial juice grape vineyards are under more restrictive or simply different soil conditions than the Cornell Vineyard Lab. Vine size (or root biology) limitations with respect to water, nutrient, disease, and pest stress on different sites may require different management than cultivation and nitrogen. To address this, current root management projects at the Cornell Vineyard Lab investigate the response of Concord grapevines to nitrogen fertilization, irrigation and pruning, weed

management, phylloxera and crop load,

rootstocks and soil type, and soil pH.

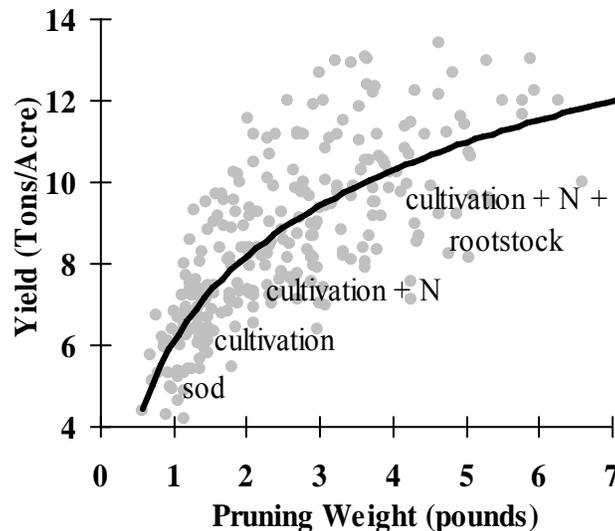


Figure 2. Relationship between vine size and yield in a mature Concord vineyard at the Cornell Vineyard Lab in Fredonia, NY. Incremental increases in vine size and productivity were achieved by decreasing weed competition for water (cultivation), increasing mineral nutrient availability (nitrogen fertilizer), and decreasing pest pressure (phylloxera resistant rootstock).

Root Management to Control Vine Water Status: An Example

Vineyard water management to control vine size and fruit quality in Eastern Washington and Central California is simple. . . turn on the irrigation when needed. Although this may be an oversimplification to vine water relations, the fact is that controlling vineyard water is more difficult in the precipitation rich eastern US. Here is an example of how root and floor management has been used to help control vine water status in eastern Concord vineyards.

The competitive effects of permanent sod row middles on Concord productivity are well known (Shaulis and Steel, 1969). However, the deleterious effects of long-term cultivation are also recognized (Wander, 1946). These include an increased risk of erosion, decreased soil organic matter, and reduced soil

permeability. In the mid-1950's, researchers recommended a system of incomplete or "trashy" cultivation in which partial weed cover was maintained at all times on non- or moderately erodable sites (Fleming and Alderfer, 1956). Trashy cultivation achieved near maximum productivity while reducing soil and water losses from runoff and the gradual decline in organic matter from continuous cultivation. For highly eroded sites, the recommended practice was to establish a sod for two or three years followed by several years of cultivation, a compromise that reduced productivity during established sod years but conserved soil resources.

No-tillage has replaced cultivation as the predominant method of vineyard floor management in New York vineyards. In two studies conducted in the mid-1980's, vine size, yield, and juice soluble solids were similar for vines receiving either three or four annual

cultivations or a single application of glyphosate (Roundup®) herbicide in the row middles (Pool, Dunst and Lakso, 1990; Pool et al., 1995). Besides reducing the risk of erosion, the no-till approach also allows for better equipment access during wet seasons which can be important for timely fungicide applications or harvest.

Cover crops are often touted as an organic alternative to cultivation or herbicides for vineyard row middle management. Legume cover crops have also been suggested for their value in fixing nitrogen and buffering nitrogen release into the soil. These questions were addressed in a floor management experiment conducted in a mature Concord vineyard at the Vineyard Lab in Fredonia from 1991 to 1994 (Pool, Lakso et al., 1995). Treatments included mulch, bloom herbicide, cultivation, mowed and unmowed orchard grass, Kentucky bluegrass, crown vetch, white clover, annual ryegrass, and annual ryegrass killed with herbicide at bloom. Vine size was lowest in treatments with living covers after grape bloom and the vine size reducing effect of the covers was greater during drier seasons. All living covers, regardless of species, depressed vine size and did not contribute to higher grapevine tissue nutrient concentrations. Mulch and killed rye treatments had the largest vine size and yield. The mulch treatment consisted of annual applications of straw at 5 tons per acre. The killed rye treatment consisted of annual rye drilled in August (10 lbs. per acre) and killed with glyphosate at bloom. The allelopathic effect of rye decomposition substantially reduced weed

germination and subsequent growth between grape bloom and re-seeding.

These research results indicate that actively growing covers, particularly during the post-bloom period, are too competitive with ownrooted Concord in New York, and depress vine size and yield. Eliminating weeds and extending the weed-free period increases grapevine productivity primarily through vine water relations. It is also interesting to note that in a separate experiment, supplemental irrigation could not overcome the competitive effect of sod (Lakso, 1998). Eliminating weeds is better than trying to overcome their competition for water. In conclusion, mulch and killed rye treatments have been shown to maximize vineyard weed suppression, both spatially and temporally, leading to improved grapevine water relations and greater vineyard productivity.

Are Rootstocks the Answer to Vineyard Water Management in the East?

In the West Tier experiment, own-rooted and grafted (C3309) Concord were compared under the same pruning and floor management conditions. The C3309 roots in the experiment (relatively deep-gravel soil) had deep root distribution and were phylloxera resistant. As a result, Concord vines grafted to C3309 rarely showed signs of water stress even in dry years. Own-rooted Concord vines, on the other hand, with relatively shallow and spreading root systems were susceptible to competition for water with weeds on the vineyard floor.

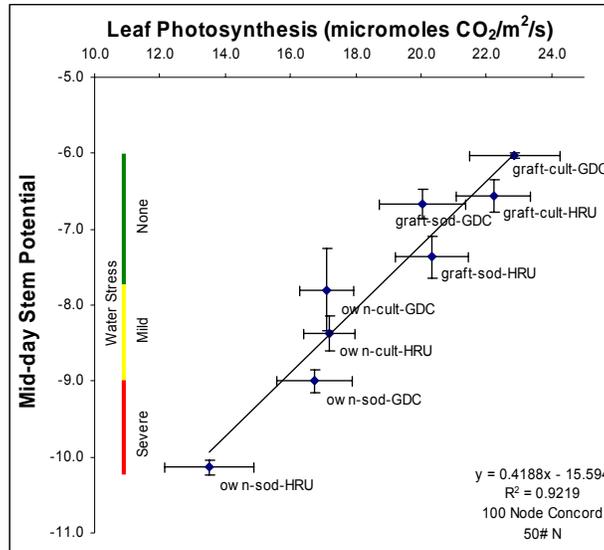


Figure 3. Leaf photosynthesis and mid-day stem potential of Concord during a dry growing season.

Figure 3 demonstrates several aspects of vine water relations in Concord. First, there was a direct relationship between stem potential and photosynthesis, confirming that the lower photosynthetic rates were because of water stress and not some other factor like mineral nutrition or mildew. Second, the figure shows the effect of management practices on vine water relations. All of the Concord vines grafted to C3309 rootstock are in the upper right of the figure, meaning they had good vine water status and high photosynthesis. Among the grafted vines, the ones with reduced weed competition through cultivation were the least water stressed. Own-rooted Concord vines tended to be in the lower left of the figure, meaning they were under more water stress with lower photosynthetic rates (25% to 50% lower than the max). Again, vines with weed free row middles had higher photosynthetic rates than ones with heavy weed competition.

Integrate Root Management Decisions with Vineyard Goals

In the Concord juice industry, producers shoot for large vines, high yields, and juice quality based on a minimum juice soluble solids

standard. With this vineyard goal in mind, C3309 rootstock may make sense to increase vine size with less effort placed on vineyard floor management. In dry years, Concord on C3309 maintains vine size and yield and produces more sugar per acre than own-rooted vines. In wet years, however, Concord on C3309 can have excessive vine size with larger berries size and diluted juice soluble solids. This can be a small issue for Concord producers (as long as the juice soluble solids reach the minimum value) but a fairly large issue for wine grape producers trying to maximize juice quality.

In dry climate viticulture, researchers are using regulated deficit irrigation to control canopy growth and berry size for wine quality. Mild water stress can slow down shoot growth without significantly inhibiting leaf photosynthesis. This helps maintain a well exposed and open canopy. Mild water stress at the right time will also yield smaller berries with concentrated juice components and a higher skin to pulp ratio. Selecting a rootstock efficient at acquiring water and unresponsive to floor management would not be wise choice

if the vineyard goals were to control vine size and juice quality with root management.

Conclusion

Fruit quality with respect to such components as juice soluble solids, flavor compounds and berry size, are influenced by the exposed leaf area to fruit weight ratio. Both sides of this crop load term are influenced by vine size. A vineyard manager can directly influence vine size by manipulating the supply and availability of soil resources to the vine. Weed management, nutrient management, and rootstock selection are all tools a vineyard manager can use to achieve the desired vine size. In the eastern, U.S., the variability in environmental factors such as precipitation and soil chemistry make it important for vineyard managers to use floor and rootstock tools in combination to achieve quality fruit production.

References

- Fleming, H. K. and R. B. Alderfer (1956). Cultivation and Concord production. Pennsylvania State University Agricultural Experiment Station Bulletin 616.
- Jordan, T. D., R. M. Pool, T. J. Zabadal and J. P. Tomkins (1980). Cultural Practices for Commercial Vineyards, New York State College of Agriculture and Life Sciences, Cornell University.
- Lakso, A. N. (1998). Row middle management and irrigation vine effects. 6th Annual Lake Erie Regional Grape Program, Westfield, NY, Cornell and Penn State Cooperative Extension.
- Pool, R. M., R. M. Dunst and A. N. Lakso (1990). Comparison of sod, mulch, cultivation, and herbicide floor management practices for grape production in nonirrigated vineyards. Journal of the American Society for Horticultural Science 115(6): 872-877.
- Pool, R. M., A. N. Lakso, R. M. Dunst, J. A. Robinson, A. G. Fendinger and T. J. Johnson (1995). Weed Management. Organic Grape and Wine Production Symposium, Third N. J. Shaulis Symposium, Geneva, NY, New York State Agricultural Experiment Station.
- Shaulis, N., H. Amberg and D. Crowe (1966). Response of concord grapes to light, exposure and geneva double curtain training. American Society for Horticultural Sciences 89: 268-280.
- Shaulis, N. and R. D. Steel (1969). The interaction of resistant rootstock to the nitrogen, weed control, pruning, and thinning on the productivity of Concord grapevines. Journal of the American Society for Horticultural Science 91: 122-129.
- Wander, I. W. (1946). Physical and chemical studies of soils in north central Ohio vineyards. Ohio Agricultural Experiment Station Bulletin 663.
- Winkler, A. J., J. A. Cook, W. M. Kliever and L. A. Lider (1974). General Viticulture. Berkeley, University of California Press.

Experience with Rootstock Varieties in Germany

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Abstract

The Phylloxera (*Viteus vitifolii* or *Daktulosphaira vitifoliae*) invasion and its devastation of European vineyards at the end of the 19th century resulted in a number of rootstock breeding programs throughout Europe. All major rootstocks currently used in Germany derive from a *V. berlandieri* x *V. riparia* population established by Sigmund Teleki. During the last 50-60 years rootstocks of this origin, e.g. Kober 5 BB, 5 C Geisenheim, SO₄ and 125AA have spread across most cool climate areas worldwide.

Introduction

Phylloxera (*Viteus vitifolii* or *Daktulosphaira vitifoliae*) is the most dangerous pest in viticulture, devastating large viticultural areas of Europe at the end of the 19th and the beginning of the 20th century. Only the use of rootstocks deriving from American *Vitis* species, could overcome this problem and rescue European viticulture (Müller, 1930, Schenk, 1990). All major rootstocks currently used in Germany derive from a *V. berlandieri* x *V. riparia* population established by Sigmund Teleki in Hungary at the end of the 19th century. During the last 50-60 years rootstocks of this origin, e.g. Kober 5 BB, 5 C

Phylloxera damages on grafted vines, reported recently, appear to be primarily caused by secondary parasites and can be completely eliminated by organic fertilizers or by rootstocks with complete phylloxera resistance.

A range of rootstock trials were established at different sites in several German viticultural regions. From these the results of five trials with diverse growing conditions indicate a significant rootstock site interaction. On sites with extreme growing conditions generally larger differences could be found.

Geisenheim, SO₄ and 125AA have conquered most cool climate areas worldwide.

Recently phylloxera damages have been reported on grafted vines in different parts of the world (Granett et al. 1987, 1991; Marcus, 1991, 1992; Presser et al., 1993; Remund and Boller, 1994; Sopp et al., 1998; Redl, 1999). This raises the question of a possible new phylloxera outbreak and ways to prevent it. Field observations of the extension service of the state of Hessen pointed towards a possible interaction between soil management and phylloxera damage. To examine this, a number of field trials were established on different phylloxera infested sites in the vicinity of

Geisenheim, only one with significant damage is reported here.

Good site adaptation and a positive effect on scion performance is essential for a 'good' rootstock. Due to their long-term nature, rootstock trials are rare, mostly conducted on one site only and usually only with a small numbers of genotypes. In an attempt to increase the knowledge about the site adaptation of rootstocks and their effect on scion performance, field trials were established at a number of locations in different German grape growing areas. The data of four of these experiments are presented here. New rootstock hybrids from Geisenheim were also included in some of these experiments, to compare their performance with that of existing rootstock varieties.

Material and Methods

Effect of soil management on phylloxera

The trial site is located at Kiedrich. The soil is a loamy clay and phylloxera had been detected in 1995. The infestation spread across the complete vineyard and most vines were quite weak. The treatments were: control (40 kg N ha⁻¹ as NPK-fertiliser), NPK (120 kg N ha⁻¹ as NPK), Cyanamid (120 kg N ha⁻¹ as Cyanamid), Humus (10 m³ composted cow manure ha⁻¹). While the mineral fertilizer was applied annually in late spring, the organic fertilizer was only applied in spring of 1997 and 1999.

Plant growth was measured with several parameters. For an overview plants were grouped according to their vigour and appearance in six groups from 0 (vine dead) to 9 (very strong growth). At harvest time yield, total soluble solids, juice pH and titratable acidity were registered. Phylloxera population was assessed using an artificial scale from 1

(no phylloxera) to 9 (many nodosities, lots of phylloxera at different stages of development, more than one animal feeding on one nodosity) described earlier (Porten and Huber, 2003). In addition the biological activity was assessed with several techniques (data are not presented here).

Rootstock trials

Hattenheim: The soil type is a fertile sandy loam derived from glacial deposits (Loess) with 10% lime. The trial was planted in 1988 on a mild south facing slope with Riesling clone 198-10 Gm on 29 different rootstocks with 3 replicates. The planting density was 4550 vines per ha and the soil was cultivated.

Hochheim: The soil type at Hochheim/Rheingau is a well drained corbicular lime soil with 20% lime and a clay content of 13%. The vineyard was planted in 1987 on a mild south-westerly slope with a plant density of 4600 vines per ha. A sod culture was established in every second row. The other rows and the under vine space were cultivated. There were 32 rootstocks in the trial with 3 replicates. The scion variety was White Riesling clone 198-10 Gm.

Oberwesel: The site at Oberwesel is very typical for the 'Mittelrhein' region situated on a south-westerly slope with an inclination of 38%. The soil derives from slate, is well draining, has a gravel content of 30 to 50% and no free active lime. The vines were planted in 1985 at a planting density of 4300 vines per ha. The soil was cultivated and 16 different rootstock varieties grafted with White Riesling clone 198-10 Gm were planted in 2 replicates.

Leiwen: The soil type at Leiwen/Mosel is also very typical for the area. It derives from slate, is well draining, having a gravel content of 30 to 50% and contains no free lime. The trial site is a south-westerly slope with an inclination of

up to 75 %. Vines were planted in 1994 at a density of 4600 vines per ha in the lower and 6500 vines in the upper part of the vineyard. The soil was cultivated and 12 different rootstock varieties grafted with White Riesling clone 198-10 Gm were planted in 2 replicates.

Rootstocks, included in the trials, had the following parentage:

- *V. berlandieri* x *V. riparia*: 125 AA clone 3 Gm, 5 BB clone 13-3 Gm, 5 C clone 6-13 Gm, SO 4 clone 47 Gm, 8 B clone 361-3 Gm, 75 BB, Gm 5421-33, Gm 5421-62, Gm 5375-2.
- *V. berlandieri* x *V. rupestris*: 1103 Paulsen.
- *V. riparia* x *V. rupestris*: Gm 628-1, Gm 6338-1, Gm 6338-2, Na 371-58, Na 371-65
- *V. vinifera* x *V. riparia*: 26 G Kl. 27-7 Gm, Gm 602-1
- *V. vinifera* x *V. rupestris* x *V. riparia*: Gm 6454-1, Gm 6454-2, Gm 6454-3, Gm 6454-4, Gm 6454-5
- *V. solonis* x *V. riparia*: Sori clone 14 Gm
- *V. rupestris* x *V. cinerea*: Na 5089-33
- *V. riparia* x *V. cinerea*: Börner, Na 5153-63, Na 5153-75, Na 5153-119, Na 5153-579

Plots of each trial were harvested on the same day. Yield was recorded and representative samples collected for juice analyses. The grape juice was extracted using a hand operated sample press. Total soluble solids were measured with an Atago Digital Refractometer PR-100, pH and the titratable acidity with a Metrom 632 pH-Meter in combination with a Metrom 614 Impulsomat and a Metrom Dosimat E535.

Results and Discussion

Phylloxera can cause significant damage even to grafted vines. This effect appears to be linked to soil management (Figure 1). Higher rates of nitrogen (treatments NPK and Cyanamid) enhances plant growth, with most of the plants in vigour class 7 after two years of treatment. An application of organic fertilizer (Humus) has an even larger effect with most of the plants in class 7. This might be attributed to a better nitrogen supply. The effect on phylloxera population can certainly not be attributed to nitrogen alone (Figure 2). On most of the control plants large numbers of phylloxera at various stages could be found. Both nitrogen treatments resulted in a certain reduction of the phylloxera population, but the humus application largely reduced phylloxera populations. On four of the vines no phylloxera could even be detected. The causal reason for this strong effect of humus on phylloxera is currently further investigated. First results indicate a significant involvement of the soil microflora, both for the extent of the phylloxera damage and the large reduction of phylloxera populations after humus application. Investigations are still under way.

The various trial sites had significantly different cropping levels. The highest 10-year average yields were measured at Hochheim with 1822 gm⁻² (Figure 4) and Hattenheim with 1490 gm⁻² (Figure 3). The average yields of the vineyards at Leiwen (1280 gm⁻²) and Oberwesel (998 gm⁻²) were significantly lower (Figure 5 and 6). The lower cropping levels on the latter two sites are the result of their poor and shallow gravelly soils with rather low water holding capacities, typical for many steep slope sites in Germany.

Almost no rootstock differences were detected in the trial at Hattenheim (Figure 3). While vines grafted on the rootstock hybrid Na 5089-33 produced an average 1595 gm^{-2} , even vines on Gm 55106-75 still yielded 1163 gm^{-2} . Differences in total soluble solids were also small. A certain trend to higher total soluble solids in hybrids with lower yields was apparent, but small. This indicates that on a fertile site without any extreme soil conditions most rootstocks show a good performance and the choice of rootstocks is consequently of no real importance.

Significant effects on average scion yields were measured in the rootstock trial at Hochheim (Figure 4). The highest production was found in *V. berlandieri* x *V. riparia* crosses 75 BB and SO₄ with 1822 gm^{-2} and 1788 gm^{-2} , respectively. At this site *V. rupestris* x *V. riparia* crosses gave slightly lower yields, while yields of the *V. vinifera* x *V. riparia* x *V. rupestris* group varied between the varieties. In this group 26 G achieved the highest yield (1726 gm^{-2}) and Gm 6454-3 the lowest (1299 gm^{-2}). Börner and Na 5153-75, two crosses of *V. riparia* and *V. cinerea* with complete phylloxera resistance both on roots and leaves, had an average yield of 1690 gm^{-2} . The low vigour rootstock Sori (Schumann, 1977) still reached cropping level (1593 gm^{-2}) similar to most other rootstocks, but reached only a sugar level of $18.4 \text{ }^\circ\text{Brix}$. This is most likely the result of a low leaf-to-fruit ratio.

Despite the low overall cropping level, rootstocks at Oberwesel still had a significant effect on scion performance (Figure 5). The highest yield was achieved by 125 AA with 1154 gm^{-2} , followed by Börner with 1125 gm^{-2} . Riesling grafted on the low vigour varieties Sori and Gm 628⁻¹ yielded only 831 gm^{-2} and 678 gm^{-2} , respectively. Differences between total soluble solids (TSS) were only minor, with the exception of Na 371-65 and Gm 628-1 were TSS only reached $17.7 \text{ }^\circ\text{Brix}$. This was

significantly less than the average of $18.5 \text{ }^\circ\text{Brix}$.

Yield differences were observed also in the rootstock trial at Leiwen (Figure 6). This site has two distinctly different soil types. While the soil in the lower part is deep and fertile, the soil in the upper part is both gravelly and shallow and consequently has a low water holding capacity. Except for Gm 602⁻¹ no yield differences were found in the lower part of the vineyard. Performance differences were obvious in the upper part of the site. The highest yield was achieved by vines grafted on 125 AA (1600 gm^{-2}), closely followed by SO₄ (1535 gm^{-2}). The phylloxera resistant hybrid Na 5153-579 and Börner lead to yields of 1509 and 1468 gm^{-2} , respectively. Surprising was the low yield of 1103 Paulsen of only 1075 gm^{-2} . A high drought tolerance is mostly attributed to this variety (Galet, 1988; May, 1994; Pongrácz, 1983). The yield in this trial is significantly lower than the trial average.

In the upper part of the trial site, vines grafted on 1103 Paulsen or Gm 602⁻¹ had the highest TSS with 20.0 and $20.6 \text{ }^\circ\text{Brix}$, respectively. Riesling on Börner still reached $19.9 \text{ }^\circ\text{Brix}$ but with a much higher yield. This indicates the good adaptation of Börner to dry gravelly soils.

Comparing the data of a particularly dry season (1991) to one with more wet conditions (2000) further emphasizes the high drought tolerance of *V. riparia* x *V. cinerea* crosses at Hochheim (Figure 7). Yields of vines on Na 5153-75, Börner or Na 5153-119 exceeded those of *V. berlandieri* x *V. riparia* hybrids in the dry season of 1991, with similar TSS levels. Under the wet conditions of 2000, yields of *V. berlandieri* x *V. riparia* hybrids were slightly higher than those of *V. riparia* x *V. cinerea* crosses, but on a significantly higher cropping level. TSS differences were negatively correlated with yield data.

Similar results were obtained at the Leiwent trial site (Figure 8) in the seasons 1998 (dry) and 2000 (wet). In the upper part of the vineyard in the dry season the highest yields were obtained from vines grafted on Na 5153-579 (1355 gm⁻²) or on Börner (1320 gm⁻²). The TSS of these vines reached with 20.4 and 20.7 °Brix, respectively, the level of SO₄. Yield of 1103 Paulsen (872 gm⁻²) was substantially below the trial average. In the wet season of 2000 no difference could be found between V. berlandieri x V. riparia and V. riparia x V. cinerea hybrids, except for SO₄. The high yield of SO₄ under these wet conditions emphasises the suitability of this variety for fertile sites with good water supply.

The results demonstrate the suitability of V. berlandieri x V. riparia rootstocks on most of the typical German vineyard sites. On dry locations V. riparia x V. cinerea hybrids are a valuable addition to the range of rootstocks currently used in Germany. Particularly on steep slopes and in seasons with rare rainfall V. riparia x V. cinerea hybrids were superior. Due to high phylloxera populations in most grape growing regions growers should consider the increased use of V. riparia x V. cinerea hybrids.

Conclusion

Rootstocks do affect scion performance substantially. None of the rootstocks that have been tested was superior at all sites and in all seasons. There is no universal rootstock. V. cinerea can provide not only complete phylloxera resistance, but is also capable of having a positive influence on scion performance especially on shallow, gravelly and consequently dry soils. The use of phylloxera resistant V. cinerea hybrids should therefore be more used on vineyard sites with generally dry conditions.

Acknowledgements

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Literature cited

- Galet, P., 1988: Cépages et Vignobles de France, Tome I, Les Vignes Américaines, 2e Édition, Imprimerie Déhan, Montpellier, 553 S.
- Granett, J., Goheen, A.C., Lider, L.A., White, J.J., 1987: Evaluation of grape rootstocks for resistance to type A and type B grape phylloxera. American Journal of Enology and Viticulture 38, 298-300.
- Granett, J., Benedictis, J., Wolpert, J., Weber, E., Goheen, A., 1991: Phylloxera on rise. Deadly insect pest poses increased risk in North Coast vineyards. California Agriculture 45, 30-32.
- Marcus, K., 1991: Ideal harvest in Napa, but phylloxera spreads. The Wine Spectator Dec. 15, 1991, p. 12.
- Marcus, K., 1992: Phylloxera costs put at \$1 Billion. The Wine Spectator, Jan 31, 1992, p. 7.
- May, Peter, 1994: Using Grapevine Rootstocks – The Australian Perspective. Winetitles, Adelaide, 62 S.
- Müller, K., 1930: Weinbau-Lexikon. Verlagsbuchhandlung Paul Parey, Berlin
- Pongrácz, D., 1983: Rootstocks for Grapevines, David Philip Publisher, Cape Town, 150 S.

Porten, M. & L. Huber (2003): An assessment method for the quantification of

Daktulosphaira vitifoliae (Fitch; Hemiptera: Phylloxeridae) populations in the field. J. Appl. Entomol. 127:157-162.

Presser, C., Schmid, J. & E.H. Rühl (1993): Die Reblaus - kein Problem mehr?.- Das Deutsche Weinmagazin 23: 22-25.

Redl, H. (1999): Die Reblaus auch in Österreich wieder (beängstigend?) im Kommen. - Der Pflanzenarzt 52: 8-12.

Remund, U. & E. Boller (1994): Die Reblaus - wieder aktuell? - Schweiz. Z. f. Obst- und Weinbau 130: 242-244.

Schenk, W. 1990: 100 Jahre Rebenveredlungsstation Geisenheim. Vortrag anlässlich der 100-Jahrfeier.

Schumann, F., 1977: Unterlagenwahl für trockene Lagen und kalkreiche Böden. Weinwirtschaft 113, 395 – 396

Sopp E., Bleser, E., Rühl, E.H., Hirschmann, J., Jung, C. & A. Booß (1998): Reblaus – Aktuelle Situation und Möglichkeit der Schadensbekämpfung.- Deutsches Weinbau Jahrbuch 49: 207-214.

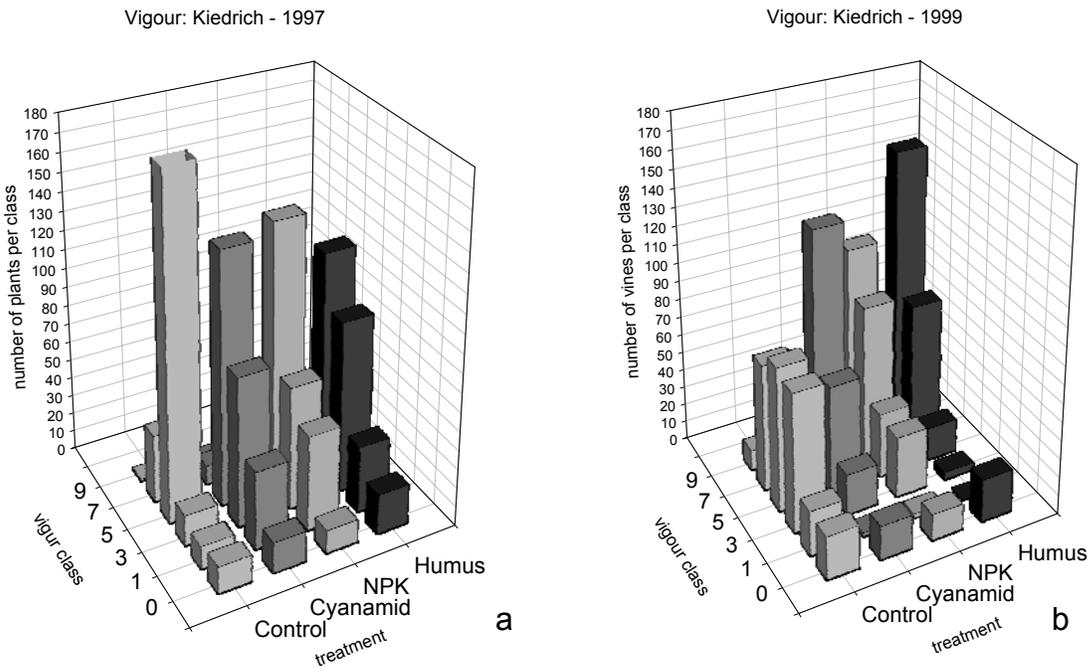


Figure 1: Effect of soil management and fertiliser application on vine vigour in a phylloxera infested vineyard: a. Vigour at Kiedrich in 1997 prior to the commencement of the trial; b. Vigour at Kiedrich in 1999.

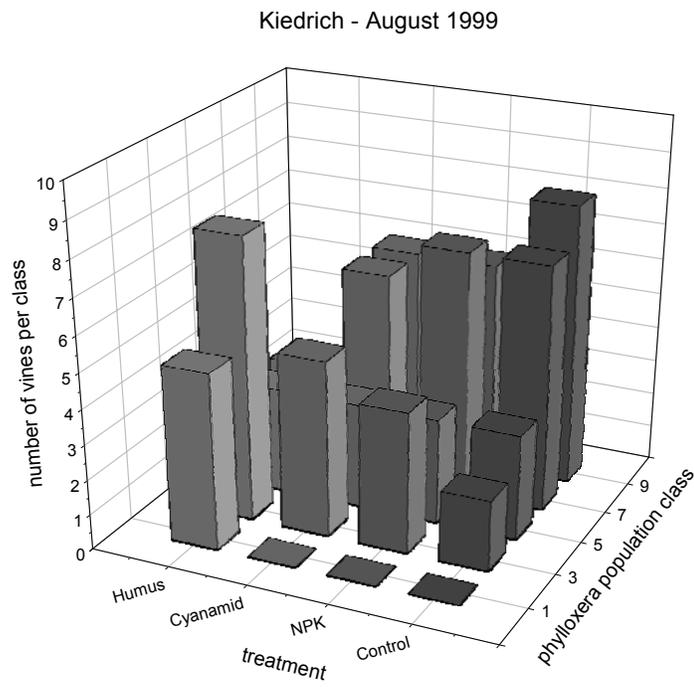


Figure 2: Phylloxera population at Kiedrich in 1999.

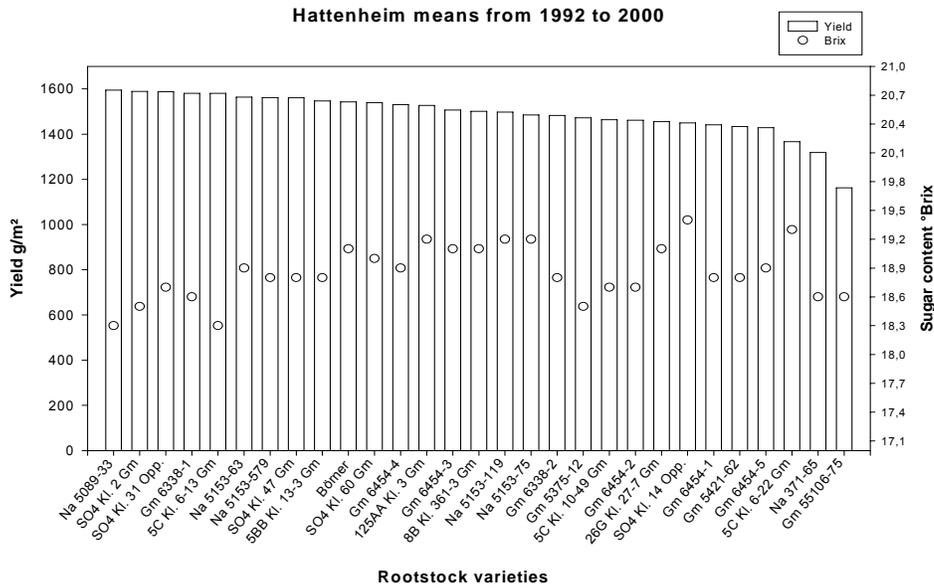


Figure 3: Effect of different rootstock varieties on yield, total soluble solids and titratable acidity of White Riesling at Hattenheim/Rheingau. Data are means of three replicates and of the years 1991 to 2000.

