AN ABSTRACT OF THE THESIS OF

Raymond Glen Shaffer for the degree of Master of Science in Horticulture presented on May 2, 2002.

Title: The Effect of Rootstock on the Performance of the *Vitis vinifera* Cultivars Pinot noir, Chardonnay, Pinot gris and Merlot

Abstract Approved: ______________________
Carmo Vasconcelos

This study reports finding of two rootstock experiments planted in 1997. The purpose of the first experiment was to evaluate the performance of Pinot noir on 19 phylloxera-resistant rootstocks and as an ungrafted vine. The purpose of the second experiment was to evaluate the performance of *V. Vinifera* cultivars Pinot noir, Chardonnay, Pinot gris and Merlot grafted to nine phylloxera-resistant rootstock, and as ungrafted vines. Data for both experiments were collected in 2000 and 2001, the fourth and fifth years of establishment respectively. Vines received supplemental irrigation and were fertilized with N-P-K during both seasons. In the first experiment, rootstock affected vegetative growth, chlorophyll content, yield, cluster weight and berry weight in both years, gas exchange measurements in 2000, and fruit composition in 2001. Of the *V. riparia x V. rupestris* rootstocks, 3309C and Schwarzmann imparted low to moderate vigor, as reflected by pruning weight. 101-14 Mgt imparted higher vigor to Pinot noir than 3309C. Based on ripening index values (soluble solids/titratable acidity, Brix/TA), ripening appeared to be earlier for vines grafted to 101-14 Mgt and Schwarzmann than for 3309C.

The *V. berlandieri x V. riparia* rootstocks, including 161-49C and 420A, imparted average to higher than average vigor. Ripening appeared to be later than average and berries larger than average for vines grafted to these rootstocks. With the exception of 110R, the *V. berlandieri x V. rupestris* rootstocks had higher than average vigor. Ripening times seemed to be average and berry weights were higher than average for vines grafted to these rootstocks. Of the remaining rootstocks 1616C performed much like the *V. berlandieri x V. rupestris* rootstocks with an even higher ripening index. Börner, Riparia Gloire, 44-53 Malègue and Gravesac all imparted low to moderate vigor. Berry weights tended to be average to lower than average. Riparia Gloire and Gravesac seemed to impart earlier ripening, while Börner and 44-53 Malègue did not. In the second experiment, the *V. berlandieri x V. riparia* rootstocks imparted more vigor, a higher yield, a higher berry weight and delayed ripening as reflected by the ripening index. 101-14 Mgt imparted a higher pruning weight, lower berry weight and earlier ripening than 3309C. 110R, 44-53 Malègue and Gravesac conferred moderate vigor as reflected by pruning weight. Riparia Gloire conferred lower vigor. Ripening times imparted by these rootstocks ranged from early for Riparia Gloire and Gravesac, to average for 110R and later for 44-53 Malègue. Berry weights were average for scion grafted to 110R and Gravesac, and low for scion grafted to Riparia Gloire and 44-53 Malègue.

The Effect of Rootstock on the Performance of the *Vitis vinifera* Cultivars Pinot noir, Chardonnay, Pinot gris and Merlot

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Raymond Glen Shaffer

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I understand that my thesis will become part of the permanent collection of Oregon State University Libraries. My signature below authorizes release of my thesis to any reader upon request.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE OF CONTENTS (CONTINUED)

DEDICATION

Dedicated to my mother, Annette.

The Effect of Rootstock on the Performance of the *Vitis vinifera* Cultivars Pinot noir, Chardonnay, Pinot gris and Merlot

CHAPTER 1: GENERAL INTRODUCTION

INTRODUCTION

Grape phylloxera (*Dactylosphaera vitifolii)* was responsible for devastating European vineyards in the late 19th Century, and has since been introduced into nearly every major grape-growing region in the world. Grafting grape scion onto resistant rootstock is the only practical means of managing phylloxera. Wine grape scion is generally of *Vitis vinifera* parentage, while rootstocks have been bred from other *Vitis* species or are a cross between *V. vinifera* and other *Vitis* species. These species include, but are not limited to, *V. berlandieri, V. riparia* and *V. rupestris*. Because these species coevolved with phylloxera in North America they have developed resistance mechanisms that are not yet fully understood.

With few exceptions the primary concern in rootstock selection should be phylloxera resistance. Rootstocks with *V. vinifera* parentage are considered susceptible to phylloxera and should therefore not be considered for all but a small minority of sites. Exceptions include sites with sandy soils, as phylloxera cannot survive in soils with less than five percent silt and clay [1]. Using rootstocks with *V. vinifera* parentage may also be justified on sites where other biotic or abiotic stresses are a greater threat than phylloxera. Examples include nematode or virus pressure, low or high pH soils, waterlogged soils and drought. There are a sufficient number of rootstocks available, that it is generally possible to find a rootstock that meets one or more of these criteria while providing adequate phylloxera resistance.

Beyond protecting the scion from biotic and abiotic threats, rootstocks can affect fruit quality such that grafting may even be desirable in the absence of these threats [2]. Perold [3] suggested that, "By choosing rootstocks that are sufficiently resistant to phylloxera without causing the vines grafted on them to grow too vigorously, and especially by grafting them with varieties that produce grapes of high quality and by limiting the size of the crop, we can obtain excellent quality in the grapes and wine produced by grafted vines". According to Ravaz [4] the highest quality fruit is obtained from vines that are kept in balance. This balance can be quantified as the ratio between reproductive and vegetative growth.

Rootstock, vine spacing, desired crop load and other cultural practices must be integrated to achieve a balance that is appropriate to the variety, desired fruit quality, site vigor and climate. Because these variables will differ from site to site no one rootstock will be most appropriate for every site within a region. However, due to similarities in climate and soil type, there may be a set of rootstocks that are more suitable than others for a given region. Rootstocks perform differently with different soils and climates, thus regional rootstock evaluations are essential in determining which rootstocks are best suited to a particular environment.

Phylloxera was not discovered at a commercial vineyard in Oregon until 1990 [5]. For that reason very little rootstock research has been done in this state. In fact, until recently, no comprehensive rootstock evaluation had been performed in the Pacific Northwest [2]. As a result, Oregon growers have had to rely on information from outside the state when making rootstock selections. Because of Oregon's unique soils, climate and cultural practices, this information may not be readily transferable [5].

Oregon is considered a cool climate viticultural region. The growing season is shorter than in other areas where grapes are grown. Growers may have difficulty ripening fruit in years when fall rains begin early.

Therefore, rootstocks that impart earlier ripening are preferred. As in other cool climate regions, poor color accumulation can present a problem with red varieties. One way to combat this problem is by increasing the skin to pulp ratio of the berries. As a result there is much interest in clones that produce smaller berries [6]. Although rootstocks are seldom selected for this reason, they have the ability to significantly affect berry size [7]. Finally, even though Oregon is known for its winter rainfall, it receives far less summer precipitation than other viticultural regions.

Soils in Oregon tend to be more acidic and more fertile than in other cool climate grape growing regions. In many of these regions high pH soils are more common, and rootstocks have often been selected for their lime tolerance. Soils in these regions are generally less vigorous than those found in Oregon vineyards. Rootstocks that impart moderate vigor in these regions may be too vigorous for the typical Oregon vineyard.

Cultural practices in Oregon differ from other viticultural regions as well. The Scott Henry training system is an example of a cultural practice that was, until recently, unique to Oregon. This system was designed as a retrofit to accommodate high vigor where a supposedly moderate vigor rootstock had been selected. Another example of Oregon's unique cultural practices is the current trend toward very low crop yield with some varieties. Pinot noir, for example was cropped at a state average of less than 4.5 tonnes per hectare in 2001 [8]. It is believed that fruit produced at such a low yield is better suited to high quality wine production. Growers can only achieve such low yields by removing clusters during the growing season. With such low yields proper vine balance can only be maintained by selecting a rootstock that controls vigor proportionately [4].

Given these requirements it is interesting to consider the rootstocks that are being used in Oregon today. Nearly 80 percent of the acreage where rootstocks are being used is devoted to Riparia Gloire and the

V. riparia x V. rupestris rootstocks 3309C and 101-14 Mgt [8]. These rootstocks are favored in other viticultural areas because they are thought to confer low vigor and earlier ripening to the grafted scion. The *V. berlandieri* x *V. riparia* rootstocks account for another 11 percent of the rootstocks planted in Oregon vineyards. These rootstocks are popular in other cool climate viticultural regions, such as Germany and Burgundy. Very little of the state's vineyard acreage is planted on the other major family, the *berlandieri* x *rupestris* rootstocks. These rootstocks are most popular in areas where high drought tolerance is required. There is limited acreage in Oregon devoted to other crossings such as 1616C (*riparia* x *solonis*) and 44-53 Malègue (*riparia* x *cordifolia* x *rupestris*). Little, if any Oregon acreage has been planted on newer crossings, such as Gravesac (*belandieri* x *riparia x rupestris*) and Börner (*cinerea* x *riparia*).

Because there has been little rootstock research conducted in Oregon, it is not known whether these rootstocks perform as they have in other trials outside the state. The trial used in this study was planted in 1997 at Oregon State University's Woodhall III Vineyard in the southern Willamette Valley. Its objective is to provide growers with specific information about the performance of a number of rootstocks in an Oregon vineyard. Oregon's most widely used rootstocks were selected for this trial, as well as some rootstocks that are not being used here but might be well suited to the state's unique viticultural demands. The data presented here were collected during the 2000 and 2001 seasons.

LITERATURE REVIEW

Vegetative growth

One of the most noted effects of rootstock is the vigor that is conferred to the scion. According to Rives [9], there are two ways in which scion vigor can be affected by rootstock. The first of these is the influence of the graft union or affinity [10]. Stocks that tend to form poor unions will give erratic results, with the most common response being reduced vigor [1]. Examples of this are 161-49C, which imparts very low vigor and has very low affinity with *vinifera*, and Riparia Gloire and 420A, which have low affinity and impart low vigor to grafted scion. Rupestris St. George, 140Ru and 99R are examples of Rootstocks that have a high affinity with *vinifera* and impart high vigor to grafted scion.

Affinity is not the only consideration in the effect rootstock has on scion vigor: the higher vigor rootstocks Dog Ridge, Salt Creek and 5BB all have poor affinity with *vinifera*. The second consideration is the rootstock's rooting pattern and its efficiency in nutrient uptake [1]. In an Austrian study, 31 field-grown rootstocks were divided into five groups based on their vigor [11]. Rupestris du Lot, 99R and 3309C were in the very low vigor group. Amos, 1103P, 140 Ru, G1, G9 and 1616C were in the low vigor group. Cosmo 10, 8B, 125AA, 420A, 725P, 41B, 333EM, Riparia Sirbu and 101-14 Mgt were in the middle vigor group. Fercal, Fercal 242, and Aripa were in the high vigor group. And 5BB, R27, 225 Ru, Riparia Portalis, G26 and Börner were in the high vigor group. Nutrient uptake roughly paralleled vigor. Börner and 5BB, for example, had a higher than average uptake of all the nutrients measured, while 99R and Rupestris du Lot had a lower than average uptake of most of the nutrients measured.

It is interesting to note that affinity and rootstock vigor are both important in influencing the vigor which a rootstock confers to the scion, and that the determining factor seems to vary among rootstocks. The high vigor that 99R, 140 Ru and Rupestris St. George (also "du Lot") confer to the scion is apparently due to affinity, while the high vigor conferred by 5BB is a result of its own vigor.

Vine vigor can be assessed via several different methods. Pruning weight has typically been used to measure the effect of rootstock on the vigor of numerous cultivars under a variety of conditions [2, 12]. Because pruning weights can only be obtained when a vine is dormant, shoot length and diameter have been used to assess vigor during the growing season [13, 14].

Gas exchange

The effect of rootstock on scion gas exchange parameters has been well documented [15]. Rootstock has been shown to affect scion photosynthetic rate, rate of transpiration [16], water use efficiency [17] and stomatal conductance [18]. This effect has not been constant, but depended very much on environment and vine status [19]. In fact researchers have used gas exchange measurements as an indication of the degree to which rootstock affects vine capacity for dealing with certain environmental stresses such as flooding [20] and drought [21].

