AN ABSTRACT OF THE THESIS OF

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Title: Rootstock Effect on the *Vitis vinifera* Cultivars Chardonnay, Merlot, Pinot gris and Pinot noir During Establishment.

Abstract approved:

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Winegrape growing is extremely dependent upon site-specific variables. To better understand the effect of rootstock-scion interaction in a cool climate region, an experimental vineyard was planted in 1997 at the Oregon State University Woodhall III property in the southern Willamette Valley.

The first experiment consists of Pinot noir (clone FPMS 2A) grafted to 19 rootstocks and an own-rooted control. Two years of growth responses and one year's harvest data were analyzed. Rootstocks affected shoot length and shoot diameter, leaf gas exchange rates, leaf chlorophyll contents, cluster size and yield components, soluble solids, pH and titratable acidity. Treatments with long, thick shoots and heavy pruning weights tended to have high chlorophyll contents, with two exceptions. The Pinot noir own-rooted control and Riparia Gloire-Pinot noir vines had elevated chlorophyll levels but shorter shoots and had smaller shoot diameters. Pinot noir grafted to 1103 Paulsen, 99 Richter, 110 Richter and 140 Ruggeri set fewer berries per cluster. 1103 Paulsen, 99 Richter, 110 Richter rootstocks effected scion fruitfulness by lowering cluster weights. 125AA Kober and 1103 Paulsen had the lowest levels of soluble solids but the highest pruning weights, indicating a lack of fruit-to-canopy balance. Establishment rate was highest for ungrafted Pinot noir vines and Pinot noir on 3309 Couderc, 4453 Malegue, 8B Teleki, Selection Oppenheim 4, 161-49 Couderc, and 420A Millardet et de Grasset and the slowest for 110 Richter, 99 Richter, and 1103 Paulsen.

The second experiment consists of a 4 x 9 factorial trial. Four *V. vinifera* scions on 9 rootstocks were planted and, as in the first experiment, physiological responses and harvest data were analyzed. Responses of the interactions of rootstock-scion were analyzed and affinity of scion to rootstock was observed. Pinot noir grafted to 110 Richter showed low leaf chlorophyll contents. Rootstock-scion interactions were observed in shoot length and diameter. *V. riparia x V. berlandieri* crosses grew longer shoots of larger diameter. 3309 Couderc, Riparia Gloire and 4453 Malegue yielded smaller vines regardless of scion choice. The counts of berries per cluster were different among treatments. Affinity of scion to rootstock effected soluble solid content, pH and TA of musts, although further study into vineyard maturation is needed.

Rootstock Effect on the *Vitis vinifera* Cultivars Chardonnay, Merlot, Pinot gris and Pinot noir During Establishment

By

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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.

Michael D. McAuley, Author

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I am blessed to have had the chance to return to school to further my understanding and to contribute to a field of study I truly am passionate about. That passion was born twenty-five years ago and was modeled by Fred Peterson and Doug Nalle, two men I am grateful to know for their examples as *vignerons* and as my friends.

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CONTRIBUTION OF AUTHORS

Dr. M. Carmo Vasconcelos assisted in the development of the experimental design and writing the manuscripts.

David Jensen of the Oregon State University Statistitics Department developed the statitistical analysis program and assisted with applying appropriate statistical procedure.

Steve Castagnoli coordinated data collection and assisted with the statistical analysis and data interpretation for the project.

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Chapter 1: General Introduction

In horticulture, grafting is the craft of joining two pieces of living plant tissue together forming one viable plant with the resulting plant having characteristics of both parts.

The practice of grafting scion wood to rootstock is common in the production of woody perennials although it is not a modern-day technique. According to Hartman, Kester and Davies [1], evidence of grafting can be found as early as 1000 BC in China. In the Bible, Paul the Apostle speaks of grafting "good" olives to "wild" olive trees (Romans 11:17-24).

Grafting scion selections onto rootstocks has a number of advantages. In production applications, grafting is used to gain beneficial attributes of the rootstock, the scion, or a combination of the two. Increasing disease resistance, combating pest damage, increasing hardiness, modification of vegetative vigor, and modification of reproductive growth are all reasons to graft.

Although, all of the aforementioned reasons play into the decision of rootstock choice in a wine grape vineyard, the most overwhelming pressure for rootstock use comes from susceptibility to the soil pest phylloxera.

Grafting European wine grape (*Vitis vinifera*) scions onto rootstock became necessary because of the North A merica grape phylloxera (*Daktulosphaira vitifolia* Fitch) infestation of Old and New World vineyards. Professor J. E. Planchon of Montpellier, France discovered the insect in 1868 on vinifera roots [2, 3]. Phylloxera was found in Australia in 1875 [4], in California vineyards in the late 1850's [5] and, in South Africa in 1886 [6]. The worldwide practice at the time was to grow vines on their own roots, and these own-rooted vines suffered stunted root growth and root death when attacked by phylloxera. Because of the severity of phylloxera damage, the infected vines degenerated and died. Within 35 years of the initial identification of the pest in France, two-thirds of Europe's established vineyards were destroyed.

Exterminating the pests by flooding and the use of soil applied chemical eradicants was tried with varying degrees of success in the short term. Irrigating vineyards with white wine and burying live toads in the vineyards did not work at all [7].

In 1872, the French ampelographer Laliman discovered that the North American grape *Vitis aestivalis* was not killed by phylloxera [8] and speculated (correctly) that American Vitis species had co-evolved with phylloxera and were resistant to the pest. Native American Vitis species were collected and for roughly forty years European viticulturists worked on breeding trials and the evaluation of phylloxera-resistant hybrids and rootstocks. In North America, Australia, and South Africa work on hybrid and rootstock development was also being conducted. Hybrids for direct production rarely yielded fruit capable of making wine acceptable to winemakers. Unaccustomed to the varietal characteristics of the New World grapes, researchers and industry deemed that even the best efforts of hybridization were not the answer.

Vinifera selections were used in the rootstock breeding trials at all locations, and rootstocks of vinifera parentage such as AXR nos. 1 and 2, Jacquez, and Harmony were being used in South Africa and California for establishing commercial vineyards. This decision proved unwise, for as the Italian, American, and French scientists had warned the vinifera parentage would render the hybrids susceptible to phylloxera damage. Vineyard decimation because of this weakness has come to pass, and at the present, the industry standard is to plant on rootstocks with no Vinifera heritage.

With the large selection of phylloxera-resistant rootstock material available, an analysis of variability in terms of vigor, fruit composition, yield and yield components is needed to best choose plant material for specific criteria.

This research examines:

1) The influence of rootstock on the physiological growth responses, yield, and fruit composition of an establishing Pinot noir vineyard.

2) How rootstocks interact with four different scion selections (Chardonnay, Merlot, Pinot gris and Pinot noir) with regards to shoot morphology, physiological responses, yield, and fruit composition in a young vineyard.

Chapter 2: Literature Review

Rootstock effect on vigor

Vegetative growth is an increase in the size of an organism [9, 10]. The size of woody perennial scionwood can be greatly affected by the choice of the rootstock it is grafted upon. A common example of size manipulation is the use of dwarfing rootstocks in tree fruit production [11, 12, 13, 14]. The smaller trees are easier to propagate, maintain, and harvest [11]. Orchards on dwarfing rootstocks have higher yields per hectare and are less costly to farm [11, 12].

Ornamental propagation also benefits from vigor manipulation by way of rootstocks. Woody perennial landscape plants are often grafted to modify foliage pattern and plant size [15]. Increased growth as measured by shoot number yield has been demonstrated in grafted rose bushes over own-rooted rose [16].

Grapevine scion growth has been known to be dependent on the rootstock it is grafted upon [8, 17, 18]. Research has analyzed the causes of differences in growth observed in grafted grapevines. Two independent studies [19, 20] concluded that there was a vigor response of the scion, which is called own-vigor; vigor appropriated by the rootstock, called given vigor; and the growth corresponding to a given pair of rootstock and scion, which they called affinity.

Many studies have been done examining the effect that rootstock has on grape scion vigor. Rankings of rootstocks into categories such as high, medium and low vigor are common. Composite rankings of many studies [4, 8, 18] can be used as a general guide. However, care must be taken because particular vines can perform differently depending on location. Factors such as growing season, sunlight interception, soil moisture, soil pH, soil lime content, and soil salinity affect the performance of a grapevine [4, 5, 7, 8, 18, 21, 22, 23, 24, 25].

Ferroni and Scalabrelli reported that own-rooted vines of both Chardonnay and Trebbiano toscano had shorter shoot lengths and lower pruning weights than when the scions were grafted to 1103 Paulsen and Kober 5BB, although the grafted vines showed no difference between the two rootstock treatments [25].

Carbonneau and Casteran saw that Cabernet sauvignon grafted to Selection Oppenheim #4 yielded 5% greater pruning weights on loose-gravely soils and 21% greater pruning weights on heavier sandy soils than Cabernet sauvignon on 101-14 Millardet et de Grasset [23].