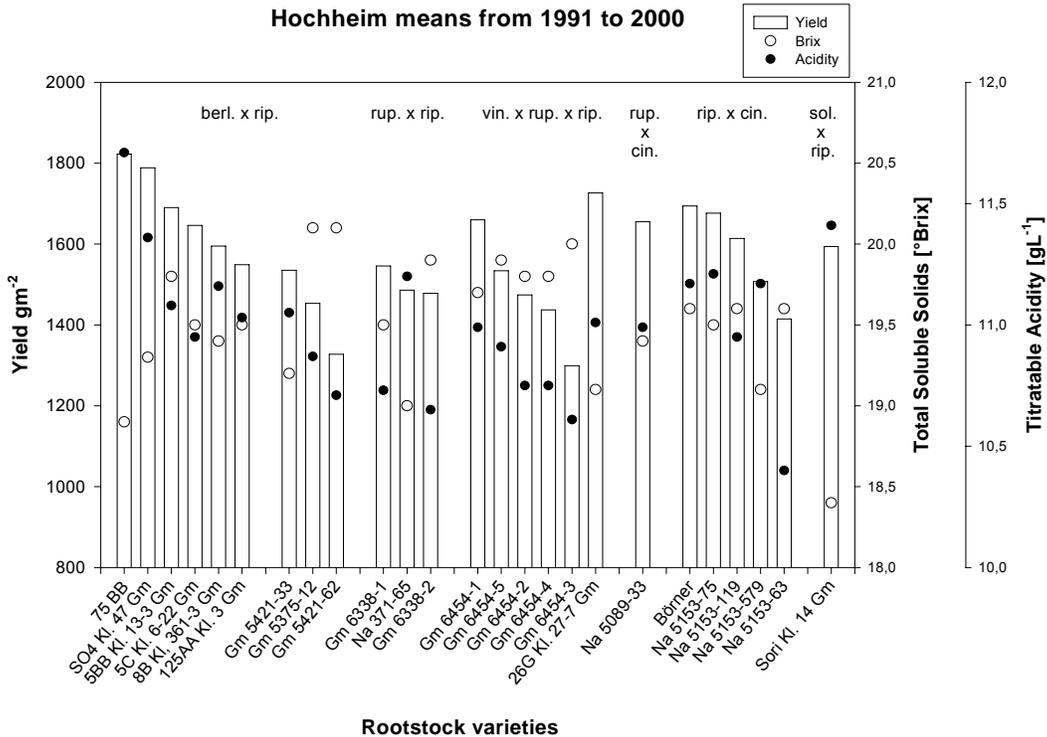


Figure 4: Effect of different rootstock varieties on yield, total soluble solids and titratable acidity of White Riesling at Hochheim/Rheingau. Data are means of three replicates and of the years 1991 to 2000. Abbreviations: berl. = *Vitis berlandieri*, rip. = *Vitis riparia*, rup. = *Vitis rupestris*, vin. = *Vitis vinifera*, cin. = *Vitis cinerea*, sol. = *Vitis solonis*.

Oberwesel means from 1987 bis 1996

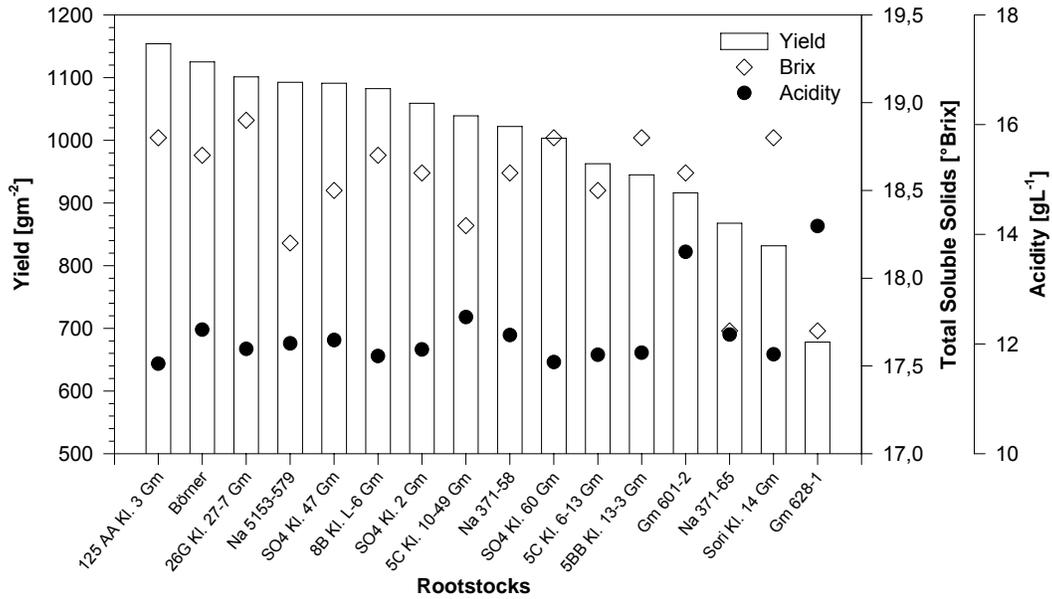


Figure 5: Effect of different rootstock varieties on yield, total soluble solids and titratable acidity of White Riesling at Oberwesel/Mittelrhein. Data are means of two replicates and of the years 1987 to 1996.

Leiwen means from 1997 to 2000

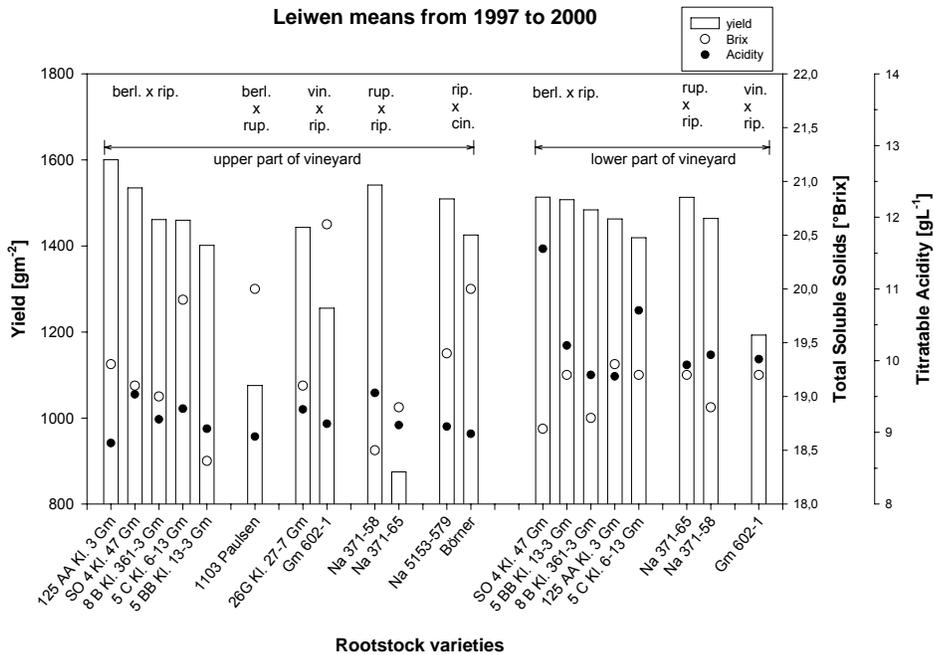


Figure 6: Effect of different rootstock varieties on yield, total soluble solids and titratable acidity of White Riesling at Leiwen/Mosel. Data are means of two replicates and of the years 1997 to 2000. Abbreviations: berl. = *Vitis berlandieri*, rip. = *Vitis riparia*, rup. = *Vitis rupestris*, vin. = *Vitis vinifera*, cin. = *Vitis cinerea*. The soil of the upper part of the vineyard was more shallow and gravelly than the soil of the lower part.

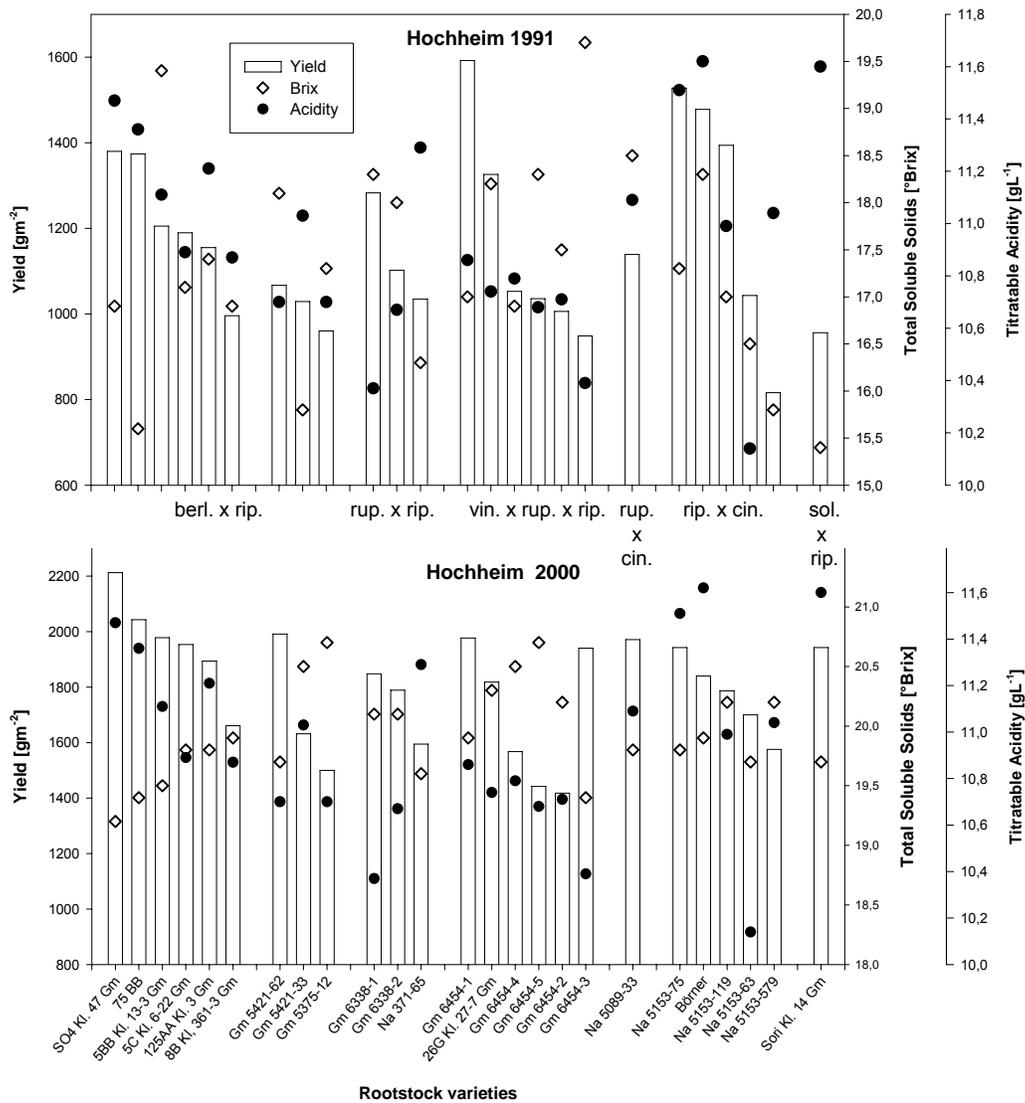


Figure 7: Comparison of a dry (1991) and a wet (2000) season at Hochheim/Rheingau. Effect of different rootstock varieties on yield, total soluble solids and titratable acidity of White Riesling. Data are means of three replicates. Abbreviations: berl. = *Vitis berlandieri*, rip. = *Vitis riparia*, rup. = *Vitis rupestris*, vin. = *Vitis vinifera*, cin. = *Vitis cinerea*, sol. = *Vitis solonis*.

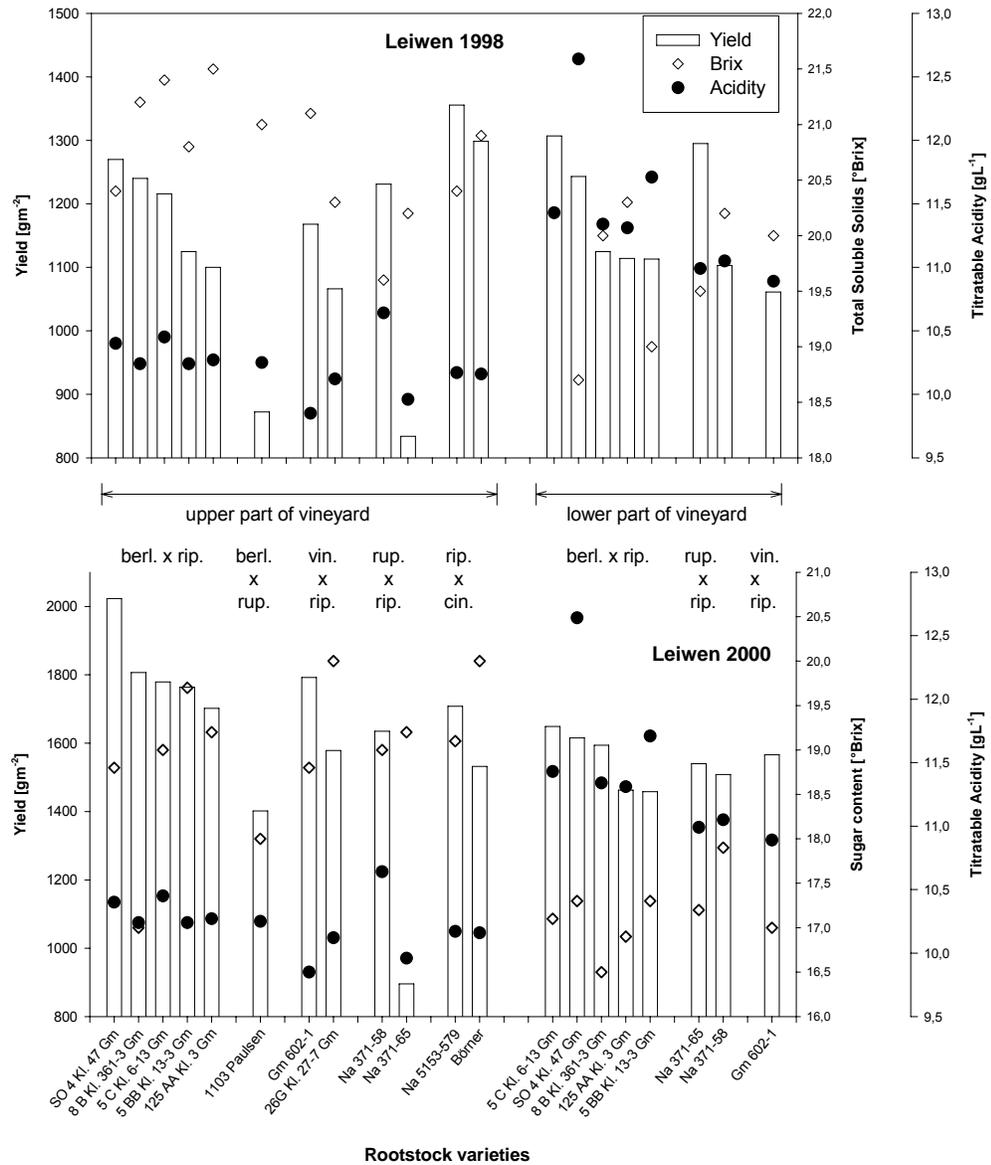


Figure 8: Comparison of a dry (1998) and a wet (2000) season at Leiwen/Mosel. Effect of different rootstock varieties on yield, total soluble solids and titratable acidity of White Riesling. Data are means of three replicates. Abbreviations: berl. = *Vitis berlandieri*, rip. = *Vitis riparia*, rup. = *Vitis rupestris*, vin. = *Vitis vinifera*, cin. = *Vitis cinerea*, sol. = *Vitis solonis*.

Selection of Rootstocks: Implications for Quality

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Choice of rootstock is among the most important decisions a grower or vintner makes and the implications for quality are enormous. If the rootstock vigor is either inadequate or excessive for the site and planting density, keeping the vineyard in balance will be a struggle for the life of the vineyard. California growers have been agonizing over rootstock choices as the industry has expanded into new production areas, has adopted new vineyard designs into which planting materials must be integrated, and has aspired to the higher quality wines.

This paper will address two aspects of rootstocks. First of all, summary data will be presented about rootstock evaluations that have been conducted over the past ten years. Secondly, interaction of rootstock with pruning level will be examined next and the implications of that choice on vine growth and yield components.

Rootstock Evaluation

The destruction of California vineyards planted on AXR#1 rootstock by type B phylloxera, as well as the continued infestation of own-rooted vineyards, led to a revolution in rootstock use in coastal and northern winegrape regions. Most soils in these regions are ideal for phylloxera infestation. With the nearly complete reliance upon AXR#1 and St. George rootstocks over 25 years, viticulturists had little experience on which to base selection of alternative rootstocks.

In California locations where phylloxera is the predominant soil pest, the choice of rootstocks should be limited to those selections or hybrids of *V. rupestris*, *V. riparia*, and *V. berlandieri* which have been used successfully in Europe and other grape growing regions. The summary of rootstock attributes below is compiled from a combination of vineyard experiments and grower experience.

Vitis berlandieri x *V. riparia* hybrids

Teleki 5C is one of the most widely used rootstocks, in part due to its abundant supply from nurseries. It grows well in moist fertile sites where scions on it can become quite vigorous. In sites where water supply is limited, even temporarily, growth of scions on 5C can be restricted. Drought in young plantings can delay training and vine development, while drought in mature vineyards can result in substantial leaf loss and even fruit shriveling. In heavy soils (clays and clay loam) it appears to be an excellent choice. Recent data suggests that 5C matures more slowly than other rootstocks and as it matures and its roots explore more of the soil volume, its drought tolerance improves dramatically. Until about 1990, Teleki 5C in California was erroneously labeled "SO₄."

Kober 5BB has a relatively limited history of use in California. Much like 5C, it seems to perform well on heavy soils. It seems to be more drought tolerant than either 5C or 420A but less so than 110R and St. George. Several cases have arisen where vines on 5BB have died from what was diagnosed as *Phytophthora* crown and root rot. Growers having sites prone

to standing water or with a history of *Phytophthora* should avoid using 5BB.

420A Mgt is a low vigor rootstock. Despite being of similar parentage as 5C and 5BB, it appears in most cases to be the least vigorous. It can be more difficult to root and graft, so vines may cost more as a result. It may prove to be most useful in close plantings or on rich soils where reduced growth is desired. Although originally thought to be sensitive to drought, it now appears to be simply low in vigor. Vineyard managers report that it requires more water to achieve growth similar to scions on other rootstocks. It is susceptible to potassium deficiency.

Vitis riparia x *V. rupestris* hybrids

3309 Couderc is a moderately vigorous rootstock. It appears to be a good candidate for close spacing where no particular site limitation can be seen. It has virtually no resistance to nematodes. Recently, it has acquired a bad reputation for its apparent sensitivity to latent viruses (or virus-like diseases) when grafted to uncertified field selections of scion wood. Although in dry-farmed sites it has performed better than expected, supplementary irrigation is recommended, especially in locations prone to hot weather spells after veraison to prevent pre-harvest leaf loss and sunburning.

101-14Mgt is a moderate vigor rootstock. In current usage it appears to be similar to 3309C but in the past few years has superseded 3309C in use in coastal areas. Experience in Australia showed 101-14 to have nematode resistance but that needs to be confirmed in California.

V. berlandieri x *V. rupestris* hybrids

110 Richter can be recommended for hillsides or dry-farmed sites where drought is likely. In these sites, it generally outyields St George and has a better yield: pruning ratio. In deep, fertile sites it can be overly vigorous. On very heavy soils, some growers report that 110R has shown

what appears to be potassium deficiency, although this needs to be further investigated for confirmation.

1103 Paulsen and 140 Ruggeri were both selected in Sicily and are both prized throughout the world for their drought resistance. Sources disagree as to whether their resistance is greater than 110R, but clearly they merit further attention. Both rootstocks are being planted and are preferred in sites prone to drought. Data in research trials suggest that they are vigorous rootstocks under conditions of ample water and fertility.

Species selections

St. George (syn = *Rupestris* du Lot) is a rootstock with a long history of use in California. Its main use is in dry-farmed vineyards. Although it is not drought-resistant *per se*, it avoids water stress by developing a deep root system. Therefore, it should not be used in soils which are shallow or where soil layering prevents deep rooting. St. George typically has a low yield:prunings ratio, because it has both heavier prunings weights and lower yields. The reduced crop load is primarily a function of reduced fruitset. St. George is often recommended as a rootstock for large, tight clustered varieties such as Zinfandel and Chenin blanc where the reduced set is an advantage. Its use should generally be avoided for small clustered varieties, such as Pinot noir or Chardonnay, or in varieties with a tendency for bloomtime shatter, such as Merlot.

Rootstock Interaction

With the loss of AXR#1, winegrape growers have had to choose different rootstocks with little background information about how those rootstocks would affect scion growth, crop load and ripening characteristics. Several experiments have been established to provide some insight into rootstock performance, among them the one reported here. Based on

an earlier observation that rootstocks varied in their partitioning of capacity and in their ability to ripen resultant crop loads, this study was established to investigate the possibility that the optimal formula for balanced pruning may vary for different rootstocks. The experiment attempted to determine the effects of initial vine size, rootstock, and pruning formula on crop yield and vegetative growth.

Materials and Methods

The vineyard was planted in 1984 and trained to a vertical shoot-positioned trellis system. The spacing was 3 m by 2 m (row by vine). The soil was a clay loam (1.2 m rooting depth) with variable amounts of gravel throughout the experimental site. Irrigation was provided by means of a drip system. The vineyard was located in Oakville, Napa Valley, California, an area with a climatic rating of high Region II or low Region III, depending on the year. Beginning in 1995, Cabernet Sauvignon vines grafted on four rootstocks, 3309 Couderc, Teleki 5C, 110 Richter, and O39-16, were balance pruned to formulae ranging from 5 to 12.5 buds per pound of one and two-year old prunings. Data are presented as the mean of the final three years of study (1997-1999).

Results

Rootstock effects on yield were pronounced (Table 1). Vines on O39-16 produced significantly lower yields, averaging 5.2 kg/vine compared to 6.5 for 3309C, 7.2 for 5C, and 7.8 kg/vine for 110R. The responsible components were the number of clusters per shoot and number of shoots per vine. Clusters per shoot averaged 1.98 for vines on 110R and 5C to lows of 1.88 and 1.77 for 3309C and O39-16, respectively. The number of shoots per vine averaged 23 for vines on O39-16 compared to 28 to 31 for the other stocks.

Differences in the number of shoots across the various rootstocks were not caused by effects on bud viability as indicated by number of shoots per bud retained (Table 2). Rather, the average pruning weights of vines on rootstock O39-16 decreased in each successive year; therefore, vines on O39-16 retained fewer and fewer buds. Conversely, the rootstock 110R maintained larger pruning weights resulting in the retention of a consistent number of buds per vine at each formula across the years.

Increasing pruning formulae increased crop yields directly through the number of shoots and therefore clusters per vine (Table 1). The increases in clusters per vine were offset by compensating reductions in berry set, in the number of shoots that developed per bud retained at pruning, and in the number of clusters per shoot. A two-and-a-half fold increase in pruning formula raised crops only 35 % from 5.7 kg/vine at the 5 bud formula to 7.7 kg/vine at 12.5 buds per pound of prunings.

Because the number of buds retained is a function of vine size, larger initial vine sizes increased yields curve-linearly through the number of shoots per vine and subsequent number of clusters per vine. However, a significant multiple interaction was noted between initial vine size and pruning formula: there was a direct depressing effect from the total buds per vine, such that the decrease in bud viability by pruning formula was more extreme on large vines than on small (data not shown). Initial vine size did not affect set, cluster weight, or clusters per shoot.

Overall yield was dependent on site capacity (initial pruning weight) and rootstock through effects on number of buds retained and subsequent cluster numbers. Rootstock had additional effects on berry weight and clusters per shoot such that an average sized vine produced 2.6 kilograms more crop if planted on 110R or 5C (data not shown). Increasing

pruning formula increased number of buds retained but decreased individual bud viability and fruitfulness.

Initial vine size defined total vegetative growth, as measured by total leaf areas/vine (Figure 1) or final pruning weight. Rootstock also influenced the distribution of capacity as vigor. Vines on O39-16 and 5C produced shorter shoots than vines on 3309C or 110R. When multiplied by the number of shoots per vine, total leaf areas were 6.7 m²/vine on O39-16 vs. 8.1 on 5C, 9.2 on 3309C, and 9.8 on 110R. Lower total vegetative growth on O39-16 was due both to fewer shoots per vine and less leaf area per shoot.

Increasing pruning formula repartitioned vegetative capacity. Higher pruning formulae suppressed individual shoot growth and subsequent leaf areas per shoot. It also caused a decrease in bud viability such that 2.5 fold increases in pruning formula resulted in only 1.7 fold increases in number of shoots (Table 2). The resulting total leaf areas per vine, however, did not differ by pruning formula. Vines of any given initial pruning weight produced similar total leaf area irrespective of pruning formula (Figure 1). For example, a vine with 2.2 kg of prunings produced approximately 9 sq. m. of canopy no matter how it was pruned. Even at formulas as low as 5 buds per pound of prunings, the total vegetative capacity expressed as leaf area was unchanged.

There was no effect of initial vine size on shoot length (Figure 1). Pruning formula, not total shoots per vine, regulated vigor. The site capacity (represented by normalized pretreatment pruning weights taken in 1994) and rootstock determined the total growth possible; pruning formula merely distributed it according to the number of shoots.

The standardized residual (in m²/vine) was partitioned by rootstock (Figure 1) and demonstrated the rootstocks 3309C and 110R produced the largest canopies per kg of prunings while 5C and O39-16 produced the least. Bud viability was the only component of vegetative growth to exhibit a significant pruning-rootstock interaction.

TABLE 1: Influence of rootstock and pruning formula on yield components of Cabernet Sauvignon at the Oakville Experimental Vineyard, 1997-1999.

Rootstock							
Rootstock	Berry Wt (gm)	Berries/Cluster	Cluster Wt (gm)	Clusters/Shoot	Shoots/Vine	Clusters/Vine	Yield (kg/vine)
3309C	1.14	110	122	1.88	29	54	6.52
5C	1.23	110	134	1.99	28	54	7.18
110R	1.18	112	131	1.97	31	61	7.83
O39-16	1.16	113	131	1.77	23	40	5.21
Signif. Level	NS	NS	NS	0.007	0.01	0.001	0.0003

Pruning Formula							
Pruning Formula	Berry Wt (gm)	Berries/Cluster	Cluster Wt (gm)	Clusters/Shoot	Shoots/Vine	Clusters/Vine	Yield (kg/vine)
5 buds/lb	1.17	122	142	1.99	20	40	5.69
7.5 buds/lb	1.18	113	131	1.95	25	48	6.27
10.0 buds/lb	1.18	107	124	1.85	31	58	7.14
12.5 buds/lb	1.18	104	121	1.82	35	63	7.66
Signif. Level	NS	0.0001	0.0001	0.005	0.0001	0.0001	0.0001

TABLE 2: Influence of rootstock and pruning formula on shoot growth and development of Cabernet Sauvignon at the Oakville Experimental Vineyard, 1997-1999.

Rootstock						
Rootstock	Buds/ Vine	Shoots/ Bud	Shoots/ Vine	Length (cm)	Total Leaf Area/ Vine (m ²)	Dormant Shoot Weight (gm)
3309C	35.2	0.86	29	133	9.2	67
5C	32.7	0.88	28	125	8.1	63
110R	38.2	0.84	31	133	9.8	67
O39-16	25.2	0.92	23	125	6.7	58
Signif. Level	0.002	0.05	0.01	NS	0.008	0.01

Pruning Formula						
Pruning Formula	Buds/ Vine	Shoots/ Bud	Shoots/ Vine	Length (cm)	Total Leaf Area/ Vine (m ²)	Dormant Shoot Weight (gm)
5.0 buds/lb	21.6	0.95	20	166	8.8	93
7.5 buds/lb	28.7	0.88	25	135	8.4	67
10.0 buds/lb	36.4	0.87	31	117	8.7	52
12.5 buds/lb	44.5	0.80	35	98	7.8	45
Signif. Level	0.0001	0.0001	0.0001	0.0001	NS	0.0001

TABLE 3: Influence of rootstock on final pruning weight of Cabernet Sauvignon grown at the Oakville Experimental Vineyard, 1995-1999.

Pruning Weights*					
Rootstock	1995 (kg/vine)	1996 (kg/vine)	1997 (kg/vine)	1998 (kg/vine)	1999 (kg/vine)
3309C	2.28	1.94	1.56	1.92	1.82
5C	2.41	1.89	1.52	1.77	1.61
110R	2.67	2.09	1.89	2.06	1.91
O39-16	2.01	1.47	1.18	1.36	1.21
Signif. Level	NS	NS	0.01	0.006	0.006

Pruning Weights*					
Pruning treatment	1995 (kg/vine)	1996 (kg/vine)	1997 (kg/vine)	1998 (kg/vine)	1999 (kg/vine)
5.0 buds/lb	2.37	2.07	1.79	1.98	1.76
7.5 buds/LB	2.42	1.80	1.52	1.77	1.61
10.0 buds/LB	2.29	1.70	1.40	1.69	1.62
12.5 buds/LB	2.28	1.81	1.43	1.68	1.57
Signif. Level	NS	0.02	0.001	0.0002	NS

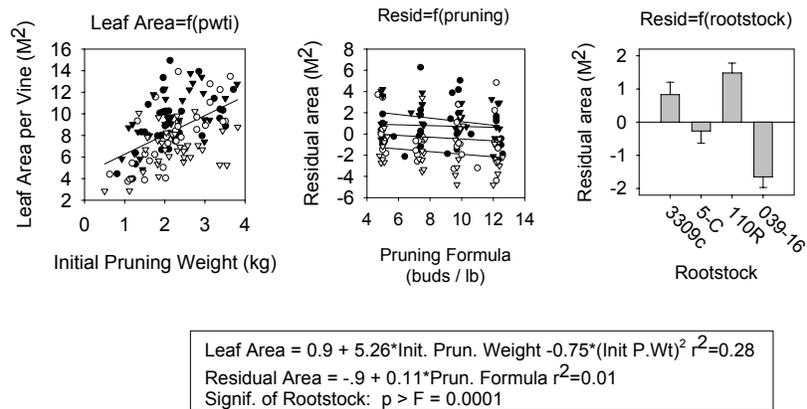
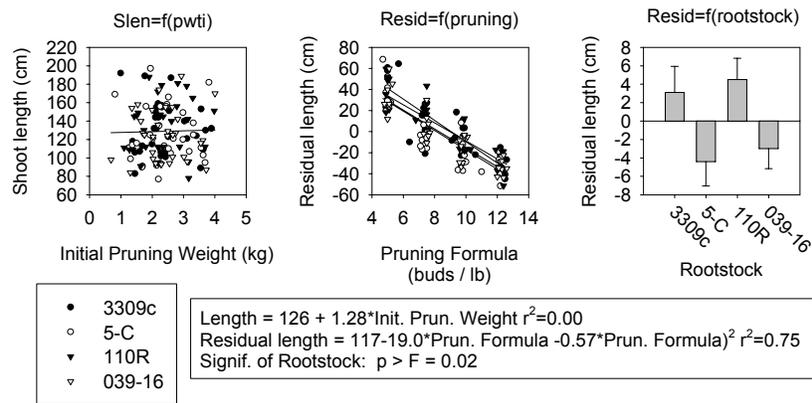
TABLE 4: Effect of rootstock and pruning formula on four growth parameters selected as criteria for choosing an optimal pruning formula. Use of pruning formula as a continuous variable allowed precise determination of treatment effects. Lack of interaction between treatment effects or with initial vine size indicates pruning formula can be adjusted to optimize each rootstock for any of the growth parameters tested. Oakville Experimental Vineyard, 1997-1999.

Rootstock	Shoot Length (cm)	Dormant Shoot Weight (gm)	Leaf Area/Crop (cm ² / gm)	Yield to Pruning Weight Ratio
3309C	133	67	15.0	3.67
5C	125	63	12.1	4.48
110R	133	67	13.5	4.12
O39-16	125	58	14.6	4.27

Parameter	Regression equation	R ²	Prob. > T
Shoot Length (cm)	$246 - 19.0*(bud/lb) + .564*(bud/lb)^2$	0.75	0.0001
Dormant Shoot Weight (gm)	$180 - 21.9*(bud/lb) + 0.885*(bud/lb)^2$	0.82	0.0001
Leaf Area / Crop (cm ² /gm)	$20.8 - 0.85*(bud/lb)$	0.40	0.0001
Yield : Pruning Ratio	$1.84 + 0.28*(bud/lb)$	0.50	0.0001

Parameter	Pruning Formula		Rootstock		Initial Vine Size	Interactions	
	SS	Signif.	SS	Signif.	Signif.	Stk*Prune	Size*Prune
Shoot Length	75%	0.0001	2%	0.03	NS	NS	NS
Shoot Weight	82%	0.0001	3%	0.0001	NS	NS	NS
Leaf Area / Gram Crop	40%	0.0001	10%	0.0002	NS	NS	NS
Yield/Pruning Ratio	50%	0.0001	8%	0.0001	NS	NS	0.03

Figure 1: Effects of initial pruning wt (the normalized pre-treatment pruning weight) and pruning formula on vegetative growth of Cabernet Sauvignon on four rootstocks at Oakville Experimental Vineyard (1997-1999). Total canopy was dependent on initial vine size but was not dependent on pruning formula: a vine with 2.2 kg of prunings produced approximately 9-sq. m. of canopy irrespective of pruning formula. The distribution of growth as vigor (shoot length) was tightly controlled by pruning formula, dependent on choice of rootstock, but independent of initial vine size. The rootstocks 3309C and 110R expressed greater vigor at any pruning formula than did 5C or O39-16. 110R produced the largest total canopy as it best expressed the site through large initial pruning weights. The rootstock O39-16 produced the least.



Manipulating Grape Composition and Wine Quality through the use of Rootstocks

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Keywords: roostock, grapevine, maturity, anthocyanins, quality, wine, Chardonnay, Shiraz, sensory analysis

Abstract

The use of rootstocks is not only an effective means of controlling important biological pests such as phylloxera and nematodes, but it can also be used effectively to regulate grape composition and wine sensory characteristics. Between 1999 and 2003, Chardonnay grafted to 101-14, Ramsey, 1103 Paulsen, 5C Teleki, 5BB Kober, Fercal and 116-60, and Shiraz grafted to 101-14, Ramsey, 1103 Paulsen, 5C Teleki, 5BB Kober, and 116-60 were evaluated on trial sites based near Mildura, in north western Victoria.