It has been observed that the effect of rootstock on scion gas exchange measurements varies depending upon vine water status. In a study conducted at a vineyard in Switzerland 101-14 Mgt imparted higher rates of photosynthesis, transpiration and a higher water use efficiency to Pinot noir vines than 3309C [22]. Because 3309C may be more drought tolerant than 101-14 Mgt [21], the authors speculate that their results might have been different at a site where water was limiting.

Under semi-arid conditions in Italy, where water was limiting, rootstock drought tolerance had an effect on gas exchange parameters [17]. Rootstocks known to have higher drought tolerance, 140Ru and 420A, imparted higher water use efficiency than 5BB, a rootstock with poorer drought tolerance. There were no differences in water use efficiency when all vines were irrigated.

A correlation between vine vigor and photosynthetic capacity has also been suggested [16]. However this does not always appear to be the case. In a study involving Müller Thurgau planted on six rootstocks, moderate vigor rootstocks such as 3309C imparted higher rates of photosynthesis than the high vigor rootstock 140Ru [13].

Maximum quantum yield of photosynthesis

Florescence monitoring is used to detect differences in the efficiency with which absorbed light is used for PSII photochemistry [23]. This technique has been applied to other crops as a means of detecting water stress [24, 25].

Chlorophyll content

Rootstock appears to affect the chlorophyll content of scion leaves [26]. Chlorophyll content has also been shown to closely parallel photosynthetic rate [22]. The chlorophyll content of grapevine leaves has been used to assess the status of vines with induced chlorosis [27], following defoliation [28] and under drought stress [29].

Crop yield and yield components

The effect of rootstock on crop yield is one of the most investigated areas of rootstock research. Rootstocks can enhance [30] or limit [31] crop yield when compared to ungrafted vines.

It has also been noted that higher vigor vines tend to produce higher yields [32].

Yield per vine can be attributed to two factors, both of which can be influenced by rootstock: clusters per vine [33] and cluster weight [34]. The number of clusters per vine is a product of the number of shoots per vine and the number of clusters per shoot. The number of clusters per shoot is affected by rootstock [14] while the number of shoots per vine is determined largely by the number of buds left at pruning. Cluster weight is determined by berry weight and the number of berries per cluster. Both of these have been reported to be affected by rootstock [35]. It is important to note how a rootstock affects yield. For example, small berry size has been associated with higher wine quality because of the higher skin to berry ratio [6].

Fruit composition

Another important way in which rootstock can affect crop is through its influence on fruit composition. A number of studies have documented the rootstock effect on must pH [36], titratable acidity [30] and soluble solids [37]. Rootstock can influence fruit composition either directly or indirectly. An example of a direct effect would be the higher must pH that results when vines are grafted to a rootstock with a higher uptake of potassium [38]. An indirect effect would be the effect that rootstock can have on ripening time [2]. Fruit that ripens later will have lower soluble solids and pH and a higher titratable acidity. Generally more vigorous rootstocks tend to ripen fruit later than less vigorous rootstocks [39]. Indices that assign a value to fruit ripening characteristics have been used to assess the influence of rootstock on ripening time [40].

Vine balance

One might argue that the goal of cultural practices in the vineyard is to keep vines in balance. A balanced vine will produce consistently good fruit from year to year and will be productive longer. Measures of vine balance take both vegetative growth and crop yield into consideration. A ratio of 10 – 14 cm^2 of leaf area per gram of berry weight has been shown to be necessary for maximum berry weight, coloration, and protein and nitrogen content [41]. Because there is a high correlation between leaf area and pruning weight [42] it is possible to use a ratio of crop weight to pruning weight to determine vine balance. Ravaz suggests a ratio of between 4 and 15 for high-yielding varieties and a ratio of between 3 and 8 for low-yielding varieties [43]. In a study performed on Cabernet Sauvignon in Israel it was found that increasing crop load did not decrease wine quality as long as a crop to pruning weight ratio of 10 was not exceeded [44].

As mentioned above, rootstock can affect both crop load and pruning weight, and can therefore impact vine balance. Southey and Fouché [45] found that a crop to pruning weight ratio of 9 or 10 was not too high for irrigated, grafted Chenin blanc. Constantina Metallica, Dog Ridge, Ramsey 110R and Jaquez were all within this range. This ratio was too low for 143-B Mgt, probably because of excessive vigor since the pruning weights imparted by this rootstock were the highest in their trial. The crop load to pruning weight ratios imparted by 101-14 Mgt and 99 R were high. Pruning weights were also low for the vines grafted to these two rootstocks, suggesting insufficient vigor.

CHAPTER 2: THE EFFECT OF ROOTSTOCK ON THE PERFORMANCE OF PINOT NOIR

ABSTRACT

This trial was initiated in 1997 to evaluate the performance of Pinot noir on 19 phylloxera-resistant rootstocks and as an ungrafted vine in the southern Willamette Valley of Oregon. Data were collected in 2000 and 2001. Rootstock affected vegetative growth, chlorophyll content, yield, cluster weight and berry weight in both years, gas exchange measurements in 2000, and fruit composition in 2001. Of the *V. riparia x V. rupestris* rootstocks, 3309C and Schwarzmann imparted low to moderate vigor, as reflected by pruning weight. Millardet et de Grasset 101-14 imparted higher vigor to Pinot noir than 3309C. Based on ripening index values (soluble solids/titratable acidity, Brix/TA), ripening appeared to be earlier for vines grafted to 101-14 Mgt and Schwarzmann than for 3309C. The *V. berlandieri x V. riparia* rootstocks, including 161-49C and 420A, imparted average to higher than average vigor. Ripening appeared to be later than average and berries larger than average for vines grafted to these rootstocks. With the exception of 110R, the *V. berlandieri x V. rupestris* rootstocks had higher than average vigor. Ripening times seemed to be average and berry weights were higher than average for vines grafted to these rootstocks. Of the remaining rootstocks, 1616C performed much like the *V. berlandieri x V. rupestris* rootstocks with an even higher ripening index. Börner, Riparia Gloire, 44-53 Malègue and Gravesac all imparted low to moderate vigor. Berry weights tended to be average to lower than average. Riparia Gloire and Gravesac seemed to impart earlier ripening, while Börner and 44-53 Malègue did not.

INTRODUCTION

Oregon's reputation for producing quality wine was built on the success of its Pinot noir (*Vitis vinifera*). Although other wines from Oregon such as Pinot gris and Merlot have received some attention recently, Pinot noir remains the state's premier variety. It is therefore not surprising that 50 percent of Oregon's grape-growing acreage is devoted to this cultivar [8].

In 1990, when phylloxera was first discovered at a commercial vineyard in Oregon, very little of the state's grape-growing acreage was planted on phylloxera-resistant rootstocks. By 2001, 43 percent was planted on rootstocks [8]. Nearly 80 percent of this acreage is planted on Riparia Gloire and the *V. riparia x V. rupestris* rootstocks 3309 C and 101-14 Mgt [8]. These rootstocks have been used in other viticultural regions to control vine vigor and hasten ripening [10, 39]. Both of these can be desirable traits in Oregon, where controlling vine vigor can be difficult and the growing season is shorter than in many other grape-growing regions. Low vigor rootstocks are also preferable where low yields are desired because it is easier to maintain good vine balance. This may be especially important in Oregon, where Pinot noir is often cropped below 4.5 tonnes per hectare. Low vigor rootstocks may also impart a smaller berry size [7]. This is an advantage in cool climate regions, where color accumulation in Pinot noir and other red varieties can sometimes be a problem. Smaller berries increase the skin to pulp ratio, which can result in better color extraction [6].

A variety of rootstocks make up the remaining 20 percent of those currently being used in Oregon. Eleven percent are *V. berlandieri x V. riparia* rootstocks, which are popular in other cool climate viticultural areas, such as Burgundy and the German wine regions. Another four percent of the state's acreage is planted on the more complex crosses, 44-53 Malègue and 1616 Couderc. Rootstocks from the other major family of crosses, the *V. berlandieri* x *V. rupestris* rootstocks, are seldom if ever used in Oregon.

Growers have made these selections without the benefit of significant rootstock research specific to Oregon. Instead they have had to rely upon research conducted in other grape-growing regions [5]. Because of Oregon's unique environment and cultural practices such information may not be readily transferable. For this reason a rootstock trial was initiated in 1997 at Oregon State University's experimental vineyard, Woodhall III, in Alpine, Oregon. In this trial Pinot noir is grafted on 19 rootstocks and as an ungrafted vine. The primary objective of this study is to evaluate the performance of a number of rootstocks that are currently being used in Oregon relative to their performance in other trials outside the state. A secondary objective is to evaluate the performance of a number of rootstocks that are not currently being used in Oregon, with the hope of identifying promising alternatives.

MATERIALS AND METHODS

Experimental design. In 1997, Pinot noir (clone FPMS 2A) was planted as grafted vines on 19 rootstocks and as an ungrafted vine at Oregon State University's Woodhall III Vineyard near Alpine, Oregon in the southern Willamette Valley. Rootstocks, along with parentage, are listed in Table 1.1. This planting was established on a silty clay loam soil (Bellpine and Willakenzie) series with a pH of 6.1 on a 15° south-facing slope with a spacing of 2.1 m between rows and 1.2 m between vines. Vines were trained using a double Guyot training system with the training wire set at 80 cm above the ground. Vines were divided into five blocks. Each block consisted of six rows, four of which were used in data collection. The first and last rows were guard rows and were not used in data collection. Each row included five experimental units with a guard vine at each end. Each experimental unit consisted of five vines. During this experiment drip irrigation was used to deliver between 7.6 and 13.7 liters of water and 3.6 grams of 20-10-20 NPK fertilizer with micronutrients per vine every two weeks from mid-June to mid-September. Hedging was done at approximately 2.5 meters during the second week of July. Shoot positioning was done every two weeks during the growing season. Non-count shoots were removed early in the season at the 5-leaf stage.

Table 1.1. Rootstocks used in this trial and their parentage.

V. berlandieri x V. riparia	*V. berlandieri x V. rupestris*
125AA Kober	110 Richter
161-49 Couderc	1103 Paulsen
420A Mgt	140 Ruggeri
5BB Kober	99 Richter
5C Teleki	
8B Teleki	*V. riparia x V. rupestris*
SO4	101-14 Mgt
	3309 Couderc
V. riparia x V. cinerea	Schwarzmann
Boerner	
	V. riparia
V. solonis x V. riparia	Riparia Gloire
1616 Couderc	
V. berlandieri x V. riparia x V. rupestris	
Gravesac	
V. riparia x (V. cordifolia x V. rupestris)	
44-53 Malegue	
V. vinifera	
Ungrafted Pinot noir	

Data reported here were collected during 2000 and 2001. In February of 2000 and 2001 each vine was pruned to 8 and 14 buds respectively, and fruiting canes were attached to the training wire. In June of each year a representative vine from each five-vine experimental unit was chosen. One representative shoot from this vine was identified as a data shoot to be used in measurements of shoot diameter and length. The leaf at the tenth node was identified as a data leaf to be used in measurements of gas exchange and chlorophyll content. These measurements were taken, along with shoot diameter, at three times during the growing season, corresponding to bloom, lag and ripening phases (early July, August and September respectively). The same data leaves and shoots were used throughout the growing season, and the same vine within each experimental unit was used for both years.

Vegetative growth and gas exchange. The diameter of the third internode proximal to the trunk of each data shoot was measured. Shoot length was measured in July prior to hedging. The weight of one-year old wood was measured in late January 2001 and early February 2002 after pruning. Photosynthesis (A) and transpiration (E) were measured using a portable infra-red gas analyzer (CIRAS-I, PP Systems, Hitchin, Herts, SG5 IRT, UK) between 09:30 and 13:30 at photosynthetic flux densities of greater than 1000μmol/m^2/s and temperatures between 18° and 28° C. These measurements were used to calculate water use efficiency (WUE).

Chlorophyll content and maximum quantum efficiency of photosynthesis. A SPAD-502 was used to measure leaf greenness. These measurements were used to calculate leaf chlorophyll content with a previously derived regression equation [22]. A portable florescence monitoring system (FMS, Hansatech Instruments LTD, Kings Lynn, UK) was used to measure the maximum quantum efficiency of photosynthesis [23].