Snyder and Harmon conducted several studies in the mid-1900s examining the rootstock-induced performance of vinifera grapes in California's San Juaquin and Napa Valleys. One trial conducted at the

Fresno (San Juaquin Valley) site showed significant pruning weight differences in four varieties of vinifera grafted onto 420A Millardet et de Grasset and 3309 Couderc [26]. Emperor, Sultanina and Ohanes all produced larger pruning weights when grafted to 420A Millardet et de Grasset while Castiza had larger pruning weights on 3309 Couderc. When Harmon analyzed a trial of rootstock performance in the Napa Valley, the standard by which rootstocks were measured against was the most widely planted rootstock at the time, Rupestris St. George. Pruning weights of the majority of the twelve vinifera varieties in the trial were significantly lower when grafted to 420A Millardet et de Grasset, 101-14 Millardet et de Grasset, and 3309 Couderc than they were on St. George [27].

Grape differs from other woody perennials in that it is the growth paired with a trellis system that gives the vine its structure. Matching vigor with the trellis system and vine spacing appropriate to a site is one of the most important choices made when planting a vineyard [4, 5, 23, 28].

Rootstock effect on gas exchange performance

Carbon dioxide is used in the presence of sunlight by the plant in the photosynthetic carbon reduction cycle which yields carbon for plant growth, reproduction, and storage. It has been observed that the rate of photosynthesis is dependent upon, among other variables, the utilization of carbon dioxide [29]. The amount of CO_2 in the air is relatively constant at approximately 0.035% [30] and under normal conditions the amount of carbon dioxide available is not a limiting factor to photosynthesis.

Several studies have observed the ability of rootstocks to affect gas exchange, usually while considering certain stress to the plant.

Syversten (1988) performed factorial experiments where he found Valencia (cv) oranges (*Citrus sinensis* [L.] Osbeck) grafted onto Tri (cv) orange (*Poncirus trifoliata* [L.] Raf.) assimilated twice the CO_2 than Valencia grafted to sweet orange (cv) (*Citrus sininsis*, Swt) rootstock under drought conditions. Under no drought stress young (two-month-old) Valencia leaves on sweet orange rootstock had two-times the rate of gas exchange as did young Valencia leaves on Tri orange when irrigated with water with a Cl^{-1} concentration of 20 mol/m^3. Rootstock had a significant effect on carbon assimilation in grafted 'Redbush' (cv) grapefruit (*Citrus paradisi* Macf.) when the grapefruit treatments were subjected to low and high rates of Nitrogen fertilizer [31].

The level of gas exchange of 'Imperial Gala' (cv) apple trees (*Malus* x *domestica* Borkh) grafted onto three rootstocks varied between rootstocks at several stages of induced drought-stressed periods [32], although significant, not consistently.

In 1994, Düring said "...little information exists regarding the effect of rootstock genotype on photosynthesis of scion leaves" [33], but in the last decade several investigators have examined *vitis* photosynthesis parameters [34, 35, 36, 37, 38]. Most of the studies have been done considering the grafted rootstock effects on gas exchange of *Vinifera* scionwood. As with other woody perennial plants, much of this work has been performed with the input of stress and then photosynthesis response to that stress. Studies without applied stress include experiment showing the grapevine rootstocks AXR1, St. George, and Teleki 5C did not affect CO_2 assimilation of mature, field grown Cabernet sauvignon (cv) vines at the University of California Viticulture and Enology Oakville research station in Napa Valley, California [38]. In another experiment Düring observed that rootstocks Kober 5BB and Selection Oppenheim 4 positively influenced photosynthesis rates of Riesling leaves, out-performing both the ungrafted and self-grafted Riesling vines [33].

Water use efficiency (WUE) can be defined as the amount of carbon gained by the plant for the cost of water vapor lost. This calculation is valuable in determining the overall efficiency of crops and the water issues associated with growing them.

Transpiration rate is used as a factor along with photosynthesis to calculate the water use efficiency. Transpiration is the water loss of the plant mainly via stomata, although a small fraction of water is lost through the cuticle and lenticils [17].

In the previously cited studies conducted in citrus and apple where there were significant differences in carbon dioxide fixation rates among rootstocks, no differences were observed in WUE [31, 32, 39].

In grapevine studies, Düring recorded increased WUE in Riesling and Gf.Ga-47-42 (Bacchus x Seyval, cv) vines grafted onto 5BB compared to own-rooted vines [33]. Padgett-Johnson observed lower values of WUE in Carignane (cv) vines grafted to *Vitis riparia* Michaud (Riparia) than those of Carignane own-rooted vines and similar numbers to those of the riparia own-rooted treatment [37]. Iacono and his group of Italian researchers found WUE to be lower in grafted vines than ungrafted vines when subjected to water stress [40].

Rootstock effect on quantum yield of photosynthesis

The amount of sunlight usable by a plant, photosynthetically active radiation (PAR) can depend upon time of day, climate, time of year and location of plant leaves. This variability demands that the plant be able to respond to changes as to function over a wide range of environments [30, 41].

The ability for a C_3 plant to utilize PAR and CO_2 is regulated in chloroplasts in part by the enzyme ribulose-1, 5-biphosphate carboxylase/oxygenase (rubisco) [29]. The rubisco activity increases as light intensity increases, but not proportionately [41]. At lower light intensities, photosynthesis regulated by rubisco increases directly proportional to the increase in PAR, but as the sunlight increases, larger marginal increments of energy are lost. This inefficiency increases to a point where, at full sunlight, even the most efficient of plants can use only 40 - 50% of the energy striking the leaves [41, 42].

The amount of energy that can be utilized by the photosynthetic process can be measured as photosynthetic efficiency with a fluorometer as F_v/F_m by the saturation pulse method [9, 41, 42, 43]. Björkman and Demmig [42] compared 44 plants of various species from around the world including C3, C4 and CAM plants. They found the observed F_v/F_m ratios to fall within a narrow range when plants were not stressed, but when chlorophyll contents were lower (indicating stress) the ratios fell substantially.

Rootstock effect on leaf chlorophyll content

As previously mentioned, the absorption of radiation by a plant takes place in the chloroplasts by chlorophyll and other pigments. This energy capture rate is therefore dependent upon the chlorophyll levels in the green tissue [30, 36].

The plum rootstock Marianna GF 8.1 (cv) increased chlorophyll content in leaf tissue of both Prune d'Ente (cv) and Reine Claude (cv) when compared with the dwarfing rootstock Pixie 2879 (cv) [44].

Grapevine rootstocks can also have an effect on the chlorophyll content of *Vitis* scion leaf tissue. There are reports of chlorophyll changes in response to water stress [35, 36], lime induced chlorosis [24], and genotype [34].

Rootstock effect on yield and yield components

Yield can be manipulated by grafting to rootstocks, depending on the crop. de Vries and Dubois [16] report that fruitfulness measured by flower bud production in grafted roses was greater or equal to fruitfulness in own-rooted roses. Fruit tree production can show no change due to grafting scionwood onto rootstock as demonstrated in peach [45] or show large effects as reported in prune [46].

Research into rootstock effect on *Vitis* fruit production has been extensive, albeit without consensus. Rootstocks can either raise or lower crop level [23, 25, 26, 27, 47, 48, 49, 50, 51]. This variability can depend upon site selection and cultural practices. When the number of buds per vine is held constant, the mechanisms determining crop size are bud fertility (the number of clusters per shoot) [51], the number of berries per cluster [47, 48], and the size of the individual berries [25, 47, 48], the last two affecting cluster weight.

Vine balance is the concept wherein the plant organs (roots, trunk, canopy and fruit) are at optimum levels in relationship with each other to produce healthy vines and desired yields of the highest quality fruit.

In established vineyards, the term vine balance describes in particular the ratio of vegetative growth to yield. It has been shown that the two extremes of growth versus cropload are detrimental to fruit quality and vine health. Too much fruit in respect to vegetative growth (overcropping) results in delayed maturation in the current year and lower fruitfullness in the following year [5]. Too little fruit compared to vegetative growth results in reduced fruitfullness [5]. Perold [6] states that for quality fruit, vines should be composed of the best selections of scionwood grafted to moderately vigorous rootstocks and farmed to limit production.

Vineyard balance can be quantified as the ratio of leaf area to the quantity of fruit per unit measured. This ratio was demonstrated to be acceptable at 11 to $14 cm^2$ per gram of fruit [5]. Because leaf area is closely associated and can be positively correlated to winter pruned brush weight [52], the ratio of crop weight to pruning weight can be used to assess vine balance. Depending upon site, variety, and cultural practices, Ravaz determined that ratios of between 3 and 15 are appropriate for quality winegrape production [53]. Over an eleven year period the Ravaz Index was significantly different (4.37 to 5.88) when Xarel Lo. (cv) was grafted to six rootstocks [51].

Rootstock effect on fruit composition

Quality fruit is judged on suitability for the end product or use. This varies according to the crop [54]. Measures of quality such as the size of oranges [45] or plums [46], the color of strawberries [55], or fruit composition of plums [46], kiwi [55] and grapes [4, 5, 56] are commonly used.

Winegrapes are considered ripe when certain levels of soluble solids, titratable acidity, and pH are reached. Grape rootstock can affect all three of these components.

Rootstocks with short vegetative cycles will ripen fruit earlier than those that sustain growth later into the fall [8]. The earlier ripening fruit will have higher levels of soluble solids, a higher pH and lower levels of titratable acidity at a given point in time than the later ripening fruit.