During the four year evaluation period, the highest yields were observed in 116-60 (16.03 kg/vine), 101-14 (15.32 kg/vine) and Ramsey (15.22 kg/vine). The 101-14 and 116-60 rootstocks generally ripened earlier than most of the other rootstocks. Sensory analysis of wines concluded that Chardonnay grafted to 5C Teleki scored significantly higher wine scores (15.04 in 2002 and 15.42 in 2003) compared to all other rootstocks.

In Shiraz, the highest yields were observed in Ramsey (16.91 kg/vine), 116-60 (15.29 kg/vine) and 1103 Paulsen (11.64 kg/vine) during the four year evaluation period. The 101-14 and 1103 Paulsen rootstocks generally ripened earlier than most of the other rootstocks. Sensory analysis of wines in 2002

and 2003 concluded that Shiraz grafted to 101-14 scored significantly higher wine scores in 2002 compared to 116-60 and 5C Teleki, and significantly higher wine scores compared to all rootstocks in 2003. This data illustrates the potential of using rootstocks as a means of controlling grape composition and wine sensory characteristics.

Introduction

There are many advantages of using rootstocks in viticulture (May 1994). These include protection from the effects of soil-borne pests such as phylloxera and nematodes, and adaptation to problems such as drought and salinity. The use of rootstocks can also influence vine vigour. This can have important implications for canopy light interception, bunch exposure, plant pathogens, fruit composition and wine sensory characteristics (Coombe and Dry 1992; Rühl 1992; Clingeleffer 1996).

In Australia, approximately 65% of the total wine grape production is derived from the warm irrigated regions of Riverland (South Australia), Sunraysia (Victoria/New South Wales) and Riverina (New South Wales). These regions have a mean January temperature of 23.0/73.4, 23.9/75.0 and 23.8/74.8 °C/°F respectively, and generally have soils with high pH (1:5 water - 8-9).

These regions are currently phylloxera free and statistics indicate a relatively low adoption and use of rootstocks, with figures in South Australia (only Australian state with statistics on grafted vines) averaging 18.8% grafted vines (Nick Dry pers comm. 2004). In the warm irrigated regions such as Riverland, South Australia, this figure is around 40% and is probably higher in these regions because of the nematode pressure on the sandy soils (Peter Dry pers comm. 2005) and the higher productivity desired in these warmer regions.

In 1996, a project was established in collaboration with the Murray Valley Winegrape Industry Development Committee, the Victorian and Murray Valley Vine Improvement Association (VAMVVIA) and commercial winegrape growers to examine the performance of a range of rootstocks grown in the Sunraysia district. The rootstocks included Ramsey, 1103 Paulsen, 140 Ruggeri, 5BB Kober, 101-14 Millardet, 5C Teleki, 116-60 Lider and Fercal. The rootstocks were grafted to the major winegrape varieties Chardonnay, Shiraz and Cabernet Sauvignon. However, this paper will only report on the results from the Chardonnay and Shiraz research.

The aim of this research was to examine the influence of using rootstocks in a re-plant situation on the yield, grape composition and wine quality attributes for the main wine grape varieties Chardonnay and Shiraz in the Sunraysia (Victoria/New South Wales) wine production region.

Materials and Methods

Experimental sites:

In 1996, three trial sites were established with grafted vines supplied from the Victorian and Murray Valley Vine Improvement Association (VAMVVIA). The Shiraz site was located in Gol Gol (New South Wales). The Shiraz

(clone PT23 [Griffith]) was grafted to six different rootstocks; 101-14 Millardet (*Vitis riparia* x *Vitis rupestris*), Ramsey (*Vitis champini*), 1103 Paulsen (*Vitis berlandieri* x *Vitis rupestris*), 5C Teleki (*Vitis berlandieri* x *Vitis riparia*), 5BB Kober (*Vitis berlandieri* x *Vitis riparia*) and 116-60 Lider (*Vitis candicans* x 1613C). The Shiraz site consisted of three rows running east – west. Guard vines were planted on the end of each row. A randomised complete block design was used with three vines per replicate and nine replicates of each rootstock.

The Chardonnay site was located near Robinvale (Victoria). Chardonnay (clone I10V5 [UCD]) was grafted to seven different rootstocks 101-14 Millardet (*Vitis riparia* x *Vitis rupestris*), Ramsey, 1103 Paulsen, 5C Teleki, 5BB Kober, Fercal (*Vitis berlandieri* x *berlandieri* – *colombard* No. 1x333 EM) and 116-60 Lider. The Chardonnay site consisted of four rows oriented north - south. Guard vines were again planted at the end of each row. A randomised incomplete block design was used with three vines per replicate and 10-12 replicates of each rootstock. In both experimental sites, no own-roots vines were included in the experimental design due to the relatively high nematode counts in the soil (data not shown).

Maturity assessments:

Maturity testing commenced annually in mid-January, by collecting bunch samples on a weekly basis leading up to harvest. Three samples were collected from each rootstock/scion combination at each sampling time. A sample consisted of five bunches picked from the guard vines within each three vine plot. The middle vine of the three was retained for harvest. The five bunches were collected from the right, left, top, inside right and inside left of the canopy and placed in a plastic bag. Samples were transported in a 50L

insulated cooler containing ice packs back to the laboratory, where they were stored at 4°C until analysis could be conducted. Berries were removed from the five bunches, the weight of 100 berries randomly sampled was measured and recorded. These berries were then juiced using mortar and pestle and the °Brix (sugar level) was recorded using a digital refractometer (Atago PR-101).

Harvest assessments:

The aim was to harvest each rootstock/scion combination at a predetermined maturity established by industry (Chardonnay 13 Baume [23.4 °Brix], Shiraz 13.5 Baume [24.3 °Brix]). Once a rootstock/scion combination had reached its target Baume, based on maturity testing, harvest was conducted by picking a transect of 1 metre on the middle vine (predetermined harvest vine) of each particular rootstock/scion combination in the first three seasons (2000-2002). Harvest was conducted by picking a transect of 30cm on the middle vine of each particular rootstock/scion combination in the final season (2003). Yield and bunch number per vine was recorded in the field. Average bunch weight was derived by dividing yield per vine by bunch number per vine. A random 20-bunch sample was collected from each harvested plot and placed in a plastic bag. Samples were transported in a 50L esky containing ice packs back to the laboratory, where they were stored at 4°C until analysis could be conducted.

Berries were removed from each 20 bunch sample and 100 berries randomly sampled and weighed to determine the average berry weight. Juice was removed from the 100 berry sample by crushing with a mortar and pestle, strained and centrifuged at 3500rpm for 10 minutes to remove foreign material. °Brix were recorded on the centrifuged juice sample using an Atago PR-101 digital refractometer.

Juice pH and titratable acidity (TA) were recorded using a Schott-TitroLine auto-titrator.

At a later date, frozen berry samples were thawed and juiced using a blender. One gram of this homogenate was used for colour (anthocyanin) and phenolic measurements using the (Iland et al. 2000) spectrophotometer method at 520nm and 280nm respectively.

Winemaking:

In 2002 and 2003, microvinification was undertaken on selected rootstocks (101-14, 1103 Paulsen, 116-60 and 5C Teleki – based on viticultural performance) at predetermined harvest Baume (Chardonnay 13 Baume [23.4 °Brix], Shiraz 13.5 Baume [24.3 °Brix]) according to Kerridge (1983) at CSIRO Plant Industry, Merbein, Victoria. Three winemaking replicates were used for each rootstock. Wines were subjected to both spectral analyses (Somers and Ziemelis 1985) and blind sensory evaluation by a panel of professional industry winemakers.

Statistical analysis:

Results were statistically analysed for season 2000-2003 using Genstat 5, version 4.1. The Shiraz trial was analysed using ANOVA whereas the Chardonnay site was analysed using REML analysis to take account of the unbalanced design.

Statistical differences are indicated at the $\rho = 0.05$ or 95% level. Different letters are used to represent statistical differences.

Results and Discussion:

(a) Weather data

Analysis of long-term weather data (110 years) indicated that Mildura (5 km away from Gol Gol) and Robinvale have very similar climates with respect to temperature and rainfall (Figures 1 and 2 respectively). Robinvale does tend to have slightly wetter January, February and March periods while temperatures are very similar at both locations.

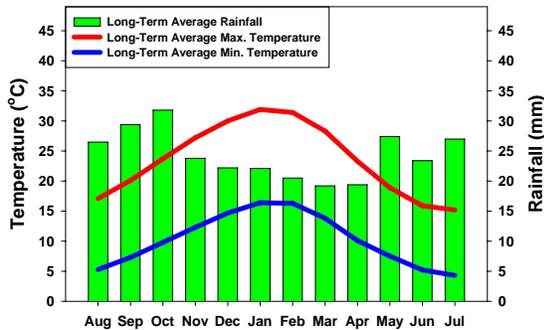


Figure 1 - Mildura Long-Term Weather Data

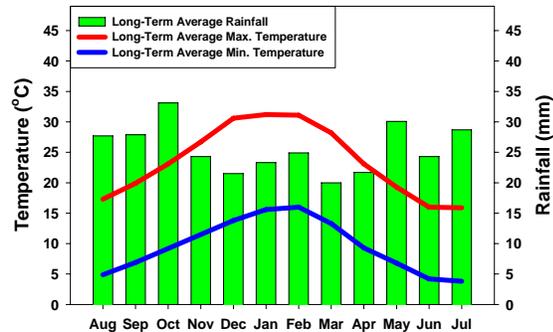


Figure 2 - Robinvale Long-Term Weather Data

Analysis of the 1999/2000 weather data revealed that above average rainfalls occurred in both November and February (Figure 3). The temperature conditions were also below normal during the November – December period and warmer during February (Figure 3). This indicates that the 1999/2000 growing season was rather atypical when compared to the long-term average data.

Analysis of 2000/2001 weather data revealed August, September and October were very wet months when compared to the district average (Figure 4). January and February were dry and very warm with January having a record high mean maximum monthly temperature of 37.1°C (Figure 4).

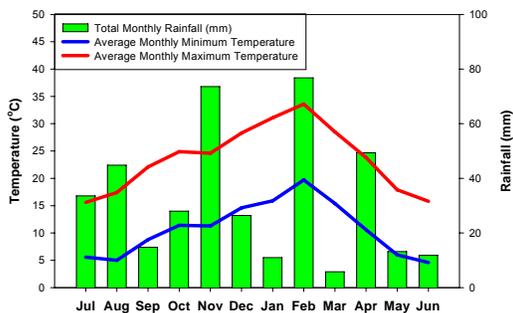


Figure 3 - Mildura Weather Data 1999/2000

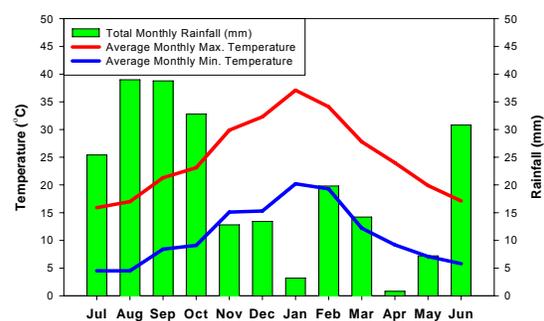


Figure 4 - Mildura Weather Data 2000/2001

Analysis of 2001-2002 weather data indicated November, December and January were very dry months when compared to Mildura Long-Term Weather data (Figure 5). September had a higher total monthly rainfall than average (Figure 5). Also, the 2001/02 season was generally cool, with below average mean monthly temperatures observed between October – March.

Analysis of the 2002-2003 weather data indicated that this was a very dry season in Mildura (Figure 6). However, there was above average rainfall in December and February. Also, the 2002/03 season was generally cool, with below monthly temperatures observed (Figure 6).

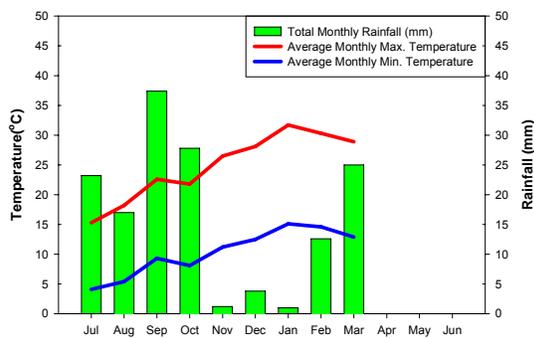


Figure 5 - Mildura Weather Data 2001/2002

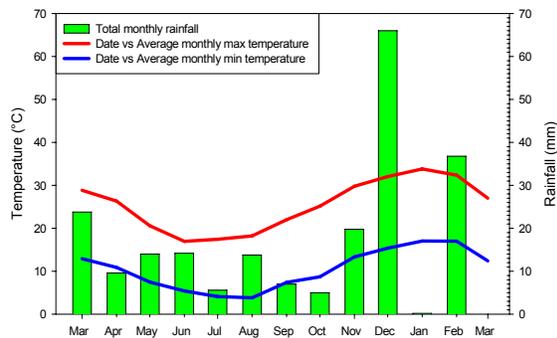


Figure 6 - Mildura Weather Data 2002/2003

(b) Berry development and ripening

Chardonnay (2002 data only)

In 2001/02, the average berry weight of all Chardonnay grafted to rootstocks increased at a similar rate until approximately day 40. After day 40, only minor changes in the average berry weight were observed (Figure 7). Ramsey and Fercal had the highest average berry weight at harvest (0.97 and 0.99g respectively). 5C Teleki had the lowest average berry weight at harvest (0.81g).

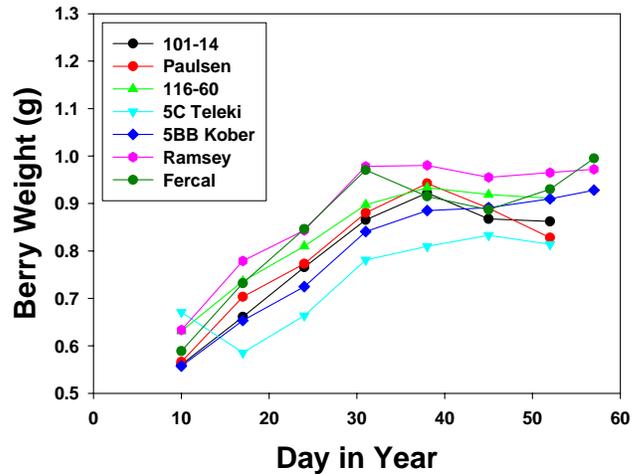


Figure 7. The average berry weight (g) of Chardonnay grafted to seven different rootstocks post-veraison to harvest during the 2001/02 season.

In 2001/02, 101-14, 1103 Paulsen, 116-60 and 5C Teleki all ripened approximately one week earlier than 5BB Kober, Ramsey and Fercal (Figure 8). Because of the cooler season, harvest date for Chardonnay was generally delayed by 2 to 3 weeks. Interestingly, between days 10 and 30, 101-14 were behind in ripening compared to most other rootstocks; however, by day 50 it had the highest °Brix (23.0) reading compared to all other rootstocks (Figure 8).

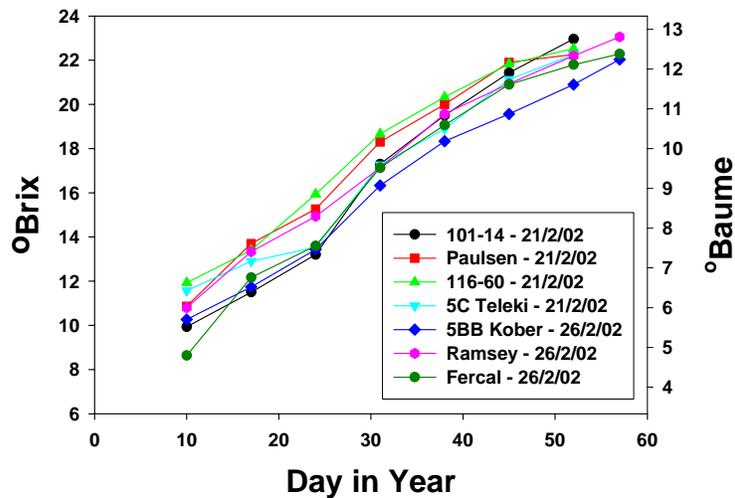


Figure 8. The average maturity (°Brix/Baume) of Chardonnay grafted to seven different rootstocks post veraison to harvest during the 2001/02 season. Harvest date indicated in graph legend.

Shiraz (2001 data only):

As the berries ripened, the average berry weight initially increased but after approximately day 40 average berry weight actually decreased (Figure 9). This is typical of Shiraz (McCarthy 2000). There were large differences between rootstocks. Ramsey exhibited the largest change in berry weight, whereas 1103 Paulsen displayed the smallest change in berry weight (Figure 9).

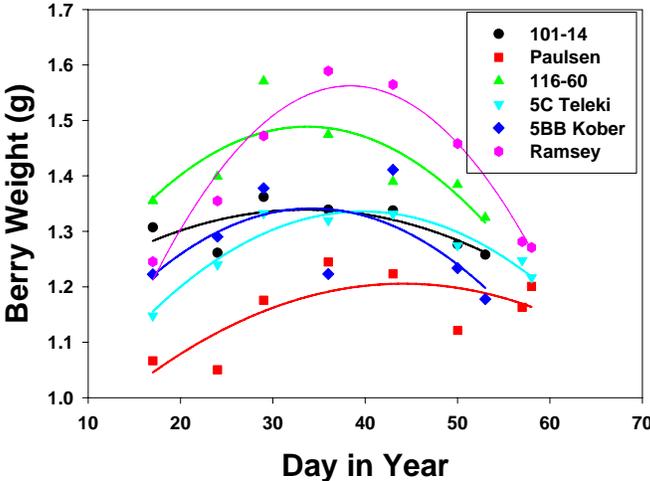
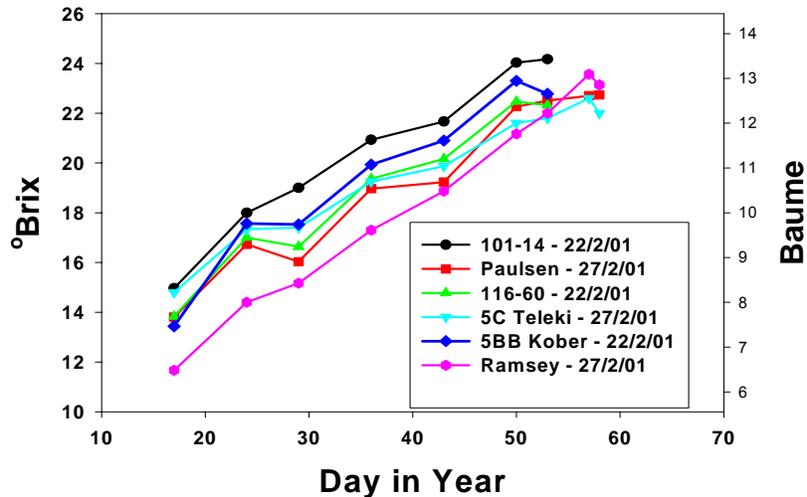


Figure 9. The average berry weight (g) of Shiraz grafted to six rootstocks post-veraison to harvest during the 2000/2001 season.

In the 2000/01 season, the 101-14, 116-60 Lider and 5BB Kober rootstocks ripened earlier than all other rootstocks and were harvested on the 22/2/01 (Figure 10). The remaining rootstocks: 1103 Paulsen, 5C Teleki and Ramsey were harvested on the 27/2/01 (Figure 10).

Figure 10. The average maturity (°Brix/Baume) of Shiraz grafted to six different



rootstocks post-veraison to harvest during the 2000/01 season. Harvest date indicated in graph legend.

(c) Yield and grape composition data (4 year summary only)

Chardonnay

During the four year evaluation period, the highest yields were observed in 116-60 (16.03 kg/vine), 101-14 (15.32 kg/vine) and Ramsey (15.22 kg/vine) (Table 1). This yield difference appeared to be a function of increased bunch numbers and bunch size in these particular rootstocks (Table 1). While there was up to a week difference in the rate of ripening to 13 Baume (23.4 °Brix), there was generally only a small difference in the juice pH (~0.1 pH unit) and TA (~0.5 g/L) at harvest (Table 1).

Shiraz

In Shiraz, the highest yields were observed in Ramsey (16.91 kg/vine), 116-60 (15.29 kg/vine) and 1103 Paulsen (11.64 kg/vine) over the four year evaluation period. These yield differences between the different rootstocks resulted in up to 6 weeks difference in the rate of ripening to 13.5 Baume (24.3 °Brix) in some years (2000 data not shown) (Table 1). Again the yield differences appeared to be a function of increases in bunch number per vine and average bunch weight (Table 1). During the four year evaluation period, the earlier ripening rootstocks, 101-14,

1103 Paulsen, and 5C Teleki tended to have slightly lower juice pH and higher TA's at 13.5 Baume (24.3 °Brix) (Table 1). The highest colour and total phenol levels were observed in Shiraz grafted to 101-14 (1.25 mg/g and 1.32 au/g respectively), 5C Teleki (1.33 mg/g and 1.37 au/g respectively) and 5BB Kober (1.36 mg/g and 1.37 au/g respectively) compared to the other rootstocks.

(d) Wine Assessment data (2002 and 2003 wines)

Chardonnay

The performance of Chardonnay grafted to 101-14, 1103 Paulsen, 116-60 and 5C Teleki was also examined through sensory analysis of wines made from microvinification methods (Kerridge 1983). Wines were made in 2002 and 2003 and evaluated in September 2004 at CSIRO Plant Industry, Merbein, Victoria by a panel of 6 industry winemakers (Figure 11).

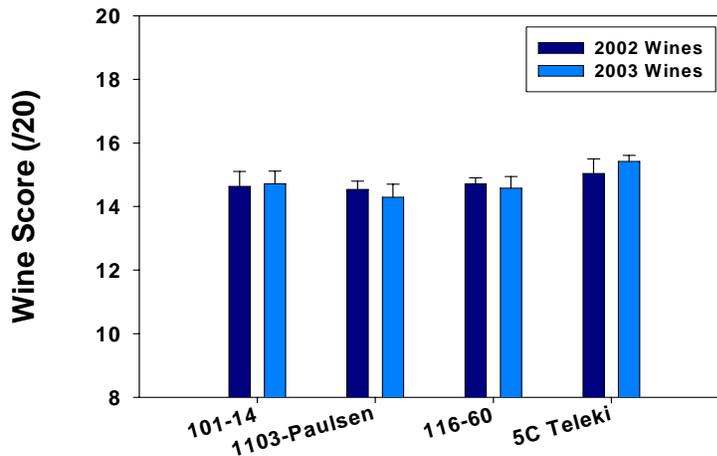


Figure 11. The mean wine score (out of 20) and standard error for wines made from Chardonnay grafted to 101-14, 1103Paulsen, 116-60 and 5C Teleki in the 2002 and 2003 seasons.

Sensory analysis of wines concluded that Chardonnay grafted to 5C Teleki scored significantly higher wine scores (15.04 in 2002 and 15.42 in 2003) compared to all other rootstocks in both 2002 and 2003.

Shiraz

The performance of Shiraz grafted to 101-14, 1103 Paulsen, 116-60 and 5C Teleki was also examined through sensory analysis of wines made from microvinification methods (Kerridge 1983). Wines were made in 2002 and 2003 and evaluated in September 2004 at CSIRO Plant Industry, Merbein, Victoria by a panel of 6 industry winemakers (Figure 12).

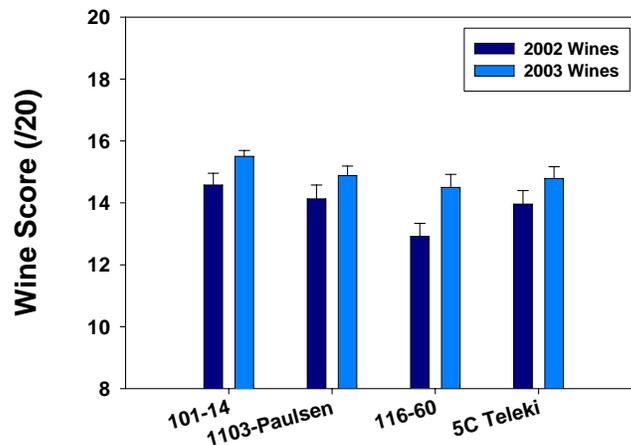


Figure 12. The mean wine score (out of 20) and standard error for wines made from Shiraz grafted to 101-14, 1103 Paulsen, 116-60 and 5C Teleki in the 2002 and 2003 seasons.

Sensory analysis of wines in 2002 and 2003 concluded that Shiraz grafted to 101-14 scored significantly higher wine scores in 2002 compared to 116-60 and 5C Teleki, and significantly higher wine scores compared to all rootstocks in 2003.

Conclusion

The best performers grafted to Chardonnay (1999-2003) were:

- **101-14** – early ripening, good yield, mid-sized berries, low pH, high TA, lower phenolics.
- **116-60** – earlier ripening, high yield, mid-sized berries, low pH, high TA, lower phenolics.
- **1103 Paulsen** – high yield, mid-sized berries, low pH, high TA, lower phenolics.

Sensory analysis of wines indicated that Chardonnay grafted to 5C Teleki scored significantly higher wine scores (15.04 in 2002

and 15.42 in 2003) compared to all other rootstocks. 101-14, 116-60 and 1103 Paulsen all seemed to score similar wine scores in both 2002 and 2003.

The best performers grafted to Shiraz (1999-2003) were:

- **101-14** – early ripening, mid-range yield, small berries, low pH, mid-range TA, high colour and phenolics.
- **1103 Paulsen** – earlier ripening, mid-range yield, small berries, mid-range colour and phenolics.

Sensory analysis of wines indicated that Shiraz grafted to 101-14 generally produced higher

wine scores compared to most other rootstocks evaluated in this trial. This rootstock project has illustrated the potential of using rootstocks as a means of controlling grape composition and wine sensory characteristics in the wine industry.

Acknowledgments

We would like to sincerely thank the MVWIDC, VMVWGGC, GWRDC for the funding to do this project and to Susan Byrne for her assistance throughout the life of the project. We would also like to thank Barry Avery and Dennis Mills for their helpful assistance over the harvest period and for providing the trial sites. We would also like to thank Yasmin Chalmers, the late Graeme Fletcher, Joanne Byrant and Glenda Kelly for their technical assistance over the past four years. Finally, we would like to thank John Hiskins and Noelene Treloar (AVS Pty. Ltd.) for organising the legal documentation during the initial stages of this project.

References

Clingeffer, P.R. (1996). Rootstocks: a means to control scion pH, ion composition and spectral parameters and meet juice and wine specifications. Quality management in viticulture. Proceedings of a Seminar organised by the Australian Society of Viticulture and Oenology, Mildura, 1996. R. Hamilton and P. Hayes (Editors), pp 22-25.

Coombe B.G and Dry P.R (1988) *Viticulture Volume 1. Resources*. Winetitles: Adelaide.

Iland, P., Ewart, A., Sitters, J., Markides., A. and Bruer, N. (2000). *Techniques for chemical analysis and quality monitoring during winemaking*. Patrick Iland Wine Promotions, South Australia.

Kerridge (1983). Small-scale winemaking in varietal assessment. Fermentation Technology: Proceedings of a Seminar organised by the Australian Society of Viticulture and Oenology, Glen Osmond, 1982. T.H. Lee (Ed.). ASVO, Adelaide, pp 71-77.

May, P. (1994). Using grapevine rootstocks – The Australian perspective. Winetitles, Adelaide 1994. 62 pages.

McCarthy, M.G. (2000). Developmental variation in sensitivity of *Vitis vinifera* L. cv. Shiraz berries to soil water deficit. *Australian Journal of Grape and Wine Research* **6**(2): 136-140.

Rühl, E.H. (1992). Rootstock evaluation for low juice pH. In Proceedings of the eighth Australian wine industry technical conference, (C.S. Stockley, R.S. Johnstone, P.A. Leske and T.H. Lee Eds.)25-29th October 1992, Melbourne, Victoria, pp 64-67.

Somers, T.C. and G. Ziemelis (1985). Spectral analysis of the components in *Vitis vinifera* grapes and wines. *Journal of Science and Food Agriculture* **36**, 1275-1284.

Table 1. Yield, bunch number, bunch weight, berry weight, Brix, pH, TA and phenolic data for Chardonnay grafted to 101-14, 1103 Paulsen, 116-60, 5C Teleki, 5BB Kober, Ramsey and Fercal.

Year	Rootstock	Yield/		Bunches/		Average		Average		Harvest		Juice		Titratable		Total	
		vine		vine		Bunch Wt.		Berry Wt.		°Brix		pH		Acidity		Phenolics	
		(kg)		(g)		(g)		(g)					(g/L)		(au/g)		
2000	101-14	16.49	ns	202.30	a	82.73	a	0.95	ns	23.60		3.60	ab	5.31	a	0.62	ns
	1103 Paulsen	15.65	a	156.30	b	99.27	b	0.98	ns	22.84		3.57	a	5.22	a	0.64	ns
	116-60	18.11	ns	174.00	ns	103.70	b	0.99	ns	22.71		3.60	ab	5.23	a	0.58	ab
	5C Teleki	19.38	b	192.90	ns	100.39	b	0.99	ns	22.86		3.58	ab	5.54	b	0.61	ns
	5BB Kober	17.38	ns	156.80	b	111.43	b	0.93	ns	22.64		3.61	b	4.95	c	0.57	a
	Ramsey	18.60	b	181.80	ns	105.16	b	0.96	ns	22.55		3.59	ab	5.28	a	0.67	c
	Fercal	17.52	ns	171.00	ns	103.74	b	0.98	ns	22.30		3.50	c	5.48	b	0.64	bc
2001	101-14	14.91	ns	290.55	a	51.66	a	0.80	a	21.14		3.83	a	4.56	a	0.56	a
	1103 Paulsen	13.24	ns	233.64	ns	57.05	a	0.69	b	21.85		3.98	b	3.73	b	0.67	bc
	116-60	15.75	ns	294.00	a	55.26	a	0.82	a	21.26		3.97	b	3.97	c	0.63	b
	5C Teleki	12.38	ns	242.40	ns	52.40	a	0.74	c	21.55		4.28	c	3.29	de	0.64	bc
	5BB Kober	14.48	ns	263.17	a	57.52	a	0.73	c	21.18		4.22	c	3.12	d	0.71	c
	Ramsey	14.07	ns	256.18	a	55.32	a	0.77	ac	21.36		4.04	d	3.71	b	0.58	ab
	Fercal	11.91	ns	178.36	b	74.49	b	0.81	a	21.71		4.23	c	3.41	e	0.53	a
2002	101-14	15.73	ns	231.82	ns	66.92	a	0.86	ab	22.96		3.61	ns	4.47	ab	0.80	ns
	1103 Paulsen	15.24	ns	222.55	ns	72.66	ab	0.83	ab	22.26		3.56	a	4.44	ab	0.86	a
	116-60	14.15	ns	202.91	ns	70.75	ab	0.91	b	22.53		3.62	ns	4.65	a	0.78	ns
	5C Teleki	12.72	ns	185.20	ns	68.55	ab	0.81	a	22.25		3.59	ab	4.39	ab	0.74	b
	5BB Kober	11.95	ns	175.17	ns	69.51	ab	0.93	bc	22.03		3.65	bc	3.82	c	0.87	a
	Ramsey	14.95	ns	193.64	ns	78.10	bc	0.97	c	23.06		3.69	c	3.99	bc	0.86	a
	Fercal	16.20	ns	200.18	ns	82.31	c	0.99	c	22.28		3.60	ab	4.18	b	0.81	ns
2003	101-14	14.15	a	347.67	a	40.68	a	0.65	b	23.47		3.90	ac	4.43	c	0.69	b
	1103 Paulsen	14.22	a	345.17	ac	42.98	a	0.63	b	23.32		3.91	a	4.42	c	0.64	b
	116-60	16.11	a	392.70	a	41.96	a	0.66	b	20.98		3.85	c	5.24	b	0.63	b
	5C Teleki	6.22	b	241.79	bc	24.77	b	0.51	c	22.25		3.91	a	4.21	c	1.08	a
	5BB Kober	6.10	b	209.27	b	31.18	ab	0.56	c	22.28		3.72	b	5.03	b	0.89	ab
	Ramsey	13.25	a	316.83	ac	40.37	a	0.67	b	22.28		3.89	ac	4.26	c	0.69	b
	Fercal	8.27	b	200.93	b	40.42	a	0.74	a	20.73		3.72	b	5.70	a	0.79	ab
4 Year Av.	101-14	15.32		268.08		60.50		0.82		22.79		3.74		4.69		0.67	
	1103 Paulsen	14.59		239.41		67.99		0.78		22.57		3.75		4.45		0.70	
	116-60	16.03		265.90		67.92		0.85		21.87		3.76		4.77		0.66	
	5C Teleki	12.68		215.57		61.53		0.76		22.23		3.84		4.36		0.77	
	5BB Kober	12.48		201.10		67.41		0.79		22.03		3.80		4.23		0.76	
	Ramsey	15.22		237.11		69.74		0.84		22.32		3.80		4.31		0.70	
	Fercal	13.48		187.62		75.24		0.88		21.75		3.76		4.69		0.69	

Table 2. Yield, bunch number, bunch weight, berry weight, Brix, pH, TA, colour and phenolic data for Shiraz grafted to 101-14, 1103 Paulsen, 116-60, 5C Teleki, 5BB Kober, and Ramsey.