Fruit yield and composition. The total fruit from each five-vine experimental unit was weighed. Thirty representative clusters from each experimental unit were used to obtain average cluster weight. Five clusters were then randomly sub-sampled to obtain 100 berry sample weights. Shoots were counted shortly after harvest and used to calculate the yield per shoot. A sub-sample of 25 clusters per experimental unit was crushed at harvest and the juice used to measure soluble solids, pH and titratable acidity. Soluble solids were measured with a digital refractometer (Palette, Atago Co. LTD, 32-10 Honcho, Itabashi-ku Tokyo 173, Japan). An auto-titrator (Mettler DL21, Mettler-Toledo AG, Analytical, Sonnenbergstrasse 74, CH-8603, Schwerzenbach) was used to measure titratable acidity and pH. Ripening index was determined by dividing the soluble solids in degrees Brix by the titratable acidity in grams per liter.

Data analysis. Data were analyzed using the SAS GLM procedure for repeated measures in mixed models for a randomized complete block design (SAS Institute Cary, NC). Means were separated with least significant differences. Because of year x rootstock interactions data was analyzed separately by year.

RESULTS AND DISCUSSION

Rootstock affected estimates of leaf chlorophyll content in both years (Table 1.2). A relationship between leaf chlorophyll content and photosynthesis has been suggested [22]. In this experiment there was a positive correlation between these two variables (r_s=0.08, p<0.01). Leaf chlorophyll content has also been used as an indicator of water stress [29]. The efficiency of energy capture by PSII as estimated by FV/FM has been shown to be sensitive to water stress as well [24, 25]. Florescence measurements were affected by rootstock in 2000 only (Table 1.2), when a positive correlation between chlorophyll content and florescence could be observed (r_s =0.08, p<0.01). However, a rootstock effect on WUE did not occur in either year (Table 1.3). This may have been because vines were irrigated throughout this experiment. Further, rootstock did not affect leaf water potential measurements taken during ripening of 2001 (data not shown). Transpiration and photosynthesis were affected by rootstock (Table 1.3). Transpiration (r_s =0.19, p<0.001) and photosynthesis (r_s =0.10, p<0.001) were both positively correlated with pruning weight, as was chlorophyll content (r_s =0.21, p<0.001) (Tables 1.2, 1.3 and 1.4). There were obvious exceptions: ungrafted vines had among the highest rates of photosynthesis and were among the lowest in vigor. Pinot noir grafted to 1616C had one of the highest pruning weights, and one of the lowest rates of photosynthesis. Exceptions to a direct relationship between rate of photosynthesis and vigor have been previously demonstrated [13]. Pruning weight was also positively correlated with both shoot length (r_s =0.35, p<0.001) and diameter (r_s =0.04, p<0.001) (Table 1.4). Pruning weight was not as well correlated to ripening index (r_s =0.02, p=ns) as to yield per vine (r_s=0.08, p<0.01) (Tables 1.4, 1.5, 1.6 and 1.7). Large differences in yield and pruning weight between years were due to differences in the number of buds left at pruning (8 in 2000 and 12 in 2001). The greater yield observed in 2001 was also affected by a greater fruit set in that year. However, these differences did not affect trends among rootstocks. Yield differences between years may have been responsible for the differences in fruit composition in 2001 that were not observed in 2000 (Table 1.7).

Table 1.2. Leaf chlorophyll content and maximum quantum yield of photosynthesis of Pinot noir grafted to various rootstocks during 2000 and 2001 (n=5).

		Max. quantum yield of photosynthesis[z] (Fv/Fm)		Chlorophyll content[z] (mg cm^{-1})	
Rootstock	Parentage	2000	2001	2000	2001
125AA Kober	*ber x rip*[y]	0.798abcde[w]	0.789	3.37a	3.17a
161-49 Couderc	*ber x rip*	0.805abc	0.783	3.24abc	3.11abc
420A Mgt	*ber x rip*	0.809a	0.759	3.09def	3.15ab
5BB Kober	*ber x rip*	0.790abcdefg	0.780	3.04def	2.92def
5C Teleki	*ber x rip*	0.793abcdefg	0.787	3.26abc	3.18a
8B Teleki	*ber x rip*	0.797abcdef	0.791	3.06def	3.01bcd
SO4	*ber x rip*	0.793abcdefg	0.784	3.07def	2.87defg
Gravesac	*ber x rip x rup*	0.778g	0.774	3.01ef	2.87defg
110 Richter	*ber x rup*	0.791abcdefg	0.784	3.03def	2.85efg
1103 Paulsen	*ber x rup*	0.787cdefg	0.783	3.07def	2.99cde
140 Ruggeri	*ber x rup*	0.789bcdefg	0.782	3.15bcd	2.94def
99 Richter	*ber x rup*	0.806ab	0.795	3.26ab	2.75g
44-53 Malegue	*rip x (cor x rup)*	0.802abcd	0.789	3.02ef	2.79fg
Boerner	*rip x cinerea*	0.785defg	0.800	2.87g	3.00cde
101-14 Mgt	*rip x rup*	0.779fg	0.785	3.02ef	2.88defg
3309 Couderc	*rip x rup*	0.795abcdefg	0.789	2.97fg	2.84efg
Schwarzmann	*rip x rup*	0.780efg	0.808	3.13cde	2.90defg
Riparia Gloire	*rip*	0.803abcd	0.803	3.05def	2.94def
1616 Couderc	*solonis x rip*	0.795abcdefg	0.786	3.08def	3.17a
Ungrafted	*vinifera*	0.804abc	0.776	3.07def	3.02bcd
Sig.[x]		*	ns	***	***
LSD		0.018	0.067	0.13	0.15

[z] Average of leaf chlorophyll content (SPAD) and max. quantum yield of photosynthesis measurements were taken during the first weeks of July, August and September in each year.
[y] ber=V. berlandieri; rip=V. riparia; rup=V. rupestris; cor=V. cordifolia.
[x] Significance for main effect of rootstock. ns=non-significant; *=P<0.05; **=P<0.01; ***=P<0.001.
[w] Means followed by the same letter were not significantly different (P>0.05) protected LSD.

Table 1.3. Gas exchange performance of Pinot noir grafted to various rootstocks in 2000 and 2001 (n=5).

		Transpiration[z] (mmol H_2O m^{-2} s^{-1})		Photosynthesis[z] (umol CO_2 m^{-2} s^{-1})		Water use efficiency[z] (A/E)	
Rootstock	Parentage	2000	2001	2000	2001	2000	2001
125AA Kober	*ber x rip*[y]	3.68a[w]	5.35	13.51ab	13.19	4.18	2.63
161-49 Couderc	*ber x rip*	2.94bc	4.55	11.86cdefg	11.69	5.13	2.79
420A Mgt	*ber x rip*	3.33ab	4.92	12.89abc	12.35	4.74	2.77
5BB Kober	*ber x rip*	2.86bc	4.99	11.04efg	12.23	4.63	2.64
5C Teleki	*ber x rip*	3.04bc	4.71	11.52cdefg	12.38	4.45	2.82
8B Teleki	*ber x rip*	3.13bc	4.78	11.59cdefg	13.22	4.37	2.93
SO4	*ber x rip*	2.92bc	4.52	11.15defg	11.35	4.36	2.74
Gravesac	*ber x rip x rup*	3.17abc	5.17	11.27defg	12.79	4.25	2.69
110 Richter	*ber x rup*	3.00bc	4.70	11.00fg	11.85	4.09	2.74
1103 Paulsen	*ber x rup*	3.65a	5.28	13.65a	13.85	4.37	2.81
140 Ruggeri	*ber x rup*	3.19abc	4.74	11.58cdefg	11.42	4.13	2.63
99 Richter	*ber x rup*	3.25abc	4.55	12.56abcde	11.11	4.69	2.63
44-53 Malegue	*rip x (cor x rup)*	3.06bc	5.11	12.06bcdef	13.19	4.86	2.84
Boerner	*rip x cinerea*	3.00bc	4.81	11.29defg	12.84	4.46	2.81
101-14 Mgt	*rip x rup*	3.27abc	4.59	11.77cdefg	10.87	4.58	2.61
3309 Couderc	*rip x rup*	3.11bc	5.27	11.79cdefg	12.67	4.60	2.62
Schwarzmann	*rip x rup*	3.20abc	5.05	11.85cdefg	12.76	4.73	2.76
Riparia Gloire	*rip*	2.77c	4.62	10.43g	12.24	4.28	2.86
1616 Couderc	*solonis x rip*	2.85bc	4.90	11.01fg	12.88	4.31	2.80
Ungrafted	*vinifera*	3.10bc	5.32	12.65abcd	13.69	4.73	2.81
Sig.[x]		*	ns	**	ns	ns	ns
LSD		0.50	0.73	1.55	1.84	1.15	0.44

[z] Average of gas exchange measurements were taken during the first weeks of July, August and September in each year.
[y] ber=V. berlandieri; rip=V. riparia; rup=V. rupestris; cor=V. cordifolia.
[x] Significance for main effect of rootstock. ns=non-significant; *=P<0.05; **=P<0.01; ***=P<0.001.
[w] Means followed by the same letter were not significantly different (P>0.05) protected LSD.

Table 1. 4. Vegetative growth of Pinot noir grafted to various rootstocks during 2000 and 2001 (n=5).

		Diameter[z] (mm)		Length[z] (cm)		Pruning weight[z] (g/vine)	
Rootstock	Parentage	2000	2001	2000	2001	2000	2001
125AA Kober	*ber x rip*[y]	9.0cde[w]	8.8a	131	116abc	350bc	574a
161-49 Couderc	*ber x rip*	8.9efg	8.7ab	129	118ab	330bcd	470abcd
420A Mgt	*ber x rip*	8.3jk	8.6abc	110	106abcde	308bcdef	486abcd
5BB Kober	*ber x rip*	8.7fghi	7.5i	112	101abcdef	312bcdef	430bcde
5C Teleki	*ber x rip*	9.6a	8.7ab	148	120a	374ab	512abc
8B Teleki	*ber x rip*	8.8efgh	8.4abcd	105	107abcde	302bcdef	370def
SO4	*ber x rip*	9.0cde	7.6hi	128	93bcdef	302bcdef	397bcde
Gravesac	*ber x rip x rup*	9.2c	7.6ghi	124	90def	284cdefg	346defg
110 Richter	*ber x rup*	8.6ghi	8.1cdef	118	93cdef	250efghi	294efg
1103 Paulsen	*ber x rup*	8.8efgh	8.2cde	136	103abcdef	436a	582a
140 Ruggeri	*ber x rup*	8.5ij	7.8efghi	125	93bcdef	354bc	478abcd
99 Richter	*ber x rup*	9.5ab	8.0defgh	128	94abcdef	322bcde	476abcd
44-53 Malegue	*rip x (cor x rup)*	8.4ij	7.6hi	111	93bcdef	270defg	312efg
Boerner	*rip x cinerea*	8.1kl	8.1cdef	89	102abcdef	192hi	328efg
101-14 Mgt	*rip x rup*	8.9cdef	8.2cde	128	103abcdef	294cdef	380cdef
3309 Couderc	*rip x rup*	8.9efg	7.9efghi	115	100abcdef	262defgh	294efg
Schwarzmann	*rip x rup*	9.2cd	8.1defg	117	90def	236fghi	305efg
Riparia Gloire	*rip*	8.6ghij	7.7fghi	113	78f	210ghi	226g
1616 Couderc	*solonis x rip*	7.9kl	8.3bcde	110	112ab	328bcd	524ab
Ungrafted	*vinifera*	9.2bc	7.9efghi	114	83ef	174i	248fg
Sig.[x]		***	***	ns	***	***	***
LSD		0.3	0.5	44	26	77	140

[z] Shoot diameter measurements are means of measurements taken during the first weeks of July, August and September in each year. Length measurements were taken only in the first week of July. Pruning weights were measured during January of 2001 and February of 2002.

[y] ber=V. berlandieri; rip=V. riparia; rup=V. rupestris; cor=V. cordifolia.

[x] Significance for main effect of rootstock. ns=non-significant; *=P<0.05; **=P<0.01; ***=P<0.001.

[w] Means followed by the same letter were not significantly different (P>0.05) protected LSD.

Table 1.5. Fruit yield and yield components of Pinot noir grafted to various rootstocks in 2000 (n=5).