Potassium uptake by the rootstock can affect grape quality [57]. Increased potassium concentrations in grape musts have a buffering effect resulting in higher pH measurements. Higher pH levels result in microbial and color instability and flat flavor profiles.

Chapter 3: Physiological Growth Responses and Fruit Yield and Composition of Pinot noir Grafted to 20 Root Selections

Abstract

Rootstock selection, along with site, variety/clone choice and trellis design, is one of the major factors in planting or replanting a vineyard. The balance between vigor and quality can be directed by pre-plant choices. In 1997 an experimental block was planted in Oregon's Willamette Valley consisting of Pinot noir (clone FPMS 2A) grafted to 19 phylloxera resistant rootstocks and an own rooted control. Photosynthesis, transpiration, water use efficiency, maximum quantum efficiency, chlorophyll content, and shoot length and diameter were measured three times during the growing season. Additionally, prunings were weighed and the fruit was analyzed for soluble solids, TA and pH. Rootstocks had an effect on shoot length, shoot diameter, pruning weights, photosynthesis, water use efficiency, chlorophyll content, berry count per cluster, berry weight, cluster weight, must soluble solids, pH and titratable acidity. Rootstock selection did not affect transpiration, quantum efficiency, or yield. Larger vines tended to have higher leaf chlorophyll content with two exceptions: own-rooted Pinot noir vines had the highest chlorophyll content but short shoots and vines grafted to Riparia Gloire had elevated chlorophyll levels but shorter and thinner shoots. The *V. rupestris x V. berlandieri* crosses of 1103 Paulsen, 99 Richter, 110 Richter and 140 Ruggeri set fewer berries per cluster, which resulted in lower cluster weights for all but 140 Ruggeri. The two treatments with the highest pruning weights, 125AA Kober and 1103 Paulsen had the lowest levels of soluble solids. Establishment rate was highest for ungrafted Pinot noir vines and Pinot noir on 3309 Couderc, 4453

Malegue, 8B Teleki, Selection Oppenheim 4, 161-49 Couderc, and 420A Millardet et de Grasset and the slowest for 110 Richter, 99 Richter, and 1103 Paulsen.

Introduction

Pinot noir is arguably the most important cultivar grown in Oregon. Forty-two percent of the 2002 Oregon wine grape harvest was Pinot noir [58]. This cool climate variety is planted on relatively few rootstocks. Forty-four percent of the vineyard acreage in Oregon is planted on phylloxera-resistant rootstock, 80% are vineyards grafted onto three selections, 101-14 Millardet et de Grasset, 3309 Couderc, and Riparia Gloire [58].

Planting vineyards on resistant rootstock is the only known practice to insure protection or resistance against grapevine decline and death due to phylloxera [5]. Although grafted vines cost up to seven times more than own-rooted vines [59, 60], the cost is minimal compared to replant costs and lost production.

Rootstock use can also be beneficial as a way of managing vineyard vigor, yield, and fruit composition [4, 5, 8, 18].

Rootstocks that impart lower vigor decrease farming costs by minimizing or eliminating hedging as a means of canopy management [61]. High vigor vines, on the other hand, have a detrimental effect on wine grapes [21]. They create dense canopies and shade fruit, delaying physiological ripeness and produce grapes with lighter color and varietal intensity and herbaceous flavors. Some rootstocks delay ripening without increasing yield [51].

Irrigation management and vine water status are issues that can be addressed by the use of rootstock. Some vines are adapted to drought conditions where others are not drought tolerant and should not be used in conditions of low water availability or dry farmed vineyards [62]. It has been shown that nutrient uptake can be altered with rootstocks [57, 63].

A comprehensive comparison of rootstocks in Oregon has been difficult because of the relatively small vineyards, few rootstock choices in those vineyards, and the wide range of growing conditions between vineyards.

In 1997 Oregon State University established an experimental block at the Woodhall III Vineyard to compare a large number of rootstocks side by side. The experiment consists of nineteen commercially available rootstocks of various parentages grafted to Pinot noir, clone UCD 2A along with self-rooted Pinot noir. The rootstocks include selections popular in Oregon, several not well represented in Oregon but used in other cool-climate growing regions in the world, and a promising few new to the industry needing examination.

The rootstock parentage (in Italics) and selections used are:

riparia x berlandieri
161-49 Couderc
5BB Kober
125AA Kober
420A Millardet et de Grasset
Selection Oppenheim 4
5C Teleki
8B Teleki
riparia x rupestris
3309 Couderc
101-14 Millardet et de Grasset
Schwarzmann

rupestris x berlandieri
1103 Paulsen
99 Richter
110 Richter
140 Ruggeri
riparia
Riparia Gloire
riparia x cinerea
Börner
riparia x solonis
1616 Couderc
riparia x rupestris x berlandieri
Gravesac
riparia x rupestris x cordifolia
4453 Malegue
Vitis vinifera
Pinot noir UCD 2A

The purpose of this study is to evaluate a large variety of rootstocks in Oregon's cool climate, to provide growers with more information on selections of plant material. This information will help with vineyard establishment and management of commercial vineyards.

Materials and methods

Experimental design

Vineyard establishment

The vineyard row spacing is 2.1m with 1.2m between vines. The experimental layout consists of five-vine experimental units replicated five times. The five blocks are set from the top to the bottom of the slope to eliminate experimental error arising from soil depth and elevation. The soil is a silty clay loam of the Jory-Bellpine association on a 15% South-facing slope. Elevation is 220m above sea level at the middle of the vineyard. Soil depth ranges from 40cm at the top of the vineyard to 60cm at the bottom.

The site was cleared of an existing vineyard in the summer of 1995 and planted to an annual cover crop in both 1995 and 1996 for erosion control and to amend the soil. Soil pH was raised to 6.1 by the addition of dolomite lime incorporated into the soil along with the cover crop in April 1997.

Green growing grafted vines were planted on July 30th and 31st, 1997. The plants were given 2L of water via a permanent drip system at planting, and then watered every week at the rate of 2L/plant. During the second week of August and the second week in September, a solution of 20-20-20 (N-P-K) fertilizer was injected through the drip system equaling 100ppm N/vine. The vines were dormant pruned to two buds in January of 1998.

In 1998, two shoots were trained up a bamboo stake. One shoot was used as the trunk and the other secured loosely to the stake as insurance to damage of the main shoot and as a source of photosynthesis. During the first week of July, the vineyard irrigation program started and the vines were watered every 10 days with 4L/vine. 20-20-20 N-P-K fertilizer was injected into the drip system at the rate of 2g/vine (100 ppm N/vine) on two dates, once in August and once in September. In January of 1999 the vines were head pruned and four buds left for the following seasons' growth.

During the 1999 growing season, the four primary shoots were secured to the fixed wires of the trellis when the shoots were long enough to be tied without damaging the shoot tips. Irrigation practices were the same as that for the previous two years except that the vines were given

6L/vine every two weeks. Fertilization practices were the same for 1999 as they were in the previous two years.

Vineyard maintenance

In 1997, 1998, and 1999, a 40cm strip was maintained weed-free in the vine row with the use of glyphosate herbicide sprayed in a winter application. Alternate inter-rows of cover crop were mowed down during the Spring and early Summer. All inter-rows were mowed at the end of July when the cover crop died back.

Sampling technique

Gas exchange, maximum quantum yield of photosynthesis, and chlorophyll content were analyzed in the summer of 1998 and 1999 three times during the year, times corresponding to bloom, lag phase and ripening time. Measurements were taken from representative shoots of two randomly chosen data vines in each treatment. The mean of the two sub-samples was used as the observed value. Individual fully expanded leaves from the tenth node (from the shoot base) were chosen and marked for the repeated gas exchange, fluorescence, and chlorophyll measurements. The shoots with the marked leaves were used for the repeated length and diameter measurements.

The pruning weights were collected in January following the 1997, 1998, and 1999 growing season on the five vines of each treatment replicate.

1999 yield and yield component data was collected on the five vines of each treatment replicate. Random clusters were chosen from the total treatment harvest and used to analyze fruit composition and berry size. Pruning weights used for the Ravaz Index calculation were collected in January of 2000.

Statistical analysis

The experiment was designed and set in the field as a random complete block design and the statistical analysis was done using SAS® v.6.12. Data homogeneity was tested. Repeated measures during the year were treated as a plot in a split-plot procedure [64].

Data collection

Plant growth

Shoot lengths (from base to tip) and diameters (maximum diameter at the center of the third internode from the base of the shoot) were measured.

Transpiration, photosynthesis and water use efficiency (WUE)

Gas exchange performance was measured with a portable infrared gas analyzer (CIRAS-1, PPSYSTEMS, Hitchin, Herts, SG5 1RT, UK) as described by Candolfi-Vasconcelos and Koblet [35]. Data was collected from 09:30h to 14:30h at photosynthetic flux densities > 1000µmol/m^2/s and leaf temperatures of 18°C to 33°C. WUE was calculated by dividing photosynthesis by transpiration and is the net carbon gain per unit of water lost.