Year	Rootstock	Yield/		Bunches/		Average		Average		Harvest	Juice		Titratable		Total		Total	
		vine		vine		Bunch Wt.		Berry Wt.			°Brix	pH	Acidity		Colour			Phenolics
		(kg)		(g)		(g)		(g)			(g/L)		(mg/g)		(au/g)			
2000	101-14	8.93	ab	127.11	ns	69.15	ns	1.02	a	26.08	3.67	ab	5.31	a	1.24	a	1.17	a
	1103 Paulsen	12.24	ac	154.00	ns	79.87	a	0.92	a	23.35	3.57	a	5.16	a	1.02	b	0.97	b
	116-60	13.11	ac	160.89	a	82.72	a	0.97	a	24.86	3.82	bc	4.18	b	0.88	b	0.92	b
	5C Teleki	6.80	b	132.05	ns	47.26	b	0.99	a	24.45	3.73	b	4.38	b	1.20	a	1.30	a
	5BB Kober	6.33	b	112.38	b	53.29	b	0.72	b	25.53	3.79	b	4.49	b	1.54	c	1.51	c
	Ramsey	14.43	c	165.67	a	87.03	a	0.97	a	25.04	3.94	c	4.27	b	1.10	a	1.21	a
2001	101-14	12.08	ac	185.00	ns	65.89	a	1.26	ns	24.17	4.10	a	3.53	ab	0.94	a	1.02	a
	1103 Paulsen	15.73	ab	195.53	ns	80.65	ab	1.20	ns	22.74	4.05	ab	3.38	a	0.70	b	0.84	bc
	116-60	18.10	b	213.60	ns	90.92	b	1.32	ns	22.32	4.10	ab	3.93	c	0.75	b	0.85	bc
	5C Teleki	10.42	ac	148.50	ns	69.24	a	1.22	ns	22.00	3.97	bc	3.45	ab	0.86	ns	0.94	ab
	5BB Kober	11.79	c	156.60	ns	76.14	ab	1.18	ns	22.78	3.91	c	3.71	bc	1.07	a	1.01	ab
	Ramsey	19.38	b	199.40	ns	97.58	c	1.27	ns	23.14	4.11	a	3.74	bc	0.66	b	0.74	c
2002	101-14	13.42	a	232.40	a	58.72	a	0.76	a	23.46	3.63	a	3.38	ns	1.38	a	1.45	a
	1103 Paulsen	13.88	a	176.18	b	78.24	a	0.88	ab	23.63	3.86	b	3.41	ns	1.18	ab	1.27	ab
	116-60	21.30	b	184.00	b	121.87	b	1.05	b	21.38	3.83	b	3.53	ns	0.95	bc	1.17	bc
	5C Teleki	11.45	a	165.15	b	67.19	a	0.83	ac	24.06	3.76	b	3.47	ns	1.39	a	1.32	ab
	5BB Kober	12.24	a	193.05	ns	62.79	a	0.87	ab	23.99	3.67	a	3.93	ns	1.30	a	1.29	ab
	Ramsey	23.56	b	223.00	a	108.29	b	0.97	bc	20.69	3.83	b	3.62	ns	0.74	c	1.03	c
2003	101-14	4.63	b	118.00	b	35.36	b	0.44	ns	20.75	4.22	b	3.26	a	1.44	a	1.64	ns
	1103 Paulsen	4.71	b	110.00	b	40.01	b	0.50	ns	23.38	4.22	b	3.58	ab	1.48	a	1.72	ns
	116-60	8.63	ab	133.00	ab	62.04	a	0.58	ns	22.20	4.28	b	3.29	a	1.49	a	1.59	ns
	5C Teleki	3.80	b	104.00	b	33.08	b	0.45	ns	21.85	3.97	ac	3.64	b	1.88	b	1.92	ns
	5BB Kober	6.43	ab	118.00	b	45.65	ab	0.54	ns	21.13	3.83	a	4.06	ab	1.56	ab	1.66	ns
	Ramsey	10.29	a	206.00	a	50.49	ab	0.52	ns	20.72	4.18	bc	3.61	ab	1.31	a	1.53	ns
4 Year	101-14	9.77		165.63		57.28		0.87		23.61	3.91		3.87		1.25		1.32	
	1103 Paulsen	11.64		158.93		69.69		0.88		23.27	3.92		3.88		1.09		1.20	
	116-60	15.29		172.87		89.39		0.98		22.69	4.01		3.73		1.02		1.14	
	5C Teleki	8.12		137.43		54.20		0.87		23.09	3.86		3.73		1.33		1.37	
	5BB Kober	9.20		145.01		59.47		0.82		23.36	3.80		4.04		1.36		1.37	
	Ramsey	16.91		198.52		85.85		0.93		22.40	4.01		3.81		0.95		1.13	

Rootstock Influence on Scion Performance

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One of the areas of viticulture frequently involved in controversy is the impact of rootstock on the performance of the scion cultivar grafted to it. The topic is often characterized by anecdotal information based on real personal experiences, but is too seldom subjected to rigorous testing of the validity of proposed relationships.

Thinking about this reminded me of the presentation Nelson Shaulis made at the American Society of Enology and Viticulture meetings where he was honored as Merit Award winner. In typical fashion for him, he challenged the audience with a slide showing two paths a scientist might take and asked which was the greater hindrance to progress in viticultural understanding. The two paths were alternatively labeled; 1) Unanswered Questions and 2) Unquestioned Answers. His view was that the latter was most often the greater hindrance.

Pre-conceived ideas and ‘scientific dogma’ about rootstocks are conditions we strive as scientists to limit, but the reality is that we are as often victims as are laymen. One reason for this is the reality that a genotype’s performance is intimately tied to the environment of its evaluation and this can influence the performance of the rootstock as well as the scion cultivar grafted to it.

A number of years ago I thought about how one might design an experiment to critically assess some of the myriad of factors derived from scion performance that might be attributed directly to the rootstock.

In 1975-76 I had the good fortune to spend a 6-month research leave at the New York Agricultural Experiment Station in Geneva, NY, with daily opportunity to discuss viticultural questions with Dr. Shaulis. During one of those conversations he related that he had been hired at Cornell as a soil scientist. One of the critical concerns of the time was the poor growth and productivity of a *Vitis labruscana* cultivar, Ives, which was valued for its deep pigmentation and other fruit qualities. His approach was typically analytical and his first question was, “is the poor performance due to above ground or below ground limits”. He did not accept that the “unquestioned answer”, a soil problem, was valid.

To test that validity, he made reciprocal bench grafts of Ives with Concord (which did not have the problems Ives did), grew, cropped and assessed performance and found the Concord on Ives roots or own-root were not different and Ives on Concord or own-root were not different; Concord performed well when it was above ground and Ives performed poorly when it was above ground. His conclusion; the problem with Ives was not below ground.

This tale is not very interesting on its face, but is relevant because when our efforts began to turn on devising a means to look at rootstock influence on the scion cultivar, I remembered.

Knowing what roots can directly do provides a physiological basis for considering how the rootstock might influence the performance of the scion. We know that roots anchor the vine

to the soil, take-up water and nutrients, production and transport of plant hormones including abscisic acid, auxins, gibberellins, and the production of ethylene (Rom, 1987).

Further, roots serve as a repository of stored carbohydrates (Edson, *et al.*, 1995; Williams and Smith, 1991) and nitrogenous compounds (Conradie, 1991; Hanson and Howell, 1995; Wermelinger, 1991; Williams and Smith, 1991), which are important in the spring growth flush prior to full canopy expression (Edson, *et al.*, 1995; Howell, 2001). Such root functions and their impact on scion response have been invoked to explain the observed response that fruit-set is reduced for scion cultivars grafted to Rupestris St. George (Wolpert, Unpublished data).

Primary Versus Secondary Scion Responses to Rootstock

To sort out the responses between primary and secondary influences, one should begin by defining what that means (Striegler and Howell, 1991). A primary root effect would be one that directly influenced a scion response such as the fruit-set response noted above. A secondary response would include a scion response such as canopy density as influenced by the rootstock's impact on scion vigor.

The last two decades, spurred by the demise of AxR-1 in California due to biotype-B phylloxera (Granett, *et al.*, 1987; Wolpert, 1992), the spread of phylloxera to additional New World viticultural areas and the potential for solving additional soil problems has resulted in a re-emphasis of rootstock evaluation and breeding efforts (Anwar, *et al.*, 2002; Goodman, *et al.* 1993; Kocis, *et al.*, 1999; Striegler, *et al.* 1993; Walker, 1992). Along with this increased effort has been a desire to better understand what is within the physiological range of possible impact(s) that rootstock choice can have on the response of

the scion cultivar (Delas, *et al.*, 1991; Grant and Matthews, 1996; Howell, 2000; Koblet, *et al.*, 1994; Main, *et al.*, 2002; Miller, *et al.*, 1988a; 1988b; Padget-Johnson, *et al.*, 2000; Williams and Smith, 1991).

There is frustration because the efforts to critically evaluate physiological responses are frequently incongruent with those efforts whose practical goal is of defining issues of stock-scion compatibility, local adaptation to climate soils and common methods of culture (Morano and Kliewer, 1994; Pool, *et al.*, 1992). The experimental approaches are different because the efforts do not have the same goals.

For these reasons the following experimental efforts were established with a goal to test two hypotheses. Hypothesis 1. The primary viticultural impact of root system choice is its influence on the vigor of the scion cultivar under conditions of culture. Hypothesis 2. Complex above-ground vine factors like date of bud burst, date of crop ripening, and levels of cold resistance are under the genetic control of the scion cultivar as influenced by the ambient environment. To test these two hypotheses, two-hybrid direct producer cultivars were selected based on specific variation in these characteristics.

Experimental Approach

Plant material

The cultivars selected were Marechal Foch (Kuhlmann 188-2) (*aka* Foch) and Vidal blanc (Vidal-256) (*aka* Vidal)(Galet, 1979; 1998). These cultivars are capable of economic production levels when grown as own-rooted and vines described by Galet (1979; 1998) have been as follows: "Marechal Foch is a complex hybrid (Kuhlmann said it was the result of a crossing of 101-14 Mgt. X Goldriesling which resulted from a cross

between Riesling and Courtiller musque). It produces small blue-black berries on winged cylindrical clusters". With regard to Vidal, Galet (1979; 1998) notes, "Vidal blanc is also a complex hybrid resulting from a crossing of Ungi blanc (syn. Trebbiano) and Seibel 4986. It produces small greenish-white berries on medium large cylindrical clusters." It also has a winged cluster (Howell, Unpublished data).

Bud burst for Vidal is commonly 10-14 days later than Foch (Anderson, et al. 1980) and harvest is 4-6 weeks later (Howell, unpublished data). Cold hardiness assessments in both the laboratory and in the vineyard suggest that Foch is much more cold hardy in both bud and wood than is Vidal (Howell, unpublished data). Finally, Foch is less vigorous at the same locations regardless of soil type (if that soil is acceptable for viticultural purposes) and achieves less Vine Size (as expressed as annual cane pruning weights) than does Vidal (Howell, unpublished data).

Grafting treatments

Mature dormant canes of both cultivars were collected from a selected Michigan State University vineyard and provided to a commercial nursery for bench grafting. All material for either scion or rootstock use was from the same source vineyard and collected from healthy, vigorous vines (exceeding 0.65 kg of cane prunings/ meter of row). Vines were grown for a year in the nursery and shipped for planting the following spring as dormant vines.

Upon receipt, vines were sorted by fresh weight, and similar weight class groupings were created for each replicate. Thus, initial vine fresh weight was blocked when the replicates were planted.

Field plot design

Vines were planted on a 2.4 x 3.0 meter spacing within and between rows, respectively. The soil is a Kalamazoo sandy loam.. Each vine was trained to Hudson River Umbrella (a bilateral cordon at the top wire) with a height of 1.8 m. Vines were trained with double-trunks with a single cordon arising from each (Howell, 2000; 2003).

Four-vine plots were planted with an ungrafted guard vine between each plot. The blocked vines, based on initial vine fresh weights, were organized to produce five replicates. Each block was arranged as a factorial with scion cultivar being one factor and rootstock cultivar being the other.

Crop control

Mature vines were pruned to five-node canes and two-node renewal spurs. Pruning severity was different for each cultivar based on previous work. Foch was pruned to 30 nodes for the initial 0.5kg of cane prunings and 10 additional nodes for each subsequent 0.5kg. Vidal was pruned similarly except that the severity of the pruning was greater based on its much greater bud fruitfulness (Howell, *et al*, 1987). A 15+10 pruning severity was employed. After pruning no additional crop control or canopy management was imposed.

Statistical analysis

After a three-year establishment/training period the vines were cropped and pruned for an additional three years. Data were collected for four-years subsequent to the sixth growing season after planting and subjected to analysis of variance as a 2X 2 factorial (Steel and Torrie, 1980) annually and on the 4-year mean values. Main effects and interactions were assessed and selected relationships subjected to orthogonal contrasts and correlation analysis.

Results

The data are presented as the average values for four years data. Individual season data have been analyzed and are in nearly identical conformity with the mean data. This presentation is in the interest of brevity.

Impact on Growth Characteristics.

Data in Table 1 suggest that roots had primary influence on vine size. Both root and scion influenced # of nodes retained due to the impact on vine size by roots and the different pruning severity employed for the two scion cultivars (30+10 for M. Foch and 15+10 for Vidal blanc). Shootless nodes (blind nodes) data are a general bud hardiness indicator and the data show this to be exclusively under the control of the scion cultivar.

Impact on Yield and Yield Components.

The data in Table 2 show vine yield, cluster number, berry weight, berries/cluster, and cluster weight to be under the control of the scion cultivar. Rootstock had no measurable impact.

Impact on Fruit Composition Values.

The data in Table 3 show measurable impacts of both scion and rootstock cultivars. The scion differences can be explained based on the widely different harvest dates of the two cultivars (M. Foch is 4-5 weeks earlier than Vidal blanc in Michigan). The root influence would seem to be best explained by the yield difference (albeit not statistically significant) shown in Table 2. The lower sugar and pH and higher titratable acidity support this interpretation.

Impact on Vine Phenology and Damage Caused By Spring Freeze in Year-2.

The data in Table 4 suggest that these phenomena are exclusively under the control of the scion cultivar. The values shown for the root influence are very nearly identical. The scion data matched exactly the response of

own-rooted vines of that cultivar (data not shown).

Discussion

In previous reports we have striven to sort the differences between primary impacts of the rootstock from those deemed secondary as an influence on some other aspect of crop performance (Howell, 1987; 2000; Howell, et al., 1997; Howell and Perry, 1990; Miller, et al., 1988a; 1988b; Striegler and Howell, 1993). This concern is only heightened as one considers potential sources of variability among vines within a vineyard and indeed, among characteristics within an individual vine's canopy (Howell and Shaulis, 1980; Howell and Wolpert, 1978). One must account for such sources of variability before it is possible to focus upon a specific viticultural factor, such as rootstock choice, with confidence that the factor is directly responsible for a specific vine response or set of vine responses. This requires careful experimental design (Cochran and Cox, 1957) and the employment of a stratified random sampling procedures (Cochran, 1977).

It is difficult to establish experiments that can effectively distinguish between primary impacts and secondary impacts of rootstocks (Striegler and Howell, 1991). For example, if one measures a response of a scion cultivar on different rootstocks as related to ripening date, one must first ask; 'was the crop level the same'? If not the same then the difference could be simply crop influenced as could occur between two-vines of identical scion/rootstock status. If the crop was the same, one must ask; 'was the shoot density the same'? If not, the dense canopy vines could explain the difference. Similarly, was the leaf area-fruit weight ratio the same? In all cases, real differences did occur, but none was identifiable as a direct response to the root system.

This frustration has been exacerbated by a growing sense that anecdotal information derived from general trials of adaptive response has been too often suggested as the basis for sorting out the complex scion/rootstock issues. “I know the rootstock effects are real; I’ve tasted the wines”, is not an uncommon, non-critical comment.

Critical experiments in this area of viticultural research are difficult to establish and thus are seldom reported. A further concern is the tendency for such evaluations to be of “local” value and rootstocks are sought for their performance and local adaptation, and basic physiological questions are considered of long-term, but secondary importance. The reality is we need both.

While not ignoring the numerous reports of root influence on the scion cultivar that are readily mediated via water relations (Padget-Johnson, et al., 2000) and growth regulators (Padget-Johnson, *et al.*, 2000; Pool, 1974, 1975; Wolpert, unpublished data) the data reported here support the hypothesis that most of the complex, multiple gene-influenced phenological responses by scion cultivars grafted to grape rootstocks are controlled by the scion genotype and its expression in the environment of culture. This seems reasonable from an evolutionary perspective as the fruit-bearing portion of the vine is annually exposed to a varying array of abiotic and biotic stresses potentially limiting the ability of the organism to create genetic diversity via sexual reproduction (Howell, 2000; 2001). Complex plant factors such as onset of growth in the spring, growing season length, cold resistance and fruit maturity can all be limited by an inadequate root system, but when conditions approach optimum, the genetic characteristics of the scion are paramount. If one cultures own-rooted vines with inadequate nutrients or water, the aboveground portion suffers. Application of excess water or nutrients does

not solve the problem; it just creates new problems. That roots are major organs critical to the success of the vine is beyond discussion. That roots can limit scion growth via some soil borne stress should not cause one to suggest that the roots can be all encompassing in transferring the root’s genotypic proclivities, whether positive or negative, to the scion.

This is not an exercise in sophistry. As noted earlier, there is renewed effort in breeding for the array of soil borne problems listed above. If rootstock choice is capable of direct influence on the scion with regard to complex genetic factors such as ripening, bud burst, cold hardiness, wine quality, and susceptibility to leaf diseases and insect predation, then it is absolutely necessary for such abilities to be demonstrated in a quantifiable way so that selection methods can be developed and employed by our breeders. In their absence, rationality requires that we be straightforward to our viticultural practitioners about what is and what is not within the ability of root systems to influence their vines’s growth, and fruit productivity and quality. In doing so we may contribute to clarification rather than confusion on the matter of rootstock influence on the scion cultivar. This work also suggests the next step in a progression of efforts to understand complex scion rootstock interactions on commercially important cultivars and rootstocks. Now is the time to set-up a similar trial employing “early” and “late” scions, such as Chardonnay and Cabernet Sauvignon, respectively, grafted to putatively “short” and “long” vegetative cycle rootstocks such as Riparia Gloire (short) and 420 A Mgt (long). As there appears to be a relationship between vegetative cycle length of the rootstock and the vigor of the scion grafted to it (Poncracz, 1983) this choice, on non-limiting soils would match rootstocks with different vegetative cycles, but striking differences in suggested influence on scion cultivar vigor. The choice of an intermediate

range rootstock (1103 P) could provide a midpoint between Riparia Gloire and 420 A in the potential impact on scion cultivar.

Conclusions

The data reported here suggest that vine phenomena resulting from genetically complex, environmentally influenced controls are most likely to be under the primary control of the scion cultivar. There are numerous examples of differences among vines grafted to different rootstocks. This report does not seek to suggest otherwise. What is sought is an approach to the analysis of such responses that will allow a rigorous determination of the specificity of that response to rootstock.

This is important because there are important breeding efforts aimed at solving soil borne problems and if direct impacts of rootstock can be effectively demonstrated, then the opportunity to improve vine culture would be greatly enhanced. If it is not possible to demonstrate such direct impact of the rootstock, then we are at a disadvantage when anecdotal information gleaned from non-critical experiments encourage us to seek the answer to the production concern in rootstock choice rather than in a simpler, more logical approach via the modification of vine culture.

Literature Cited

Anderson, K. A., G. S. Howell and J. A. Wolpert. 1980. Phenological development of different *Vitis* cultivars. *Fruit Varieties J.* 34:5-7.

Anwar, S. A., M. McHenry and D. Ramming. 2002. A search for more durable grape rootstock resistance to root knot nematode. *Am. J. Enol. Vitic.* 53:19-23.

Cochran, W. G. 1977. *Sampling Techniques.* John Wiley & Sons. New York, NY.

Cochran, W. G. and G. M. Cox. 1957. *Experimental Designs.* John Wiley & Sons. New York, NY.

Conradie, W. J. 1991. Translocation and storage by grapevines as effected by time of application. *Proc. Int. Symposium Nitrogen on Grapes and Wines. Am. Soc. Enol. Vitic.* Pp. 32-42.

Delas, J., C. Molot and J. P. Soyer. 1991. Effects of nitrogen fertilization and grafting on the yield and quality of the crop of *Vitis vinifera* cv. Merlot. *Proc. Int. Symposium Nitrogen on Grape and Wine. Am. Soc. Enol. Vitic.* Pp.242-248.

Edson, C. E., G. S. Howell and J. A. Flore. 1995. Influence of crop load on photosynthesis and dry matter partitioning of Seyval grapevines. III. Seasonal changes in dry matter partitioning, vine morphology, yield and fruit composition. *Am. J. Enol. Vitic.*46:478-485.

Galet, P. 1979. *A Practical Ampelography.* Transl. L. T. Morton, Cornell University Press. Ithaca, NY.

Galet, P. 1998. *Grape Varieties and Rootstock Varieties.* Oenoplurimedia, Chaintree, France.

Goodman, R. N., R. Grimm and M. Frank. 1993. The influence of grape rootstocks on the crown gall infection process and tumor development. *Am. J. Enol. Vitic.* 44:22-26.

Granett, J., A. C. Goheen, L. A. Lider and J. J. White. 1987. Evaluation of grape rootstocks for resistance to type A and type B grape phylloxera. *Am. J. Enol. Vitic.* 38:298-300.

- Grant, R. Stanley and M. E. Matthews. 1996. The influence of phosphorous availability, scion and rootstock on grapevine shoot growth, leaf area, and petiole phosphorus. *Am. J. Enol. Vitic.* 47:217-224.
- Howell, G. S. 1987. *Vitis* rootstocks. In *Rootstocks for Fruit Crops*. R. C. Rom and R. F. Carlson (Eds.), pp.451-472. John Wiley and Sons, New York, NY.
- Howell, G. S. 2000. Grapevine cold hardiness: Mechanisms of cold acclimation, mid-winter hardiness maintenance and spring deacclimation. Proceedings of the ASEV 50th Anniversary Annual Meeting. pp.35-48.
- Howell, G. S. 2001. Sustainable grape productivity and the growth-yield relationship. A review. *Am. J. Enol. Vitic.* 52:165-174.
- Howell, G. S. 2003. Selecting an appropriate trellis/training system based on specific variety characteristics. Proc. 22nd Annual Horticulture Industry Show, Springdale, AR 10-11 JAN. pp.121-129.
- Howell, G. S., T. K. Mansfield and J. A. Wolpert. 1987. Influence of training system, pruning severity and thinning on yield, vine size and fruit quality of Vidal blanc grapevines. *Am. J. Enol. Vitic.* 38:105-112.
- Howell, G. S., J. A. Flore and D. P. Miller. 1997. Cultivar, rootstock, and twig portion affect cold resistance to peach (*Prunus persica* (L.) Batch). *Advances Hort. Sci.* 11:30-36.
- Howell, G. S. and R. L. Perry. 1990. Influence of cherry rootstock on the cold hardiness of twigs of the sweet cherry cultivar. *Scientia Horticulturae* 43:103-108.
- Howell, G. S. and N. Shaulis. 1980. Factors influencing within-vine variation in the cold resistance of cane and primary bud tissues. *Am. J. Enol. Vitic.* 31:158-161.
- Howell, G. S. and J. A. Wolpert. 1978. Nodes per cane, primary bud phenology, and spring freeze damage to Concord grapevines. A preliminary note. *Am. J. Enol. Vitic.* 29:229-232.
- Kocsis, L., J. Granett, M. A. Walker, H. Lin and A. D. Omer. 1999. Grape phylloxera populations adapted to *Vitis berlandieri* x *V. riparia* rootstocks. *Am. J. Enol. Vitic.* 50:101-108.
- Miller, D. P., G. S. Howell and R. K. Striegler. 1988a. Cane and bud hardiness of selected grapevine rootstocks. *Am. J. Enol. Vitic.* 39:55-59.
- Miller, D. P., G. S. Howell and R. K. Striegler. 1988b. Cane and bud hardiness of own-rooted White Riesling and scions of White Riesling and Chardonnay grafted to selected rootstocks. *Am. J. Enol. Vitic.* 39:60-66.
- Morano, L. and W. M. Kleiwer. 1994. Root distribution of three grapevine rootstocks grafted to Cabernet Sauvignon grown on a very gravelly clay loam soil in Oakville, California. *Am. J. Enol. Vitic.* 45:345-348.
- Padget-Johnson, M., L. E. Williams and M. A. Walker. 2000. The influence of *Vitis riparia* rootstock on water relations and gas exchange of *Vitis vinifera* cv Carignane scion under non-irrigated conditions. *Am. J. Enol. Vitic.* 51: 137-143.

- Pongracz, D. P. 1983. Rootstocks for Grapevines. David Phillip, Cape Town, S. Africa.
- Pool, R. M. 1974. Relation of cytokinins, abscisic acid, and metabolites of abscisic acid to vine growth and leaf function in *Vitis*. Ph. D. Thesis, Cornell University, Ithaca, New York.
- Pool, R. M. 1975. Effect of cytokinin on *in vitro* Development of "Concord" flowers. *Am. J. Enol. Vitic.* 26:43-46.
- Pool, R. M., G. E. Howard, R. M. Dunst, W. G. Smith and A. M. Wise. 1992. Rootstock research in the northeast United States. Pp. 69-75. In: *Rootstock Seminar. A Worldwide Perspective.* Am. Soc. Enol. Vitic.
- Rom, R. C. 1987. Roots. *In Rootstocks for Fruit Crops.* R. C. Rom and R. F. Carlson (Eds.), pp.5-28. John Wiley and Sons, New York, NY.
- Steel, R. G. D. Steel and J. H. Torrie. 1980. *Principles and Procedures of Statistics. A Biometrical Approach.* McGraw-Hill, New York, NY.
- Striegler, R.K. and G. S. Howell. 1991. Influence of rootstock on the cold hardiness of Seyval grapevines. I. Primary and secondary effects on growth, canopy development, yield, fruit quality, and cold hardiness. *Vitis* 30:1-10.
- Striegler, R. K., G. S. Howell and J. A. Flore. 1993. Influence of rootstock on the response of Seyval to flooding stress. *Am. J. Enol. Vitic.* 44:313-319.
- Walker, M. A. 1992. Future directions for rootstock breeding. Pp. 60-68. In: *Rootstock Seminar: A Worldwide Perspective.* Am. Soc. Enol. Vitic.
- Wermelinger, B. 1991. Nitrogen dynamics: physiology and modeling. *Proc. Int. Symposium on Nitrogen on Grapes and Wine.* Pp.23-31.
- Williams, L. E. and R. J. Smith. 1991. The effect of rootstock on partitioning of dry weight, nitrogen and potassium, and root distribution of Cabernet Sauvignon. *Am. J. Enol. Vitic.* 42: 118-122.
- Wolpert, J. A. 1992. Rootstock use in California: History and future prospects. Pp. 52-59. In: *Rootstock Seminar: A Worldwide Perspective.* Am. Soc. Enol. Vitic.

Table 1. Main Effects of Four-year's Data on Influence of Reciprocal Grafts of Marechal Foch (Foch) and Vidal blanc (Vidal) on Vine Growth Characteristics.^Z

Characteristic	Scion			Roots		
	Foch	Vidal	F ^Z	Foch	Vidal	F ^Z
Vine Size (kg/vine)	1.88	2.14	ns	1.66	2.37	**
Nodes Retained	37	27	**	29	34	*
Shootless Nodes	5	16	***	11	10	ns

^Z – ns, *, **, and *** indicate not statistically different and statistical significance at the 0.05, 0.01 and 0.001 levels of probability, respectively.

Table 2. Main Effects of Four-year's Data on Reciprocal Grafts of Marechal Foch (Foch) and Vidal blanc (Vidal) on Vine Yield and Yield Components.^Z

Characteristic	Scion			Roots		
	Foch	Vidal	F ^Z	Foch	Vidal	F ^Z
Yield/Vine (kg)	8.01	9.77	**	8.81	9.39	ns
Cluster Number/Vine	131	61	***	94	99	ns
Berry Weight (g)	1.1	1.7	***	1.3	1.4	ns
Berries/Cluster	37	115	***	96	93	ns
Cluster Weight (g)	74	185	***	132	132	ns

^Z – ns, *, **, and *** indicate not statistically different and statistical significance at the 0.05, 0.01 and 0.001 levels of probability, respectively.

Table 3. Main Effects of Four-year's Data of Reciprocal Grafts of Marechal Foch (Foch) and Vidal blanc (Vidal) on Fruit Composition Values.^Z

Characteristic	Scion			Roots		
	Foch	Vidal	F ^Z	Foch	Vidal	F ^Z
°Brix	19.8	19.8	ns	21.6	19.5	*
Sugar per Vine (kg)	1.59	1.93	**	1.77	1.83	ns
pH	3.41	3.31	**	3.40	3.31	**
Titrateable Acidity (g/l)	11.5	11.7	ns	11.2	12.1	*

^Z – ns, *, **, and *** indicate not statistically different and statistical significance at the 0.05, 0.01 and 0.001 levels of probability, respectively.

Table 4. Main Effects of Four-year's Data on Reciprocal Grafts of Marechal Foch (Foch) and Vidal blanc (Vidal) on Vine phenology and the Impact of a Spring Freeze Event in Year Two.^Z

Phenology	Scion			Roots		
	Foch	Vidal	F ^Z	Foch	Vidal	F ^Z
Date of Bud Burst	1.5	12.1	**	7.0	7.0	ns
Days from Bud Burst to Veraison	90	104	**	98	96	ns
Harvest Date	1	29	***	16	14	ns
% Primary Bud Mortality Due to Spring Freeze in Year-2	10	2	**	6	5	ns

^Z – ns, *, **, and *** indicate not statistically different and statistical significance at the 0.05, 0.01 and 0.001 levels of probability, respectively.

Posters

Performance of 'Gewurztraminer' on Six Rootstocks Under Marginal Climatic Conditions

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Abstract

Use of rootstocks, a standard practice in viticulture can provide resistance or tolerance to biotic and abiotic stresses, and affect vine growth, yield, and fruit and wine qualities. Growth and cold hardiness of *Vitis vinifera* 'Gewurztraminer' on rootstocks 'Riparia Gloire' (*V. riparia*), 'St. George' (*V. rupestris*), '3309 Couderc' (*V. riparia* x *V. rupestris*), '110 Richter' (*V. berlandieri* x *V. rupestris*), '1103 Paulsen' (*V. berlandieri* x *V. rupestris*), and 'MG 420A' (*V. berlandieri* x *V. riparia*) were tested at two research sites in Southeast Nebraska, USA. Rootstocks did not significantly affect the vegetative growth of young 'Gewurztraminer' vines, but they modified cold hardiness of the scions; vines on '3309 Couderc' and 'MG 420A' were the most cold hardy. Significant differences in vine pruning weight and cold hardiness were observed between the two research sites. The vine growth at the Peru site ended up with much larger and hardier vines than at the Nemaha site. In a state such as Nebraska, using cold hardy rootstocks may be helpful if attempting to grow European grape cultivars.

Introduction

Rootstocks have been widely employed in viticulture since the devastating pest phylloxera (*Phylloxera vitifoliae* Fitch.) was found in the 1870s. Grafting desired cultivars to selected rootstocks of North American *Vitis* species or their hybrids is a standard vineyard practice in most parts of the world (Weaver, 1976). Besides the resistance to phylloxera, rootstocks have been proven to have resistance or tolerance to numerous organisms including nematodes (Magoon and Magness, 1937); and diseases (Brown et al., 1999); providing tolerance to environmental stresses such as salinity (Walker et al., 2000, 2002), drought (Carbonneau, 1985) and stressful temperatures (Striegler and Howell, 1991). Rootstocks exert effects on vine growth, yield, and fruit and wine qualities (Vaile, 1937; Walker et al., 1998). However, own-rooted vines grew as well as grafted ones in some regions., e.g., the Pacific northwestern U.S. and British Columbia (Boselli et al., 1992; Reynolds and Wardle, 2001).

Winter damage to grapevines frequently occurs in temperate-zone vineyards, with different

Vitis species or cultivars exhibiting varied degrees of cold hardiness (Miller et al., 1988a). Most hybrid *Vitis* species cannot tolerate extreme winter temperatures lower than -35°C , while *vinifera* cultivars cannot survive temperatures of -15°C to -25°C , depending on cultivar (Clark, 1936; Plocher and Parke, 2001). We hypothesized that *vinifera* grapes will be protected from winter cold and phylloxera in Nebraska if rootstocks are employed. Here we report the first three years' results of rootstock trials on newly-planted *V. vinifera* 'Gewurztraminer'.

Materials and Method

Two sites, one in Nemaha County and one near Peru in Otoe County (both in Southeast Nebraska, USA), were chosen as research sites in 1998. The Nemaha site is at 40.28° lat., 95.62° long., and 333 m elevation; the soil type is Monona silt loam with a moderate slope toward the south. The Peru site is located at 40.53° lat., 95.80° long., and 329 m elevation; the soil type is Marshall silty clay loam with a slight slope to the northeast. A micro-weather station (Campbell Scientific Inc., Utah, USA) equipped for accession of daily or hourly air temperature (at 1.5m height), soil temperature (at 10 cm depth), solar radiation, precipitation, wind speed, and relative humidity data was installed at each site.

Six rootstocks were employed for this research: 'Riparia Gloire' (Gloire), *V. riparia*, 'St. George', *V. rupestris*, '3309 Couderc' (3309, *V. riparia* x *V. rupestris*), '110 Richter' (110, *V. riparia* x *V. rupestris*), '1103 Paulsen' (1103, *V. berlandieri* x *V. riparia*), and 'MG 420A' (420A, *V. berlandieri* x *V. riparia*). The scion cultivar used for these experiments was *V. vinifera* 'Gewurztraminer'. At the Peru site, rootstock '110 Richter' was not included. All materials, grafted or own-rooted 'Gewurztraminer', were purchased from Sonoma Grapevines Inc. (CA, USA) in the

spring of 1999. A completely Randomized Design (CRD) was used with six rootstocks plus the own-rooted control, with four replications for each rootstock and six vines per replication. Data were analyzed with the Mixed Model of SAS® VA (SAS Institute, Cary, NC) for analysis of variance, multiple comparison and interactions.

