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1. Introduction

This bulletin focuses on using grape rootstocks to control vegetative and reproductive activities of the grapevine through modifying vine physiology. Several studies have focused on scion and root interactions that have specific regulative mechanisms in key physiological processes for roots in general, for example, water and mineral absorption when they operate under limiting conditions due to drought, pests, disease or other factors (Keller, 2010). However, our knowledge of rootstock physiology is limited as evident in commercial viticulture where 90 percent of all the *vinifera* vines of the world are still grafted to fewer than 10 rootstocks.

Moreover, rootstocks are chosen mainly for their tolerance to a limited number of expected soil conditions, particularly related to water availability or soil pH (Keller, 2010). Roots anchor the vine to the soil, take-up water and nutrients, produce and transport plant hormones including abscisic acid, auxins, gibberellins, and ethylene (Rom, 1987). Furthermore, roots serve as a repository of stored carbohydrates (Edson et al., 1995) and nitrogenous compounds (Wermelinger, 1991), both critical to fueling the flush of spring growth prior to full canopy expression.

However, the effect of rootstocks on important quantifiable viticultural parameters is ambiguous largely due to our inability to effectively separate the observables with respect to their cause. This, of course, often makes a determination speculative. Additionally, a genotype's performance is intimately tied to the environment of its evaluation. This relationship can influence the rootstock's performance, as well as the scion cultivar grafted to it, producing yet another limitation on the validity of any conclusion drawn about the rootstock effect.

No matter how we elect to move forward, determining direct responses to root influences requires an initial defining of two key terms (Striegler and Howell, 1991). A *primary rootstock effect* would be one that directly influenced a scion response via well documented aspects of root morphology or physiology. A *secondary root effect* would include an indirect scion response influenced by the rootstock's direct impact on scion vigor. Canopy density is an example of the secondary root effect.

2. History and purpose

The speedy migration of grapevines from their origins in Eurasia to locations around the world occurred principally due to the ease of transporting, rooting and transplanting their hardwood cuttings. The primary advantage of an own-rooted vine is its capacity to annually develop replacement shoots from its below-ground components should trunks or other above-ground structures become seriously compromised or killed and need replacement. Winter injury due to excessively cold temperatures or damage from machinery are frequent causes. Alternatively, a second advantage is adjacent own-rooted vines can be conveniently used to generate replacement components by bringing down an existing cane and rooting it in the desired location, a process known as “layering” (Figure 1).

Sourcing own-rooted vines from a nursery where they are relatively easy to produce will generally reduce the costs of vineyard establishment as compared to those developed through grafting onto another variety functioning as a rootstock. Grafting was not practiced until growers were faced with soil maladies and pests. The practice of grafting compatible scion varieties of grapes onto rootstocks is not a new technique; in fact, the process was described by Roman author Columela in 70 AD (Figures 2 and 3).

Until the middle of the 19th century, vines in Europe were primarily grown on their own roots. This practice was forced to change when the Phylloxera root aphid,

Figure 2. Scions grafted to rootstocks following bench grafts and the callusing process.

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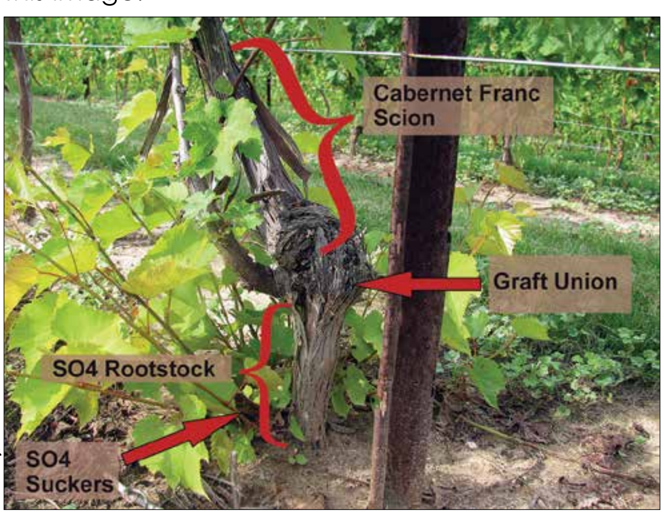
Figure 3. Below, Cabernet Franc on SO4 rootstock in a northern Michigan vineyard. Suckers of SO4 rootstock are seen arising from below ground in this image.