Rootstock	Parentage	Shoots per vine	Yield (kg/vine)	Clusters/ shoot	Cluster weight (g)	Berry weight (g)	Berries/ cluster
125AA Kober	*ber x rip*[z]	8.7	1.66a[x]	1.6	119a	1.27a	97
161-49 Couderc	*ber x rip*	8.6	1.53abcde	1.7	104abc	1.14abcd	92
420A Mgt	*ber x rip*	8.6	1.89a	1.8	122a	1.14abcd	109
5BB Kober	*ber x rip*	8.0	1.79abc	2.0	113ab	1.14abcd	99
5C Teleki	*ber x rip*	9.8	1.86ab	1.8	110abc	1.10bcde	102
8B Teleki	*ber x rip*	9.2	1.65abcde	1.7	106abc	1.10bcde	99
SO4	*ber x rip*	8.6	1.71abcd	1.9	105abc	1.13bcd	93
Gravesac	*ber x rip x rup*	9.2	1.59abcde	1.7	104abc	1.06cde	99
110 Richter	*ber x rup*	8.9	1.47abcde	1.7	96abc	1.10bcde	89
1103 Paulsen	*ber x rup*	9.0	1.86ab	1.9	110abc	1.21ab	90
140 Ruggeri	*ber x rup*	9.1	1.73abcd	1.8	105abc	1.16abc	91
99 Richter	*ber x rup*	8.7	1.57abcde	1.8	99abc	1.08bcde	91
44-53 Malegue	*rip x (cor x rup)*	8.5	1.50abcde	1.8	95abc	1.10de	94
Boerner	*rip x cinerea*	7.6	1.54abcde	2.0	101abc	1.06cde	97
101-14 Mgt	*rip x rup*	9.0	1.32cde	1.8	82c	1.02de	79
3309 Couderc	*rip x rup*	8.6	1.55abcde	1.8	103abc	1.10bcde	96
Schwarzmann	*rip x rup*	8.1	1.16de	1.7	89bc	0.99e	91
Riparia Gloire	*rip*	8.4	1.39bcde	1.7	97abc	0.98e	100
1616 Couderc	*solonis x rip*	9.0	1.65abcde	1.7	105abc	1.10bcde	98
Ungrafted	*vinifera*	11.1	1.17e	1.5	91bc	1.03cde	90
Sig.[y]		ns	*	ns	*	***	ns
LSD		ns	0.48	ns	28.4	0.13	28

[z] ber=V. berlandieri; rip=V. riparia; rup=V. rupestris; cor=V. cordifolia.

[y] Significance for main effect of rootstock. ns=non-significant; *=P<0.05; **=P<0.01; ***=P<0.001.

[x] Means followed by the same letter within rootstock were not significantly different (P>0.05) protected LSD.

Table 1.6. Fruit yield data for Pinot noir grafted to various rootstocks in 2001 (n=5).

Rootstock	Parentage	Shoots per vine	Yield (kg/vine)	Clus./ shoot	Cluster weight (g)	Berry weight (g)	Berries/ cluster
125AA Kober	*ber x rip*[z]	15.5a[x]	5.4 a	2.1	165a	1.28ab	133abc
161-49 Couderc	*ber x rip*	14.5abc	4.0 bcdef	1.9	145abcd	1.28ab	113bcdef
420A Mgt	*ber x rip*	15.6a	4.7 abc	2.0	155ab	1.17abcd	134ab
5BB Kober	*ber x rip*	13.4cdef	4.5 abcd	2.2	154ab	1.29ab	119bcdef
5C Teleki	*ber x rip*	14.2abcd	4.1 bcde	2.0	147abcd	1.19abcd	124abcde
8B Teleki	*ber x rip*	13.7bcdef	3.6 efgh	2.1	124de	1.14bcd	111ef
SO4	*ber x rip*	14.7abc	4.0 cdef	2.0	136bcde	1.09cd	129abcde
Gravesac	*ber x rip x rup*	13.6bcdef	3.7 defg	2.2	124de	1.20abcd	103f
110 Richter	*ber x rup*	13.5bcdef	3.4 efgh	2.0	133bcde	1.18abcd	114bcdef
1103 Paulsen	*ber x rup*	15.2ab	4.9 ab	2.1	150abc	1.31ab	115bcdef
140 Ruggeri	*ber x rup*	15.2ab	4.1 bcdef	1.9	141bcde	1.27ab	111def
99 Richter	*ber x rup*	15.6a	3.9 cdef	1.9	135bcde	1.23abc	110ef
44-53 Malegue	*rip x (cor x rup)*	12.4def	3.8 defg	2.2	134bcde	1.08cd	125abcde
Boerner	*rip x cinerea*	14.0abcde	3.7 defg	1.9	147abcd	1.08cd	139a
101-14 Mgt	*rip x rup*	14.1abcde	3.2 fgh	1.8	119e	1.06d	113cdef
3309 Couderc	*rip x rup*	13.4cdef	3.9 cdef	1.9	148abc	1.14bcd	132abcd
Schwarzmann	*rip x rup*	12.5def	3.3 efgh	1.9	139bcde	1.20abcd	117bcdef abcde
Riparia Gloire	*rip*	12.3ef	2.9 gh	1.9	127cde	1.07cd	119f
1616 Couderc	*solonis x rip*	13.9abcde	3.9 cdef	1.9	152ab	1.29ab	119bcdef
Ungrafted	*vinifera*	12.0f	2.7 h	1.9	119e	1.19abcd	100f
Sig.[y]		***	***	ns	**	*	*
LSD		1.8	0.92	0.29	23.6	0.16	20

[z] ber=V. berlandieri; rip=V. riparia; rup=V. rupestris; cor=V. cordifolia.
[y] Significance for main effect of rootstock. ns=non-significant; *=P<0.05; **=P<0.01; ***=P<0.001.
[x] Means followed by the same letter within rootstock are not significantly different (P>0.05) protected LSD.

Table 1.7. Fruit composition data for Pinot noir grafted to various rootstocks in 2000 and 2001 (n=5).

		pH		Titratable acidity (g/L)		Brix		Ripening index (Brix/TA)	
Rootstock	Parentage	2000	2001	2000	2001	2000	2001	2000	2001
125AA Kober	*ber x rip*[z]	3.16	3.03bcd[x]	7.35	7.63abc	23.1	21.3bc	3.15	2.80efg
161-49 Couderc	*ber x rip*	3.17	3.03bcd	7.12	7.45abcd	23.8	22.7a	3.36	3.09bcdef
420A Mgt	*ber x rip*	3.14	2.97de	7.79	7.83ab	23.3	21.2c	3.00	2.72fg
5BB Kober	*ber x rip*	3.15	2.99cde	7.58	7.85ab	24.0	22.1abc	3.21	2.84efg
5C Teleki	*ber x rip*	3.18	3.03bcd	6.43	7.39abcde	23.3	22.4abc	4.72	3.04cdefg
8B Teleki	*ber x rip*	3.17	3.01bcde	7.50	7.44abcd	23.6	22.6ab	3.15	3.04cdefg
SO4	*ber x rip*	3.17	2.97de	7.56	7.60abc	23.4	22.0abc	3.11	2.90defg
Gravesac	*ber x rip x rup*	3.14	3.04bcd	7.73	6.81efg	23.4	22.6ab	3.03	3.34abc
110 Richter	*ber x rup*	3.15	3.01bcde	7.39	7.08cdefg	23.4	21.9abc	3.18	3.10bcdef
1103 Paulsen	*ber x rup*	3.12	3.03bcd	7.53	7.51abcd	23.3	22.1abc	3.10	2.96cdefg
140 Ruggeri	*ber x rup*	3.12	3.06abc	7.75	7.16cdef	23.8	22.8a	3.08	3.19bcde
99 Richter	*ber x rup*	3.13	3.06abc	7.45	7.04cdefg	23.3	22.1abc	3.14	3.16bcde
44-53 Malegue	*rip x (cor x rup)*	3.13	2.98de	7.71	7.54abcd	23.5	21.0c	3.06	2.81efg
Boerner	*rip x cinerea*	3.14	2.95e	7.77	7.94a	23.0	21.0c	3.05	2.66g
101-14 Mgt	*rip x rup*	3.10	3.07ab	7.76	6.78efg	23.6	22.7a	3.06	3.38abc
3309 Couderc	*rip x rup*	3.15	3.01bcde	6.85	7.26bcde	23.2	21.3bc	3.41	2.95cdefg
Schwarzmann	*rip x rup*	3.16	3.11a	7.32	6.54fg	23.7	22.6ab	3.25	3.50ab
Riparia Gloire	*rip*	3.14	3.01bcde	7.41	7.02cdefg	23.4	22.1abc	3.18	3.19bcde
1616 Couderc	*solonis x rip*	3.18	3.08ab	7.42	6.96defg	23.4	22.8a	3.18	3.28abcd
Ungrafted	*vinifera*	3.18	3.06ab	6.93	6.50g	23.5	23.1a	3.42	3.63a
Sig.[y]		ns	***	ns	***	ns	*	ns	**
LSD		0.17	0.07	1.91	0.63	1.10	1.34	2.10	0.43

[z] ber=V. berlandieri; rip=V. riparia; rup=V. rupestris; cor=V. cordifolia.
[y] Significance for main effect of rootstock. ns=non-significant; *=P<0.05; **=P<0.01; ***=P<0.001.

[x] Means followed by the same letter within rootstock are not significantly different (P>0.05) protected LSD.

Ungrafted *V. vinifera* is typically lower in vigor than *V. vinifera* grafted to phylloxera resistant rootstocks [46]. Ungrafted vines may produce either larger or smaller berries than grafted vines, depending on variety [2]. In this study, ungrafted Pinot noir was low in vigor, as reflected by pruning weight (Table 1.4), in both years and produced berries of average weight (Tables 1.5 and 1.6). Based on 2001 ripening index values, ungrafted vines ripened fruit earlier than all grafted vines in both years (Table 1.7).

Of the *V. riparia x V. rupestris* rootstocks, Galet [39] suggested that 3309C is more vigorous than 101-14 Mgt. This observation was confirmed by subsequent research [45]. However, other research has shown 3309C to be either less or more vigorous than 101-14 Mgt depending upon scion variety [35]. In this study, Pinot noir grafted to 101-14 Mgt had higher pruning weights than 3309C or Schwarzmann (Table 1.4). Both 101-14 Mgt [47] and Schwarzmann [48] have been shown to decrease berry size relative to other rootstocks. In this trial 101-14 Mgt imparted low berry weight in both years and Schwarzmann in one year, while 3309C imparted average berry weight in both years (Table 1.5 and 1.6). 101-14 Mgt is known for its capacity to ripen fruit early [10]. This quality has also been observed in vines grafted to Schwarzmann [49]. In 2001 of this trial both of these rootstocks imparted early ripening based on ripening index values (Table 1.7). Pinot noir grafted to the *riparia x rupestris* rootstocks produced must of higher than average pH and soluble solids, and lower than average titratable acidity. Must from Pinot noir grafted to 3309C was lower than average in all of these parameters, as this rootstock appeared to delay ripening.

420A has been referred to as “a weak rootstock, slightly more vigorous than Riparia Gloire” [39]. In Italy, however, it is known as a moderate vigor rootstock [50]. Other studies have found 161-49C to impart low vigor [51]. In this trial imparted vigor for vines grafted to the *V. berlandieri* x *V. riparia* rootstocks, including 420A and 161-49C, ranged from average to higher than average in both years (Table 1.4). Pinot noir grafted to the *V. berlandieri* x *V. riparia* crosses also produced average or larger than average berries in both years (Tables 1.5 and 1.6). Must pH values from these vines were average or lower than average in 2001 and titratable acidities higher than average (Table 1.7). Soluble solids measurements varied, but all ripening index values were average or lower than average. In the case of these rootstocks, higher vigor appeared to delay ripening. This is in contrast to the findings of Parejo et al. [51], where the *V. berlandieri* x *V. riparia* rootstocks seemed to impart earlier ripening in comparison to the *V. berlandieri* x *V. rupestris* rootstocks.