Maximum quantum efficiency of photosynthesis (Fv/Fm)

The maximum quantum efficiency of photosynthesis (Fv/Fm) was measured with a portable fluorescence monitoring system (FMS1, Hansatech Instruments LTD, Kings Lynn, UK).

Chlorophyll content

A portable chlorophyll meter (SPAD-502, Minolta CO., LTD, Japan) was used in the field to measure leaf greenness reflected and transmitted off of the leaf. Representative leaf samples not marked for measurements were collected and the chlorophyll was extracted [65] and measured by color spectrophotometry [66] using a Shimadzu UV-1601 spectrophotometer (Shimadzu Corporation, 3 Kanda-Nishikicho 1-chome, Chiyoda-ku. Tokyo 101, Japan). A regression curve between the extracted chlorophyll and the value generated with the chlorophyll meter was calculated [36]. The regression curve was used to relate the SPAD reading to the actual chlorophyll content of the leaves.

Yield components and pruning weights

The five-vine replicate makes up the experimental unit. Pruning weights, fruit yield, and Ravaz Index calculations were made using the total unit weights. The fruit was harvested on October 7th, 1999, the vines were pruned and prunings weighed in January 2000. Annual biomass was estimated by the sum of fruit yield and pruning weight. The percent of fruit in the annual biomass represents the fruit fraction of the biomass.

Fruit Composition

Random representative twenty-five cluster samples were taken from the five vine replicates and used for juice analysis. 100 berries were taken out of a separate five-cluster sample and weighed for use in berry weight and berries per cluster calculations.

A digital refractometer (Palette, Atago CO., LTD, 32-10 Honcho, Itabashi-ku Tokyo 173, Japan) was used to measure soluble solids (°Brix). An auto-titrator (Mettler DL21, Mettler-Toledo AG, Analytical, Schwerzenbach) was used to analyze the juice pH and titratable acidity (TA).

Results and discussion

One objective in the first two years of the experiment was to establish a healthy vineyard by using commercially accepted vineyard procedures. Water and fertilizer were applied liberally and the vineyard did not show visible signs of stress. The fruit was removed from the vine post-bloom in the first year to promote vegetative growth.

There were no significant differences attributed to a rootstock-growing phase interaction or a rootstock-year interaction in any of the physiological growth responses.

Shoot length, shoot diameter and pruning weights were affected by rootstock. Although the idea of a 'de-vigorating' rootstock can be misleading, several rootstocks in this trial affected growth negatively, resulting in smaller vines.

Transpiration and sunlight use efficiency showed no rootstock effect. Photosynthesis measures of gas exchange and water use efficiency were affected by rootstock during certain periods of the growing season.

Estimates of the leaf chlorophyll content showed a rootstock effect at both lag time and during ripening.

The 1999 yields were not affected by the rootstock choice. Although yield was not different, vegetative growth was different in 1999 and accounts for the differences observed in the Ravaz Index. Berries per cluster, berry weight, and the cluster weight were affected by the rootstock but yield was not. Soluble solids, pH and titratable acidity were affected by the rootstock choice.

Table 3.1: Shoot length and shoot diameter of Pinot noir grafted to 20 rootstocks. Data from three measurements in 1998 and three measurements in 1999 were pooled (n = 30).

Vitis Parentage / Rootstock	Shoot length (cm)	Shoot diameter (mm)
riparia x berlandieri		
161-49 Couderc	134 bcdef [a]	9.33 abc
5BB Kober	141 abcd	9.10 bc
125AA Kober	138 abcde	9.43 abc
420A Millardet et de Grasset	138 abcde	9.42 abc
Selection Oppenheim 4	143 abc	9.20 abc
5C Teleki	148 a	9.62 a
8B Teleki	141 abcd	9.59 a
riparia x rupestris		
3309 Couderc	126 ef	8.97 cde
101-14 Millardet et de Grasset	132 cdef	9.37 abc
Schwarzmann	131 cdef	9.02 cde
rupestris x berlandieri		
1103 Paulsen	150 a	9.57 ab
99 Richter	145 ab	9.63 a
110 Richter	130 def	8.98 cde
140 Ruggeri	142 abc	9.28 abc
riparia		
Riparia Gloire	126 ef	8.56 e
riparia x cinerea		
Börner	114 g	8.61 de
riparia x solonis		
1616 Couderc	149 a	9.29 abc
riparia x rupestris x berlandieri		
Gravesac	135 bcde	9.04 cd
riparia x rupestris x cordifolia		
4453 Malegue	136 bcde	9.07 cd
Vitis vinifera		
Pinot noir UCD 2A	122 fg	8.96 cde
Significance [b]	***	***
LSD	12	0.48
Rootstock x time interaction [c]	ns	ns

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of rootstock. *** = $p < 0.001$.

[c] Significance for interaction. ns = non-significant at $p = 0.05$.

Table 3.2: Transpiration and maximum quantum yield of photosynthesis of Pinot noir grafted to 20 rootstocks. Data from three measurements in 1998 and three measurements in 1999 were pooled (n = 30).

Vitis Parentage / Rootstock	Transpiration (mmol $H_2O/m^{-2} s^{-1}$)	Maximum quantum yield of photosynthesis (Fv/Fm)
riparia x berlandieri		
161-49 Couderc	4.40	0.774
5BB Kober	4.16	0.764
125AA Kober	4.49	0.778
420A Millardet et de Grasset	4.52	0.776
Selection Oppenheim 4	4.08	0.777
5C Teleki	4.12	0.776
8B Teleki	3.73	0.783
riparia x rupestris		
3309 Couderc	4.24	0.772
101-14 Millardet et de Grasset	4.53	0.769
Schwarzmann	4.23	0.786
rupestris x berlandieri		
1103 Paulsen	4.37	0.768
99 Richter	4.32	0.771
110 Richter	4.38	0.766
140 Ruggeri	4.42	0.778
riparia		
Riparia Gloire	4.01	0.776
riparia x cinerea		
Börner	4.53	0.776
riparia x solonis		
1616 Couderc	4.44	0.777
riparia x rupestris x berlandieri		
Gravesac	4.09	0.783
riparia x rupestris x cordifolia		
4453 Malegue	4.30	0.780
Vitis vinifera		
Pinot noir UCD 2A	4.52	0.787
Significance [a]	ns	ns
LSD	na	na
Rootstock x time interaction [b]	ns	ns

[a] Significance for the main effect of rootstock. ns = non-significant at p = 0.05.

[b] Significance for interaction.

Table 3.3: Photosynthesis (μmol $CO_2/m^{-2}\ s^{-1}$) of Pinot noir grafted to 20 rootstocks. Data from 1998 and 1999 was pooled (n = 10).

Vitis Parentage / Rootstock	Bloom	Lag	Ripening
riparia x berlandieri			
161-49 Couderc	11.46	9.60 bc [a]	9.02 ab
5BB Kober	12.08	8.95 bcd	8.21 bc
125AA Kober	11.90	9.58 bc	8.63 abc
420A Millardet et de Grasset	12.55	9.29 bcd	9.11 ab
Selection Oppenheim 4	11.64	8.13 cd	7.91 bc
5C Teleki	12.02	8.85 bcd	7.86 bc
8B Teleki	12.10	7.57 d	6.95 c
riparia x rupestris			
3309 Couderc	12.22	9.36 bcd	8.52 abc
101-14 Millardet et de Grasset	11.43	8.76 bcd	8.17 bc
Schwarzmann	11.46	9.77 abc	8.38 bc
rupestris x berlandieri			
1103 Paulsen	13.32	8.74 bcd	8.26 bc
99 Richter	12.45	8.80 bcd	7.91 bc
110 Richter	11.32	9.71 bc	8.54 abc
140 Ruggeri	13.32	9.65 bc	8.19 bc
riparia			
Riparia Gloire	10.86	8.58 bcd	8.62 abc
riparia x cinerea			
Börner	10.43	10.29 ab	9.18 ab
riparia x solonis			
1616 Couderc	12.85	9.37 bcd	7.82 bc
riparia x rupestris x berlandieri			
Gravesac	11.78	8.61 bcd	7.97 bc
riparia x rupestris x cordifolia			
4453 Malegue	12.00	8.69 bcd	8.16 bc
Vitis vinifera			
Pinot noir UCD 2A	11.49	11.64 a	10.55 a
Significance [b]	ns	**	*
LSD	na	1.88	2.06

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of rootstock. ns = non-significant p = 0.05, * = $p < 0.05$, ** = $p < 0.01$.

Table 3.4: Water use efficiency of Pinot noir grafted to 20 rootstocks. Data from 1998 and 1999 was pooled (n = 10).