Ron Perry, MSU

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Figure 1. Tempranillo vines in Spain established using the practice of “layering.”

Daktulosphaira vitifoliae (Fitch), native to eastern North America, entered France attached to imported roots and soon spread throughout the continent. By the 1880s, French, and later other European vineyards, were nearly destroyed growing on highly susceptible Vinifera own-rooted varieties, which proved to be phylloxera-sensitive. Two Americans came to the rescue in France by collecting rootstocks native to Texas and Missouri and shipping plants to devastated regions. For their efforts, Thomas Volney Munson of Denton, Texas, and Hermann Jaeger of Neosho, Missouri, were awarded the Chevalier du Merite Agricole (1888) and the French Grand Cross of the Legion of Honor (1893), respectively. The insect was rampant and devastated the French economy. Thousands of bundles of Texas and Missouri Phylloxera-resistant rootstocks were shipped to France for grafting (www.texoma.com/personal/twining/viticult/muncen.htm and www.MissouriRuralist.com - April 2009).

Extensive experimentation and breeding followed in France to identify which selections of North American species and their hybrids were most suitable for use as rootstocks in European vineyards. Those early rootstock selections resulted in the foundation of progeny for subsequent contemporary breeding programs and development of commercial clones. With grapes, resistance to pests and disease is the single most important cultural requirement for rootstock selection as compared to other fruit species where the focus tends to value propagation, vigor control or enhanced precocity. Choosing the appropriate grape rootstock can diminish the need to use pesticides, lowering costs and increasing economic and environmental sustainability.

3. Grape species sourced as rootstocks

Grapes belong to the Vitaceae family of plants. The genus Vitis is comprised of over 50 species which are broadly distributed, largely between the 25° and 50° N latitudes in eastern Asia, Europe, the Middle East and North America. Euvitis is divided into two primary sub-groups: 1) bunch grapes and 2) Muscadines. Bunch grapes include species *V. vinifera*, native to Eastern Europe, and *V. labrusca*, native to eastern North America and the genetic source of Concord, Niagara and their companions. Tendrils of the bunch grape varieties are mostly forked. They have bark that exfoliates or shreds. The bark of their canes does not have lenticels and possesses nodes with a diaphragm. Muscadines are native to the southeastern United States and the genetic source for *Vitis rotundifolia*. They are different in many ways. Tendrils are simple, the bark is tight and non-exfoliating, and the bark of their canes has lenticels and has nodes without a diaphragm.

T.V. Munson provided the French scientists with plants of the following species native to Texas and Missouri: V. Rupestris, V. Riparia, V. x Champini, V. Berlandieri and V. Candicans. The initial breeding programs in France and Europe focused on hybridizing to combine genotypic characteristics to satisfy requirements. Those needs were and remain today focused on resistance to Phylloxera, calcareous soils and drought; the latter due to irrigation restrictions in most appellations. Contemporary breeding programs in America today have added resistance to nematodes and canopy vigor control to these goals.

4. Primary rootstocks

The primary and initial rootstocks used in breeding programs and their general characteristics are described below.

- *Vitis vinifera* (own-rooted)
  - » Grows well in high pH soils
  - » Highly susceptible to Phylloxera and nematodes
- *Vitis riparia (*the "riverbank" grape)
  - » Likes moist soils
  - » Does not like high pH or calcareous soils.
  - » Tolerant to Phylloxera
  - » Propagates easily
- *Vitis rupestris* ("St.George" or "Rupestris du Lot")
  - » Drought-tolerant
  - » Does not like high pH or calcareous soils
  - » Tolerant to Phylloxera
  - » Propagates easily
- *Vitis berlandieri*
  - » Tolerates high pH or calcareous soils
  - » Resists Phylloxera
  - » Does not propagate easily

5. Interspecific hybrids

Crosses and their resultant rootstock progeny (families) and their characteristics, developed by breeders in Europe in the 20th century, are described next.