According to Pongràcz, the *V. berlandieri* x *V. rupestris* rootstocks 1103P, 110R 140Ru and 99R all impart high vigor. Howell [1] ranks 110R and 1103P lower than 99R and 140Ru in imparted vigor. Parejo et al. [51] found that 140Ru, 1103P and 110R rank in this order from highest to lowest imparted vigor. Ezzahouani and Williams found 99R, 110R and 1103 ranked this in order from highest to lowest [47]. In the present study, 1103P imparted the highest pruning weight of all rootstocks in both years (Table 1.4). 140Ru and 99R also imparted high vigor. However, 110R imparted only moderate pruning weight. Pinot noir grafted to 1103P and 140Ru produced berries of higher weight in both years, while Pinot noir grafted to 99R and 110 R produced average weight berries (Tables 1.5 and 1.6). Parejo et al. [51] stated that higher vigor in the *V. berlandieri* x *V. rupestris* rootstocks led to delayed ripening, but that was not the case in the present study. In the second year of evaluation, must from Pinot noir grafted to these rootstocks had average to higher than average soluble solids and pH and average titratable acidity (Table 1.7). All of these vines had average ripening index values. Unlike the *V. berlandieri* x *V. riparia* rootstocks, higher vigor did not appear to delay ripening for vines grafted to 1103P, 140Ru and 99R.

Of the remaining rootstocks in this trial, 1616C performed very much like the *berlandieri x rupestris* rootstocks. Although Galet [39] refers to 1616C as a weak rootstock, it has demonstrated high vigor on a fertile site in California [52]. 1616C imparted high pruning weights in both years of this trial (Table 1.4). Berry weights for Pinot noir grafted to this rootstock were average in 2000 and higher than average in 2001 (Tables 1.5 and 1.6). Must from vines grafted to 1616C had high pH and soluble solids, and low titratable acidity in 2001 (Table 1.7). Despite high vigor conferred by 1616C, the ripening index values were among the highest.

According to Wolpert [52], Riparia Gloire has a reputation for low vigor even in fertile sites but little is known about the performance of this rootstock under current viticultural practice. In this trial, Riparia Gloire imparted very low pruning weight in both years (Table 1.4). Berry weights from Pinot noir grafted to Riparia Gloire were also among the lowest for both years (Tables 1.5 and 1.6). Must from the fruit of Pinot noir grafted to this rootstock were of lower than average pH and titratable acidity, and average soluble solids (Table 1.7). Ripening index values were average for these vines.

Börner is a new rootstock, known primarily for its outstanding phylloxera resistance [53]. Its performance had not been evaluated in a field trial in the U.S. prior to this study. In this study, vines grafted to Börner had low pruning weights in both years (Table 1.4). This rootstock has small, delicate roots and is slow to establish. Vigor did appear to increase slightly in the second year. Berry weights were average in 2000 and lower than average in 2001 (Tables 1.5 and 1.6). Must pH and soluble solids from these vines were the lowest, and titratable acidity the highest in 2001 (Table 1.7). Vines grafted to Börner had the lowest ripening index value.

44-53 Malègue has been rated a moderate vigor rootstock [1]. In this study, it imparted low to moderate pruning weight in both years (Table 1.4). Berry weights were among the lowest (Tables 1.5 and 1.6). Must from Pinot noir grafted to this rootstock had lower than average soluble solids and pH and higher titratable acidity (Table 1.7). The ripening index value for these vines was also low, in contrast to previous assertions that they ripen their grapes well [10].

Gravesac is another newer release that has not been evaluated extensively in the US. In this study, Pinot noir grafted to Gravesac had lower than average pruning weights (Table 1.4). Berry weights for these vines were average in both years (Tables 1.5 and 1.6). Must from these vines was higher than average in pH and soluble solids in 2001 and lower than average in titratable acidity (Table 1.7). The ripening index for Pinot noir grafted to Gravesac was among the highest.

CONCLUSION

Oregon vineyard sites tend to be high in vigor, yet Pinot noir is cropped at very low levels. Under these circumstances, rootstocks that impart low or moderate vigor are useful in maintaining proper vine balance. Further, because of Oregon's short growing season, rootstocks that impart earlier ripening are often preferred. Rootstocks are generally not selected for their effect on berry size. However this trait could provide an advantage in cool climate areas, where color accumulation can be problematic.

Riparia Gloire and the *V. riparia x V. rupestris* rootstocks, 101-14 Mgt and 3309C, are the most widely used in Oregon. It has been suggested that these rootstocks impart low to moderate vigor and earlier ripening [39]. In this trial, 101-14 Mgt imparted higher vigor and 3309C imparted an average ripening time (Table 1.8). Riparia Gloire imparted both low vigor and earlier ripening. All three of these rootstocks imparted lower berry weights. The *V. berlandieri* x *V. riparia* rootstocks, which are popular in other cool climate viticultural regions, all imparted higher vigor and ripening that was, except for 161-49C, average or later than average. Berry weight for Pinot noir grafted to these rootstocks were all average or heavier than average. Of the *V. berlandieri* x *V. rupestris* rootstocks, which are not widely used in Oregon, all but 110R imparted higher vigor. Unlike the *berlandieri* x *V. riparia* rootstocks, ripening was not delayed by increased vigor. Berry weight for Pinot noir grafted to these rootstocks was among the highest. Of the more complex crosses, 44-53 Malègue imparted moderate vigor, delayed ripening and a smaller berry weight. 1616C imparted higher vigor and early ripening, while berry weight was average.

Of rootstocks that are not currently being used in Oregon, Schwarzmann incorporated even lower vigor than 3309C with the early ripening of 101-14 Mgt, while also imparting low berry weight (Table 1.8). Gravesac imparted moderate vigor with earlier ripening and low berry weight. 110R imparted both earlier ripening and low vigor. However, because this rootstock has typically been thought to impart higher vigor [10] this result should be viewed with caution.

Ungrafted Pinot noir combined the desirable characteristics of low vigor, early ripening and smaller berries (Table 1.8). However, in all but a small minority of cases, it would be unwise to plant ungrafted *V. vinifera* in any area where phylloxera is present.

Table 2.8. Vigor vs. ripening time and berry weight for Pinot noir grafted to various rootstock.

	Ripening time				
	very early	early	average	late	very late
very high vigor			1103P^{5}		
vigorous	1616C^{3} 101-14 Mgt^{1}	99R^{3} 140R^{4} 161-49C^{4}	5C^{3} 8B^{3}	125AA^{4} 5BB^{4} SO4^{3}	420A Mgt^{3}
moderate vigor	Gravesac^{2}		3309C^{2}	44-53 Malegue^{1}	Boerner^{2}
low vigor	Schwarzmann^{2}	110R^{3}			
very low vigor	Ungrafted^{2}	Riparia Gloire^{1}			

Relative berry weight is designated as follows: 1=very low, 2=low, 3=average, 4=high, 5=very high.

Rootstock selections should be based on the requirements of each individual site and the objectives of the grower. No single rootstock, or even group of rootstocks, will suit the requirements of every site within an appellation. It is important to consider differences is soil type, climate, etc. when attempting to apply the results of a rootstock trial to a particular site. It is especially important to note that the vines in this trial were irrigated during both years of this experiment. Nevertheless, results from this trial may give growers more information on which to base their rootstock choices.

CHAPTER 3: THE EFFECT OF ROOTSTOCK ON THE PERFORMANCE OF MERLOT, CHARDONNAY, PINOT GRIS AND PINOT NOIR

ABSTRACT

This trial was planted in 1997 to evaluate the performance of four varieties grafted to nine phylloxera-resistant rootstock, and as an ungrafted vine in the southern Willamette Valley of Oregon. Data were collected in 2000 and 2001. The *V. berlandieri x V. riparia* rootstocks imparted more vigor, a higher yield, a higher berry weight and delayed ripening as reflected by the ripening index (soluble solids/titratable acidity, Brix/TA). 101-14 Mgt imparted a higher pruning weight, lower berry weight and earlier ripening than 3309C. 110R, 44-53 Malègue and Gravesac conferred moderate vigor as reflected by pruning weight. Riparia Gloire conferred lower vigor. Ripening times imparted by these rootstocks ranged from early for Riparia Gloire and Gravesac, to average for 110R and later for 44-53 Malègue. Berry weights were average for scion grafted to 110R and Gravesac, and low for scion grafted to Riparia Gloire and 44-53 Malègue. Of the varieties, Merlot had high leaf chlorophyll content, and low rates of gas exchange. Pruning weight was highest for Chardonnay. Pinot noir had high yield and a greater number of berries. Interactions between rootstock and variety for variables chlorophyll content, shoot diameter, pruning weight and juice pH and T.A. indicate that different scion varieties perform differently on a given rootstock.

INTRODUCTION

At the time phylloxera was discovered in a commercial vineyard in Oregon in 1990, very little of the state's vineyard acreage was planted on phylloxera-resistant rootstocks. Today 43 percent of the state's 11,100 vineyard acres are planted on rootstocks [8]. Rootstock selection during the past decade in Oregon has been based primarily on information from outside the region [5]. Very little rootstock research has been performed in Oregon; and of that, none had been performed on a variety other than Pinot noir. In fact, until recently, no comprehensive rootstock evaluation had been performed in the Pacific Northwest [2]. In addition, few rootstock trials have been performed as a factorial, although it has been known since the early use of rootstocks that different scion varieties perform differently on different rootstocks. In other words, different *Vitis vinifera* cultivars are known to have different affinities for a given rootstock [7]. In order to provide growers with more information specific to Oregon, this trial was planted in 1997 at Oregon State University's experimental vineyard, Woodhall III, near Alpine, Oregon.

All of the nine rootstocks selected for this trial are believed to have adequate phylloxera resistance. Oregon's most widely used rootstocks were selected, as well as some rootstocks that are not being used here but might be well suited to the state's unique viticultural demands. Riparia Gloire (*Vitis riparia)* and the *V. riparia x V. rupestris* rootstocks, 3309C and 101-14 Mgt, account for nearly 80 percent of all rootstocks in use in Oregon [8]. These rootstocks are believed to impart low vigor and early ripening in other viticultural regions [39]. Both of these attributes could be advantageous in Oregon, where excessive vine vigor is often a problem and the growing season is shorter than in other grape-growing regions. In addition, low vigor rootstocks often impart a low berry weight [7]. This can be an advantage with red varieties in cooler climates, where color accumulation is sometimes problematic. An increased skin to pulp ratio facilitates color extraction, and is often the basis for clonal selection [6]. The *V. berlandieri x V. riparia* rootstocks SO4, 420A Mgt and 5BB are popular in many cool climate viticultural regions such as Burgundy and the German appellations. In Oregon they account for 11 percent of rootstocks in current use. Like the other *V. berlandieri x V. rupestris* rootstocks, 110R has not been widely planted in Oregon. These rootstocks are favored in regions where higher drought tolerance is desired. The two remaining rootstocks are more complex crossings. 44-53 Malègue is being used on a limited basis in Oregon. Gravesac is a newer release, which is not yet being used in the state.

The varieties selected for this trial included four of Oregon's five most planted cultivars: Pinot noir, Pinot gris, Chardonnay and Merlot (*V. vinifera*) [8]. Pinot noir is Oregon's most planted variety, accounting for 50 percent of vineyard acreage. Pinot gris is the state's second most planted variety. Acreage devoted to this variety has increased rapidly over the past few years. Chardonnay was, until recently, the state's most widely planted white variety. It is still the third most planted of all varieties. Merlot acreage has also seen a rapid increase in the past several years. Most of this acreage is in the Columbia Valley and the state's southern appellations: the Rogue, Umpqua and Applegate valleys.

For these four varieties, Jackson and Schuster recommended the following types of rootstocks [54]. Vigorous rootstocks are recommended for Chardonnay, except on fertile soils. Vigorous rootstocks are also recommended for Pinot gris. For Merlot, low to moderate vigor rootstocks are recommended. And vigorous to moderately vigorous rootstocks are suggested for Pinot noir.

The objective of this experiment was to determine if rootstocks that are commonly used in Oregon perform as they have in other trials outside the state. Another objective was to evaluate a few rootstocks that are not being used in Oregon, but which may be well suited to the state's unique soils, climate and cultural practices.