Vitis Parentage / Rootstock	Bloom	Lag	Ripening
riparia x berlandieri			
161-49 Couderc	2.85	2.35	2.59 ab [a]
5BB Kober	3.02	2.50	2.44 abc
125AA Kober	2.80	2.31	2.45 abc
420A Millardet et de Grasset	3.32	2.23	2.59 ab
Selection Oppenheim 4	2.91	2.26	2.39 abc
5C Teleki	2.94	2.45	2.42 abc
8B Teleki	3.12	2.44	2.45 abc
riparia x rupestris			
3309 Couderc	3.03	2.28	2.62 ab
101-14 Millardet et de Grasset	2.85	2.29	2.18 c
Schwarzmann	3.11	2.32	2.49 abc
rupestris x berlandieri			
1103 Paulsen	2.96	2.29	2.50 abc
99 Richter	2.92	2.27	2.29 bc
110 Richter	2.99	2.28	2.52 ab
140 Ruggeri	3.11	2.36	2.35 abc
riparia			
Riparia Gloire	3.26	2.38	2.41 abc
riparia x cinerea			
Börner	2.85	2.15	2.45 abc
riparia x solonis			
1616 Couderc	3.09	2.26	2.30 bc
riparia x rupestris x berlandieri			
Gravesac	3.14	2.25	2.42 abc
riparia x rupestris x cordifolia			
4453 Malegue	3.00	2.25	2.35 abc
Vitis vinifera			
Pinot noir UCD 2A	3.17	2.53	2.65 a
Significance [b]	ns	ns	*
LSD	na	na	0.34

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of rootstock. ns = non-significant $p = 0.05$, * = $p < 0.05$.

Table 3.5: Leaf chlorophyll content (mg/cm^2) of Pinot noir grafted to 20 rootstocks. Data from 1998 and 1999 was pooled (n = 10).

Vitis Parentage / Rootstock	Bloom	Lag	Ripening
riparia x berlandieri			
161-49 Couderc	2.28	2.65 bcd [a]	2.78 abcd
5BB Kober	2.53	2.73 bcd	2.42 cde
125AA Kober	2.41	3.02 abc	2.64 abcde
420A Millardet et de Grasset	2.43	3.17 ab	2.75 abcde
Selection Oppenheim 4	2.51	2.55 cd	2.57 bcde
5C Teleki	2.50	2.98 bcd	2.67 abcde
8B Teleki	2.62	2.78 bcd	2.54 bcde
riparia x rupestris			
3309 Couderc	2.32	2.56 cd	2.50 bcde
101-14 Millardet et de Grasset	2.22	2.65 bcd	2.14 e
Schwarzmann	2.45	2.97 bcd	2.62 bcde
rupestris x berlandieri			
1103 Paulsen	2.41	2.53 cd	2.18 de
99 Richter	2.46	2.83 bcd	2.35 cde
110 Richter	2.31	2.47 d	2.36 cde
140 Ruggeri	2.60	2.70 bcd	2.33 cde
riparia			
Riparia Gloire	2.48	3.14 ab	3.11 ab
riparia x cinerea			
Börner	2.12	2.74 bcd	2.89 abc
riparia x solonis			
1616 Couderc	2.63	3.04 abc	2.62 bcde
riparia x rupestris x berlandieri			
Gravesac	2.44	2.88 bcd	2.56 bcde
riparia x rupestris x cordifolia			
4453 Malegue	2.43	2.78 bcd	2.44 cde
Vitis vinifera			
Pinot noir UCD 2A	2.77	3.51 a	3.25 a
Significance [b]	ns	**	**
LSD	na	0.53	0.62

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of rootstock. ns = non-significant p = 0.05, ** = $p < 0.01$.

Table 3.6: Yield and vegetative growth data of Pinot noir grafted to 20 rootstocks for the 1999 season (n = 5).

Vitis Parentage / Rootstock	Yield (kg/m^2)	Pruning weight (kg/m^2)	Ravaz Index (Yield/Pruning weight)
riparia x berlandieri			
161-49 Couderc	0.172	0.078 bcdefg [a]	2.284 cdefg
5BB Kober	0.156	0.092 abcd	1.806 ghi
125AA Kober	0.181	0.097 ab	1.967 efgh
420A Millardet et de Grasset	0.226	0.085 abcdef	2.551 abcd
Selection Oppenheim 4	0.171	0.077 bcdefg	2.390 bcdef
5C Teleki	0.172	0.091 abcde	1.867 fghi
8B Teleki	0.180	0.078 bcdefg	2.333 cdefg
riparia x rupestris			
3309 Couderc	0.183	0.062 fg	2.953 ab
101-14 Millardet et de Grasset	0.151	0.069 cdefg	2.364 cdefg
Schwarzmann	0.144	0.064 efg	2.320 cdefg
rupestris x berlandieri			
1103 Paulsen	0.132	0.106 a	1.366 i
99 Richter	0.147	0.093 abc	1.602 hi
110 Richter	0.129	0.066 defg	2.138 defgh
140 Ruggeri	0.157	0.088 abcdef	1.882 fghi
riparia			
Riparia Gloire	0.151	0.055 g	2.710 abcd
riparia x cinerea			
Börner	0.162	0.057 g	2.750 abc
riparia x solonis			
1616 Couderc	0.165	0.091 abcd	1.816 ghi
riparia x rupestris x berlandieri			
Gravesac	0.165	0.066 cdefg	2.488 abcde
riparia x rupestris x cordifolia			
4453 Malegue	0.187	0.072 bcdefg	2.669 abcd
Vitis vinifera			
Pinot noir UCD 2A	0.192	0.070 cdefg	2.999 a
Significance [b]	ns	***	***
LSD	na	0.027	0.576

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of rootstock. ns = non-significant p = 0.05, *** = $p < 0.001$.

Table 3.7: Yield component data of Pinot noir grafted to 20 rootstocks for the 1999 season (n = 5).

Vitis Parentage / Rootstock	Clusters/ shoot	Berries/ cluster	Berry weight (g)	Cluster weight (g)
riparia x berlandieri				
161-49 Couderc	1.6	66 bcde [a]	1.08 ab	71.0 bcde
5BB Kober	1.6	63 bcde	1.07 ab	67.5 cdef
125AA Kober	1.4	76 abc	1.10 ab	83.0 ab
420A Millardet et de Grasset	1.6	85 a	1.04 ab	88.4 a
Selection Oppenheim 4	1.5	70 abcde	1.06 ab	74.3 abcde
5C Teleki	1.6	68 bcde	1.06 ab	72.2 bcde
8B Teleki	1.7	66 bcde	1.09 ab	70.9 bcde
riparia x rupestris				
3309 Couderc	1.8	72 abcde	1.02 bc	73.5 abcde
101-14 Millardet et de Grasset	1.6	66 bcde	1.03 ab	68.6 bcdef
Schwarzmann	1.6	66 bcde	0.92 c	61.3 def
rupestris x berlandieri				
1103 Paulsen	1.5	58 e	1.02 bc	59.5 ef
99 Richter	1.6	59 e	1.04 ab	62.0 def
110 Richter	1.6	59 e	0.93 c	54.7 f
140 Ruggeri	1.6	60 de	1.07 ab	64.3 cdef
riparia				
Riparia Gloire	1.5	65 bcde	1.02 bc	66.0 cdef
riparia x cinerea				
Börner	1.4	77 ab	1.01 bc	77.5 abc
riparia x solonis				
1616 Couderc	1.6	62 cde	1.12 a	69.5 bcdef
riparia x rupestris x berlandieri				
Gravesac	1.7	76 abc	1.07 ab	74.8 abcd
riparia x rupestris x cordifolia				
4453 Malegue	1.7	66 bcde	1.09 ab	71.8 bcde
Vitis vinifera				
Pinot noir UCD 2A	1.7	74 abcd	1.01 bc	75.6 abcd
Significance [b]	ns	**	***	***
LSD	na	15	0.10	15.0

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of rootstock. ns = non-significant $p = 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Table 3.8: Fruit composition data of Pinot noir grafted to 20 rootstocks for the 1999 season (n = 5).

Vitis Parentage / Rootstock	Soluble solids (°Brix)	pH	Titratable acid (g/l)
riparia x berlandieri			
161-49 Couderc	22.9 abcd [a]	2.98 b	7.20 a
5BB Kober	22.8 abcde	3.03 ab	6.82 abcd
125AA Kober	22.5 de	3.01 ab	6.96 abc
420A Millardet et de Grasset	23.1 ab	3.01 ab	6.80 abcd
Selection Oppenheim 4	22.9 abcde	2.98 b	7.12 ab
5C Teleki	23.2 ab	3.02 ab	6.74 abcd
8B Teleki	23.3 a	3.03 ab	6.72 abcd
riparia x rupestris			
3309 Couderc	22.6 cde	2.99 b	6.86 abc
101-14 Millardet et de Grasset	22.9 abcd	3.05 ab	6.47 cd
Schwarzmann	22.9 abcde	3.04 ab	6.23 d
rupestris x berlandieri			
1103 Paulsen	22.5 de	3.00 ab	6.89 abc
99 Richter	22.8 bcde	3.01 ab	6.52 bcd
110 Richter	23.0 abc	3.04 ab	6.53 bcd
140 Ruggeri	22.9 abcde	3.05 ab	6.58 abcd
riparia			
Riparia Gloire	22.7 cde	3.04 ab	6.91 abc
riparia x cinerea			
Börner	22.9 abcde	2.98 b	6.87 abc
riparia x solonis			
1616 Couderc	22.9 abcde	3.06 a	6.59 abcd
riparia x rupestris x berlandieri			
Gravesac	22.7 cde	3.03 ab	6.59 abcd
riparia x rupestris x cordifolia			
4453 Malegue	22.9 abcde	3.02 ab	6.61 abcd
Vitis vinifera			
Pinot noir UCD 2A	22.5 de	3.00 ab	6.40 cd
Significance [b]	**	*	*
LSD	0.4	0.074	0.62

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of rootstock. * = $p < 0.005$, ** = $p < 0.01$.