- V. Riparia X V. Rupestris
  - » Examples include: Couderc 3309, C 3306, 101-14
  - » Drought-tolerant
  - » Sensitive to calcareous soils
- V. Riparia X V. Berlandieri
  - » Examples include: SO4, Teleki 5C, Kober 5BB, 420 A Mgt
  - » Moderate vigor
  - » Resistant to Phylloxera
  - » Tolerant of calcareous soils
- V. Berlandieri X V. Rupestris
  - » Examples include: 110 R, 140 Ru, 1103 P
  - » High vigor
  - » Tolerant of calcareous soils
  - » Resistant to Phylloxera
- V. x Champini and hybrids
  - » Examples include: "Dogridge", "Salt Creek" (a.k.a. "Ramsey"), both developed by T.V. Munson
  - » Hybrid progeny include: "Freedom" (Armillaria resistant) and "Harmony"
  - » High vigor in fertile soils
  - » Tolerant of calcareous soils

6. Rootstock performance

6.1 Benefits of rootstocks over own-rooted

There are many benefits to selecting a rootstock for a site or growing region. The choice may be targeted to include:

1. Resistance to soil pests, such as Phylloxera and nematodes.
2. Promotion of a more extensive root system to improve tolerance to drought.
3. Potential reduction in vine vigor for fertile soils and sites or, in contrast, to boost vine vigor for infertile soils and sites.
4. Promotion of tolerance of calcareous soils.
5. Suppression of virus transmission by nematodes, for example the Dagger nematode as vector for fan leaf virus.
6. Tolerance of either low or high soil pH.

6.2 Soil and vine vigor

The primary role of root systems in plants is to absorb water and nutrients. Rootstocks differ in their abilities to absorb nutrients from the soil solution and transport them up the scion to where they are needed. Each rootstock or species also differs in their ability to explore the edaphic environment by developing extensive or shallow root systems (Perry, et. al., 1983). They also differ in their preferences regarding soil conditions, water status ("wet feet" or drought), soil pH, calcium carbonate (lime) and salts. The own-rooted vines of *Vitis vinifera* are moderately tolerant of high pH and lime (Cousins, 2005). In contrast, *V. Riparia* species, the North American "riverbank" grape, likes moist soils, but struggles in high pH or calcareous soils (Cousins, 2005). Rootstocks with *V. Rupestris* and *V. Berlandieri* parentage have demonstrated their preference for their native Texas habitat where soils are high in pH and calcareous content, and lack soil moisture. Breeding work in Europe has focused not only on Phylloxera tolerance, but also on tolerance to drought, high pH and high lime soils. Drought tolerance is necessary for many European appellations where vineyards must comply with strict controls prohibiting or limiting irrigation.

One of the most important differences among rootstocks is their influence upon canopy vigor. As canopy vigor has tremendous influence on fruit yield and quality parameters, as well as flower initiation, fruit ripening and winter acclimation, carefully assessing this characteristic is critical for most viticulturists and winemakers. Rootstock characteristics that influence vine vigor and, ultimately both size and density, include root architecture and distribution, drought adaptation, and efficiency of nutrient uptake.

Excessive vigor can often have harmful effects on canopy shading and fruit ripening. A weak canopy, as perhaps influenced by the rootstock, portends an open canopy with high light penetration, benefiting fruit maturation and flower initiation for next year's crop and yielding fruit with small berries. Vines grown in cool regions such as Michigan are concerned with growing too late into fall and thereby generating problems associated with insufficient fall acclimation and winter hardiness**.** Some rootstocks have a shorter or longer growth cycle than that of the scion variety (Howell, 1987). Rootstocks having a short cycle advance fruit and vine maturity, whereas those considered long, extend fruit and canopy maturation.