MATERIALS AND METHODS

Experimental design. In 1997 Pinot noir (FPMS 2A), Pinot gris (Colmar 146), Chardonnay (Dijon 95) and Merlot (UCD 3) were planted on nine rootstocks and as ungrafted vines at Oregon State University's Woodhall III Vineyard near Alpine, Oregon in the southern Willamette Valley. The rootstocks included were: Riparia Gloire (*V. riparia*); 3309C and 101-14 Mgt (*V. riparia x V. rupestris*); SO4, 5BB and 420A Mgt (*V. berlandieri x V. riparia*); 110R (*V. berlandieri x V. rupestris*); 44-53 Malègue (*V. riparia x V. cordifolia x V. rupestris*); and Gravesac (*V. berlandieri x V. riparia x V. rupestris*). This planting was established on silty clay loam soils (Bellpine and Willakenzie) with a pH of 6.1 on a 15° south-facing slope at 2.1 m between rows and 1.2 m between vines. The training system was a double Guyot with the training wire set at 80 cm above the ground. Treatments were divided among five blocks in a split-plot design. Each block contained four rows, with the outer row on each side acting as a guard row that was not used in data collection. Each row contains five experimental units, with a guard vine at each end. Experimental units consisted of five vines of the same scion-rootstock combination. During this experiment drip irrigation was used to deliver between 7.6 and 13.7 liters of water and 3.6 grams of 20-10-20 NPK fertilizer with micronutrients per vine every two weeks from mid-June to mid-September. Vines were hedged during the second week of July. Shoots were positioned every two weeks during the growing season, at which time laterals were removed.

The data reported here were collected in 2000 and 2001. In January of 2000 and 2001 each vine was pruned to 8 and 14 buds respectively, and fruiting canes were attached to the training wire. In June of each year a representative vine from each five-vine replicate was chosen. One representative shoot from this vine was identified as a data shoot to be used in measurements of shoot diameter and length. The leaf at the tenth node was identified as a data leaf to be used in measurements of gas exchange and chlorophyll content. These measurements were taken, along with shoot diameter, at three times during the growing season, corresponding to bloom, lag and ripening phases (early July, August and September respectively). The same data leaves and shoots were used throughout the growing season. The same vine within each replicate was used for both years.

Vegetative growth and gas exchange. The diameter of the third internode of each data shoot was measured. Shoot length was measured in July prior to hedging. One-year old wood was weighed at pruning in late January 2001 and 2002. Photosynthesis (A) and transpiration (E) were measured using a portable infra-red gas analyzer (CIRAS-I, PP Systems, Hitchin, Herts, SG5 IRT, UK) between 09:30 and 13:30 at photosynthetic flux densities of greater than 1000μmol/m^2/s and temperatures between 18° and 28° C. These measurements were used to calculate water use efficiency (A/E).

Chlorophyll content and maximum quantum efficiency of photosynthesis. A SPAD-502 was used to measure leaf greenness. These measurements were used to calculate leaf chlorophyll content with a previously derived regression equation [22]. A portable florescence monitoring system (FMS, Hansatech Instruments LTD, Kings Lynn, UK) was used to measure the maximum quantum efficiency of photosynthesis [23].

Fruit yield and composition. The total fruit from each five-vine replicate was weighed together. Thirty representative clusters from each replicate were used to obtain cluster weights. Five clusters were used obtain berries for 100 berry sample weights. Shoots were counted shortly after harvest and used to calculate the yield per shoot. A sub-sample of 25 clusters per experimental unit was crushed at harvest and the juice used to measure soluble solids, pH and titratable acidity. Soluble solids were measured with a digital refractometer (Palette, Atago Co. LTD, 32-10 Honcho, Itabashi-ku Tokyo 173, Japan). An auto-titrator (Mettler DL21, Mettler-Toledo AG, Analytical, Sonnenbergstrasse 74, CH-8603, Schwerzenbach) was used to measure titratable acidity and pH. Ripening index was determined by dividing the soluble solids in degrees Brix by the titratable acidity [45].

Data were analyzed statistically using the SAS GLM procedure for repeated measures of mixed models in a split plot design (SAS Institute Cary, NC). Means were separated with least significant differences. Data for ungrafted vines were analyzed separately. Because of year x rootstock interactions, data were analyzed separately by year. Where variety x rootstock interactions occurred, data were analyzed separately by variety.

RESULTS AND DISCUSSION

For all variety-rootstock combinations, scions grafted to 420A and 5BB had the highest leaf chlorophyll content, and vines grafted to 420A the highest Fv/Fm in 2001 (Table 2.1). Of all combinations for the main effect of variety, Merlot had higher leaf chlorophyll contents and higher Fv/Fm in 2001. A relationship between leaf chlorophyll content and rate of photosynthesis has been suggested [22]. A positive correlation between these two variables was observed in this experiment (r_s=0.04, p<0.01). Leaf greenness has also been used to measure water stress on grapevines [29]. Fv/Fm has been used as an indicator of water stress as well [23, 25]. However rootstock did not affect WUE in this experiment (Tables 2.2 and 2.3), possibly because vines were irrigated. Leaf water potential measurements taken in mid-September also indicated that vines were not under significant water stress (data not shown).

Table 2.1. Leaf chlorophyll content and Fv/Fm for 4 varieties grafted to 9 rootstocks in 2000 and 2001. Ungrafted vines are not included in analysis (rootstock, n=20; variety n=45).

Treatment		Max. quantum yield of photosynthesis[z] (Fv/Fm)		Chlorophyll content[z] (mg cm-1)	
Rootstock	Parentage	2000	2001	2000	2001
420A Mgt	*ber x rip*[y]	0.796[w]	0.813a	3.19ab	3.39a
5BB Kober	*ber x rip*	0.791	0.797bc	3.25a	3.07b
SO4	*ber x rip*	0.795	0.800bc	3.15bc	3.14b
Gravesac	*ber x rip x rup*	0.787	0.794bc	3.15bc	3.11b
110 Richter	*ber x rup*	0.792	0.797bc	3.11bc	3.08b
44-53 Malegue	*rip x (cor x rup)*	0.788	0.793bc	3.09c	3.06b
101-14 Mg	*rip x rup*	0.788	0.790c	3.08c	3.07b
3309 Couderc	*rip x rup*	0.794	0.793bc	3.10bc	3.04b
Riparia Gloire	*rip*	0.801	0.802b	3.14bc	3.14b
Sig. For rootstock[x]		ns	**	*	***
LSD		0.014	0.010	0.10	0.08
Variety					
Pinot noir		0.783	0.794b	3.03 b	2.90d
Pinot gris		0.784	0.791b	3.19 a	3.04c
Chardonnay		0.793	0.797b	3.14 a	3.18b
Merlot		0.789	0.809a	3.20 a	3.36a
Sig. For variety[x]		ns	***	***	***
LSD		0.009	0.007	0.06	0.08
Rootstock x variety interaction		ns	ns	ns	**

[z] Leaf chlorophyll content (SPAD) and maximum quantum yield of photosynthesis data are an average of three measurements taken during the growing season in the first weeks of July, August and September.

[y] *ber: V berlandieri; rip: V. riparia; rup: V. rupestris; cor: V. cordifolia.*

[x] Significance for main effect of rootstock or variety.

[w] Means followed by the same letter within rootstock or variety are not significantly different (P>0.05) protected LSD. ns=non-significant; *=P<0,05; **=P<0.01; ***=P<0.001.

Table 2.2. Gas exchange performance of 4 varieties grafted to 9 rootstocks in 2000 and 2001. Ungrafted vines were not included in analysis (rootstock, n=20; variety n=45).

Treatment		Transpiration[z] (mmol H2O m-2 s-1)		Photosynthesis[z] (umol CO2 m-2 s-1)		Water use efficiency[z] (A/E)	
Rootstock	Parentage	2000	2001	2000	2001	2000	2001
420A Mgt	*ber x rip*[y]	3.21 a[w]	4.73 ab	12.31 a	12.86 ab	4.54	2.92
5BB Kober	*ber x rip*	3.01 ab	4.82 ab	11.70 ab	12.26 abc	4.54	2.79
SO4	*ber x rip*	2.80 bcd	4.31 c	10.53 de	11.23 c	4.30	2.83
Gravesac	*ber x rip x rup*	2.95 bc	4.76 ab	11.43 bc	12.27 abc	4.88	2.79
110 Richter	*ber x rup*	2.94 bc	4.71 abc	10.92 bcd	11.86 abc	4.30	2.77
44-53 Malegue	*rip x (cor x rup)*	2.72 cd	4.73 ab	10.59 cde	12.00 abc	4.54	2.83
101-14 Mg	*rip x rup*	2.93 bc	4.80 ab	11.20 bcd	12.40 ab	4.56	2.81
3309 Couderc	*rip x rup*	2.98 ab	5.10 a	11.74 ab	12.87 a	4.62	2.78
Riparia Gloire	*rip*	2.60 d	4.47 bc	9.87 e	11.74 bc	4.42	2.88
Sig. For rootstock[x]		*	**	***	*	ns	ns
LSD		0.24	0.37	0.89	0.96	0.53	0.22
Variety							
Pinot noir		3.06 a	4.87	11.49 a	12.17	4.49	2.72
Pinot gris		2.99 a	4.77	11.84 a	12.34	4.68	2.87
Chardonnay		2.95 a	4.68	11.26 a	12.20	4.42	2.83
Merlot		2.63 b	4.54	9.98 b	11.95	4.50	2.87
Sig. For variety[x]		***	ns	***	ns	ns	ns
LSD		0.16	0.24	0.60	0.64	0.35	0.14
Rootstock x variety interaction		ns	ns	ns	ns	ns	ns

[z] Gas exchange data are an average of three measurements taken during the growing season in the first weeks of July, August and September.

[y] *ber: V berlandieri; rip: V. riparia; rup: V. rupestris; cor: V. cordifolia.*

[x] Significance for main effect of rootstock or variety.

[w] Means followed by the same letter within rootstock or variety are not significantly different (P>0.05) protected LSD. ns=non-significant; *=P<0,05; **=P<0.01; ***=P<0.001.

Table 2.3. Vegetative growth of 4 varieties grafted to 9 rootstocks during 2000 and 2001. Ungrafted vines were not included in analysis (rootstock, n=20; variety n=45).

Treatment		Shoot Diameter[z] (mm)		Shoot Length[z] (cm)		Pruning weight[z] (g/vine)	
Rootstock	Parentage	2000	2001	2000	2001	2000	2001
420A Mgt	*ber x rip*[y]	8.60ab[w]	8.26ab	125	110	337a	532a
5BB Kober	*ber x rip*	8.70a	7.77de	125	105	329a	501ab
SO4	*ber x rip*	8.44abc	8.27a	120	109	324a	479bc
Gravesac	*ber x rip x rup*	8.63ab	7.93abcd	120	101	308ab	413d
110 Richter	*ber x rup*	8.45abc	8.16abc	117	100	287bc	409d
44-53 Malegue	*rip x (cor x rup)*	8.31bc	7.84cd	114	96	257c	295f
101-14 Mg	*rip x rup*	8.34bc	7.95abcd	120	103	322a	446cd
3309 Couderc	*rip x rup*	8.61ab	7.91bcd	119	141	280bc	343e
Riparia Gloire	*rip*	8.17c	7.42e	107	86	214d	248g
Sig. For rootstock[x]		*	***	ns	ns	***	***
LSD		0.33	0.35	14	64	32	56
Variety							
Pinot noir		8.73a	7.85c	118b	95	277b	352cd
Pinot gris		8.20b	7.58d	129a	108	307a	404bc
Chardonnay		8.69a	8.28a	121ab	120	291ab	425ab
Merlot		8.27b	8.07b	106c	98	305a	447a
Sig. For variety[x]		***	***	***	ns	*	***
LSD		0.22	0.21	10	35	21	38
Rootstock x variety interaction		**	***	ns	ns	**	ns

[z] Shoot diameter data are an average of three measurements taken during the growing season in the first weeks of July, August and September. Shoot length measurements were taken in the first week of July. Pruning weight was measured in late January 2001 for the 2000 season, and in early February 2002 for the 2001 season.

[y] *ber: V berlandieri; rip: V. riparia; rup: V. rupestris; cor: V. cordifolia.*

[x] Significance for main effect of rootstock or variety.

[w] Means followed by the same letter within rootstock or variety are not significantly different (P>0.05) protected LSD. ns=non-significant; *=P<0,05; **=P<0.01; ***=P<0.001.