Table 3.9: Fruit composition ranking of Pinot noir grafted to 20 rootstocks for the 1999 season.

Vitis Parentage / Rootstock	Soluble solids [a] (°Brix)	pH	Titratable acid (g/l)
riparia x berlandieri			
161-49 Couderc	5 [b]	1	1
5BB Kober	13	12	8
125AA Kober	17	7	3
420A Millardet et de Grasset	3	7	9
Selection Oppenheim 4	5	1	2
5C Teleki	2	10	10
8B Teleki	1	12	11
riparia x rupestris			
3309 Couderc	16	4	7
101-14 Millardet et de Grasset	5	18	18
Schwarzmann	5	15	20
rupestris x berlandieri			
1103 Paulsen	17	5	5
99 Richter	13	7	17
110 Richter	4	15	16
140 Ruggeri	5	18	15
riparia			
Riparia Gloire	15	15	4
riparia x cinerea			
Börner	5	1	6
riparia x solonis			
1616 Couderc	5	20	13
riparia x rupestris x berlandieri			
Gravesac	20	12	13
riparia x rupestris x cordifolia			
4453 Malegue	5	10	12
Vitis vinifera			
Pinot noir UCD 2A	17	5	19

[a] Soluble solids and tartaric acid rankings are in descending order, pH in ascending order.

[b] Rankings of the same number indicate same values .

Figure 3.1: Effect of rootstock on the relationship between reproductive growth and total annual growth of Pinot noir grafted to 20 rootstocks for the 1999 growing season. Vertical and horizontal lines represent the mean of annual biomass and fruit yield, respectively (n = 5).

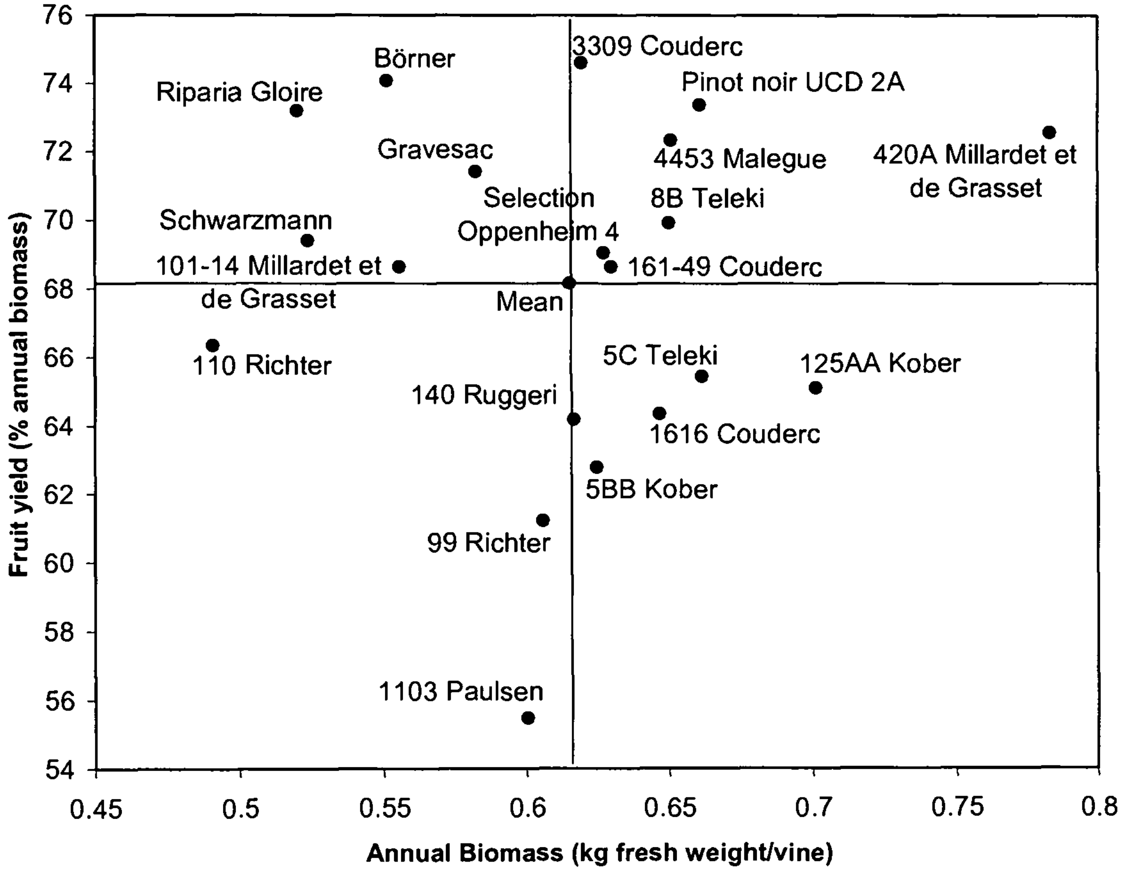
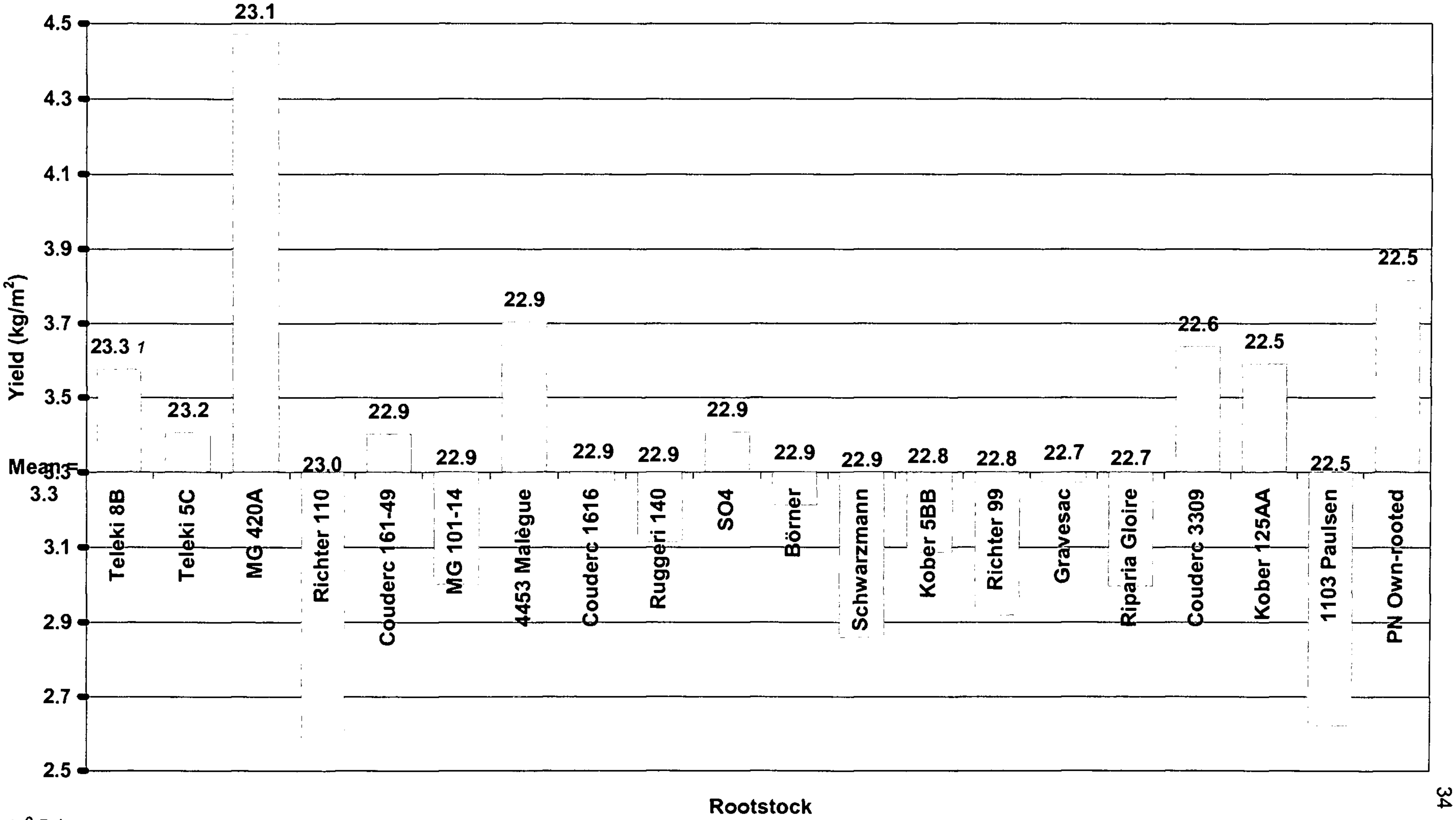


Figure 3.2: Soluble solids in relationship to the mean and the variability of yield of Pinot noir grafted to 20 rootstocks for the 1999 growing season.