Results

Temperatures of the three dormant seasons.

Generally, the winters of 1999-2000 and 2001-2002 were relatively mild, while the winter of 2000-2001 was harsh (Table 1). The lowest air temperatures were about -20°C , -24°C , and -18°C at both sites in the three winters, respectively. The lowest soil temperatures measured at 10 cm depth of soil were never lower than 0°C in the three winters.

Pruning weight was not significantly modified by rootstocks, although vines grafted on rootstocks '3309' and '420A' were the two heaviest. No significant differences among the rootstocks on vegetative growth and winter survival of 'Gewurztraminer' vines were observed following the winters of 1999-2000 and 2001-2002, but they did modify budbreak time and cold hardiness as shown by the measurements of winter survival, bud numbers from either old canes or graft unions (grafted vines) or below ground (own-rooted vines). Rootstocks '3309' and '420' hastened budbreak of scion 'Gewurztraminer', while other rootstocks delayed budbreak of scions. Number of buds that survived the cold winter of 2000-2001 (from old canes) was highest on rootstock '3309', followed by '420'.

Growth of vines in early spring should reflect performance of vines in the previous winter. In our research, vegetative indexes were taken shortly after budbreak, which should help estimate winter damage once it has happened. The vigor of 'Gewurztraminer' as represented

by pruning weight, was not significantly affected by rootstocks in either mild or harsh winters in our research, which agrees with the reports by Harmon (1949) of 'Gewurztraminer' vines on rootstocks 'St. George' and 'Dog Ridge' and by Reynolds and Wardle (2001) on rootstocks 'Couderc 3309', 'Kober 5BB', 'Teleki 5C', and 'Selektion Oppenheim 4'.

Conclusions

Three years' results of rootstock studies in Nebraska showed that vegetative growth of young 'Gewurztraminer' vines was not modified significantly by rootstocks; cold hardiness of scions was modified by rootstocks and scions grafted on '3309' and '420A' were the hardiest. Date of scion budbreak was also changed by rootstocks: '3309' and '420A' accelerated budbreak, while other rootstocks delayed budbreak of scions when compared to the own-rooted controls after the harsh winter of 2000-2001. In a state such as Nebraska, employing cold hardy rootstocks could be helpful in growing of European grape cultivars, but further evaluation is necessary as these vines mature in the ensuing years.

References Cited

- Boselli, M., M. Fregoni, A. Vercesi, and B. Volpe. 1992. Variation in mineral composition and effects on the growth and yield of Chardonnay grapes on various rootstocks. *Agriculture Ricerca* 14:138-139.
- Brown, M.V., J.N. Moore, P.Fenn, and R.W. McNew. 1999. Inheritance of downy mildew resistance in table grapes. *J.Amer.Soc.Hort.Sci.* 124:262-267.
- Carbonneau, A. 1985. The early selection of grapevine rootstocks for resistance to drought conditions. *Amer.J.Enol. Viticult.* 36:195-198.
- Clark, J.H. 1936. Injury to the buds of grape varieties caused by low temperatures. *Proc. Amer. Soc. Hort. Sci.* 34:408-413.
- Harmon, F.N. 1949. Comparative value of thirteen rootstocks for ten *Vinifera* grapes in the Napa Valley in California. *Proc. Amer. Soc. Hort. Sci.* 54:157-162.
- Magoon, C.A. and J.R. Magness. 1937. Investigation on the adaptability of grape rootstocks to Gulf Coast conditions. *Proc. Amer. Soc. Hort. Sci.* 35:466-470.
- Miller, D.P., G.S. Howell, and R.K. Striegler. 1988. Cane and bud hardiness of selected grapevine rootstocks. *Amer.J.Enol.Viticult.* 39:55-59.
- Plocher, T. and B. Parke. 2001. Northern Winework: growing grapes and making wine in cold climates. Northern Winework Inc. MN.
- Reynolds, A.G. and D.A. Wardle. 2001. Rootstocks impact vine performance and first composition of grapes in British Columbia, *HortTechnology* 11(3): 419-427.
- Striegler, R.K., G.S. Howell, and J.A. Flore. 1993. Influence of rootstock on the response of Seyval grapevines to flooding stress. *Amer.J.Enol.Viticult.* 44:313-319.
- Vaile, J.D. 1937. The influence of rootstocks on the yield and vigor of American grapes. *Proc. Amer.Soc.Hort.Sci.* 35:471-474.
- Walker, R.R., D.H. Blackmore, R.P. Clingeffer, and C.L. Ray. 2002. Rootstock effects on salt tolerance of irrigated field-grown grapevines (*Vitis vinifera* L. cv. Susltana). I. Yield and vigor inter-relationships. *Austral.J.Grape Wine Res.* 8:3-14.

Walker, R.R., P.E. Read, and D.H. Blackmore. 2000. Rootstock and salinity effects on rates of berry maturation, ion accumulation and colour development in Shiraz grapes. *Austral. J. Grape Wine Res.* 6:227-239.

Walker, R.R., P.R. Clingeleffer, G.H. Kerridge, E.H. Ruhl, P.R. Nicholas, and D.H. Blackmore, 1998. Effects of the rootstock Ramsey (*Vitis champini*) on ion and organic acid composition of grapes and wine, and on

wine spectral characteristics. *Austral. J. Grape and Wine Res.* 4:100-0110.

Weaver, R.J. 1976. *Grape Growing*. A Wiley Interscience Publication. John Wiley & Sons, New York.

Table 1. Selected temperatures at the Peru and Nemaha sites for the winters of 1999-2000, 2000-2001 and 2001-2002.

Month/Day/Year	Peru		Nemaha	
	High	Low	High	Low
12/17/99	-4°C	-21°C	-6° C	-17° C
1/22/2000	-2°C	-14°C	-4°C	-15°C
3/11/2000	+5°C	-6°C	+14°C	-6°C
12/30/2000	+8°C	-23°C	+8°C	-19°C
1/28/2001	-5°C	-24°C	-4°C	-24°C
3/11/2001	+8°C	-4°C	+8°C	-3°C
12/31/2001	-3°C	-14° C	+3° C	-13° C
2/7/2002	-6°C	-14°C	+2°C	-7°C
3/8/2002	-9°C	-18°C	-1°C	-11°C

Effect of Rootstock on Growth, Yield and Juice Quality of Vinifera, American and Hybrid Wine Grapes in Oklahoma

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Introduction

Grapes can be grown on their own roots, i.e. rooted cuttings, or grafted onto rootstocks. Various rootstocks can offer benefits such as pest resistance, tolerance of certain soil characteristics and tolerance of salts and salinity. In areas where winter freeze injury is prevalent, rootstocks impart additional risk to the vineyard since vines frozen back below the graft union must be replaced or re-grafted.

Rootstocks commonly used are either selections from hardy native species or plants resulting from crosses of various native species. Vines resulting from crosses would be expected to exhibit traits from one or both of the parents of the cross.

Methods

This paper includes partial results from trials from two locations: the Oklahoma Fruit Research Station in Perkins, OK and Woodland Park Vineyard and Winery in Stillwater, OK.

The Perkins, OK plots consisted of the following treatments:

Clone 4 'Chardonnay' - own roots or grafted to 1103 Paulsen, 140 Ruggeri,

3309 Couderc, 5BB Kober, Freedom, and St. George

Clone 1 'Cabernet Franc' - 1103 Paulsen, 140 Ruggeri, 3309 Couderc, 5BB Kober, and St. George

Vines were planted into a Teller loam soil in May, 2001. Rows were spaced 12' apart and vines within rows were spaced 8' apart. Treatments were arranged according to a randomized complete block design with five replications of two vines per plot. All vines were trained to a Geneva Double Curtain trellis.

The Woodland Park Vineyard plots consisted of the following treatments:

Own-rooted vines of 'Riesling', 'Chardonnay', 'Cabernet Franc', 'Cabernet Sauvignon', 'Vignoles', 'Chardonel', 'Chambourcin', 'Frontenac', and 'Cynthiana/Norton'

The same cultivars grafted to 3309C rootstock.

Own-rooted vines were planted in April, 2002 and grafted vines in April, 2003. All rows were spaced 12' apart and vines within rows were spaced 8' apart. Treatments were arranged according to a randomized complete

block design with five replications of three vines per plot. All vines were trained to a Geneva Double Curtain trellis.

Culture and management of all vines were as recommended by Oklahoma Cooperative Extension Service.

Data collection began in 2003 including bud break, vigor, fruit yield and quality. Fruit was harvested when a random sample of 100 berries from each treatment tested 22 degrees Brix for red cultivars and 20 degrees Brix for white cultivars. Bud break ratings were made according to Eichorn-Lorenz Grape growth charts. At harvest a random sample of 10 clusters and 100 berries were weighed to determine cluster and berry size, respectively. Yield, cluster and berry weight data were analyzed and mean separations performed using the GLM procedure within SAS (SAS, 2004). Weighted means were compared using the t test.

For juice analysis, grape berry samples of about 100 berries were harvested as described above, placed in plastic bags, and frozen within 24 hours of harvest for subsequent analysis. Frozen berries were held at approximately -15°C (5°F) until analyses were conducted.

Juice samples were prepared for analysis by holding a sample bag at room temperature until the berries were completely thawed, then gently crushing the berries in the bag to express the juice. Duplicate 5 ml samples of juice were then removed from the sample bag and evaluated for soluble solids, pH, and titratable acidity. Soluble solids were measured using a Leica model 10500-802 Auto Abbe Refractometer (Leica, Buffalo, NY). Titratable acidity and pH values were measured with a Fisher model AB15 pH meter (Fisher Scientific, Pittsburgh, PA). Titratable acidity measurements were performed using a method modified from Zoecklein et al. (1999).

Samples were titrated to an endpoint pH of 8.2 with 0.1 N NaOH and titratable acidity was calculated as percent tartaric acid. Duplicate values were averaged to give final reported values.

Results and Discussion

Early bud break followed by rapid growth predisposes vines to injury from late spring frost during April in Oklahoma. This tendency is most prominent in vineyards located in low-lying sites or sites surrounded by tall trees or other structures which block air drainage.

Vines grafted on to 3309C rootstock tended to initiate growth later in the spring in comparison to vines on their own roots. This difference was most apparent on ‘Cabernet Franc’, ‘Chardonnay’ and ‘Chambourcin’ in the frost susceptible Woodland Park Vineyard trial. The difference on ‘Cabernet Sauvignon’ and ‘Chardonnay’ was less dramatic (Figure 1).

‘Cabernet Franc’ on 3309C rootstock broke bud later and grew more slowly in the spring than did ‘Cabernet Franc’ on other rootstocks or ‘Chardonnay’ on any rootstock in the Perkins Research Station Trial (Figure 2).

Rootstocks did not significantly affect fruit yield, cluster weight or berry weight on ‘Cabernet Franc’ in the Perkins Research Station trial (Table 1). However, Freedom rootstock significantly increased average cluster weight on ‘Chardonnay’ in comparison to own rooted vines. Likewise, total fruit weight per acre was significantly lower from own rooted ‘Chardonnay’ in comparison to other rootstocks (Table 2). Rootstock did not appear to have a significant effect on pH or soluble solids for either ‘Cabernet Franc’ or ‘Chardonnay’ juice (Tables 1 and 2). Differences in titratable acidity were also minimal for ‘Cabernet Franc’ (Table 1). Differences in titratable acidity among rootstocks were more pronounced in

‘Chardonnay’ with vines rooted on 3309C having notably lower acidity and vines rooted on St. George having notably higher acidity than the average (Table 2). More data will need to be collected to determine if the observed differences remain constant over time.

Conclusions

Rootstocks show the potential to delay early spring growth and increase fruit yield and cluster size on ‘Chardonnay’ growing under Oklahoma conditions. Delayed growth in the spring can reduce crop loss to late spring frost events thus increasing vineyard profitability. Differences in juice quality among different rootstocks appear to be minimal.

Oklahoma grape growers should consider the benefits of grafted vines against the risk from winter freeze injury.

References

- McCraw, B. D., et.al. 2004. Vineyard Establishment and Management in Oklahoma. Oklahoma Cooperative Extension Service, Stillwater, OK.
www.okstate.edu/ag/asnr/hortla/frtpcns/homepage.htm
- Eichorn and Lorenz. 1977. Stages in Development of the Grapevine. The Horticulture and Food Research Institute of New Zealand Ltd.
- Rom R.C. and R. F. Carlson. 1987. Rootstocks for Fruit Crops. John Wiley and Sons. New York.
- SAS. 2004. SAS Online Doc, Version 8. SAS Institute Inc., Cary, NC.
- von Broembsen, S. and P. Mulder. 2004. Commercial Grape Insect and Disease Control – 2004. CR-6252. Oklahoma Cooperative Extension Service. Stillwater, OK.
www.osuextra.com
- Zoecklein, B.W., K.C. Fugelsang, B.H. Gump and F.S. Nury. 1999. Wine Analysis and Production. Kluwer Academic / Plenum. New York.

Acknowledgement

We wish to thank the Kerr Center for Sustainable Agriculture of Poteau, OK for funding the grower trial component of this research through their Producer Grant Program.

Figure 1. Effect of 3309C Rootstock on Bud Break (Eichorn-Lorenz Rating Scale) of Various Vinifera, American and Hybrid Grape Cultivars, Woodland Park Vineyard, Stillwater, OK.

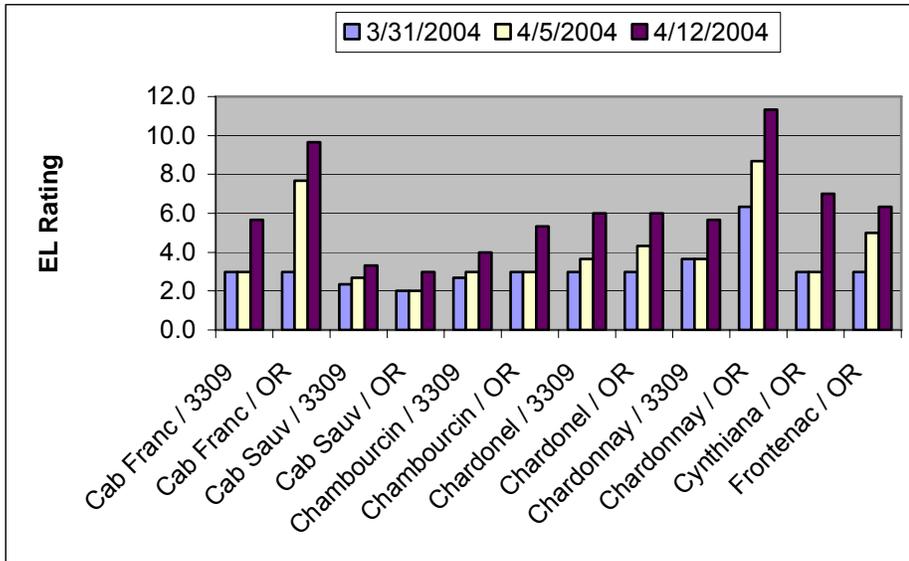


Figure 2. Effect of Rootstock on Bud Break (Eichorn-Lorenz Rating Scale) of 4th Leaf 'Cabernet Franc' and 'Chardonnay' Grape Vines. Perkins, OK

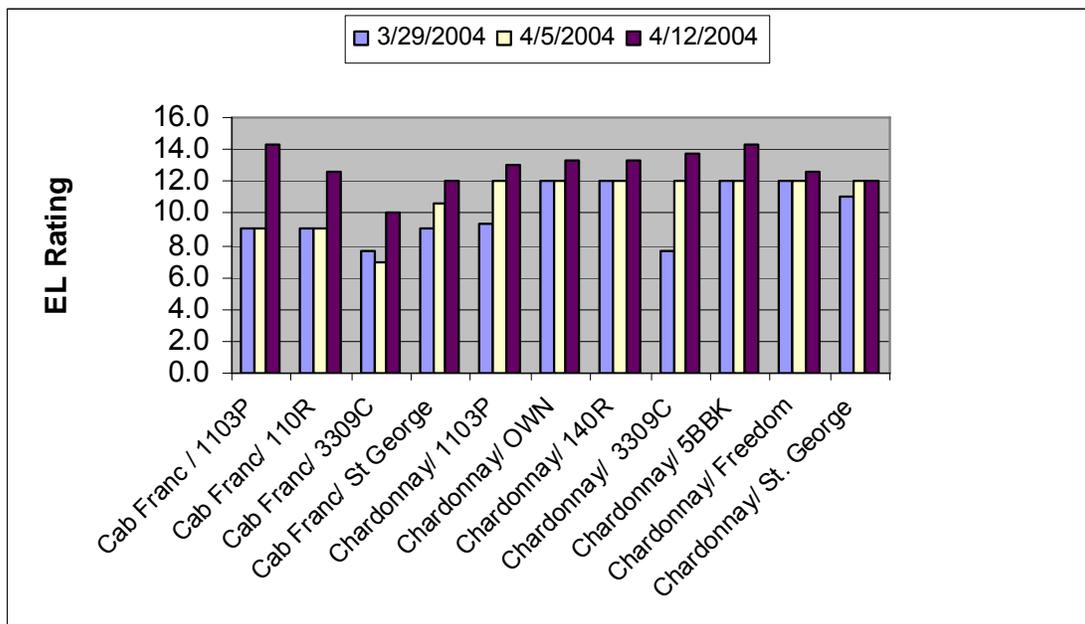


Table 1. Average Effect of Rootstock on 3rd and 4th Leaf ‘Cabernet Franc’ Fruit Yield and Quality. Perkins, OK 2003/2004

Rootstock	Harvest Date	Wt/acre (lbs) 453 plt/a	Avg Cluster Wt (g)	Avg Berry wt (g)	Avg. pH	Titrateable Acidity (% Tartaric Acid)	oBrix Avg S.S.
110R	30-Aug	15,727 a	148.8 a	16.2 a	4.19	0.38	23.13
1103P	29-Aug	13,349 a	158.1 a	16.0 a	4.21	0.37	23.10
St. George	1-Sep	12,344 a	134.3 a	16.0 a	4.29	0.39	22.44
3309C	29-Aug	10,243 a	141.9 a	16.1 a	4.24	0.36	23.33

Planted 2001; Geneva Double curtain trellis; vine spacing 8x12; means followed by same letter not significantly different according to SAS GLM.

Table 2. Average Effect of Rootstock on 3rd and 4th Leaf ‘Chardonnay’ Fruit Yield and Quality. Perkins, OK 2003/2004

Rootstock	Harvest Date	Wt/acre (lbs) 453 plt/a	Avg Berry Wt (g)	Avg Cluster wt (g)	Avg. pH	Titrateable Acidity (% Tartaric Acid)	oBrix Avg S.S.
St George	15-Aug	16,120 a	15.0 a	155.6 b	3.81	0.68	21.38
140R	16-Aug	14,786 a	15.6 a	176.2 ab	3.81	0.62	21.33
Freedom	15-Aug	14,146 a	16.0 a	205.3 a	3.85	0.63	21.21
5BBK	15-Aug	11,846 ab	16.0 a	186.9 ab	3.86	0.64	21.59
3309C	13-Aug	11,782 ab	16.0 a	187.9 ab	3.89	0.57	21.37
1103P	15-Aug	8,484 ab	16.2 a	162.9 b	3.84	0.60	21.34
Own	15-Aug	5,965 b	15.4 a	156.7 b	3.84	0.66	21.79

Planted 2001; Geneva Double curtain trellis; vine spacing 8’x12’; means followed by the same letter are not significantly different according to SAS GLM.

Photosynthetic Activity of European and American Winegrapes at Three Temperatures under controlled Environmental Conditions

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Abstract

One European (*Vitis vinifera* L.) winegrape cultivar, Pinot noir, and one American (*Vitis aestivalis* Michx.) winegrape cv., Cynthiana, were subjected to three temperature regimes for 28 days in growth chambers set at 20/15 °C, 30/25 °C, or 40/35 °C, for 16/8 h D/N to determine the influence of temperatures on chlorophyll fluorescence, photosynthetic rate, and growth of the vines. The optimum temperatures for initial chlorophyll fluorescence (F_0), photochemical efficiency (F_v/F_m), photosynthesis, and vine growth were 20/15 °C for Cynthiana and 30/25 °C for Pinot noir. High temperature (40/35 °C) reduced photosynthetic rate for both cultivars, but the reduction was more severe for Cynthiana than Pinot noir. Four weeks of exposure to intermediate or high temperature was detrimental to Cynthiana. This study concluded that the American winegrape cultivar, Cynthiana was more sensitive to high temperature (40/35 °C) than the European cultivar, Pinot noir.

Introduction

Grape has a great potential to become one of the major fruit crops in Kansas. Before Prohibition, Kansas was ranked among the top 10 states in grape and wine production (Schueneman, 1982). It was not until the early 1980s when grape growing and winemaking became one of Kansas' industries.

Adequate sunlight and irrigation, fertile soil, and dry climate provide a good environment for growing grapes. However, high temperature is one of the factors that reduces vine production, which limits introduction of new cultivars into Kansas. Heat stress negatively affects growth, yield, and berry quality, which reduces the quality of wine and table grapes (Bergqvist et al., 2001; Matsui et al., 1986). Temperatures differ dramatically during the growing season, and those over 35 °C are not uncommon in Kansas during the summer.

Photosynthesis, which is closely related to plant growth, is one of the processes most sensitive to high temperatures in grapes (Chaumont et al., 1997; Ferrini et al., 1995; Shiraishi et al., 1996). Low yield, due to low plant biomass, is attributed to low assimilation rate, acceleration of plant development, and diminishing of diurnal temperature range under heat stress (Midmore et al., 1984). Photosystem II (PS II) has been reported to be the primary site of heat injury within the photosynthetic apparatus (Björkman, 1980). The reaction center in PS II is damaged mostly near the water-splitting complex (Al-Khatib and Paulsen, 1989).

Although American type cultivars are the dominant winegrapes in Kansas, there is always a need for new cultivars, such as European types, that might have the potential for production in some areas where summer temperatures are between 37-40 °C. Considering the importance of introducing new

cultivars to Kansas, it is essential to evaluate different cultivars for heat resistance. Genotypes within grape species differ in their response to high temperatures, indicating substantial genetic variability for the trait. Therefore, this study was conducted to study the response of chlorophyll fluorescence, photosynthesis, and vine growth of the American and the European winegrape cultivars subjected to three temperatures in controlled environmental conditions.

Materials and Methods

One European winegrape cultivar, Pinot noir clone 667 rootstock 3309, was compared with own-rooted Cynthiana, the widely grown American winegrape in Kansas. Both Pinot noir and Cynthiana are black fruited cultivars used to produce red wine. Dormant one-year-old vines were planted in 1:1:1 (by volume) sand: peatmoss: perlite medium soil mix in a polyethylene pots. Plants were placed in a greenhouse set at $23/21 \pm 3$ °C day/night (D/N) temperatures, $50 \pm 10\%$ Relative Humidity (RH), and a 16/8 h D/N photoperiod. The supplemental light intensity was $200 \mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetically active radiation (PAR) (400-700 nm, measured with LI-188B Integrating Quantum/Radiometer/ Photometer and LI-190sB sensor, Li-Cor, Inc., Lincoln, NE, USA). Vines were irrigated as needed and fertilized weekly with a commercial fertilizer containing $300 \mu\text{g L}^{-1}$ nitrogen, $250 \mu\text{g L}^{-1}$ phosphorus, and $220 \mu\text{g L}^{-1}$ potassium (Miracle-Gro soluble fertilizer, Scotts Miracle-Gro Products, Inc., Consumer Products Division, Port Washington, NY 11050). After twenty-three days under greenhouse conditions, vines were pruned to a single shoot and shoot length (cm) and the number of leaves were recorded.

Four vines per cultivar for each temperature were transferred to three growth chambers maintained at $20/15$ °C ± 1 , $30/25$ °C ± 1 , or

$40/35$ °C ± 1 D/N temperatures, 16/8 h D/N photoperiods, or $450 \mu\text{mol/m}^2/\text{s}$ PAR for 28 days. Humidity was not regulated but was monitored to be in the range from $80\text{-}85\% \pm 10$ RH. Vines at high temperature were watered twice a day to full capacity to prevent secondary injury due to desiccation.

Photosystem II chlorophyll fluorescence and photosynthesis of the oldest third leaf were measured 0, 7, 14, 21, and 28 days after temperature treatments. Data are presented as the percent of the control. Initial chlorophyll fluorescence (F_0) and PS II efficiency (F_v/F_m) were measured with Hansatech Fluorescence Monitoring System (FMS). Photosynthetic rate (A) was measured with LI-6400 Portable Photosynthesis System (Li-Cor Inc., Lincoln, NE, USA).

Individual vines were harvested 28 days after temperature treatments, and number of leaves was determined. Total leaf area (LA) per vine was measured with the LI-3100 Leaf Area Meter (Li-Cor Inc., Lincoln, NE, USA), which measures LA based on one side of the leaf. Shoot biomass of the main and lateral shoots was determined after 72 h drying at 70 °C.

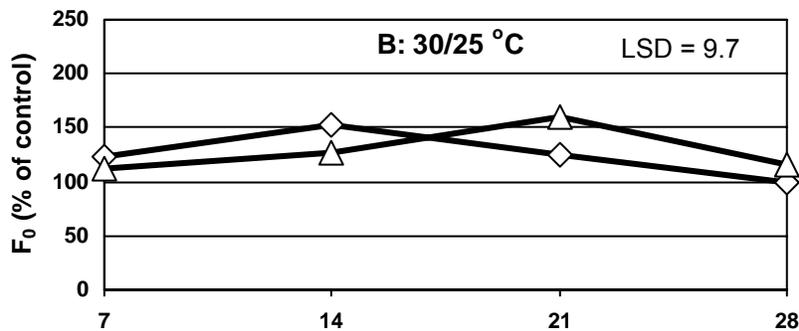
The experiment was a randomized complete block design with factorial arrangement of cultivar x temperature x time. Treatments replicated four times and the study was conducted in March and repeated in July, 2002. Data will be presented as the average of 8 vines. Treatment effect (plant response) data were analyzed using standard analysis of variance (ANOVA). Data were tested for homogeneity of variance and normality of distribution. Differences among means were tested by Fisher's protected least significant differences (LSD) ($P = 0.05$).

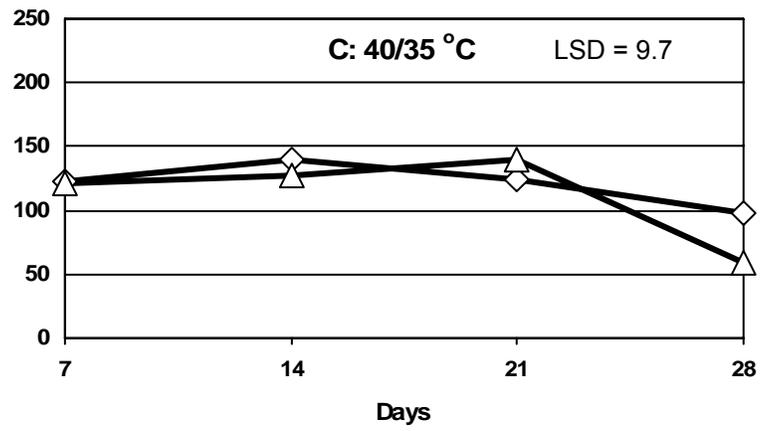
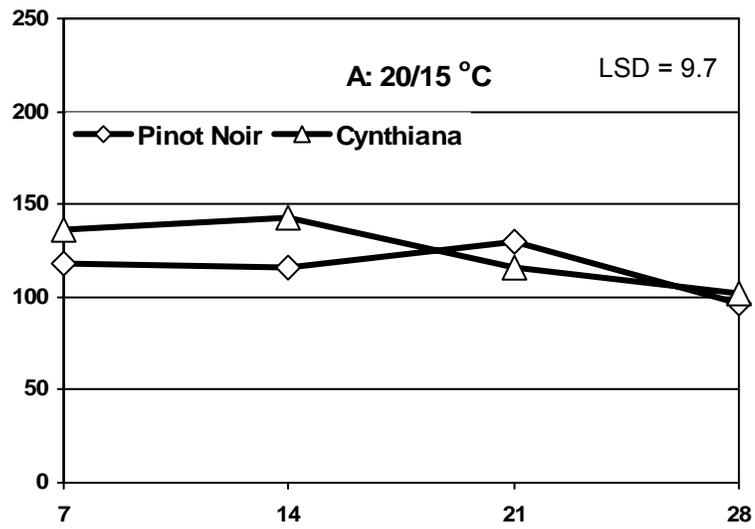
Results and Discussions

There was significant difference in initial chlorophyll fluorescence (F_0) between the two cultivars at 20/15 °C (Fig. 1A). Although Cynthiana F_0 was significantly higher than that of Pinot noir, 20/15 °C had no effect on F_0 within the cultivar for the first two weeks. Cynthiana F_0 was reduced at 21 days of exposure to 20/15 °C, while Pinot noir F_0 was increased. Twenty-eight days of 20/15 °C exposure, F_0 was reduced in both cultivars. Conversely, as the temperature increased to 30/25 °C, F_0 of Pinot noir was significantly

higher than that of Cynthiana (Fig. 1B). At 21 days of exposure to 30/25 °C, F_0 of Pinot noir was significantly reduced compared with an increase in Cynthiana. There was no significant difference in F_0 between the cultivars at seven days of exposure to 40/35 °C (Fig. 1C), whereas 28 days of exposure to 40/35 °C reduced F_0 for Pinot noir and Cynthiana by 24 and 107%, respectively.

Figure 1. Initial chlorophyll fluorescence (F_0) of Pinot noir and Cynthiana as affected by three temperatures.

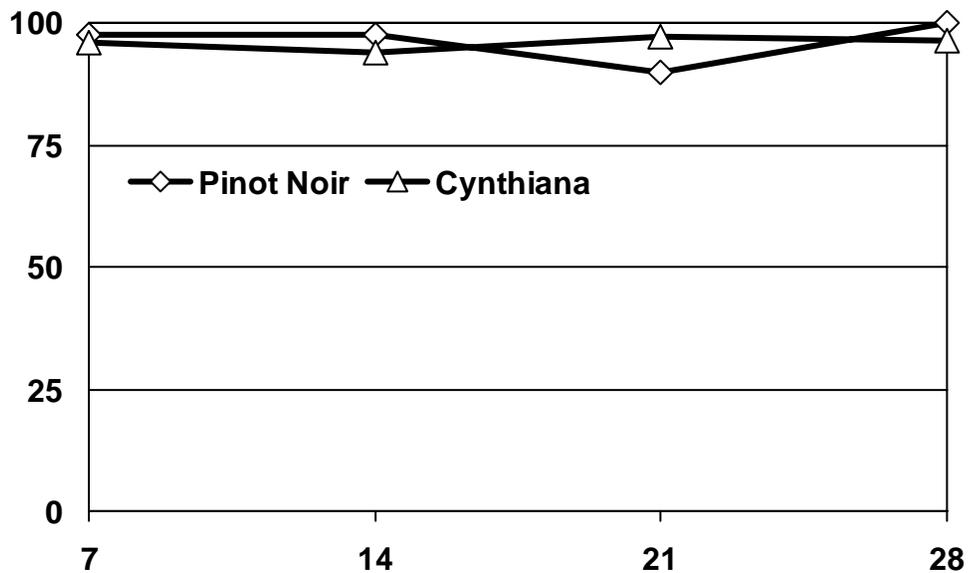


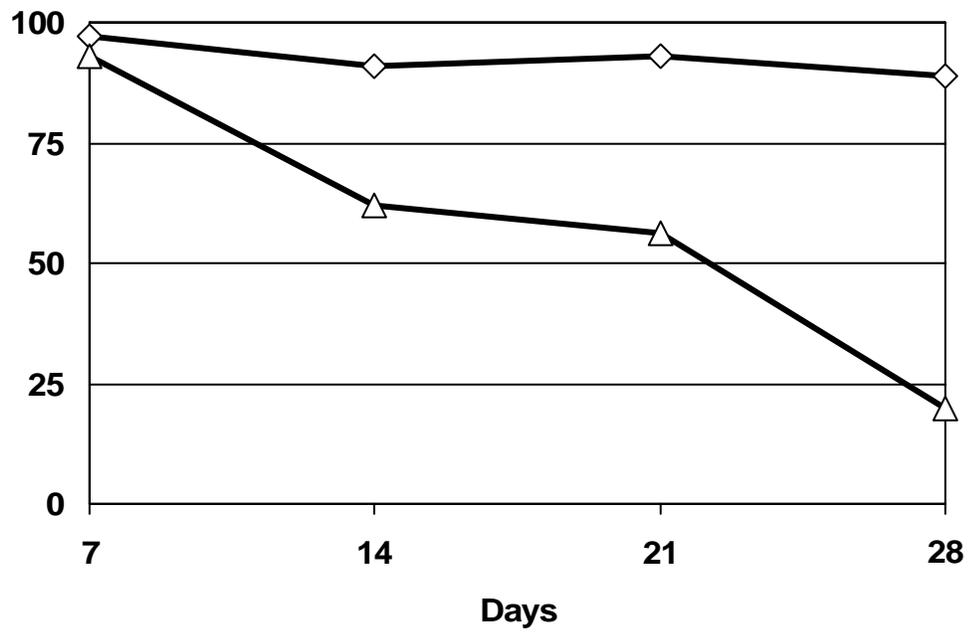
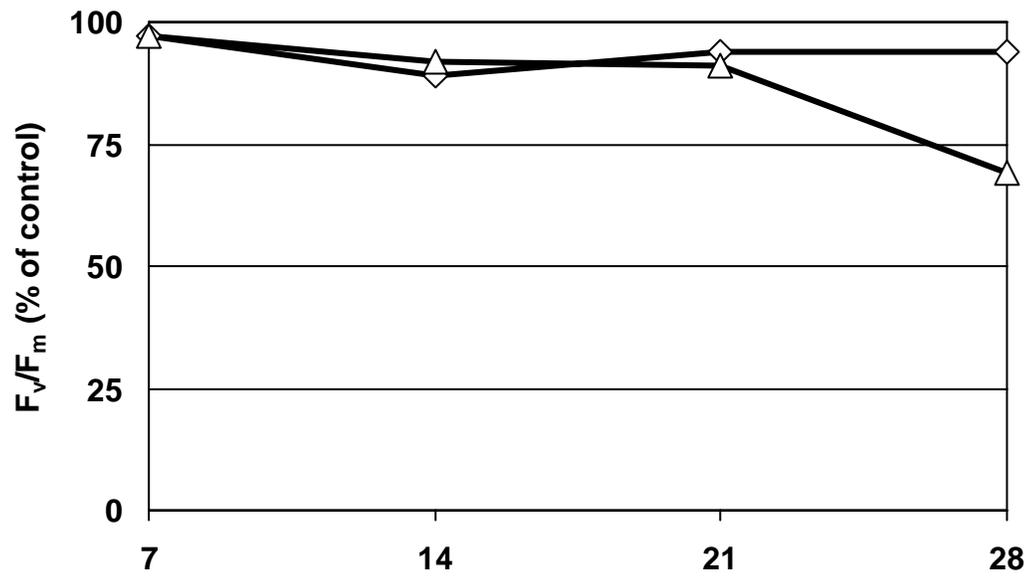


Efficiency of photochemical activity of PS II, measured by the ratio of F_v/F_m , of Cynthiana and Pinot noir was not altered by 20/15 °C after 28 days of exposure, except for a 9% reduction in Pinot noir at 21 days (Fig. 2A). An increase in F_0 for Cynthiana (Fig. 1B) after 21 days of exposure to 30/25 °C coincided with a decrease in F_v/F_m (Fig. 2B). At 28 days of exposure to 30/25 °C, F_v/F_m of Pinot noir was 36% higher than that of Cynthiana. As the temperature increased to 40/35 °C, Cynthiana

F_v/F_m was significantly reduced compared with that of Pinot noir (Fig. 2C). The F_v/F_m of Pinot noir was constant up to 21 days of exposure to high temperature, although 8% reduction was observed at 28 days compared with 360% reduction in Cynthiana. These results indicate that F_v/F_m was the most reliable fluorescence indicator of PSII photochemical efficiency for leaves produced under different growth conditions.