Although rootstock did not affect WUE, scions grafted to 420A and 5BB had the highest rate of photosynthesis and transpiration over both years (Table 2.2). Merlot had lower gas exchange rates than the other varieties for all variety rootstock combinations. Pruning weights were highest for the *V. berlandieri* x *V. riparia* rootstocks and 101-14 Mgt; and for Chardonnay (Table 2.3). There was a positive correlation between pruning weight and both shoot length (r_s=0.18, $p<0.001$) and diameter (r_s=0.03, $p<0.05$) (Table 2.3). Pruning weight was positively correlated with transpiration (r_s=0.20, $p<0.001$), photosynthesis (r_s=0.14, $p<0.001$) and leaf chlorophyll content (r_s=0.03, $p<0.05$). However there was not a direct relationship between vine vigor and rate of photosynthesis. For example, scions grafted to SO4 had a low rate of photosynthesis and transpiration, and among the highest pruning weight. Conversely, scion grafted to 3309C had high rates of transpiration and photosynthesis, and among the lowest pruning weights. Candolfi-Vasconcelos et al. [13] also found that higher rates of photosynthesis do not necessarily result in higher vigor.

Yields were also highest for scions grafted to the *V. berlandieri* x *V. riparia* rootstocks (Tables 2.4 and 2.5). These vines produced larger clusters and larger berries, but not more berries per cluster. Of the varieties, Pinot noir produced the highest yields, as well as larger clusters with more berries. However, berry weights were not greater for Pinot noir.

Table 2.4. Harvest yield and yield components for 4 varieties grafted to 9 rootstocks in 2000. Ungrafted vines were not included in analysis (rootstock, n=20; variety n=45).

Rootstock	Parentage	Shoots/ vine	Yield (kg/vine)	Clus./ shoot	Cluster weight (g)	Berry weight (g)	Berries/ cluster
420A Mgt	*ber x rip*[z]	8. bc[x]	1.25a	1.6a	91abc	1.08a	85a
5BB Kober	*ber x rip*	8. cd	1.25a	1.6a	89ab	1.11a	81ab
SO4	*ber x rip*	8. bcd	1.17a	1.7b	81a	1.08a	75bc
Gravesac	*ber x rip x rup*	8. ab	1.02bcd	1.5bc	75abc	0.98c	77b
110 Richter	*ber x rup*	8. bcd	0.92d	1.4c	74c	1.06ab	70c
44-53 Malegue	*rip x (cor x rup)*	8. cd	1.03bcd	1.6bc	78abc	0.98c	80ab
101-14 MG	*rip x rup*	9. a	1.14ab	1.6bc	77ab	0.99c	77b
3309 Couderc	*rip x rup*	8. bc	1.05bc	1.5b	82c	1.02bc	80ab
Riparia Gloire	*rip*	8. d	0.93cd	1.5bc	76bc	1.00c	76bc
Sig. For rootstock [y]		***	***	**	***	***	***
LSD		0.15	0.13	0.13	7.7	0.05	6.5
Variety							
Pinot noir		4.98	1.58a	1.8 a	102a	1.07b	95a
Pinot gris		4.98	1.19b	1.5 b	88b	1.11a	80b
Chardonnay		4.98	0.90c	1.5 b	76c	1.12a	69c
Merlot		4.89	0.66d	1.5 b	55d	0.82c	69c
Sig. For variety[y]		ns	***	***	***	***	***
LSD		0.10	0.08	0.09	5.14	0.03	3.7
Rootstock x variety interaction		ns	ns	ns	ns	ns	ns

[z] *ber: V berlandieri; rip: V. riparia; rup: V. rupestris; cor: V. cordifolia.*
[y] Significance for main effect of rootstock or variety.

[x] Means followed by the same letter within rootstock or variety are not significantly different (P>0.05) protected LSD. ns=non-significant; *=P<0,05; **=P<0.01; ***=P<0.001.

Table 2.5. Harvest yield and yield components for 4 varieties grafted to 9 rootstocks fin 2001. Ungrafted vines were not included in analysis (rootstock, n=20; variety n=45).

Rootstock	Parentage	Shoots/ vine	Yield (kg/vine)	Clus./ shoot	Cluster weight (g)	Berry weight (g)	Berries/ cluster
420A Mgt	*ber x rip*[z]	14.6a[x]	4.45a	2.0	154a	1.21b	127 a
5BB Kober	*ber x rip*	13.1cd	4.10b	2.2	145ab	1.27a	115 bc
SO4	*ber x rip*	13.9ab	3.89b	2.1	135c	1.21b	114 bc
Gravesac	*ber x rip x rup*	13.7bc	3.50c	2.0	127cd	1.19bc	108 cd
110 Richter	*ber x rup*	13.5bc	3.36c	2.1	120de	1.19b	102 d
44-53 Malegue	*rip x (cor x rup)*	12.4de	3.40c	2.1	133c	1.08e	124 a
101-14 MG	*rip x rup*	13.8bc	3.28c	2.0	121de	1.11de	110 cd
3309 Couderc	*rip x rup*	13.1bcd	3.49c	2.0	136bc	1.14cd	120 ab
Riparia Gloire	*rip*	11.8e	2.81d	2.1	117e	1.13de	105 d
Sig. For rootstock [y]		***	***	ns	***	***	***
LSD		0.8	0.33	0.17	10.0	0.06	9.0
Variety							
Pinot noir		13.7a	3.82a	2.0b	137	1.14a	121 a
Pinot gris		14.0a	3.38b	1.9c	129	1.14a	114 b
Chardonnay		12.6b	3.39b	2.0b	133	1.14a	117 ab
Merlot		13.0b	3.75a	2.3a	129	1.24b	104 cd
Sig. For variety[y]		***	***	***	ns	***	***
LSD		0.5	0.22	0.11	6.7	0.04	6.0
Rootstock x variety interaction		ns	ns	ns	ns	ns	ns

[z] *ber: V berlandieri; rip: V. riparia; rup: V. rupestris; cor: V. cordifolia.*
[y] Significance for main effect of rootstock or variety.

[x] Means followed by the same letter within rootstock or variety are not significantly different (P>0.05) protected LSD. ns=non-significant; *=P<0,05; **=P<0.01; ***=P<0.001.

Soluble solids were highest in juice from scions grafted to 101-14 Mgt and 5BB (Table 2.6). Titatable acidity was lowest, and pH highest in juice from scions grafted to Gravesac and Riparia Gloire. Gravesac, 101-14 Mgt and Riparia Gloire. Although juice composition data are included in Table 6, comparisons between varieties are less meaningful because of differing harvest dates for the varieties.

Table 2.6. Fruit composition data for four varieties grafted to nine rootstocks for 2000 and 2001. Ungrafted vines were not included in analysis (rootstock, n=20; variety n=45).

		Titratable acidity (g/L)		pH		Soluble solids (degrees Brix)		Ripening index (Brix/TA)	
Treatment		2000	2001	2000	2001	2000	2001	2000	2001
Rootstock	Parentage								
420A Mgt	*ber x rip*[z]	7.36bcd[x]	6.36a	3.13b	3.13a	24.4ab	22.1de	3.35b	3.61e
5BB Kober	*ber x rip*	7.73a	6.31ab	3.11b	3.18ab	24.3abc	23.1ab	3.19b	3.87cd
SO4	*ber x rip*	7.71ab	6.31ab	3.12b	3.15bcd	24.3ab	22.7bc	3.20b	3.77de
Gravesac	*ber x rip x rup*	7.03d	5.82cd	3.18a	3.19a	24.4ab	22.8bc	3.56a	4.05bc
110 Richter	*ber x rup*	7.53abc	6.07bc	3.12b	3.17abc	24.2bc	22.9abc	3.25b	3.96cd
44-53 Malegue	*rip x (cor x rup)*	7.54abc	6.25ab	3.12b	3.11e	24.5ab	21.8e	3.31b	3.62e
101-14 MG	*rip x rup*	7.60abc	5.68d	3.11b	3.20a	24.3abc	23.4a	3.23b	4.29a
3309 Couderc	*rip x rup*	7.30cd	6.10bc	3.12b	3.14cd	23.9c	22.5cd	3.32b	3.81de
Riparia Gloire	*rip*	7.07d	5.68d	3.17a	3.19a	24.6ab	22.8bc	3.55a	4.22ab
Sig. For rootstock[y]		***	***	***	***	*	***	***	***
LSD		0.35	0.27	0.04	0.03	0.33	0.5	0.17	0.25
Variety									
Pinot noir		7.53a	7.31a	3.14b	3.01d	23.5c	21.9c	3.13b	3.03c
Pinot gris		7.69a	6.24b	3.02c	3.11c	23.7bc	23.3a	3.10b	3.76b
Chardonnay		7.57a	6.22b	3.32a	3.17b	23.7bc	22.5b	3.16b	3.66b
Merlot		6.92b	4.50c	3.04c	3.36a	26.4a	23.0a	3.92a	5.19a
Sig. For variety[y]		***	***	***	***	***	***	***	***
LSD		0.24	0.18	0.02	0.02	0.22	0.3	0.11	0.17
Rootstock x variety interaction		***	ns	**	ns	ns	ns	***	ns

[z] *ber: V berlandieri; rip: V. riparia; rup: V. rupestris; cor: V. cordifolia.*
[y] Significance for main effect of rootstock or variety.

[x] Means followed by the same letter within rootstock or variety are not significantly different (P>0.05) protected LSD. ns=non-significant; *=P<0,05; **=P<0.01; ***=P<0.001.

Interactions between variety and rootstock occurred for variables shoot diameter, pruning weight, pH and T.A. in 2000; and leaf chlorophyll content and shoot diameter in 2001 (Table 2.7). Little research has addressed the interaction between variety and rootstock although, according to Teleki, Couderc observed that some cultivars did well on one rootstock, but poorly on another [1]. It has been suggested that the vigor of grafted vines is not only determined by rootstock vigor, but by the affinity between the scion and rootstock as well [7]. The interactions between rootstock and variety found in this experiment support this assertion.

Table 2.7. Interaction between variety and rootstock on vine vigor, leaf chlorophyll content and fruit composition during the 2000 and 2001 seasons. Only significant interactions are listed.

		CH[y]	ME	PG	PN	CH	ME	PG	PN
		2000 Shoot diameter (mm)				2000 Pruning weight (cm)			
420A Mgt	*ber x rip*[x]	9.62	8.40	8.13	8.28	356	312	370	308
5BB Kober	*ber x rip*	8.44	9.22	8.45	8.68	322	340	340	312
SO4	*ber x rip*	8.26	8.25	8.23	9.01	340	304	348	302
Gravesac	*ber x rip x rup*	8.66	8.12	8.54	9.20	296	274	376	284
110 Richter	*ber x rup*	8.86	8.12	8.21	8.61	274	356	268	250
44-53 Malegue	*rip x (cor x rup)*	8.45	8.19	8.17	8.44	252	248	258	270
101-14 MG	*rip x rup*	8.29	8.29	7.84	8.94	312	338	342	294
3309 Couderc	*rip x rup*	9.09	8.02	8.48	8.86	264	353	242	262
Riparia Gloire	*rip*	8.55	7.83	7.76	8.55	204	220	222	210
Sig.[y]		ns	ns	***	**	ns	ns	***	ns
		2000 pH				2000 Titratable acidity (g/L)			
420A Mgt	*ber x rip*	3.33	3.03	3.00	3.14	7.33	6.71	7.60	7.79
5BB Kober	*ber x rip*	3.25	2.98	3.06	3.15	8.17	7.62	7.54	7.58
SO4	*ber x rip*	3.30	3.01	2.99	3.17	7.76	7.25	8.25	7.56
Gravesac	*ber x rip x rup*	3.36	3.19	3.04	3.14	7.14	5.68	7.60	7.73
110 Richter	*ber x rup*	3.36	2.96	3.02	3.15	7.54	7.66	7.52	7.39
44-53 Malegue	*rip x (cor x rup)*	3.33	3.06	2.96	3.13	7.49	6.61	8.33	7.71
101-14 MG	*rip x rup*	3.29	3.03	3.03	3.10	7.80	7.22	7.62	7.76
3309 Couderc	*rip x rup*	3.31	3.00	3.02	3.15	7.63	7.23	7.48	6.85
Riparia Gloire	*rip*	3.34	3.13	3.08	3.14	7.25	6.31	7.29	7.41
Sig.[x]		ns	*	ns	ns	ns	*	ns	ns
		2001 Shoot diameter (mm)				2001 Chlorophyll content			
420A Mgt	*ber x rip*	8.62	7.90	7.96	8.56	3.43	3.52	3.44	3.16
5BB Kober	*ber x rip*	7.82	8.45	7.28	7.52	3.05	3.42	2.91	2.92
SO4	*ber x rip*	9.44	8.61	7.51	7.55	3.16	3.38	3.17	2.87
Gravesac	*ber x rip x rup*	8.52	7.58	7.99	7.61	3.01	3.28	3.28	2.87
110 Richter	*ber x rup*	7.86	8.79	7.86	8.14	3.09	3.40	2.98	2.85
44-53 Malegue	*rip x (cor x rup)*	8.50	7.79	7.51	7.57	3.28	3.38	2.79	2.79
101-14 MG	*rip x rup*	8.21	7.79	7.62	8.17	3.39	3.05	2.93	2.89
3309 Couderc	*rip x rup*	7.90	8.28	7.60	7.86	2.97	3.45	2.89	2.84
Riparia Gloire	*rip*	7.63	7.51	6.89	7.66	3.26	3.36	3.01	2.94
Sig.[x]		**	***	**	ns	*	ns	***	ns

[z] *ber: V berlandieri; rip: V. riparia; rup: V. rupestris; cor: V. cordifolia.*

[y] ME: merlot; CH: Chardonnay; PN: Pinot noir; PG: Pinot gris.