1 ° Brix

Pinot noir grafted to 1103 Paulsen and 99 Richter had the strongest overall vegetative growth measured by shoot length and shoot diameter and pruning weights (Tables 3.1 and 3.6). 5C Teleki had both above average shoot lengths and diameters (Table 3.1). 1616 Couderc and Selection Oppenheim 4 imparted long shoots, 8B Teleki positively effected shoot diameter, and 125AA Kober and 140 Ruggeri had larger pruning weights (Tables 3.1 and 3.6). Howell [18] rates 99 Richter as a rootstock that imparts above average scion vigor, although Parejo, *et al.* [51] observed that the pruning weights of 140 Ruggeri were higher than 1103 Paulsen and Selection Oppenheim 4. Pouget [21] found Selection Oppenheim 4 to have higher pruning weights of the latter three rootstocks.

Pinot noir grafted to 3309 Couderc, Riparia Gloire and Börner yielded low shoot lengths, shoot diameters and pruning weights (Tables 3.1 and 3.6). Pinot noir own-rooted vines had smaller shoots measured by length and diameter (Table 3.1). Schwarzmann had low shoot diameters and pruning weights (Table 3.1). 110 Richter showed lower shoot diameter (Table 3.1). Howell [18] and Pouget [21] also observed poor performance from 3309 Couderc and Riparia Gloire. Parejo, *et al.* [51] recorded that 110 Richter and 161-49 Couderc were the least vigorous selections in his trial.

Pinot noir own-rooted or grafted to Börner had elevated rates of photosynthesis during both lag and ripening periods of 1998 and 1999 with no differences between the two years (Table 3.3). Schwarzmann and 161-49 Couderc rated significantly higher at lag time, while 8B Teleki performed poorly (Table 3.3).

The WUE of Pinot noir own-rooted vines, and vines of Pinot noir grafted to 161-49 Couderc and 420A Millardet et de Grasset was higher at ripening (Table 3.4). Low photosynthetic rates were recorded in vines grafted to 8B Teleki rootstock at lag phase and ripening time, and Selection

Oppenheim 4 at ripening time (Table 3.4). WUE was low on the vines grafted to 101-14 Millardet et de Grasset during ripening (Table 3.4).

The highest chlorophyll contents were recorded at lag and ripening for the Riparia Gloire and Pinot noir treatments, and at lag for the 420A Millardet et de Grasset vines (Table 3.5). Low leaf chlorophyll contents were observed during lag and ripening in 1103 Paulsen, during lag in Selection Oppenheim 4, 3309 Couderc and 110 Richter, and during ripening in 101-14 Millardet et de Grasset (Table 3.5). Candolfi-Vasconcelos [36] reported 101-14 Millardet et de Grasset had higher concentrations of chlorophyll than 3309 Couderc.

Vines with greater shoot length and diameter also tended to have higher chlorophyll content (R^2 values of 0.1635 for shoot length and 0.3279 for shoot diameter) with a few exceptions: ungrafted vines had the highest chlorophyll content but not the longest shoots (Tables 3.1 and 3.5). Vines grafted to Riparia Gloire had high chlorophyll content but low shoot length and diameter (Tables 3.1 and 3.5).

The number of berries per cluster, berry size and cluster size were all affected by rootstock. 125AA Kober, 420A Millardet et de Grasset and Börner had significantly higher counts of berries per cluster, which translated into higher cluster weights (Table 3.7). *V. rupestris x V. berlandieri* crosses 1103 Paulsen, 99 Richter, 110 Richter and 140 Ruggeri set fewer berries per cluster, which resulted in lower cluster weights for all but 140 Ruggeri. Gravesac produced large berries, but this did not affect cluster size. 1616 Couderc had lower berry counts and compensated with higher berry weight. 1103 Paulsen and 99 Richter both had significantly lower berry counts and correspondingly low cluster weights. 110 Richter produced fewer berries per cluster, small berry weights and hence, the smallest clusters in the trial.

Although yield did not differ among rootstocks, it is beneficial to look at the balance between canopy and fruit load. The young vines were not cluster thinned or hedged and hence reflected how the rootstock effects the canopy/yield balance. Ravaz wrote in his 1903 work titled *Sur la brunissure de la vigne* [53] that pruning weight was highly correlated to leaf area because longer shoots have more leaves. By taking the quantity of fruit harvested from a vine and dividing it by the pruning weight of that vine, one creates a ratio by which to analyze the vine balance. A low ratio implies that the vines are too vegetative for the amount of fruit hanging, too high and the vines are over-cropped. Ravaz used this ratio to compare vines at a particular site, not vines among sites. The Ravaz Index values for the PNx20 trial ran from a low of 1.37 for 1103P and a high of 3.00 for the ungrafted treatment (Table 3.6).

Figure 3.1 shows the total amount of biomass (combined weight of fruit and prunings) compared to fruit yield as a percentage of the total weight. This can be used as an index of vine establishment. The upper right-hand quadrant indicates the vines with above average mass that yielded above average proportions of fruit. The ungrafted Pinot noir vines along with Pinot noir grafted to 3309 Couderc, 4453 Malegue, 8B Teleki, Selection Oppenheim 4, 161-49 Couderc, and 420A Millardet et de Grasset fall into this quadrant. It is interesting to note that the grafted vines in this quadrant performed similarly to the ungrafted Pinot noir during establishment. Vines grafted to 110 Richter, 99 Richter, and 1103 Paulsen were the slowest to establish.

Fruit composition data is listed on Table 3.8. °Brix, pH, and TA were significantly influenced by rootstock . Of the top five treatments ranked by soluble solids concentration, four had rootstocks that were of *riparia x berlandieri* parentage (Table 3.9). Grapevines grafted to 8B Teleki, 5C Teleki, 420A Millardet et de Grasset, and 161-49 Couderc ranked 1, 2, 3, and 5, respectively. Two traditional cool climate rootstocks, 3309 Couderc and 101-14 Millardet et de Grasset were not among treatments earliest to ripen: Pinot noir on 3309 Couderc ranked 16th and Pinot noir on 101-14

Millardet et de Grasset ranked tied for 5th. Of interest are the two rootstock selections previously mentioned at the extremes of the Ravaz ranking, 1103 Paulsen and own-rooted Pinot noir. Pinot noir on these two root selections yielded the two lowest juice soluble solids.

Values for pH and titratable acidity fell within relatively tight ranges (Table 3.8). Vines on Selection Oppenheim 4 had low pH levels and higher titratable acids. Vines grafted to 3309 Couderc and Börner had lower pH measurements. 1616 Couderc had the highest pH and own-rooted Pinot noir, 101-14 Millardet et de Grasset, and Schwarzmann the lowest titratable acid levels.

Figure 3.2 illustrates the relationship of sugar concentration of each rootstock treatment to yield. Vines grafted to 420A Millardet et de Grasset, 8B Teleki and 5C Teleki had above average sugar accumulation as well as above average yields. 8B Teleki and 420A Millardet et de Grasset were also vines that had high establishment rates.

Conclusions

As has been demonstrated in other *Vitis* trials and even trials studying different crops, rootstock usage can affect the scion performance. Although phylloxera resistance remains the overwhelming factor for using rootstocks in vineyards, research and experience have provided knowledge that can be used to select rootstocks that will allow growers certain growth and crop manipulations.

There is not one ideal rootstock for any given location, considering the variability of soils, microclimates, and growing seasons, let alone factor in profitability and market pressure for certain wine varietals and styles. Nonetheless, studying the available information and creating comprehensive field trials such as this experiment can help reduce growers' risks.

Considering the short growing season and cool climate of the Willamette Valley, efficient photosynthesizers could have an advantage in establishing canopies and ripening fruit. In Oregon the three most common rootstocks in use are 3309 Couderc, 101-14 Millardet et de Grasset, and Riparia Gloire [58], none of which performed high in carbon dioxide assimilation. Only Riparia Gloire outperformed any other rootstock in any physiological growth response, that being water use efficiency during ripening in 1999. These three rootstock selections did impart smaller shoots and lower pruning weights lending themselves to the smaller vine, close spacing vineyard preferred in cool climates. Smaller vines were also grown on Schwarzmann, Börner, and Gravesac. These three rootstocks are new to Oregon and inclusion in this experiment will be beneficial as the vineyard trial matures.

During the establishment period of a vineyard, generally accepted in the wine industry as the first five years of vine growth, vine structure and root growth are desirable and promoted. Crop load is generally not 100% of vineyard capacity until the end of the establishment period. For the economic viability of a winegrape vineyard it is important to bring a full crop to bear as soon as possible without compromising the long-term health of the vineyard or reducing fruit quality. It would then be desirable to have vines approach their mature size and fruiting capacity early, effectively shortening the establishment period. 8B Teleki is a rootstock that falls into the same establishment rate range as 3309 Couderc, which is commonly used in Oregon. Therefore 8B Teleki may warrant more analysis. The establishment rate of vines is important to follow, and in the future could include root mass data to measure the below ground structure and compare it to the above ground mass to analyze the balance of the vine.

As this vineyard is only in the third leaf, this data should not be used solely to make planting decisions for commercial vineyards. Harvest and composition data are especially suspect when vineyards are immature and the vineyard has yet to realize its potential. Instead, the changes and dynamics of this experimental vineyard should be monitored and analyzed to better understand the future responses.