Figure 2. Photosystem II efficiency (F_v/F_m) of Pinot noir and Cynthiana as affected by three temperatures.

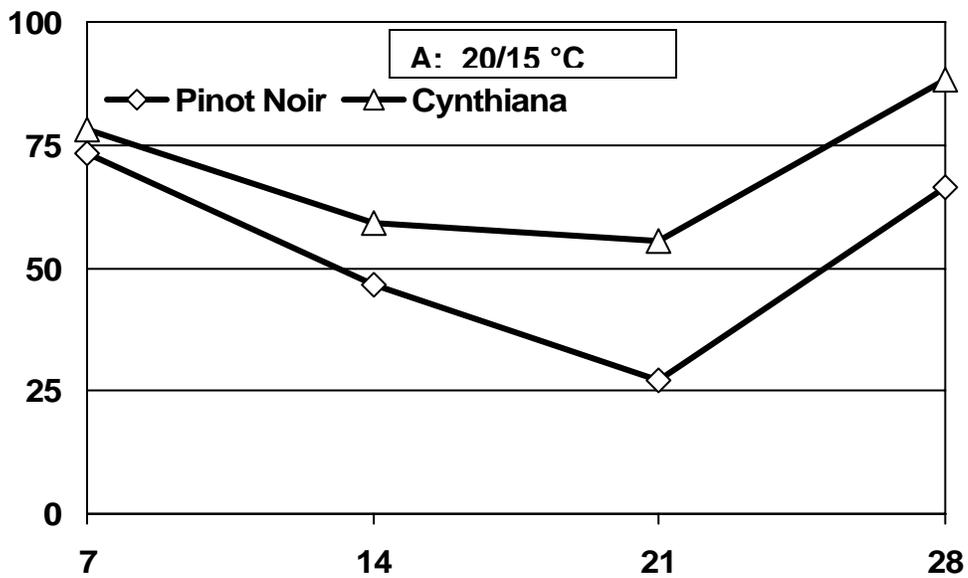


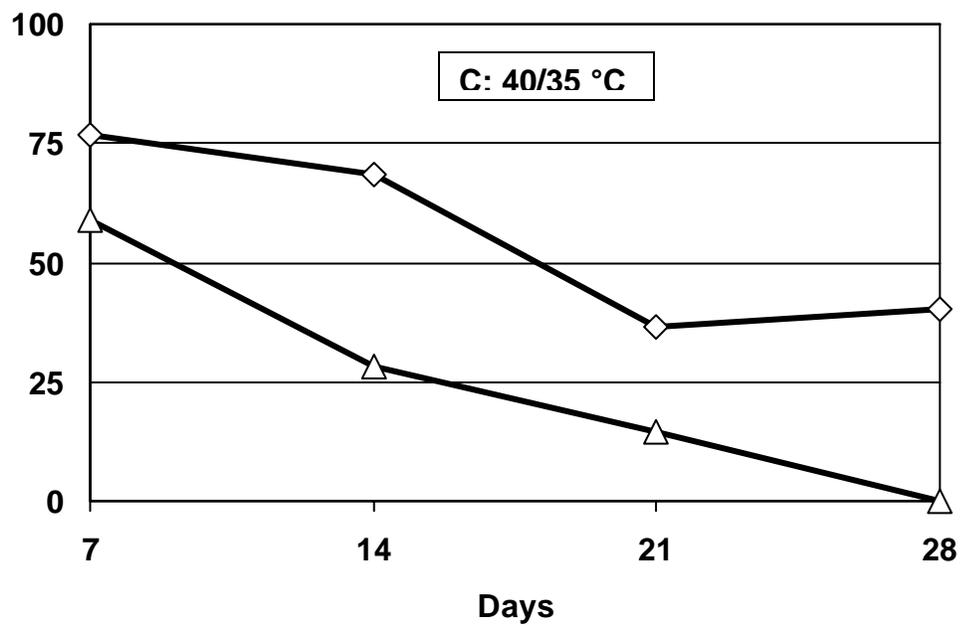
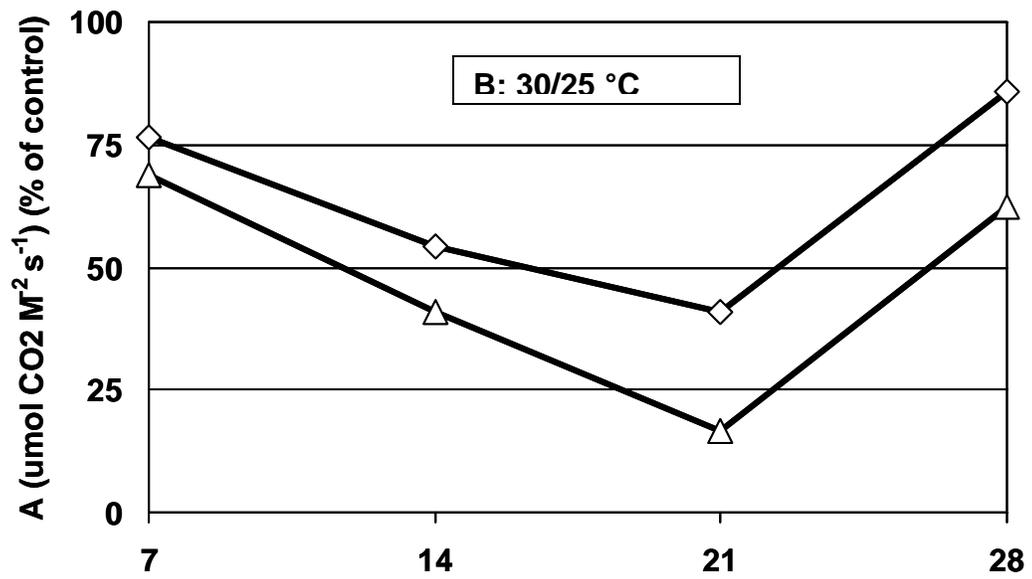


The photosynthetic rate (A) of both cultivars was significantly affected by temperature treatments (Fig. 3A). Twenty-eight days after treatments, Cynthiana had the highest rate at 20/15 °C, whereas Pinot noir highest rate was at 30/25 °C (Fig. 3B). As the temperature

increased to 40/35 °C, a continuous reduction in photosynthesis was detected in Cynthiana to a zero level at 28 days of exposure (Fig. 3C), while Pinot noir photosynthetic rate was reduced by 48% of the rate at seven days of exposure.

Figure 3. Photosynthetic rate (A) of Pinot noir and Cynthiana as affected by three temperatures.





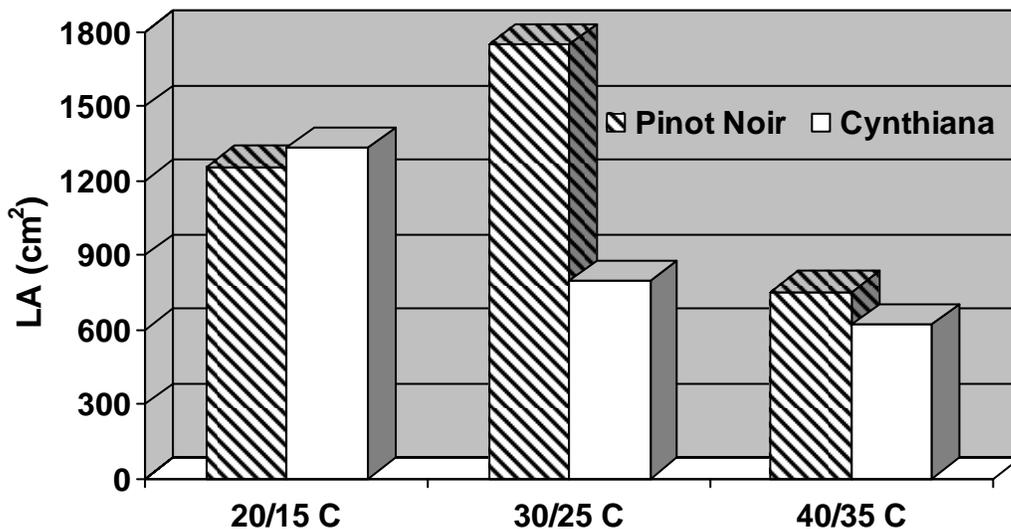
Photosynthesis is closely related to plant growth and development. Therefore, low plant biomass is attributed to a low photosynthetic rate and damage to the photosystem II under heat stress. There was significant difference in total leaf area (LA) between the two cultivars in response to temperature treatments (Fig. 4A). At 20/15 °C, LA of Cynthiana was the greatest compared to the other two temperatures, but was not significantly different from LA of Pinot noir. As the temperature increased to 30/25 °C, LA of Pinot noir was the greatest compared to the low and high temperatures, and was significantly greater than that of Cynthiana. Leaf area of Cynthiana was reduced by 67% compared to that of 20/15 °C. At the highest temperature (40/35 °C), both cultivars showed significant reduction in LA.

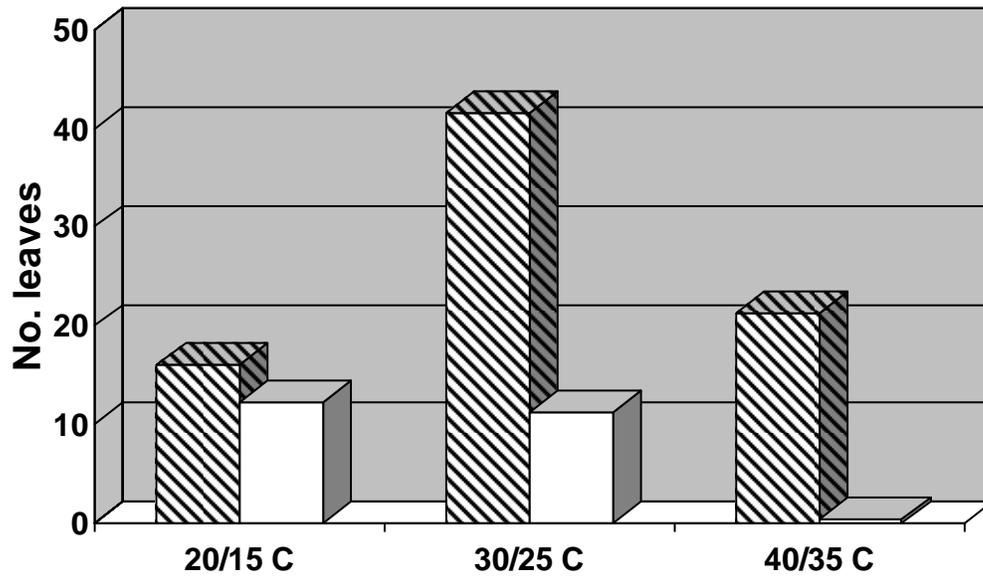
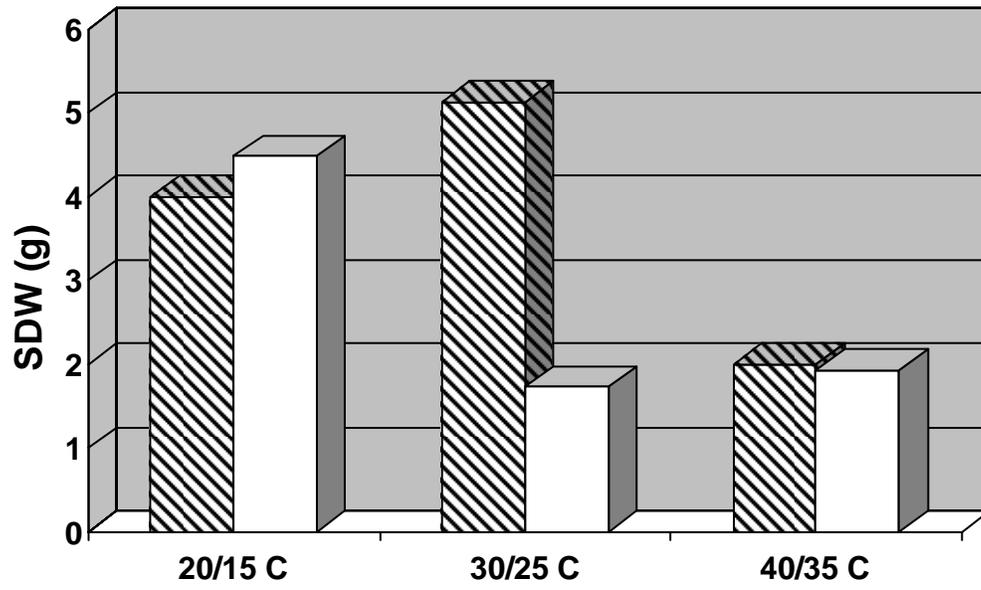
The response of shoot biomass of both cultivars (Fig. 4B) was similar to the response of LA to temperature treatments (Fig. 4A). Shoot growth of Cynthiana and Pinot noir was the highest at 20/15 and 30/25 °C, respectively.

As the temperature increased to 40/35 °C, there was 156% and 131% reduction in shoot biomass of Pinot noir and Cynthiana, respectively, compared with the highest shoot biomass of each cultivar. No significant difference was observed between the two cultivars at 40/35 °C.

The number of leaves at the medium and high temperatures was significantly different between the two cultivars (Fig. 4C). As the temperature increased from 20/15 to 30/25 °C, number of leaves for Pinot noir was 269% higher than that for Cynthiana. Leaf development was significantly reduced by 40/35 °C in both cultivars, although Pinot noir leaf development was 40 folds higher than that of Cynthiana. The 40/35 °C was detrimental to leaf growth in Cynthiana, as leaf development was almost non-existent at these temperatures. Cynthiana leaves were more susceptible to high temperature than the shoots. Leaves of Cynthiana at 40/35 °C senesced earlier than the shoots, turning brown and falling off, leaving bare shoots.

Figure 4. Leaf area (LA), shoot biomass (SDW), and number of leaves of Pinot noir and Cynthiana as affected by three temperatures 28 days after exposure.





Conclusions

- The optimum temperatures for photosynthetic rate, initial chlorophyll fluorescence (F_0), photosystem II efficiency (F_v/F_m), and vine growth were 20/15 °C for the American cultivar, Cynthiana, and 30/25 °C for the European cultivar, Pinot noir.
- Pinot noir was more heat resistant than Cynthiana.
- Four weeks of 40/35 °C exposure were more detrimental to the leaves of Cynthiana than to the shoots.

Literature Cited

Al-Khatib, K. and G.M. Paulsen. 1989. Enhancement of thermal injury to photosynthesis in wheat plants and thylakoids by high light intensity. *Plant Physiol.* 90:1041-1048.

Bergqvist, J., N. Dokoozlian, and N. Ebisuda. 2001. Sunlight exposure and temperature effect on berry growth and composition of Cabernet Sauvignon and Grenache in the Central San Joaquin Valley of California. *Amer. J. Enol. Vitic.* 52:1-7.

Björkman, B.T. 1980. Photosynthetic response and adaptation to temperature in higher plants. *Ann. Rev. Plant Physiol.* 31:491-543.

Chaumont, M., M.L. Osorio, M.M. Chaves, H. Vanacker, J.F. Morot-Gaudry, J. Francois, and C.H. Foyer. 1997. The absence of photoinhibition during the mid-morning depression and photosynthesis in *Vitis vinifera* grown in semi-arid and temperate climates. *J. Plant Physiol.* 150:743-751.

Ferrini, F., G.B. Mattii, and F.P. Nicese. 1995. Effect of temperature on key physiological responses of grapevine leaf. *Amer. J. Enol. Vitic.* 46:375-379.

Matsui, S., K. Ryugo, and W.M. Kliewer. 1986. Inhibition of Napa Gamay and Thompson seedless berry development by heat stress and its partial reversibility by applications of gibberelic acid and Promalin. *Acta Hort.* 179:425-426.

Midmore, D.J., P.M. Cartwright, and R.A. Rischer. 1984. Wheat in tropical environments. II. Crop growth and grain yield. *Field Crop Res.* 8:207-227.

Schueneman, T. 1982. The grape in Kansas: Poised for a winegrowing comeback? *J. Vinifera Wine Growers* 6:225-234.

Shiraishi, S.I., T.C. Hsiung, M. Shiraishi, and M. Kitazaki. 1996. Effects of temperature on the photosynthesis rate of grape cultivars. *Science Bulletin of Faculty Agri. Kyushu Univ.* 51:9-16.

Rootstock Effects on Sunbelt Productivity and Fruit Composition

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Abstract

Sunbelt is a Concord-type juice grape suitable for warm climates. Initial reports indicated that yields for Sunbelt were in the 2.5- to 5- ton range. This is somewhat low for production on a commercial scale. An experiment was initiated to examine the potential for rootstocks to increase vine capacity and yield of Sunbelt grapes. Treatments included own-rooted Sunbelt and Sunbelt grafted onto Couderc 3309, 1103 Paulsen and Extra rootstocks. Data were collected for two years on a bilateral cordon (BC) training system and then vines were converted to a Geneva Double Curtain (GDC) training system, and an additional two years of data were collected. Vines on BC were severely out of balance (low yields and high pruning weights) but were better balanced on GDC. There were few statistically significant differences in either yield or fruit composition among rootstocks when vines were grown on either BC or GDC. Yields in the second year on each training system and among rootstocks were 3.6 to 6.1 tons/acre on BC and 10 to 12.9 tons/acre on GDC. In this short term study Sunbelt produced adequate yields when grown on its own roots with proper canopy management. Use of rootstocks did not consistently increase yield.

Introduction

The Arkansas Agricultural Experiment Station released the juice grape cultivar, Sunbelt (*Vitis*

labruscana Bailey) in 1993 (Moore *et al.* 1993). Sunbelt fulfills the need for a processing grape that can be grown in hot areas where Concord grapes display uneven fruit ripening associated with high temperatures (Cawthon and Morris 1984). Sunbelt is similar to Concord in most plant and fruit characteristics, differing primarily in its ability to ripen evenly under high temperatures. Clusters are small; berries are blue, large, and seeded. Soluble solids concentration and harvest date correspond closely with those of Concord when compared under hot climatic conditions. However, the color, acidity, and pH of Sunbelt are superior to Concord for juice production under these conditions. Yield of Sunbelt grapes was low (2.5 to 5 tons/acre) in initial testing (Moore *et al.* 1993). Higher yields are desirable for commercially grown juice or wine grapes.

The use of rootstocks is increasing in eastern and mid-western US viticultural districts. The primary use of rootstocks is for pest resistance (Howell 1987). However rootstocks also influence vegetative growth, yield, and fruit composition (Main *et al.* 2002, May 1994).

The objective of this research was to examine the potential of Sunbelt, grafted to rootstocks representative of native eastern United States grape species, to increase vine capacity and yield without negative impact on fruit composition.

Materials and Methods

Three rootstocks and own-rooted vines were evaluated in this study: Couderc 3309 [3309C] (*V. riparia* tomentose x *V. rupestris*), Paulsen 1103 [1103P] (*V. berlandieri* Reseguier No. 2 x *V. rupestris* du Lot), Extra (*V. lincecumii* Big Berry) x (*V. labrusca* x *V. vinifera* (Triumph)). Extra is a vigorous T.V. Munson hybrid that grows well in south Texas (Munson 1909). Sunbelt scion wood was grafted in the spring of 1997 to 1103P, 3309C and Extra by Sunridge® Nurseries Inc., Bakersfield, CA. These vines and own-rooted vines were planted at the Arkansas Agricultural Research and Extension Center, Fayetteville, AR, as one-year-old dormant vines in April 1998. Soil classification was a Captina silt loam (fine-silty, mixed, mesic Typic Fragiudults) at pH 6.8. The soil had been in grapes for many years and soil amendments were used to increase pH in the past but were not applied during this study. Three replications of four-vine plots were established on a high wire bilateral cordon (BC) training system. The BC training system was converted to a Geneva Double Curtain (GDC) system in 2002 due to low yields and excessive vine growth. Cordon height was 6 ft, and vine spacing was 6 ft x 10 ft with north-south orientation. The GDC system had a four-foot separation between canopies, was shoot positioned two times per year, and was drip irrigated. Vines were balance pruned to a 60 + 10 level (60 buds retained for the first pound of prunings and an additional 10 buds left for each additional pound of dormant prunings removed) on 5-node canes with a 100 bud maximum. Data were collected on the BC system during the 2000 and 2001 seasons and on the GDC system during the 2003 and 2004 seasons.

Cluster weight and yield were determined by counting clusters and harvesting individual vines. Yield (tons/acre) was extrapolated based on fruit weight x the number of vines/acre

given the vine and row spacing. Dormant pruning weights were taken, and the Ravaz index (lbs. fruit/lbs. dormant cane prunings) was calculated (Bravdo *et al.* 1984). The Ravaz index is an indication of vine balance: a value of 5 to 10 for *V. vinifera* cultivars indicates the vine is balanced, a value greater than 12 indicates over cropping, while a value less than 3 indicates excessive vine size (Smart and Robinson 1991).

Fruit composition (percentage soluble solids, pH, titratable acidity, berry weight) was determined from four-cluster samples in 2000 and 2001 and from 150-berry samples in 2003 and 2004. For berry size, frozen berries were removed from the rachis and weighed in 2000 and 2001. In 2003 and 2004, 100 berries were randomly collected from each four-vine plot, frozen and weighed to determine berry weight. For compositional analyses, berries were thawed overnight at 70°F. The grapes were pureed for 10 sec in a blender at low speed. The puree was placed in a 250-mL beaker, covered with a watch glass, and heated in a water bath (185°F) until the samples reached 160°F. One hundred fifty mL of juice was collected to which 100 µL of Scottzyme Pec 5L (Scott Laboratories, Petaluma, CA), a pectolytic enzyme, was added. Hot puree was squeezed through 2 layers of grade 60 cheesecloth. The hot-pressed juice was cooled to room temperature (70°F) prior to centrifugation for 10 min at 13,250 rcf. This hot-press method extracts color, acids, and minerals from the skin. Standard methods for juice analysis were then followed (Zoecklein *et al.* 1995). Percentage soluble solids were measured using a refractometer. Total red color is an indication of anthocyanin content and is a measurement of juice diluted with 1M HCL at 520 nm. Potassium was determined using a Spectro Model D ICP (Spectro Analytical Instruments, Inc. Fitchburg, MA).

Analysis of variance was done with SAS/STAT software (version 8.01 SAS Institute Inc., Cary, NC) using the PROC ANOVA procedure. Means within year were separated by Least Significant Difference at $p \leq 0.05$.

Results

Fruit harvest dates were Aug. 23, 2000, Aug. 28, 2001, Sept. 13, 2003 and Aug. 19, 2004. Percentage soluble solids of Sunbelt grapes will easily reach 18 to 19% in Arkansas. In this study, vines from all rootstock/scion combinations were picked at the same time at a minimum of 16% soluble solids. It should be noted that 2000 was an unusually stressful period for the vines. In 2000, there was an abnormally warm veraison period with 12 days of 96°F or higher prior to harvest, followed by another 12 days post harvest of 96°F or higher that included 9 days above 100°F. This was followed by an early killing freeze that occurred while the vines were actively growing.

Yield

Bilateral Cordon. In 2000, the young vines were in their third leaf, and no differences were seen among treatments for cluster weight, berries per cluster, or yield (Table 1). The vines on 1103P and 3309C rootstock had more clusters per vine than own-rooted vines. The early-freeze in 2000 resulted in unripened periderm and low pruning weights that did not reflect observed vine growth. Therefore, the pruning weight and Ravaz index data are not shown for 2000.

In 2001, differences in yield were observed among treatments on the BC system. Fruit yields from vines on Extra and 1103P rootstocks were lower than own-rooted and vines grafted on 3309C. Own-rooted vines and vines grafted on 3309C had more clusters per vine than other treatments. There were no

differences in pruning weights or Ravaz indices among treatments.

The BC system with 6-ft row spacing did not seem appropriate for this grape due to a high level of vegetative growth. Shoots extended onto the ground between rows where they were trimmed by regular mowing. Actual pruning weights could have been higher than stated. The vines were out of balance on the BC system as indicated by Ravaz indices of 3.3 and lower. Leaving more buds per vine might have increased fruit yields and decreased vegetative growth. However, due to the close in-row-spacing the vines were converted to a GDC system in 2002.

Geneva Double Curtain. Newly trained cordons on GDC resulted in an unusually high bud number and subsequently a high number of clusters per vine and high yield in 2003 (Table 1). The rootstock Extra yielded a lower number of clusters per vine, lower cluster weight and fewer berries per cluster than 3309C. There were no differences in berry weights among treatments. Yield was lower from vines grafted on Extra rootstock than other treatments and vines grafted on 3309C had the highest yield. Pruning weights on GDC were much lower than on BC. Own-rooted vines had a lower pruning weight than vines grafted on 1103P rootstock at a similar yield. The high yields and low pruning weight in 2003 resulted in high Ravaz indices that indicated vines were potentially out of balance.

In 2004, the yields were lower and the vines were in better balance (Table 1). There were no differences among rootstock treatments for clusters per vine, cluster weight, berries per cluster, berry weight, or yield. Yield ranged from 10 to 12.9 tons/acre, which is substantially higher than the 3.5- to 6.1-tons/acre range for the second year of the BC training system. In a California experiment on Sunbelt grapes grafted to Chenin blanc vines

and trained to a GDC training system, average yields of 12 and 9.6 tons/acre were obtained in a two-year study (Striegler *et al.* 2002). Pruning weight was higher on vines grafted to 1103P than own-rooted vines just as it was in 2003. The mean Ravaz index was in the 9 to 13 range, which indicates the vines were in better balance in 2004.

Vines grafted on Extra rootstock produced numerically and/or statistically lower fruit yield on both BC and GDC as compared to own-rooted vines. There was a numerically higher yield from the vines grafted on 3309C vines as compared to yield from own-rooted vines on both the BC and GDC training systems. However, the difference was only statistically significant in 2003.

Fruit Composition

Bilateral Cordon. In 2000, there were some differences in fruit composition among rootstock treatments (Table 2). Even with high daytime temperatures in 2000, Sunbelt had excellent values for soluble solids, pH, titratable acidity, and color. Similar results were seen for Sunbelt grapes grown in the hot San Joaquin Valley of California (Striegler *et al.* 2002). In 2001, soluble solids were higher for fruit grown on 3309C vines than for own-rooted vines at an equivalent yield.

Geneva Double Curtain. In 2003, there were few differences in fruit composition among rootstock treatments. All treatments achieved at least 16% soluble solids at the same date even with the high yields shown in Table 1. In 2004, there were again few differences in fruit composition among rootstock treatments. Titratable acidity was lowest for vines grafted on 3309C rootstock. There appeared to be a tendency toward a slightly lower titratable acidity for 3309C rootstock as compared to the other treatments when viewed over all years. Potassium content was lower in juice from

vines on 3309C and Extra rootstocks than for own-rooted vines or vines grafted to 1103P rootstock. It is interesting to note the decline in juice potassium values over the years. This plot had high soil potassium values, so fertilization consisted primarily of nitrogen and magnesium addition each year.

Conclusions

This experiment examined the response of Sunbelt grapevines to grafting on three rootstocks over a four-year period. Excessive vine size and low yield in the 2000 and 2001 seasons indicated that the vines were not in balance on the BC training system. Doubling the canopy area by converting to GDC brought vines to a commercially acceptable 10 to 12.9 tons/acre among all treatments in 2004 while still producing adequate pruning weights and good fruit composition. Since the BC training system did not have proper vine balance, for treatment comparisons, it is important to focus on results from the 2004 season when vines were trained to the GDC system. Statistically significant differences between treatments were seldom observed. Performance of vines grafted on 3309C and 1103P was generally equivalent to the performance of own-rooted vines. Therefore, unless there are mitigating factors, such as soil pests, the use of a rootstock does not appear necessary for Sunbelt grapes.

References Cited

- Bravdo, B., Y. Hepner, C. Loinger, S. Chohen, and H. Tabacaman. 1984. Effect of crop level and crop load on growth, yield, must and wine composition, and quality of Cabernet Sauvignon. *Am. J. Enol. Vitic.* 36:125-131.
- Cawthon, D.L. and J.R. Morris, 1983. Uneven ripening of 'Concord' grapes. *Ark. Farm Res.* 32(1):9.

- Main, G., J. Morris, and K. Striegler. 2002. Rootstock effects on Chardonnay productivity, fruit, and wine composition. *Am. J. Enol. Vitic.* 53:37-40.
- May, P. 1994. Using Grapevine Rootstocks: The Australian Perspective. p. 62. *Winetitles*, Adelaide.
- Moore, J.N., J.R. Morris, and J.R. Clark. 1993. 'Sunbelt', A new juice grape for the South-central United States. *HortScience*. 28(8):859-860.
- Munson, T.V. 1909. Foundations of American Grape Culture, pp. 252, T.V. Munson and Son, Denison, TX, Reprinted 1975, The Denison Public Library, Denison, TX.
- Smart, R. and M. Robinson. 1991. Sunlight into Wine: A Handbook of Winegrape Canopy Management, p. 88. *Winetitles*, Adelaide.
- Howell, G.S. Vitis rootstocks. In *Rootstocks for Fruit Crops*. R.C. Rom and R.F. Carlson. (Eds.), pp. 451-474. Wiley and Sons, New York (1987).
- Striegler, R.K., J.R. Morris, R.T. Threlfall, G.L. Main, C.B. Lake, and S.G. Graves. 2002. Effect of minimal input systems on yield and juice quality of 'Sunbelt' grapes grown in the San Joaquin Valley of California. *HortScience*. 37(6) 867-870.
- Zoecklein, B.W., K.C. Fugelsang, B.H. Gump, and F.S. Nury. 1995. *Wine Analysis and Production*. Chapman & Hall, New York.

Table 1. Effect of rootstock on yield parameters of Sunbelt grapes grown on bilateral cordon and Geneva Double Curtain training systems.

Year and rootstock	Clusters per vine	Cluster weight (g)	Berries per cluster	Berry weight (g)	Yield (tons/acre)	Pruning weight (lbs/vine)	Ravaz index
Bilateral Cordon							
2000							
Own	43 c ^a	105 a	27 a	3.9 a	3.6 a	. ^b	. ^b
Extra	49 bc	80 a	21 a	3.9 a	3.2 a	.	.
1103P	58 ab	85 a	23 a	3.7 a	3.9 a	.	.
3309C	70 a	85 a	22 a	3.9 a	4.8 a	.	.
2001							
Own	61 a	114 a	23 a	5.0 a	5.5 a	4.7 a	3.3 a
Extra	48 b	97 ab	19 a	5.2 a	3.6 b	5.9 a	1.9 a
1103P	49 b	91 b	19 a	4.9 a	3.6 b	5.3 a	1.9 a
3309C	72 a	106 ab	23 a	4.6 b	6.1 a	5.3 a	3.3 a
Geneva Double Curtain							
2003							
Own	174 ab	123 a	28 a	4.5 a	17.1 b	1.6 b	29.9 ab
Extra	153 b	106 b	23 b	4.7 a	13.0 c	1.8 ab	22.4 b
1103P	185 ab	120 a	27 a	4.5 a	17.6 b	2.3 a	21.7 b
3309C	218 a	123 a	27 a	4.6 a	21.3 a	1.9 ab	31.5 a
2004							
Own	104 a	144 a	33 a	4.4 a	12.1 a	2.5 b	13.4 a
Extra	94 a	133 a	29 a	4.6 a	10.0 a	3.3 ab	8.9 b
1103P	112 a	131 a	28 a	4.6 a	11.8 a	3.9 a	9.1 b
3309C	111 a	146 a	31 a	4.7 a	12.9 a	2.8 b	13.0 a

^a Means within column, year and training system with the same letter(s) are not significantly different at $p \leq 0.05$

^b Data not shown for 2000 due to an early freeze that did not allow normal periderm ripening and subsequently gave pruning weights that did not match observed growth.