[x] Significance for main effect of rootstock.

Of the ungrafted vines, variety had an effect on shoot diameter and length, and leaf chlorophyll content in both years, and on pruning weight in 2001 (Table 2.8). Based on pruning weight, Chardonnay appeared to be the most vigorous of the ungrafted vines, and Pinot noir the least vigorous. Chardonnay also had higher leaf chlorophyll contents.

Table 2.8. Variables affected by variety for ungrafted vines in 2000 and 2001 (n=5).

	Chlorophyll content[z] (mg cm^{-1})		Shoot diameter[z] (mm)		Shoot length[z] (cm)		Pruning weight[z] (g)	
Variety	2000	2001	2000	2001	2000	2001	2000	2001
Chardonnay	3.41a[x]	3.37a	8.6b	8.2a	121ab	99b	298	448a
Merlot	3.06b	3.37a	7.8c	7.9b	106c	107a	246	430b
Pinot gris	3.39a	2.93b	7.7c	6.3c	127a	72d	206	262c
Pinot noir	3.07b	3.02b	9.2a	7.9b	117b	82c	174	249d
Sig.[y]	***	**	***	***	***	**	ns	*
LSD	0.06	0.09	0.17	0.19	8	19	20	25

[z] Leaf chlorophyll content (SPAD) and shoot diameter data are an average of three measurements taken during the growing season in the first weeks of July, August and September. Shoot length was measured once in July, and pruning weight in January.
[y] Significance for main effect of variety.

[x] Means followed by the same letter within rootstock or variety are not significantly different (P>0.05) protected LSD. ns=non-significant; *=P<0,05; **=P<0.01; ***=P<0.001.

Patterns based on parentage were apparent for many dependent variables. Of the *V. riparia x V. rupestris* rootstocks 101-14 Mgt is thought to impart lower vigor than 3309C [39]. Research has confirmed this observation [45]. However greater imparted vigor from 101-14 Mgt has also been seen, both experimentally [35] and in commercial vineyards in Oregon [55]. In this experiment, scions grafted to 101-14 Mgt had higher pruning weight than 3309C, and was nearly as high as the *V. berlandieri x*

V. riparia rootstocks in pruning wood produced (Table 2.3). Yields and berry weights for both rootstock-scion combinations were average or slightly below average (Tables 2.4 and 2.5). 101-14 Mgt is thought to impart earlier ripening than 3309C [10] and appeared to do so in this experiment in 2001, when it imparted the highest ripening index to scion. In that year juice from the fruit of scion grafted to 101-14 Mgt had high soluble solids and low titratable acidity, while these measurements were average for fruit from scions grafted to 3309C (Table 2.6).

Scions grafted 420A Mgt, 5BB and SO4 had the highest pruning weights of all vines for both years. Galet referred to 420A Mgt as "a weak rootstock, slightly more vigorous than Riparia Gloire [39]. In Italy, however, it is thought to impart moderate vigor [50]. In this experiment, pruning weights conferred by 420A Mgt were the highest in both years (Table 2.3). Yields were also highest for vines grafted to the *V. berlandieri x V. riparia* rootstocks for both years (Tables 4 and 5). 5BB has been shown to impart lower berry weight with some varieties [2]. Berry weight was highest for scion grafted to the *V. berlandieri x V. riparia* rootstocks, including 5BB (Tables 2.4 and 2.5). Must from fruit produced by scion grafted to the *V. berlandieri x V. riparia* rootstocks tended to have higher than average titratable acidity (Table 6). Titratable acidity affected ripening index values, which ranged from average to lower than average.

Like the other *V. berlandieri x V. rupestris* rootstocks, 110R is thought to confer high vigor [39]. However Parejo et al. found 110R to confer lower vigor than other *V. berlandieri x V. rupestris* rootstocks. In this experiment 110R conferred only moderate vigor as reflected by pruning weight (Table 2.3). Berry weight for scion grafted to this rootstock was average, and yields ranged from low to average (Tables 2.4 and 2.5). Measurements of pH, titratable acidity, soluble solids and the ripening index were also average (Table 2.6).

Of the remaining rootstock-scion combinations, scion grafted to 44-53 Malègue had lower than average pruning weights and berry weight, and slightly lower than average yields. Juice from fruit produced by these vines had average titratable acidity. Low soluble solids were responsible for a low ripening index value.

Gravesac is a relatively new crossing that has not been widely tested in the US. Scion grafted to Gravesac produced average pruning weight and yield, and average to lower than average berry weight (Tables 2.3, 2.4 and 2.5). Juice from these vines had lower than average titratable acidity, higher than average pH and average to higher than average soluble solids (Table 2.6). Gravesac conferred higher ripening indices in both years.

Riparia Gloire conferred the lowest pruning weight and yield of any of the grafted vines (Tables 2.3, 2.4 and 2.5). Berry weight also tended to be lower than average. Titratable acidity was lower and pH and soluble solids higher than average in juice from scion grafted to Riparia Gloire (Table 2.6). These vines had among the highest ripening index values for both years.

CONCULSION

Differences between previously reported studies and the results from this experiment underscore the need for regional rootstock trials. For example, in this experiment scions grafted to 420A Mgt had the highest pruning weight, 110R imparted moderate rather than high vigor, while 101-14 Mgt imparted higher vigor than 3309C.

Riparia Gloire and the *V. riparia x V. rupestris* rootstocks, 101-14 Mgt and 3309C, are the most widely planted in Oregon. They are reportedly useful for controlling vigor and ripening fruit early [39]. In this trial 101-14 Mgt was not a low-vigor rootstock, although it did impart earlier ripening and lower berry weight (Table 2.9). 3309C was an average performer in all of these parameters. Riparia Gloire imparted the lowest vigor and early ripening, as well as low berry weight. The *berlandieri x riparia* rootstocks are used to a lesser degree in Oregon, but are popular in other cool climate viticultural regions. In this experiment, these rootstocks imparted high vigor and larger berries. With the exception of 5BB, these rootstocks also ripened fruit later. 44-53 Malègue, which is used to a small degree in Oregon, imparted moderate vigor and low berry weight. However, this rootstock also appeared to delay ripening.

Of the rootstocks that are not being used in Oregon, 110R performed much like 3309C (Table 2.8). However, because of its reputation for high vigor, further evaluation is necessary before this rootstock can be recommended to Oregon growers. Finally, Gravesac imparted moderate vigor and early ripening. Berries from scion grafted to this rootstock were of average weight. Although this rootstock is not being use in Oregon, results here indicate that it could be a successful addition.

Rootstock selections should be based on the requirements of each individual site and the objectives of the grower. No single rootstock, or even group of rootstocks, will suit the requirements of every site within an appellation. The results of any rootstock trial should be applied with caution to a particular site, particularly where differences in soil type and climate exist. It should be noted that this trial was performed with irrigation. The results may, therefore, be more applicable to irrigated sites. Nevertheless, results from this trial may give growers more information on which to base their rootstock choices.

Table 1.9. Vigor vs. ripening time and berry weight.

	Ripening time		
	early	average	late
vigorous	101-14 Mgt[1]	5BB[3]	420A Mgt[3] SO4[3]
moderate vigor	Gravesac[2]	110R[2] 3309C[2]	44-53 Malegue[1]
low vigor	Riparia Gloire[1]		

Relative berry weights are indicated by numbers. 1=low, 2=moderate, 3=high.

CHAPTER 4: GENERAL CONCLUSION

Phylloxera was discovered in an Oregon vineyard twelve years ago. Since that time, there has been a steady increase in the use of grafted vines. Oregon growers have sought suitable rootstocks for the state's unique soils, climate and cultural practices. Rootstock selection has been based on information from outside the state, as well as trial and error. Riparia Gloire and the *V. riparia* x *V. rupestris* rootstocks, 101-14 Mgt and 3309C, are the most widely used in the state. These rootstocks have been said to impart low to moderate vigor and earlier ripening [10, 39]. Both of these traits could be beneficial at most vineyard sites in Oregon, where soils tend to be fertile and the growing season is shorter than in other wine grape producing areas. Whether or not these rootstocks actually impart lower vigor and earlier ripening in Oregon relative to other rootstocks has been largely unknown. Nor have newer rootstocks, such as Börner and Gravesac, been screened for potential benefit to the Oregon industry.

In this study 101-14 did not impart low vigor in either experiment, although it did impart earlier ripening in both experiments. 3309C imparted lower vigor than 101-14, and would be considered a moderate vigor rootstock in agreement with the literature [8]. Scion grafted to 3309C ripened fruit later than 101-14 Mgt, as was suggested by Pongràcz [10]. Riparia Gloire imparted low vigor and average to earlier ripening in both experiments.

Of the *V. berlandieri* x *V. riparia* and *V. berlandieri* x *V. rupestris* rootstocks, all but 110R imparted higher vigor. And while none imparted early ripening, higher vigor did not appear to delay ripening as much with the *V. berlandieri* x *V. rupestris* rootstocks as it did with the *V. berlandieri* x *V. riparia* rootstocks. 110R imparted moderate vigor in this trial, in contrast to its reputation as a vigorous rootstock [39]. However, further evaluation is necessary before this rootstock can be recommended to Oregon growers.

1616C, which is used to a small degree in Oregon, imparted the unusual combination of higher vigor and earlier ripening in the Pinot noir trial, suggesting it might be a good choice for less fertile sites in Oregon. 44-53 Malègue, which is also used to a small extent in Oregon, imparted moderate vigor in both experiments. However, it also appeared to delay ripening.

Of the other rootstocks screened in this trial, two were identified that may be of potential benefit to Oregon growers. Schwarzmann, also a *V. riparia x V. rupestris* rootstock, imparted lower vigor than 101-14 Mgt and ripened fruit just as early in the Pinot noir experiment. Gravesac performed well in both experiments, imparting moderate vigor and ripening fruit early.

Finally, color accumulation can be a problem with red varieties grown in cool climates. A popular method of dealing with this problem is by selecting small-berried clones, thereby increasing the skin to pulp ratio [6]. Although it has been well established that rootstocks have the capacity to affect the size of berries produced by their grafted scion, this has not been widely used as a method to improve color extraction in cool climates. In this trial the rootstocks that imparted low or moderate vigor also tended to impart lower berry weights. Riparia Gloire, 101-14 Mgt and 44-53 Malègue imparted the lowest berry weights. Gravesac, Schwarzmann, 3309C and Börner also imparted lower than average berry weights.

The results of this experiment should be applied with caution to a particular site. The further the climate and soils etc. of a site are from those described in this trial, the less applicable the results may be. It is particularly important to note that the vines used in this study are relatively young (in the 4th and 5th years of establishment). The performance of a given rootstock may change over time. It is also important to note that these vines were being irrigated during both years of data collection. This may account for some of the differences between this trial and other, previous trials. Nonetheless, the results from this evaluation should provide growers in this region with more information about the performance of these rootstocks that will assist them in making future rootstock selections.

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