Short-cycle rootstocks can enhance cold acclimation of the vine. Howell (2005) suggests short-cycle rootstocks would be most desirable for a cool climate, like that of Michigan. Yet it is worth noting that insufficient vigor can yield a canopy unable to ripen the crop and that needs to be taken into account.

The viticulturist has the goal of reaching an optimum level of vigor for the site and variety. Therefore, the right rootstock must be chosen for the site and variety planted. Detailed knowledge of the site is critical to predict vine vigor. Critical factors include soil rooting depth, soil chemistry, cation exchange capacity, soil particle size, slope, water-holding capacity, drainage, precipitation, climate and site history.

The viticulturist can adjust site and vigor by deploying various management practices aimed at one or more of these factors to influence vine vigor such as irrigation, fertilization, weed control and tillage. Additionally, the careful choice of trellis system to train and support the desired canopy is also critical to achieving targeted results. Once established, as with site selection, the rootstock component is a variable that cannot be changed without significant loss of investment. The decision affects the performance and life of the vineyard, which demands substantial research and careful analysis upfront to maximize the fit and minimize the risk.

6.3 Influence of rootstocks on fruit yield and quality

The "talking-heads" of the wine world, its writers, food and wine critics, and public relation representatives, make the general assumption that vines grown on their own roots produce fruit and wine with superior quality compared to those grown on rootstocks. In fact, some wine regions and businesses, particularly where Phylloxera does not exist and where the majority of vineyards remain established on their own roots, use this as a quality, even purity, distinction to promote their brand and its products. However, the truth is that the influence of rootstock on wine quality remains an indirect one in that it is more a secondary effect of rootstock influence on canopy vigor (Howell, 2005).

Some rootstocks have been found to directly promote excess vigor and canopy shading resulting in inferior wine quality from harvested fruit (Pouget, 1987). A closer examination of research on specific compounds associated with quality or sensory experience offer additional insight. Wine made of Shiraz on six rootstocks in Australia showed similar levels of anthocyanins as that produced from own-rooted fruit (Walker, et al. 2000).

Another study conducted by Harbertson and Keller (2012) demonstrated that rootstocks, including own-rooted vines, had little influence on the fruit and wine chemistry produced by Chardonnay, Merlot and Syrah vines in Washington over three years. Specifically, in this study, rootstocks had no effect on grape anthocyanins and tannins.

In British Columbia, yield, fruit weight and berry weight did not differ among nine scion varieties when grown on own roots compared to four rootstocks over seven years (Reynolds and Wardle, 2001). In this study, variety differences among scions mediated the impact of grape rootstock upon cropping and fruit composition.

Performance of a scion variety can be variable depending on the scion and rootstock combination. In a study conducted in Texas, 39 varieties demonstrated variability in vine vigor, winter hardiness, yield and juice pH after nine years when comparing two rootstocks to own-rooted vines (Lipe and Perry, 1988).

There have been numerous rootstock trials through the years. One of the challenges in assessing the effects of rootstock on fruit quality lays with the researcher's ability to control variables such as crop load and leaf to fruit ratio. A perceived rootstock effect may in actuality be a function of rootstock influence on canopy vigor and its interaction with site and soil conditions.

6.4 Resistance to pests

Phylloxera. The practice of using rootstocks was minimal until Phylloxera began killing vineyards and then rapidly spread throughout Europe in the 19th century. Today, grape growing regions also contend with other edaphic threats such as nematodes and the viruses vectored by them. Phylloxera is found throughout North America, originating in the eastern part of the continent. The pest is an aphid, which feeds on roots known as "nodosities" in a nymph form as well as on leaves. Their feeding deforms the roots and eventually debilitates fine root function progressing to vine death (Howell, 1987). Optimum soil conditions for Phylloxera are those that have significant portions of clay or fine soil particles. Phylloxera infestation is less common in coarse soils. Specifically, Phylloxera is not present in Chilean soil or in regions in Europe such as Rueda, Spain, where many older vineyards are own-rooted (Figure 4) and established on coarse or gravelly soils, which do not support Phylloxera populations.