,mjn

Table 2. Effect of rootstock on juice chemistry and color of Sunbelt grapes grown on bilateral cordon and Geneva Double Curtain training systems.

Year and rootstock	Soluble solids (%)	pH	Titratable acidity (g/L)	Total red color (a.u.)	Potassium (mg/L)
Bilateral Cordon					
2000					
Own	18.4 ab ^a	3.51 a	11.3 a	68 b	2434 a
Extra	18.1 b	3.42 b	10.7 ab	67 b	2518 a
1103P	19.1 a	3.44 b	10.6 ab	72 ab	2913 a
3309C	18.6 ab	3.46 b	9.8 b	80 a	2650 a
2001					
Own	16.3 b	3.61 a	8.4 b	44 a	2542 a
Extra	17.0 ab	3.48 b	8.4 b	47 a	2416 a
1103P	16.3 b	3.49 b	9.4 a	45 a	2563 a
3309C	17.5 a	3.53 ab	8.2 b	53 a	2405 a
Geneva Double Curtain					
2003					
Own	16.8 a	3.44 a	8.3 ab	61 a	2418 a
Extra	16.9 a	3.41 a	8.4 a	56 a	2339 a
1103P	16.8 a	3.42 a	8.5 a	57 a	2351 a
3309C	16.1 a	3.44 a	7.9 b	48 a	2187 a
2004					
Own	16.4 a	3.39 a	11.2 a	71 a	2332 a
Extra	15.9 a	3.36 a	11.0 a	58 a	2161 c
1103P	16.8 a	3.37 a	10.9 a	77 a	2250 b
3309C	15.8 a	3.39 a	10.0 b	60 a	2095 c

^a Means within column, year and training system with the same letter(s) are not significantly different at $p \leq 0.05$.

Effect of Rootstock on Fruit Composition, Yield, Growth, and Vine Nutritional Status of Cabernet franc

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Abstract

An experiment was designed to evaluate the impact of selected rootstocks on fruit composition, yield, vegetative growth, and vine nutritional status of Cabernet franc grapevines in the Altus viticultural area. This experiment shows results for three seasons (2000-2002) in a commercial vineyard near Altus, Arkansas. Cabernet franc vines grafted onto 3309 Couderc (control), 110 Richter, Freedom, and 44-53 Malègue rootstocks were planted in 1998. The trellis system was a four-arm Kniffen, and the vineyard was not irrigated. Few statistically significant differences between rootstocks were observed for yield, fruit composition, or nutritional status. Vines grafted onto 3309 Couderc rootstock sustained winter injury in 2000/2001 likely due to severe water deficit at veraison. Vegetative growth, as indicated by dormant pruning weight, was greatest for vines grafted onto 110R and Freedom. Fruit from vines grafted to Freedom had higher pH as compared to fruit from the other treatments. Vegetative growth and field observations suggest that vines grafted onto Freedom might benefit from conversion to a divided canopy due to increased vine size.

Introduction

The use of rootstocks is increasing in the eastern and midwestern United States. The primary use of rootstocks is for pest resistance (Hardie and Cirami 1988; Howell 1987). However, rootstocks also influence yield, vegetative growth, and fruit and wine composition (Main et al. 2002; May 1994; Rühl, 1989). The use of rootstocks in Arkansas for wine grapes is not well documented. The Altus Viticultural area is located in the Ozark Mountain viticultural area where the climate is variable with about 265 frost-free days. Rainfall is generally adequate with some drought years. Historically, grapes in this area have not been irrigated. Phylloxera is present, and rootstocks are recommended for *Vitis vinifera* cultivars. The history of this grape-growing area dates to the 1870s, but *V. vinifera* grapes are relatively new, and interest in growing hardy cultivars of this species has blossomed.

The objectives of this experiment were to evaluate the impact of selected rootstocks on fruit composition, yield, vegetative growth, and vine nutritional status of Cabernet franc grapevines grown in the Altus viticultural area.

Materials and Methods

The experiment was established at Post Familie Vineyards near Altus, AR. Cabernet franc vines were bench grafted (Sonoma Grapevines, Inc. acquired by Vintage Nurseries, Wasco, CA) and planted in 1998 as two-year old vines. The vines were spaced 2.13 m x 3.35 m (vine x row), and the row orientation was east/west. The trellis system was four-arm Kniffen and the vines were not irrigated. The soil type is Linkers fine sandy loam with a pH of 6.2. Vines were trained to retain four (12-16 node) canes and 2-4 renewal spurs. Rootstocks used included a range of *Vitis* species (Pongracz, 1983). They were Couderc 3309 [*V. riparia* x *V. rupestris*; (3309C)], Richter 110 [*V. berlandieri* x *V. rupestris*; 110R], 44-53 Malègue [*V. riparia* x (*V. cordifolia* x *V. rupestris*); (44-53M)], and Freedom [seedling of 1613C by seedling of Dog Ridge]. The rootstock 3309C is the most often recommended rootstock for use in the eastern United States (Wolf and Poling 1995) and is the control treatment for this experiment. Data compiled by Howell (1987) list resistance to stress factors on a 1 to 5 scale with 5 being most resistant. The ratings corresponding to rootstocks used in this experiment were: 3309C - 1, 4,1; 110R - 4,4,2; 44-53M - 2,4,4; and Freedom - 2,2,4 respectively for drought, phylloxera, and nematode resistance.

Temperature and rainfall data are reported from the University of Arkansas Fruit Substation near Clarksville, AR. This location is the closest recordings station to the experimental site with similar elevation and consistent collection of weather data.

Fruit composition (percentage soluble solids, pH, titratable acidity, berry weight) was determined at harvest from a non-frozen three-basal cluster sample. In 2002, fruit color and

organic acids were measured on previously frozen fruit that had been heated. Petiole samples were collected from the most recently mature leaf at veraison. Yield components and pruning weight were collected for each vine. A 100-berry sample was taken from random positions on basal clusters at harvest to determine berry weight. Cluster weights were determined from cluster count per vine divided by yield per vine. Nutrient levels in petioles were measured using a Spectro Cirros inductively coupled plasma spectrometer (Spectro Analytical Instruments, Fitchburg, MA). Standard methods for juice composition measurement were used unless otherwise noted (Zoecklein et al. 1995).

Color measurements in 2002 were made on hot-pressed juice. Polyethylene bags containing 150 g of frozen grapes were placed at room temperature (25°C) for 18 hr. The grapes were placed in an 8 oz (350 mL) blender cup and blended (Galaxie, Osterizer) for five sec on the lowest speed (did not break the seeds), poured into a 250-mL beaker, and covered with a watch glass. The beakers were placed in a hot water bath set at 81°C. Samples were stirred and temperatures were monitored. When samples reached 71°C, beakers were removed from the water bath. A 125-ml sample was then squeezed through cheesecloth. After the samples cooled to room temperature, 45 mL of the juice was centrifuged at 13,250 rcf for 15 min, decanted, and used for analysis.

Color was measured using a Colorgard system / 05 with transmission accessory (BYK Gardner, Columbia, MD) and a Helios Beta UV-VIS spectrophotometer (Thermo Electron Corporation, Waltham, MA). The Colorgard system was standardized with deionized water for Commission Internationale de l'Eclairage (CIE) Lab transmission values of 'L' = 100, 'a' = 0, and 'b' = 0. Absorbance was read on the spectrophotometer at 280 nm and 520 nm to

measure total phenolics and total red pigment color respectively, using a known level of sample diluted with hydrochloric acid. Hot-pressed juice was also used for measurement of organic acids (L (+) tartaric acid, L (-) malic acid, and L (+) lactic acid), sugars (D (+) glucose and D (-) fructose) using the (HPLC) method described by Walker et al. (2003).

Data were analyzed by analysis of variance using the SAS statistical software (version 8.2; SAS Institute, Cary, NC). Least significant difference was used to separate means within year and Duncan's multiple range test was used to separate three-year means. Both tests were at $p \leq 0.05$.

Results

Fruit Composition

Choice of rootstock had little effect on fruit composition (Table 1). Fruit was harvested in 2000 at low soluble solids due to vines being subjected to high temperatures and water deficit. There was little to no difference due to rootstock for soluble solids or acidity among years, or for the three-year mean. Freedom had a higher pH than the other rootstocks for the three-year mean.

Yield components

Differences in yield between rootstock treatments were observed in the 2000 and 2002 seasons (Table 1). However, the differences were not consistent and therefore, the three year mean yield did not differ significantly. In 2000, 3309C had reduced yield compared to 110R and 44-53M. In 2001, there were no differences in yield, while in 2002 Freedom had higher yield than 44-53M. There were no differences in pruning weights in the initial year, but in 2001 and 2002 and for the three-year mean, Freedom had greater pruning weights and 44-53M had lower pruning

weights than the other rootstocks. Vines grafted on 3309C rootstock displayed a 22% mortality rate in 2001 as compared to zero mortality for vines grafted on the other rootstocks.

The Ravaz index (yield per vine/pruning weight per vine) (Ravaz 1903) is an indication of vine balance: a value of 5 to 10 indicates the vine is balanced, a value greater than 12 indicates over cropping, while a value less than 3 indicates excessive vine size (Smart and Robinson 1991). Using these criteria, all of the rootstocks produced vines in an acceptable range of balance for the three-year mean. Freedom had a lower Ravaz index each year, averaging 5.4.

Components of yield were impacted somewhat by choice of rootstock (Table 1). Vines grafted on 110R rootstock had more clusters than vines grafted onto Freedom rootstock (three year mean data). Cluster weight was highest for vines grafted on Freedom. Vines grafted on Freedom rootstock had larger berries than vines grafted on 110R or 44-53m. The number of berries per cluster was not affected by rootstock treatment.

Mineral Nutrition

Data for veraison petiole nutrient content are shown in Table 2. These data were collected in 2001 and 2002. Few differences were found between rootstock treatments within individual years. However, the two year mean data indicate that nitrogen was higher for vines grafted on 3309C than vines grafted 110R or 44-53M. The phosphorus content of petioles was highest for vines grafted on 110R rootstock, but overall phosphorus levels appeared to be quite low (Funt et al. 1997). Vines grafted on Freedom rootstock displayed the highest potassium and the lowest manganese content in petioles. Iron content in petioles was lower for vines grafted to 44-53M

than for vines grafted to 3309C or Freedom. The magnesium, boron and zinc content in petioles was not influenced by rootstock choice (data not shown).

Juice color and composition

Hot-pressed juice was made in the final year of the study and color was determined. There were no significant differences in color among rootstock treatments (Table 3). Freedom had a higher total phenolics level than 3309C or 110R. Glucose, fructose, tartaric acid, malic acid and citric acid were measured and no differences were found among rootstocks (Table 4).

Discussion

Temperature and rainfall at the site played a major role in the status of the vines (Figures 1 and 2). Maximum temperatures in 2001 and 2002 were generally below 35°C during veraison. Rainfall was also adequate and evenly distributed in the 30 days prior to harvest with 2002 having twice as much rain as 2001. Rainfall in 2000 was abundant through mid-July creating lush vegetation. This however was followed by 60 days with less than 4 cm of total rainfall and maximum temperatures often above 35°C. Conditions in 2000 were further exacerbated by a record-setting early October freeze. This resulted in winter injury to vines on 3309C causing a 22% mortality rate. There was no mortality for 3309C in the other years of the experiment. The rootstock 3309C is not known for drought resistance but is regarded as being cold hardy (Howell 1987). The unusual conditions of drought and cold injury demonstrates a need for irrigation.

The consistently large vine size (Ravaz Index of 5.4) for Freedom along with field observations indicate that the Freedom vines tended to be overly vigorous for a Four Arm

Kniffen training system. Our data indicate that Cabernet franc vines grown on Freedom rootstock would benefit from conversion to a divided canopy system. Also, under irrigated conditions vegetative growth would have been even greater.

Freedom has been shown to increase juice pH and potassium (Ruhl 1989, Main et al. 2002). In the present study, Freedom had higher pH than 110R or 3309C and higher petiole potassium than any other rootstock. No differences were seen in the petiole potassium or magnesium in 44-53M compared to the other rootstocks. This is in contrast to Boulay (1982), who reported that 44-53 M has a preferential uptake of potassium that can lead to magnesium deficiency. If these vines were grown under irrigation, the results might have been different since irrigation has been shown to increase potassium content (Morris and Cawthon 1982).

The rootstock 3309C was used as a control in this experiment. The rootstocks 110R and 44-53M were most comparable to 3309C being similar in many attributes measured. Freedom had more vegetative growth, higher fruit pH, and higher petiole potassium than 3309C making it less desirable for this training system.

Conclusions

Under the conditions of this study, few differences were observed in Cabernet franc vines grown on different rootstocks. Vines grafted to 3309C sustained winter injury in 2000/2001 likely due to stress from severe water deficit at veraison and throughout the remainder of the growing season in 2000. Freedom had high fruit pH and petiole potassium. Freedom vines also had the highest vegetative growth as indicated by dormant pruning weights. Vine size for this treatment was excessive for a Four Arm Kniffin system,

and vines would likely benefit from conversion to a divided canopy system. Further experimentation is needed to determine the long-term effects of these rootstocks on vine performance. In addition, rootstock evaluation experiments need to be conducted under irrigated conditions in the Altus viticultural district.

Literature Cited

Boulay, H. 1982. Absorption différenciée des cépages et des portegreffes en Languedoc. *Prog. Agric. Vitic.* 99:431-434.

Funt, R.C., M. A. Ellis, and C. Welty. 1997. Tissue analysis for small fruit sampling, cultural values, and fertilizer recommendations. *Midwest Small Fruit Pest Management Handbook. Bulletins 861* The Ohio State University. pp. 166-173.

Hardie, W.J., and R.M. Cirami. 1988. Grapevine rootstocks. *In Viticulture. Vol. 1.* B.G. Coombe and P.R. Dry (Eds.), pp. 154-176. Australian Industrial Publishers, Adelaide.

Howell, G.S. 1987. *Vitis* rootstocks. *In Rootstocks for Fruit Crops.* R.C. Rom and R.F. Carlson. (Eds.), pp. 451-474. Wiley and Sons, New York.

Main, G., J. Morris, and K. Striegler. 2002. Rootstock effects on Chardonnay productivity, fruit and wine composition. *Am. J. Enol. Vitic.* 53:37-40.

May, P. 1994. Using Grapevine Rootstocks: The Australian Perspective. p.62. Winetitles, Adelaide.

Morris, J.R. and D.L. Cawthon. 1982. Effect of irrigation, fruit load, and potassium fertilization on yield, quality, and petiole analysis of Concord (*Vitis labrusca* L.) grapes. *Am. J. Enol. Vitic.* 33:145-148.

Pongracz, D.P. 1983. Rootstocks for Grapevines. 150 pp. David Philip, Cape Town.

Ravaz, L. 1903. Sur la brunissure de la vigne. *C.R. Acad. Sci.* 136:1276-1278.

Ruhl, E.H. 1989. Uptake and distribution of potassium by grapevine rootstocks and its implication for grape juice pH of scion varieties. *Aust. J. Exp. Agric.* 29:707-712.

Smart, R., and M. Robinson. 1991. Sunlight into Wine: A Handbook of Winegrape Canopy Management, pp. 88. Winetitles, Adelaide.

Walker, T., J. Morris, R. Threlfall, and G. Main. 2003. Analysis of wine components in Cynthiana and Syrah wines. *J. Ag. Food Chem.* 51:1543-1547.

Wolf, T.K., and E.B. Poling. 1995. *The Mid-Atlantic Winegrape Growers Guide.* pp. 126. North Carolina State University, North Carolina.

Zoecklein, B.W., K.C. Fugelsang, B.H. Gump, and F.S. Nury. 1995. Wine Analysis and Production. p. 621. Chapman and Hall, New York.

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Table 1. Effect of rootstock on fruit composition and yield components of Cabernet franc grapevines, Altus, Arkansas.

Rootstock	2000	2001	2002	3 yr mean
	Soluble Solids (%)			
3309 Courdec	17.4 a ^a	20.1 a	21.1 a	19.5 a
110 Richter	17.0 a	18.9 b	21.1 a	19.0 a
44-53 Malègue	16.4 a	20.2 a	21.9 a	19.5 a
Freedom	17.7 a	20.3 a	21.1 a	19.7 a
	pH			
3309 Courdec	3.59 a	3.61 b	3.72 a	3.64 b
110 Richter	3.48 a	3.52 c	3.79 a	3.59 b
44-53 Malègue	3.48 a	3.60 b	3.85 a	3.64 b
Freedom	3.59 a	3.69 a	3.85 a	3.71 a
	Titratable acidity (g/L as tartaric acid)			
3309 Courdec	5.84 a	4.60 a	4.29 a	4.91 a
110 Richter	5.91 a	4.91 a	4.33 a	5.05 a
44-53 Malègue	6.03 a	4.76 a	4.21 a	5.00 a
Freedom	6.04 a	4.60 a	4.28 a	4.97 a
	Yield (t/Ha) extrapolated from yield per vine			
3309 Courdec	8.6 b	13.3 a	18.2 ab	13.4 a
110 Richter	11.2 a	13.8 a	18.5 ab	14.5 a
44-53 Malègue	11.4 a	12.8 a	16.1 b	13.4 a
Freedom	9.8 ab	12.4 a	21.3 a	14.5 a
	Pruning weight (kg/vine)			
3309 Courdec	1.33 a	0.70 c	2.11 b	1.38 b
110 Richter	1.39 a	1.09 b	2.11 b	1.53 b
44-53 Malègue	0.99 a	0.64 c	1.59 c	1.07 c
Freedom	1.54 a	1.59 a	2.65 a	1.92 a
	Ravaz Index (yield per vine/pruning weight per vine)			
3309 Courdec	5.1 b	17.0 a	6.2 b	9.4 a
110 Richter	6.4 ab	10.6 ab	6.3 b	7.8 ab
44-53 Malègue	8.4 a	15.6 a	7.3 a	10.5 a
Freedom	4.9 b	5.6 b	5.8 a	5.4 b
	Clusters per vine			
3309 Courdec	93 ab	86 a	75 a	86 ab
110 Richter	113 a	97 a	71 a	98 a
44-53 Malègue	112 a	75 a	67 a	88 ab
Freedom	86 b	72 a	65 a	76 b
	Cluster weight (g)			
3309 Courdec	68.9 a	113.5 a	173.2 a	107.6 b
110 Richter	71.3 a	102.1 a	186.5 a	106.7 b
44-53 Malègue	74.1 a	125.1 a	176.0 a	114.9 b
Freedom	83.7 a	126.8 a	234.6 a	131.1 a
	Berry weight (g)			
3309 Courdec	1.28 a	1.37 ab	1.56 a	1.40 ab
110 Richter	1.34 a	1.23 b	1.56 a	1.38 b
44-53 Malègue	1.29 a	1.35 ab	1.48 a	1.37 b
Freedom	1.44 a	1.50 a	1.57 a	1.50 a
	Berries per cluster			
3309 Courdec	52 a	81 a	111 a	81 a
110 Richter	49 a	75 a	120 a	81 a
44-53 Malègue	57 a	89 a	119 a	88 a
Freedom	57 a	78 a	151 a	96 a

^a Means within column and variable having the same letter(s) are not significantly at $p \leq 0.05$. Note that the mean separation shown for the 3 yr mean assumes that the year x rootstock interaction was not significant.

Table 2. Effect of rootstock on petiole nutrient content of Cabernet franc grapevines, Altus, Arkansas.

Rootstock	<u>2001</u>	<u>2002</u>	<u>2 Year mean</u>
	Nitrogen (%)		
3309 Courdec	1.36 a	1.01 a	1.19 a
110 Richter	1.22 a	0.91 a	1.07 b
44-53 Malègue	1.20 a	0.94 a	1.07 b
Freedom	1.32 a	1.03 a	1.17 ab
	Phosphorous (%)		
3309 Courdec	0.13 ab	0.16 ab	0.15 b
110 Richter	0.19 a	0.23 a	0.21 a
44-53 Malègue	0.09 b	0.10 b	0.10 c
Freedom	0.10 b	0.14 b	0.12 bc
	Potassium (%)		
3309 Courdec	2.01 a	2.08 a	2.05 b
110 Richter	2.05 a	2.10 a	2.08 b
44-53 Malègue	1.96 a	2.12 a	2.04 b
Freedom	2.81 a	2.42 a	2.61 a
	Iron (mg/kg)		
3309 Courdec	44 a	47 a	46 a
110 Richter	37 a	47 a	42 ab
44-53 Malègue	23 a	30 a	26 b
Freedom	23 a	41 a	32 a
	Manganese (mg/kg)		
3309 Courdec	272 a	306 a	289 a
110 Richter	251 a	312 a	281 a
44-53 Malègue	213 a	202 ab	208 ab
Freedom	132 a	83 b	108 b

^a Means within column and variable having the same letter(s) are not significantly different at $p \leq 0.05$. Note that the mean separation shown for the 2 yr mean assumes that the year x rootstock interaction was not significant

Table 3. Effect of rootstock on Cabernet franc juice color^a, Altus, Arkansas, 2002.

Rootstock	Color Difference Meter			Chroma ($a^2 + b^2$) ^{1/2}	Hue Angle (°)	Absorbance @ 520 nm	Hue A ₅₂₀ /A ₄₂₀	Total Phenolics	Total red Pigment
	'L'	'a'	'b'						
3309 Courdec	15.7 a ^b	45.7 a	15.0 a	48.5 a	18.4 a	4.18 a	0.67 a	15.4 b	42.3 a
110 Richter	15.1 a	46.2 a	14.2 a	48.4 a	18.1 a	4.40 a	0.70 a	15.3 b	40.1 a
44-53 Malègue	13.6 a	44.4 a	11.1 a	46.3 a	7.5 a	3.91 a	0.66 a	18.9 ab	54.8 a
Freedom	13.1 a	45.4 a	10.1 a	46.8 a	12.0 a	4.84 a	0.63 a	28.8 a	54.3 a

^a Juice samples derived from hot pressed grapes and adjusted to pH 3.5 before reading on all tests but total phenolics and total red pigment.

^b Means within column having the same letter(s) are not significantly different at p≤0.05.

Table 4. Effect of rootstock on hot pressed Cabernet franc juice sugars and acids, Altus, Arkansas, 2002.

Rootstock	Glucose (g/L)	Fructose (g/L)	Tartaric (g/L)	Malic (g/L)	Citric (g/L)
3309 Courdec	101.5 a ^a	107.1 a	6.72 a	1.02 a	0.22 a
110 Richter	102.2 a	107.8 a	6.81 a	1.27 a	0.22 a
44-53 Malègue	102.6 a	107.4 a	6.63 a	1.26 a	0.21 a
Freedom	106.0 a	110.3 a	6.82 a	1.54 a	0.24 a

^a Means within column having the same letter(s) are not significantly different at p≤0.05.

Table 5. Effect of rootstock on mineral content of Cabernet franc juice, Altus, Arkansas, 2002.

Rootstock	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
3309 Courdec	310.1	4030	140.9	131.0 a ^a	103.7	55.8	10.0	1.8	3.3	1.5
110 Richter	373.8	4537	97.9	131.6 a	98.3	16.3	5.1	1.5	1.2	1.3
44-53 Malègue	311.8	4583	108.0	116.9 ab	95.4	54.3	6.2	0.8	1.1	1.1
Freedom	286.6	4605	103.7	109.2 b	95.2	87.7	5.3	2.3	1.0	0.9

^a Means within column having the same letter(s) are not significantly different at p≤0.05.

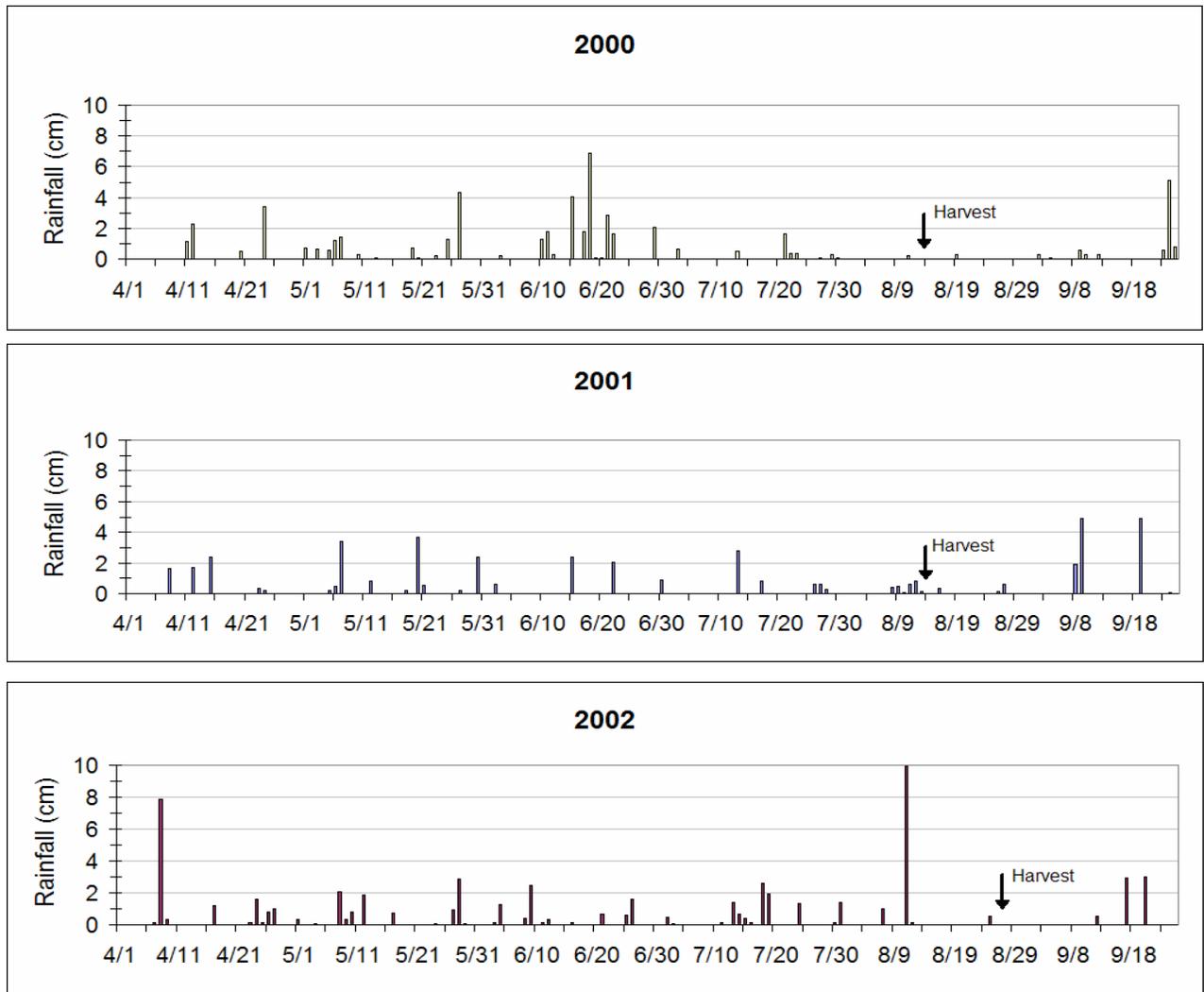


Figure 1. Rainfall during growing season 2000-2002, Arkansas Fruit Experiment Station, Clarksville, AR.

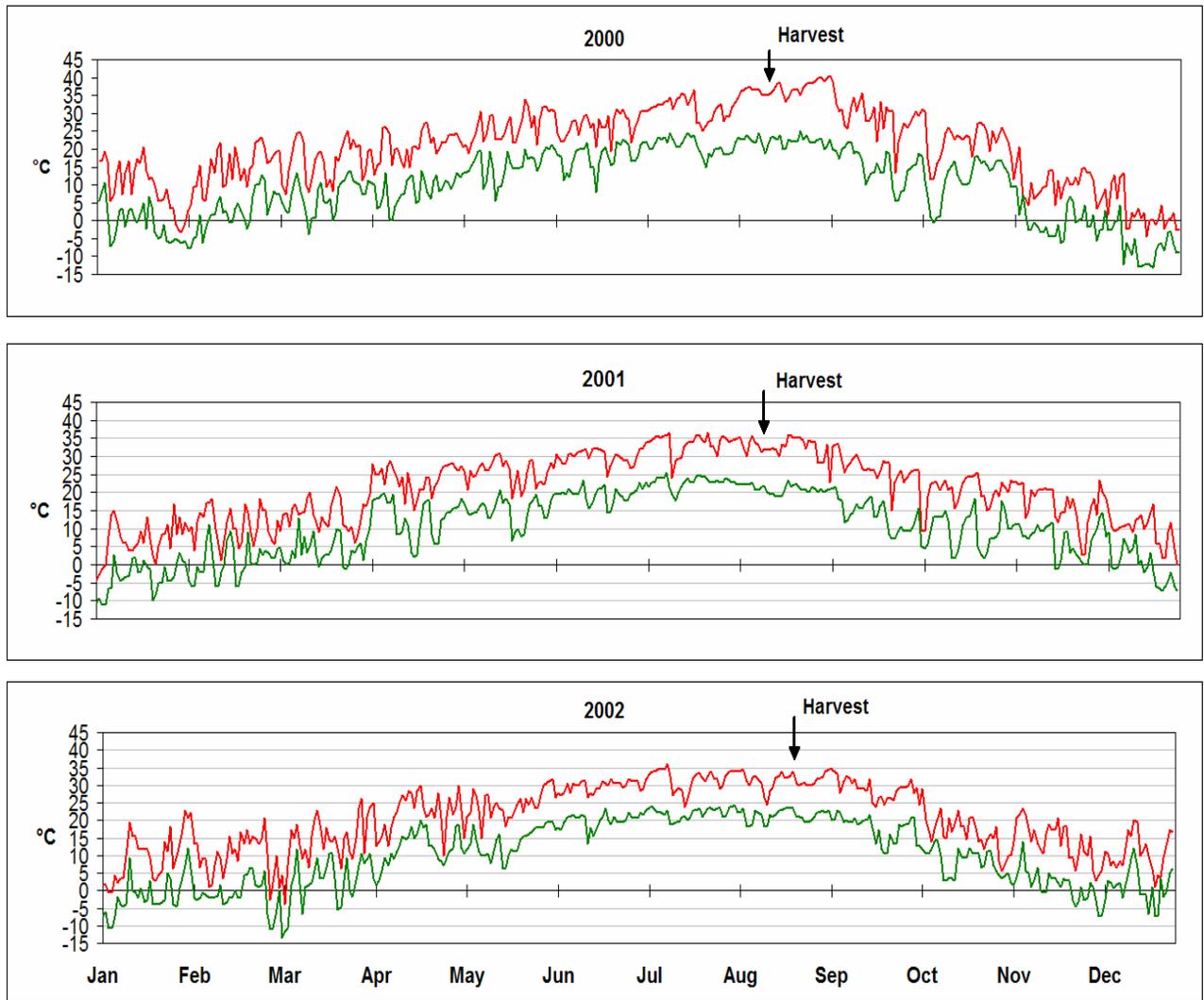


Figure 2. Maximum and minimum temperature during 2000-2002, Arkansas Fruit Experiment Station, Clarksville, AR.

Influence of Rootstock on the Cold Hardiness of Potted Seyval Grapevines during Acclimation and Deacclimation

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Abstract

A potted vine experiment was conducted to determine if grapevine rootstocks can directly influence cold hardiness of scion tissues during acclimation and deacclimation. In this experiment, rootstocks were selected which have been reported to differ in length of vegetative cycle and time of bud burst. Treatments were own-rooted Seyval (Sey/own), and Seyval grafted to Seyval (Sey/Sey), Cynthiana (Sey/Cyn), Riparia Gloire (Sey/RGl), and St. George (Sey/StG). Cold hardiness and water content of primary buds and canes were measured periodically during acclimation and deacclimation.

Rootstock had little effect on cold hardiness or water content during acclimation. However, significant rootstock effects were observed for the deacclimation period. Sey/Cyn canes had greater cold hardiness and lower water content than the other treatments during the deacclimation period. Buds on Sey/Cyn vines responded in a similar manner but to a lesser degree. Percentage shootless nodes was also reduced by use of Cynthiana as a rootstock. Primary buds and canes increased in cold hardiness and decreased in water content during acclimation. An inverse relationship was observed during deacclimation with cold hardiness decreasing and water content increasing as a deacclimation proceeded.

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Introduction

Insufficient cold hardiness is a major factor which limits viticulture in the eastern United States and Canada. The potential for cold injury and resultant economic loss exists each dormant season. Cultural manipulation of vine cold hardiness has previously been reviewed by various authors (Dethier and Shaulis, 1964; Howell, 2001; Pool and Howard, 1984; Shaulis, 1971; Shaulis et al., 1968; Wample et al, 2001). Practices used to minimize cold injury in vineyards can be categorized into those which are done prior to establishment and those which are done after the vineyard is established (Dethier and Shaulis, 1964). The most critical of these are pre-establishment decisions such as site and cultivar selection. When a *Vitis vinifera* L. or less vigorous interspecific hybrid cultivar is chosen, cultivar selection will also involve the selection of an appropriate rootstock.

Rootstocks have received attention as a possible means of increasing grapevine cold hardiness (Hubackova and Hubacek, 1984; Miller et al, 1988a, 1988b; Shamtsyanet, 1984; Striegler and Howell, 1991; Wolf and Pool, 1988). Miller et al. (1998a) compared the cold hardiness of Kober 5BB, Couderc 3309, and Section Oppenheim No. 4 rootstocks for 3 seasons. Differences in bud hardiness were variable and seldom statistically significant. However, consistent and often statistically significant differences between rootstocks in cane cold hardiness were observed. Couderc 3309 canes were more cold resistant than canes from Kober 5BB vines. Selection Oppenheim No. 4 canes were generally intermediate in cold hardiness.

In a subsequent experiment, cold hardiness of White Riesling growing on its own roots and grafted to Kober 5BB, Couderc 3309, and Selection Oppenheim No. 4 was examined (Miller et al, 1998b). Rootstock influenced

scion cold hardiness to a limited extent. Grafted vines had significantly hardier canes in one of three years studied and scions grafted to Couderc 3309 had significantly fewer shootless nodes in one of the four years studied. Other reports have indicated more substantial increases in scion cold hardiness by rootstock (Hubackova and Hubacek, 1984; Pool and Howard 1984; Shamtsyan et al., 1984). Rootstock selection has also been suggested as a means of reducing cold injury to roots in areas of China where soil temperatures reach extremely low levels during winter (Xiu-wu et al., 1987). Differences in root cold hardiness were measured and *V. amurensis* x *V. riparia* hybrids were recommended over the less cold hardy and commonly used Beta rootstock.

In contrast, Shaulis et al. (1968) found that vine cold hardiness was not affected by various rootstocks during a long term study at Geneva, NY. Similar results were obtained when primary bud cold hardiness of Chardonnay grafted to Elvira and Couderc 3309 was measured (Wolf and Pool, 1988). Rootstock did not have a consistent effect on primary bud cold hardiness.

Lack of agreement concerning the influence of rootstock on scion cold hardiness is not surprising considering the complexity of the problem. The design and conduct of rootstock experiments is difficult due to the confounded nature of stock-scion relationships (Howell, 1987). The ability to separate primary effects from secondary effects is crucial for accurate interpretation of results (Striegler and Howell, 1991).

Timing and frequency of sampling are also important in cold hardiness experiments. Cold injury occurs primarily due to intracellular freezing or desiccation stress resulting from extracellular freezing (Burke et al, 1976; Howell, 2001). The type and amount of injury

observed is often related to when the freezing episode occurs during the dormant season. For example, -15 C would cause little injury in the winter when vines are at their maximum hardiness, but could cause considerable injury in the fall before vines become fully hardy or in the spring as vines are losing hardiness. Thus, it is instructive to subdivide the dormant season into three periods which are acclimation, mid-winter, and post-rest/deacclimation (Howell, 2001).

Sampling for cold hardiness in most of the previously reported studies was concentrated in the mid-winter period. The effect of rootstock on cold hardiness of grapevine scion tissues has not been fully investigated during acclimation and deacclimation. Reports of reduced root hydraulic conductance with declining daylength during acclimation (Fennell et al., 1986; Wolpert and Howell, 1986b) and the close association between tissue water content and cold hardiness during acclimation and deacclimation (Jiang and Howell, 2002; Wolpert and Howell, 1984; Wolpert and Howell, 1985a, 1985b; Wolpert and Howell, 1986a) provide a possible mechanism for primary rootstock effects.

Thus, the objective of this study was to determine if rootstock has a direct (primary) effect on cold hardiness of primary buds and canes of Seyval during acclimation and deacclimation.

Materials and Methods

The experiment was conducted at the Horticulture Research Center, East Lansing, MI. Treatments included own-rooted Seyval, and Seyval grafted to Seyval, Cynthiana (*Vitis aestivalis* Michaux), Riparia Gloire (*Vitis riparia* Michaux), and St. George (*Vitis rupestris* Scheele). These rootstocks were selected based on reported differences in length of vegetative cycle and timing of bud

burst (Pongracz, 1983). Riparia Gloire has a short vegetative cycle and early bud burst; St. George has a long vegetative cycle and early bud burst; and Cynthiana has a long vegetative cycle and late bud burst. Sey/RGI vines were only used during the acclimation period due to a shortage of plant material.

Vines were obtained from a commercial nursery and planted into 18.9 L pots using a sterile medium of 50% sandy loam soil, 30% spagnum peat, and 20% sand (by volume) in early June. Potted vines were placed on a flat gravel-covered area and arranged in blocks. Vine spacing was 0.9 m x 0.9 m. A single wire trellis (1.7 m height) was constructed and shoots were trained upward along jute twine which was tied to the wire. Two shoots were allowed to develop per vine. The vines were defruited and lateral shoots removed on a regular basis. Vines were watered as needed (generally twice a week). Soluble 20-20-20 fertilizer was mixed with water and applied to vines on 23 June, 8 July, 23 July, and 30 July. All vines appeared healthy and there were no visible symptoms of nutrient deficiency. Applications of mancozeb, triadimefon, and carbaryl were applied at seven to ten day intervals to control fungal diseases and insects. Weeds around pots were controlled with applications of paraquat and fluazifopbutyl.

Canes were sampled periodically during the acclimation and deacclimation portion of the dormant season. Selection of canes was based on exposure status, cane diameter, and internode length (Howell and Shaulis, 1980). Persistent lateral status was not considered because lateral shoots were removed as part of the training procedure. All canes were well-exposed during the previous growing season and were of medium diameter (7-9 mm) and internode length (5-9 cm).

Tissue Maturation and Cold Hardiness

The number of nodes and the number of mature nodes were counted on vines during the acclimation period to determine the extent of cane maturation. Tissue maturation was assessed visually according to browning of periderm. Mature nodes were expressed as a percentage of total nodes.

At the time of sampling, entire canes were removed from vines, cut to sixteen nodes, and randomly divided into two groups for separate determination of cold hardiness and water content. Canes were returned to the laboratory within two hours of sampling and stored at 1 C until they were prepared. Samples were stored for no longer than 12 hours in this manner. Samples consisted of node-internode pieces which were 3 to 6 cm long. Node-internode pieces were prepared and segregated according to their position on a cane. The following categories were used; nodes one to four, nodes five to eight, nodes nine to twelve, and nodes thirteen to sixteen. Nodes were counted from the base to the apex of the cane. Each category was equally represented in a replicate so that cane positional effects on cold hardiness and water content were avoided (Wolpert and Howell, 1985a, 1985b).

Controlled freezing tests were used to measure cold hardiness. The freezing technique used was similar to that of Wolpert and Howell (1985a). Four samples (one from each of the cane position categories) per treatment were inserted into each of several vacuum flasks and placed into a chest freezer (Revco Ultra Low™). Samples were in contact with aluminum foil to facilitate heat removal and moist cheesecloth to inoculate samples which prevented supercooling. Freezer temperature was manually lowered to provide a sample cooling rate of 5 C/h or less. Tissue temperature was monitored by a thermocouple (26 gauge copper-constantan) which was

inserted into the pith of a representative sample in each flask. Flasks were removed at selected temperatures and allowed to warm slowly overnight at 1 C. A temperature range was chosen such that the warmest temperature produced no injury and the coldest temperature was lethal to all tissues. Test temperatures were replicated four times in the freezer. Thawed samples were placed in humid chambers for 10 to 14 days, after which; tissues were sectioned and rated alive or dead by the method of tissue browning (Stergios and Howell, 1973). Dead buds had primordia which were brown and water soaked, while dead canes had phloem and cambium layers which were brown. The modified Spearman-Kärber equation was used to calculate T_{50} values (temperature at which 50% of tissues would be killed) for tissue viability data (Bittenbender and Howell, 1974). Cold hardiness was expressed as T_{50} values.

Water content was determined on primary buds (primordium + bud scales) and 2 cm segments by placing four to eight tissues (one or two from each of the cane position categories) per treatment into each of four glass weighing vials fitted with ground-glass stoppers. Tissues were weighed, oven-dried for 36 hours at 70 C (vials open), and reweighed. Water content was expressed as grams water/gram tissue dry weight.

Shootless nodes were counted in the spring following bud burst. Shoots were allowed to grow approximately 15 cm before data were collected. Shootless nodes were expressed as a percentage of total nodes.

Data within sample dates were subjected to AOV and mean separation was by Tukey's HSD test or Duncan's Multiple Range Test (Steel and Torrie, 1980). Arc-sine transformation was performed on percentage data before AOV (Steel and Torrie, 1980).

Results

Acclimation

Sey/Sey canes had a higher % mature nodes than canes from the other treatments early in the acclimation period (Table 1). By 1 October cane maturation was essentially complete and only minor differences existed between the treatments. The reduction in % mature nodes observed for most treatments on 29 October is probably an artifact caused by the difficulty encountered in counting total nodes. Counting of total nodes on 29 October was problematic because green shoot tips of canes had been killed by frost and were brown, dehydrated, and shrunken. Although the differences were not always statistically significant, tissue maturation appeared to be closely related to cold hardiness during the early stages of acclimation.

Sey/Sey primary buds were more cold hardy than buds from the other treatments on 3 September (Table 2). Rootstock effects were also observed on 15 October during acclimation. On that date, Sey/own and Sey/Sey buds had a lower water content than buds from the other treatments. Also, cold hardiness differences were observed on 15 October when primary buds of Sey/own were hardier than buds of Sey/RG1 or Sey/StG. Primary bud water content decreased and cold hardiness increased as acclimation proceeded.

Rootstock had little effect on cold hardiness and water content of canes during acclimation (Table 2). Sey/Sey canes had a greater degree of cold resistance than canes from the other treatments on 3 September. Canes from Sey/StG vines had the highest water content on 15 October and 29 October. Water content of canes decreased until mid-October where a plateau of 0.75 to 0.85 g/g tissue dry wt was reached. Cane cold hardiness increased throughout the acclimation period. Increase in

cold hardiness after mid-October were not related to water content. A killing frost was recorded on 12 October (Figure 1) and its occurrence seemed to be closely associated with the point in the acclimation process that increasing cold hardiness was no longer related to decreasing water content. This was also observed in previous research using Concord (Wolpert and Howell, 1985b).

Deacclimation

Primary bud cold hardiness and water content were influenced by rootstock primarily late in the deacclimation period (Table 3). On 31 March, Sey/own buds had a lower water content than buds from the other treatments and Sey/Cyn buds were hardier than Sey/StG buds. Water content of Sey/own and Sey/Sey buds was significantly lower than that of Sey/StG on 14 April. Primary buds exhibited increased water content and decreased cold hardiness during the deacclimation period. Large increases in water content of primary buds were seen between 31 March and 14 April.

Significant rootstock effects on cane water content and cold hardiness were perceived during deacclimation (Table 3). Sey/StG canes deacclimated earlier than canes from other treatments. Although the differences were not always statistically significant, Sey/StG canes had the highest water content and lowest cold resistance throughout the deacclimation period. In addition, Sey/Cyn canes were delayed in their deacclimation response when compared to Sey/StG canes. Canes from Sey/Cyn vines had the lowest water content and highest cold resistance during deacclimation. Sey/Cyn canes were 8.5 C hardier than Sey/StG canes on 31 March. The general trend observed was that canes increased in water content and decreased in cold hardiness as deacclimation proceeded.

Sey/Cyn vines had significantly fewer shootless nodes than vines from the other treatments (Table 4). Air temperatures for the dormant season are given in Figure 1.

Discussion

Rootstock and Acclimation

Rootstock had a small effect on cane maturation during acclimation. Sey/Sey canes had a greater percentage of mature nodes early in the acclimation period. Although a rootstock effect was noted, this result does not support the idea that rootstocks with a short vegetative cycle (early acclimation) positively influence scion cane maturation and cold hardiness since Sey/RG1 canes did not exhibit accelerated cane maturation or increased cold hardiness. Riparia Gloire vines are reported to have the shortest vegetative growth cycle among the rootstocks used in this study (Pongracz, 1983). Similar results were obtained by Basler (1984) using well-exposed shoots on grafted vines in the field. He found no differences in cane maturation due to rootstock even though several of the rootstocks he used were reported to impart early or late cane maturation. These findings suggest that the observed differences in cane maturation among various *Vitis* species (and consequently rootstocks) may result from factors originating in the shoot system rather than in the root system. Thus, the observation that *V. riparia* vines respond to decreasing photoperiod by reducing shoot growth, increasing periderm development and primary bud cold hardiness, and initiating bud dormancy is significant for acclimation of own-rooted vines but may not be important for acclimation of scions grafted to *V. riparia* (Fennell and Hoover, 1991).

Generally, water content decreased and cold hardiness increased during acclimation. There was one notable exception to this pattern. Increases in cane cold hardiness were not

accompanied by further decreases in water content of canes following a killing frost. Apparently, there is a change in the cold acclimation process of grapevines which is closely associated with the first killing frost. These data and those of Wolpert and Howell (1985b) suggest that grapevine cold hardiness increases are closely associated with advancing tissue maturity and declining tissue water content. The second stage of acclimation begins after the first killing frost and increases in cold hardiness seem to be related to decreasing air temperature. A two stage model of woody plant acclimation has previously been proposed by Weiser (1970).

Rootstock and Deacclimation

Consistent rootstock effects on cold hardiness and water content were observed during deacclimation when rootstocks which differ widely in relative timing of bud burst were evaluated. Primary bud cold hardiness was affected less by rootstock than was cane cold hardiness. However, Sey/Cyn buds were harder than Sey/StG buds on the last two sample dates. Examination of data for canes revealed that Sey/Cyn canes were lower in water content and higher in cold hardiness than Sey/StG canes during the entire deacclimation period. Cumulative injury was also reduced by rootstock as Sey/Cyn vines had a significantly lower percentage of shootless nodes than Sey/StG vines.

The slower rate of deacclimation observed for Sey/Cyn canes may be due to the ability of this treatment to resist deacclimation during exposure to warm temperatures or to reharden upon exposure to low temperatures once deacclimation has begun. Both of these mechanisms have been observed for grapevine buds (Damborska, 1978; Wample et al, 2001). Further research on the involvement of roots in the deacclimation process is necessary before

the observed delay in deacclimation by Cynthiana rootstock can be fully explained.

In general, water content increased and cold hardiness decreased during deacclimation. Large increases in water content of primary buds were often observed late in the deacclimation period.

Conclusions

Choice of rootstock had little effect on cold hardiness or water content during acclimation. A different situation existed during deacclimation. Sey/Cyn canes had a lower water content and higher level of cold hardiness than the other treatments throughout the deacclimation period. Sey/Cyn primary buds responded in a similar manner but to a lesser degree. The following proposals are consistent with the data collected in this study: (1) rootstocks with early bud burst deacclimate sooner than rootstocks with late bud burst; (2) the root system appears to be equally important as above-ground tissues in determining the rate of deacclimation; and (3) under certain circumstances, rootstocks are able to transmit differences in the rate of deacclimation to scion tissues.

Significant rootstock effects were observed for cumulative cold injury as indicated by percent shootless nodes data. Percentage shootless nodes was significantly lower for Sey/Cyn vines when compared with Sey/own, Sey/Sey, or Sey/StG vines.

Primary buds and canes increased in cold hardiness and decreased in water content during acclimation. One significant exception was noted. Increases in cold hardiness after the occurrence of a killing frost were not accompanied by further decreases in water content. This suggests that grapevine cold acclimation occurs in two stages: (1) cold hardiness increases in the first stage were

closely associated with advancing tissue maturity and declining water content of tissues; and (2) the second stage of acclimation began after the first killing frost and increases in cold hardiness were no longer related to tissue maturation and water content.

Cold hardiness decreased and water content increased in primary buds and canes during deacclimation. Primary buds showed large increases in water content during deacclimation with levels reaching 2.11 to 2.76 g/g tissue dry wt. at the scale crack stage of bud development.

Literature Cited

- Basler, P. 1984. Cane growth and maturation with various grape rootstocks. *Schweizerische zeitschrift fur Obst-und Weinbau*, Wadenswil. 120:277-283 (1984). (*Vitis* Abstr. 23:3C20; 1984).
- Bittenbender, H.C. and G. S. Howell, Jr. 1974. Adaptation of the Spearman-Kärber method for estimating the T_{50} of cold stressed flower buds. *J. Amer. Soc. Hort. Sci.* 99:187-190.
- Burke, M.J., L.V. Gusta, H.A. Quamme, C.J. Weiser, and P.H. Li. 1976. Freezing and injury in plants. *Ann. Rev. Plant. Physiol.* 27:507-528.
- Damborska, M. 1978. The effect of higher winter temperatures on changes of the frost resistance of grapevine buds. *Vitis*. 17:341-349.
- Dethier, B.E. and N. Shaulis. 1964. Minimizing the hazard of cold in New York vineyards. *Cornell Ext. Bul.* 1127.
- Fennell, A., E. Hoover, and A.H. Markhart II. 1986. Changes in root hydraulic conductance in *Vitis labrusca* (Concord) and *Vitis riparia*

- during short-day induced cold acclimation. HortScience 21:885 (Abstr.)
- Fennell, A., and E. Hoover. 1991. Photoperiod influences growth, bud dormancy, and cold acclimation in Vitis labruscana and Vitis riparia. J. Amer. Soc. Hort. Sci. 116:270-273.
- Howell, G.S. 1987. Vitis rootstocks. In: Rootstocks for Fruit Crops. R.C. Rom and R.F. Carlson (Eds.). pp.451-472. John Wiley and Sons, New York..
- Howell, G.S. 2001. Grapevine cold hardiness: mechanisms of cold acclimation, mid-winter hardiness maintenance and spring deacclimation. In: Proceedings of the ASEV 50th Anniversary Annual Meeting, pp 35-48.
- Howell, G.S. 1988. Cold hardiness: how small a difference in relative hardiness is viticulturally important? In: Proceedings of the Second International Symposium for Cool Climate Viticulture and Oenology. R.E. Smart, R.J. Thornton, S.B. Rodriguez, and J.E. Young (Eds.). pp. 105. New Zealand society for Viticulture and Oenology, Auckland..
- Howell, G.S. and N. Shaulis. 1980. Factors influencing within-vine variation in the cold resistance of cane and primary bud tissues. Am. J. Enol. Vitic. 31:159-161.
- Hubackova, M. and V. Hubacek 1984. Frost resistance of grape buds on different rootstocks. Vinohrad, Bratislava 22:55-56 (1984) [Vitis Abstr. 23:3C30; 1984].
- Jiang, H. and G.S. Howell. 2002. Correlation and regression analysis of cold hardiness, air temperatures, and water content of Concord grapevines. Am J. Enol. Vitic. 53: 227-230.
- Miller, D.P. 1986. Cold hardiness of grapevine rootstocks and their effect on scion cold hardiness and time of bud burst. M.S. Thesis, Michigan State University (1984).
- Miller, D.P., G.S. Howell, and R.K. Striegler 1988a. Cane and bud hardiness of selected grapevine rootstocks. Am. J. Enol. Vitic. 39:55-59,
- Miller, D.P., G.S. Howell, and R.K. Striegler. 1988b. Cane and bud hardiness of own-rooted White Riesling and scions of White Riesling and Chardonnay grafted to selected rootstock. Am. J. Enol. Vitic. 39:60-66.
- Pongracz, D. P. 1983. Rootstocks for grapevines. 150 pp. David Philip, Cape Town.
- Pool, R.M. and G.E. Howard. 1984. Managing vineyards to survive low temperatures with some potential varieties for hardiness. In: Proceedings of the International Symposium on Cool Climate Viticulture and Enology. D.A. Heatherbell, P.B. Lombard, F.W. Bodyfelt, and S.F. Price (Eds.). pp. 184-197. Oregon State University, Corvallis.
- Shamtsyan, S.M., E.G. Mikeladze, S.P. Abramidze, and N.G. Radmadze. 1984. The effect of grafting on grapevine frost resistance. Soobshchenija Akademii Nauk, Tbilisi 113:145-148 [Vitis Abstr. 23:3C23; 1984].
- Shaulis, N. 1971. Vine hardiness a part of the problem of hardiness to cold in New York vineyards. Proc. N.Y. State Hort. Soc. 116:158-167.
- Shaulis, N., J. Einset, and A.B. Pack. 1968. Growing cold-tender grape varieties in New York. N.Y. State Agr. Ext. Sta. Bul 821.
- Steel, R.G.D. and J. H. Torrie. 1980. Principles and Procedures of Statistics. A biometric approach. (2nd ed.) 633 pp. McGraw-Hill, Inc. New York.
- Stergios, B.G. and G.S. Howell, Jr. 1973. Evaluation of viability tests for cold stressed plants. J. Amer. Soc. Hort. Sci. 98:325-330.

- Striegler, R.K. and G.S. Howell. 1991. Influence of rootstock on the cold hardiness of Seyval grapevines. I. Primary and secondary effects on growth, canopy development, yield, fruit quality and cold hardiness. *Vitis*. 30:1-10.
- Wample, R.L., S. Hartley, and L. Mills. 2001. Dynamics of grapevine cold hardiness. In: Proceedings of the ASEV 50th Anniversary Annual Meeting. pp. 81-93.
- Weiser, C.J. 1970. Cold resistance and acclimation in woody plants. *HortScience* 5:403-410.
- Wolf, T.K. and R.M. Pool. 1988. Nitrogen fertilization and rootstock effects on wood maturation and dormant bud cold hardiness of cv. Chardonnay grapevines. *Am. J. Enol. Vitic.* 39:308-312.
- Wolpert, J.A. and G.S. Howell. 1984. Effects of cane length and dormant season pruning date on cold hardiness and water content of Concord bud and cane tissues. *Am. J. Enol. Vitic.* 35:237-241.
- Wolpert, J.A. and G.S. Howell. 1985. Cold acclimation of Concord grapevines. I. Variation in cold hardiness within the canopy. *Am. J. Enol. Vitic.* 36:185-188.
- Wolpert, J.A. and G.S. Howell. 1985. Cold acclimation of Concord grapevines. II. Natural acclimation pattern and tissue moisture decline in canes and primary buds of bearing vines. *Am J. Enol. Vitic.* 36:189-194.
- Wolpert, J.A. and G.S. Howell. 1986. Cold acclimation of Concord grapevines. III. Relationship between cold hardiness, tissue water content, and shoot maturation. *Vitis* 25:151-159.
- Wolpert, J.A. and G.S. Howell. 1986. Effect of night interruption on cold acclimation of potted 'Concord' grapevines. *J. Amer. Soc. Hort. Sci.* 111:16-20.
- Xiu-wu, G., F. Wang-heng, and W. Guang-jie. 1987. Studies on cold hardiness of grapevine roots. *Vitis*. 26:161-171.

Table 1. Effect of rootstock on the number and percentage of mature^y nodes during acclimation. Horticulture research center, East Lansing, MI.

Sample Date	Cane Maturation Indices	ROOTSTOCK				
		Own	Seyval	Cynthiana	Riparia Gloire	St/George
3-Sep	# mature nodes	0.2b ^z	4.8a	0.0b	0.3b	0.4b
	% mature nodes	0.7b	15.4a	0.1b	0.3b	0.3b
17-Sep	# mature nodes	9.1ab	11.1a	6.5b	7.1b	8.1ab
	% mature nodes	31.8ab	39.3a	23.5b	27.6b	25.9b
1-Oct	# mature nodes	16.7	19.1	15.4	16.5	17.3 n.s.
	% mature nodes	61.1b	64.5a	60.4b	61.3b	64.6a
15-Oct	# mature nodes	19.36b	21.8a	17.5b	14.7c	14.9c
	% mature nodes	67.0a	65.5ab	66.9a	59.2c	61.8bc
22-Oct	# mature nodes	18.7	20.5	19.6	19.6	20.3 n.s.
	% mature nodes	60.4bc	62.5ab	63.8ab	63.8ab	56.6c

^y Cane maturation was determined visually according to browning of periderm.

^z Mean separation within rows by Duncan's Multiple Range Test, p = 0.05

Table 2. Effect of rootstock on cold hardiness^z and water content^y of primary buds and canes of Seyval grapevines during acclimation. East Lansing, MI.

Graft combination	Sample Dates									
	3 Sept		17 Sept		1 Oct		15 Oct		29 Oct	
	T ₅₀	H ₂ O	T ₅₀	H ₂ O	T ₅₀	H ₂ O	T ₅₀	H ₂ O	T ₅₀	H ₂ O
					Primary Buds					
Seyval/own	-3.7b ^x	2.59	-7.0	1.71	-9.8	1.39	-15.3a	0.94b	-16.0	0.97
Seyval/Seyval	-5.4a	2.02	-8.5	1.75	-10.0	1.31	-14.3ab	1.02ab	-14.5	0.97
Seyval/Cynthiana	-3.7b	2.22	-6.3	1.84	-9.0	1.31	-14.0abc	1.10ab	-16.8	1.00
Seyval/Rip. Gloire	-3.9b	2.24	-6.5	1.94	-10.5	1.41	-11.5c	1.19a	-16.5	0.88
Seyval/St. George	-3.5b	2.47	-6.8	1.74	-10.3	1.25	-12.5bc	1.23a	-16.0	1.14
					Canes					
Seyval/own	-3.7b	1.88	-8.0	1.16	-9.8	0.92	-12.0	0.75b	-16.8	0.78b
Seyval/Seyval	-5.6a	1.39	-7.8	1.15	-10.5	0.87	-12.3	0.76b	-16.8	0.79b
Seyval/Cynthiana	-3.9ab	1.64	-6.0	1.24	-9.0	0.86	-11.5	0.76b	-16.0	0.76b
Seyval/Rip. Gloire	-3.7b	1.78	-6.8	1.32	-9.8	0.98	-11.3	0.85a	-16.5	0.79b
Seyval/St. George	3.9ab	1.83	-7.0	1.21	-9.5	0.96	-11.3	0.84a	-14.8	0.86a

^zT₅₀ in °C.

^yg H₂O/g dry wt.

^xmean separation by Tukey's HSD Test, p=0.05

Table 3. Effect of rootstock on cold hardiness^z and water content^y of primary buds and canes of Seyval grapevines during deacclimation. East Lansing, MI.

Graft combination	Sample Dates							
	3 Mar		17 Mar		31 Mar		14 Apr	
	T ₅₀	H ₂ O	T ₅₀	H ₂ O	T ₅₀	H ₂ O	T ₅₀	H ₂ O
				Primary	Buds			
Seyval/own	-18.3	0.80	-13.8	0.83	-12.5ab ^x	0.95b	-4.5	2.11b
Seyval/Seyval	-17.5	0.88	-12.8	1.00	-10.0ab	1.05a	-2.5	2.04b
Seyval/Cynthiana	-17.0	0.85	-13.3	0.92	-13.3a	1.07a	-4.5	2.50ab
Seyval/St.George	-17.8	0.86	-13.3	0.97	-8.5b	1.10a	-2.8	2.76a
				Canes				
Seyval/own	-21.3	0.77	-14.0b	0.79b	-12.8b	0.94	-6.8b	1.09b
Seyval/Seyval	-21.0	0.80	-14.5b	0.80b	-9.5b	0.95	-3.5c	1.13ab
Seyval/Cynthiana	-21.3	0.77	-18.8a	0.74b	-17.8a	0.84	-9.3a	1.02c
Seyval/St. George	-19.3	0.80	-13.3b	1.03a	-9.3b	1.04	-3.0c	1.17a

^zT₅₀ in °C.

^yg H₂O/g dry wt.

^xmean separation by Tukey's HSD Test, p=0.05

Table 4. Effect of rootstock on the percentage of shootless nodes of Seyval grapevines. Horticultural Research Center. East Lansing, MI.

Rootstock	Shootless nodes (%)
Own	55.9ab ^z
Seyval	46.3b
Cynthiana	22.2c
St. George	66.8a

^zMean separation by Duncan's Multiple Range Test, p=0.05.

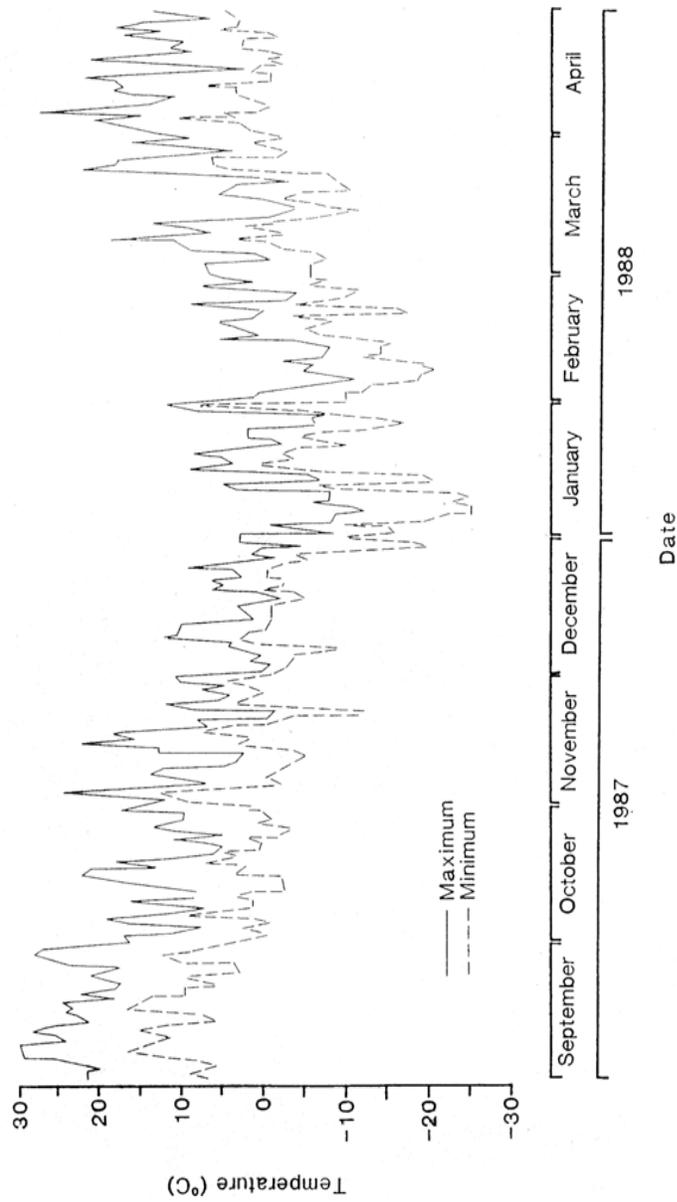


Figure 1. Maximum and minimum air temperatures (°C) during acclimation, mid-winter, and deacclimation. East Lansing, MI.

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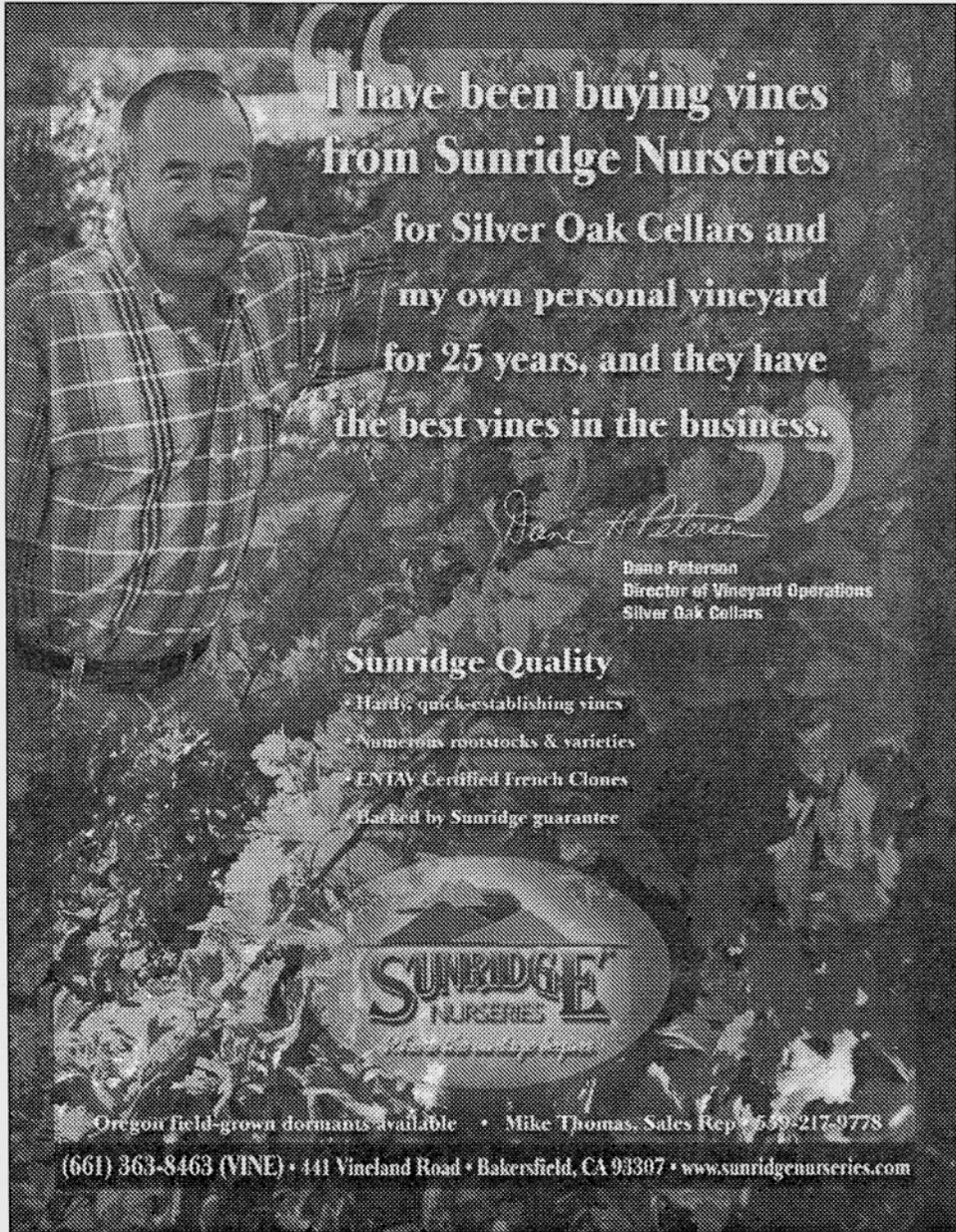
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