Ron Perry, MSU

Figure 4. One hundred-year-old vineyard site in Rueda, Spain, where vines are own-rooted.

Nematodes. Nematodes are microscopic worms, which can feed on plant roots and cause considerable damage directly or by vectoring virus diseases. Some wine grape production regions, Australia and California for example, view nematodes as a greater and more common threat to vine health and consistent cropping than Phylloxera (May, 1994). The influence of these growing regions plus the deterioration of available chemical fumigants and a move towards more sustainable practices have focused research programs in the United States on developing a new generation of rootstocks with nematode resistance (Cousins, 2011; Walker, 2012).

Plant parasitic nematodes important to grapevines in Michigan are rootknot (*Meloidogyne incognito*), dagger (*Xiphinema Americana* and *X. index*) and root lesion (*Pratylenchus vulnus*) (Pest Management Strategic Plan for the North Central Region Grape Industry, 2007). Dagger nematode not only feeds on plant roots, but also is responsible for vectoring fan leaf virus among other viruses that affect grapes. Unfortunately, many of the older established rootstocks are not resistant to dagger nematode. Nematodes readily infest coarse and droughty soils. Broadest resistance to nematodes appears to be found with use of the rootstocks "Ramsey", "Freedom", and several others in the Teleki series. Rootstock 5C, however, is the only one that has been specifically tested. Rootstock resistance to nematodes is not broad-spectrum, but depends on the nematode species.

7. Rootstocks for Michigan

Based on rootstock trials and assessments in Michigan and New York, several rootstocks are popular among commercial juice and wine producers. Many of these rootstocks were developed in Europe in the early part of the 20th century and the latter part of the 19th (Galet and Morton, 1979).

7.1 Descriptions of current rootstocks

3309 Couderc. One of the more popular rootstocks used in Michigan and eastern North America is also known as 3309 or 3309 C. This rootstock is a hybrid of *V. Riparia* X *V. Rupestris*, selected by Georges Couderc in France in 1881 (Galet and Morton, 1979). Early trials conducted by Dr. Nelson Shaulis at Cornell University demonstrated that American varieties, as well as several French-American hybrids, were more productive and cold hardy following planting in grape replant sites when grafted onto this rootstock. The 3309 rootstock is considered resistant to Phylloxera. Cane hardiness is very good on this rootstock (Howell, 1987). Vine vigor is moderate, but slightly more vigorous than those grafted on 101-14. The 3309 is a medium-cycle rootstock and is susceptible to feeding by dagger and root knot nematodes.

101-14 Mgt (Millaret et de Grasset). Like its earlier sibling the 3309, this rootstock was developed in France in 1882 as a result of a cross between *V. Riparia X V. Rupestris* by Professor Millardet and Marquis de Grasset (Galet and Morton, 1979). The 101-14 is steadily gaining in popularity throughout North America and, in particular, the Midwest and eastern United States. On most sites, 101-14 produces a moderately vigorous vine, somewhat less vigorous than those of 3309. It is also characterized by high tolerance to Phylloxera, moderate resistance to dagger and root knot nematodes, and is a popular rootstock for clay soils.

SO4. Selektion Oppenheim 4, a.k.a SO4, is a hybrid of *V.Berlandieri* X *V. Riparia* created at the viticulture school of Oppenheim, Germany, in 1904 (Galet and Morton, 1979). The rootstock has resistance to Phylloxera and moderate resistance to many nematode species. Scion vigor is considered moderate and has adapted well to Michigan conditions. It appears to confer "medium to short-cycling" on scion varieties regarding fruit and canopy maturation period (Howell, 2005).

Riparia gloire de Montpellier. Riparia gloire was selected at the Portalis estate near Montpellier, France (Galet and Morton, 1979), and is commonly referred to as simply Riparia, which is a selection of *Vitis riparia*, a wild grape species native to the northeastern and Midwestern United States. This was an original selection made in the 19th century to address the Phylloxera problem in France. This is another short-cycle rootstock used where scions are low in vigor similar or less than 101-14. This rootstock is shallow-rooted and drought susceptible, but with good tolerance to wet soils, highly resistant to Phylloxera, and with moderate resistance to nematodes.

7.2 Other rootstocks of interest for Michigan

Schwarzmann. The origin of Schwarzmann is relatively unknown with some suggesting it is a seedling selection derived from a cross between *V. Riparia X V. Rupestris* of the Millardet 101 series (Galet and Morton, 1979). Australian studies have determined it is slightly more vigorous than 101-14 and 3309 C. It is highly resistant to Phylloxera and root knot and dagger nematodes. There is little testing history in Michigan, however.

Freedom. Freedom was developed at the University of California-Davis and is a cross between Dogridge (*V. X Champini*) and 1613 Couderc (*V. Solonis X* Othello). It is susceptible to Phylloxera but highly resistant to a broad spectrum of nematode species and Armillaria root rot (*Armillaria mellea*). This rootstock is vigorous like most *V. X Champini* hybrids, but has application to sites with an infestation history ("hot spots") with Armillaria root rot in Michigan. It has been tested in Michigan demonstrating survival after two years planted in hot spots that killed cherry trees. This rootstock needs further testing, especially on coarse soil sites frequently subject to drought conditions.

New rootstocks untested in Michigan. *Rootstock testing is needed in Michigan.* The process is long term and complex (scion variety selection and controlling crop levels). Rootstocks have been developed in California (VR O39-16 and GRN series) by the University of California-Davis (Walker, 2012) and the USDA, for example "Matador", "Minotaur" and "Kingfisher" (Cousins, 2011), which demonstrate high and broad resistance to nematodes. Unfortunately, the species and crosses used to develop these rootstocks suggest these new rootstocks may be vulnerable to cold injury.

8. Summary and recommendations

In Michigan, rootstocks with *Vitis vinifera* parentage should not be used because of insufficient Phylloxera resistance. There are safer effective choices. Many rootstocks preferred in Europe are recommended precisely to address their most critical and dominant abiotic (calcareous soils, high pH, high salinity and droughty soils) and biotic (Phylloxera) stresses. Many regions in Europe, by virtue of appellation rules, are not allowed to irrigate and thus drought tolerance is a major abiotic stress. Here we do not confront many of these problems in that most of our vineyards in Michigan are slightly acidic and many are established in coarse soils with drip irrigation.

Rootstocks do not have a direct effect on vine cold hardiness and fruit quality, therefore our primary goals for rootstock research and subsequent selection should be based on developing improvements in vine cold-tolerance, Phylloxera and nematode resistance in a short-cycle package with the potential of improving fruit quality at harvest in cool climate viticulture. Rootstocks that influence the scion with a short cycle and do not incite excessive vigor will help us avoid cold injury and ensure crops mature sufficiently in fall. That is the final goal. Now more than ever, soil and site conditions must take precedence in determining the right choice.

Table 1. Synoptic table of the principal characteristics of rootstocks of interest for Michigan.

Rootstock	Parentage	Vigor	Phylloxera resistance	Nematode resistance	Drought resistance	Wet feet (tolerance)	Influence maturity
3309 C	V. riparia x V. rupestris	Moderate-High	High	Susceptible	Low	High	Mid
101-14 Mtg.	V. riparia x V. rupestris	Low-Moderate	High	Low	Low-Moderate	High	Early
SO4	V. berlandieri x V. riparia	Moderate	High	Low	Low	High	Mid
Riparia Gloire	V. riparia	Low	High	Moderate	Low	High	Early
Swarzmann	V. riparia x V. rupestris	Low-Moderate	High	High	Low-M	High	Early
Freedom	1613 C x V.champinii	High	Susceptible	High	Low	Low	Late

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