Chapter 4: Physiological Growth Responses and Fruit Yield and Composition of Pinot noir, Chardonnay, Merlot and Pinot gris Grafted to Nine Root Selections

Abstract

This experimental vineyard was planted in 1997 to study the effect of nine rootstocks on four *Vitis vinifera* scions in the cool climate region of Oregon's' Willamette Valley. Chardonnay, Merlot, Pinot gris and Pinot noir were grafted to proven and promising cool climate rootstocks. Physiological growth data was collected three times a year over a period of two years. In addition, harvest data, must analysis, and pruning weights were were collected in the fall and winter of the second year. Rootstock-scion interactions were observed in shoot length and diameter. *V. riparia x V. berlandieri* crosses grew longer shoots of larger diameter. 3309 Couderc, Riparia Gloire and 4453 Malegue yielded smaller vines regardless of scion choice. Gas exchange and sunlight use efficiency was not affected. Chlorophyll contents in varied with the scion-rootstock combinations, Pinot noir grafted to 110 Richter exhibited low levels of leaf chlorophyll content and short shoots. Berries per cluster counts were different among treatments. This variability explained most of the variation in cluster weight on each of the four cultivars. Affinity of scion to rootstock affected ripening when analyzed by soluble solid content, pH and titratable acidity.

Introduction

Pinot noir, Chardonnay, Merlot and Pinot gris are four of the most important winegrape cultivars grown in Oregon. Pinot noir and Chardonnay are the two most popular varieties planted, comprising 75% of the states production for a total value of $25,935,000 in 2002 [58]. Pinot gris plantings have increased faster than any other white variety over the last five years, accounting for 1526 acres by 2002. Merlot has become the most popular red variety in the warmer Southern Oregon and Columbia River viticultural regions, with 559 acres planted.

The presence or threat of phylloxera necessitates the use of resistant rootstock in many areas [5, 60], and vine management is a further compelling reason for rootstocks to be utilized [4, 5, 8, 18]. Forty-four percent of the vineyard acreage in Oregon is planted on rootstock, 80% of that is grafted onto three selections, 101-14 Millardet et de Grasset, 3309 Couderc, and Riparia Gloire [58].

Although it is well known that a *Vitis vinifera* cultivar will perform differently depending on the rootstock it is grafted to, it is also known that different varieties perform differently when grafted to the same rootstock [20]. Studying the affinity of a given cultivar to a certain rootstock is the objective of this variety x rootstock factorial experimental block at Oregon State University's Woodhall III Vineyard near Alpine, Oregon.

The choice of the four varietals used was based upon economic value and cultural preferences, and although Cabernet sauvignon had a higher farm gate value than Merlot in 2002 [58], Cabernet sauvignon was a poor choice for the cool climate site. The clonal selections used in this experiment are:

Chardonnay UCD 95
Merlot UCD 3
Pinot gris Colmar 146
Pinot noir UCD 2A

Resistance to phylloxera was the primary criteria for choosing rootstocks for this trial. Other factors considered when developing this experiment were current viticulture practices, nematode resistance, adaptability to the chemical and physical properties of Oregon soils, and the influence of a rootstock to the scion vegetative growth and crop. The five most common rootstocks used in Oregon and four promising cool climate selections were included in a factorial design of rootstock-scionwood. The rootstock parentage (in Italics) and selections used are:

riparia x rerlandieri
5BB Kober
420A Millardet et de Grasset
Selection Oppenheim 4
riparia x rupestris
3309 Couderc
101-14 Millardet et de Grasset
rupestris x berlandieri
110 Richter
riparia
Riparia Gloire
riparia x rupestris x berlandieri
Gravesac
riparia x rupestris x cordifolia
4453 Malegue

The Oregon State University Woodhall III rootstock trial vineyard was established in 1997 to compare the interaction of economically important winegrape scions and promising rootstocks. The initial two years of analysis will serve to investigate rootstock-scionwood combinations and their effect on vineyard establishment, and to start an ongoing viticultural database designed to assist growers in choosing appropriate plant materials for their specific needs.

Materials and methods

Experimental design

Vineyard establishment

The vineyard is laid out on 2.1m rows with 1.2m between vines. Five blocks of five-vine experimental unit replications are set from the top to the bottom of the slope to eliminate experimental error arising from soil depth and elevation. The soil is a silty clay loam of the Jory-Bellpine association on a 15% South-facing slope. Elevation is 220 m above sea level at the middle of the vineyard. Soil depth ranges from 40 cm at the top of the vineyard to 60 cm at the bottom.

The site was cleared of an existing vineyard in the summer of 1995 and planted to an annual cover crop in both 1995 and 1996 for erosion control and to amend the soil. Soil pH was raised to 6.1 by the addition of dolomite lime incorporated into the soil along with the cover crop in April 1997.

Green growing vines were planted on July 30th and 31st, 1997. The plants were given 2L of water via a permanent drip system at planting, and then watered every week at the rate of 2L/plant. During the second week of August and the second week in September, a solution of 20-20-20 (N-P-K) fertilizer was injected through the drip system equaling 100 ppm N/vine. The vines were dormant pruned to two buds in January of 1998.

In 1998, two shoots were trained up a bamboo stake. One shoot was used as the trunk and the other secured loosely to the stake as insurance to damage of the main shoot and as a source of photosynthesis. During the first week of July, the vineyard irrigation program started and the vines were watered every 10 days with 4L/vine. 20-20-20 N-P-K fertilizer was injected into the drip system at the rate of 2g/vine (100 ppm N/vine) on two dates, once in August and once in September. In January of 1999 the vines were head pruned and four buds left for the following seasons' growth.

During the 1999 growing season, the four primary shoots were secured to the fixed wires of the trellis when the shoots were long enough to be tied without damaging the shoot tips. Irrigation practices were the same as that for the previous two years except that the vines were irrigated 6L/vine every two weeks. Fertilization practices were the same for 1999 as they were in the previous two years.

Vineyard maintenance

In 1997, 1998, and 1999, a 40cm strip was maintained weed-free in the vine row with the use of glyphosate herbicide sprayed in a winter application. Alternate inter-rows of cover crop were mowed down during the Spring and early Summer. All inter-rows were mowed at the end of July when the cover died back.

Sampling technique

Gas exchange, maximum quantum yield of photosynthesis, and chlorophyll content were analyzed in the summer of 1998 and 1999 three times during the year, times corresponding to bloom, lag phase and mid-ripening time. Measurements were taken from representative shoots of two randomly chosen data vines in each treatment. The mean of the two sub-samples was used as the observed value. Individual fully expanded leaves from the tenth node (from the base) were chosen and marked for the repeated gas exchange, fluorescence, and chlorophyll measurements. The shoots with the marked leaves were used for the repeated length and diameter measurements.

Yield and yield component data was collected on the five vines of each treatment replicate. Random clusters were chosen from each replicate harvest and used to analyze fruit composition and berry size.

Statistical analysis

The experiment was designed and set in the field as a random complete block design and the statistical analysis was done using SAS® v.6.12 (SAS Institute Cary, NC). For the multiple year data collection, there were no year effects. Repeated measures during the year were treated as a plot in a split-plot procedure [64]. When there was a variety x rootstock interaction, varieties were analyzed separately. Because of sample size variability, own-rooted treatments were disregarded.

Data collection

Plant growth

Shoot lengths (from base to tip) and diameters (maximum diameter at the center of the third internode from the base of the cane) were measured. Fresh dormant one-year-old cane weights were collected during pruning.

Transpiration, photosynthesis and water use efficiency (WUE)

Gas exchange performance was measured with a portable infrared gas analyzer (CIRAS-1, PPSYSTEMS, Hitchin, Herts, SG5 1RT, UK) as described by Candolfi-Vasconcelos and Koblet [35]. Data was collected from 09:30 h to 14:30 h at photosynthetic flux densities > 1000 μmol/m^2/s and leaf temperatures of 18°C to 33°C. WUE was calculated by dividing photosynthesis by transpiration and is the net carbon gain per unit of water lost.

Maximum quantum efficiency of photosynthesis (Fv/Fm)

The maximum quantum efficiency of photosynthesis (Fv/Fm) was measured with a portable fluorescence monitoring system (FMS1, Hansatech Instruments LTD, Kings Lynn, UK).

Chlorophyll content

A portable leaf greeness meter (SPAD-502, Minolta CO., LTD, Japan) was used in the field to measure the spectra of light reflected and transmitted. Representative leaf samples not marked for measurements were collected and the chlorophyll was extracted [65] and measured by color spectrophotometry [66] using a Shimadzu UV-1601 spectrophotometer (Shimadzu Corperation, 3 Kanda-Nishikicho 1-chome, Chiyoda-ku. Tokyo 101, Japan). Regression between the extracted chlorophyll and the values generated with the leaf greeness meter were calculated for each variety [36]. The regression curve was used to relate the SPAD reading to the actual chlorophyll content of the leaves.

Yield components and pruning weights

The five-vine replicate makes up the experimental unit. Pruning weights, fruit yield, and Ravaz Index calculations were made using the total unit weights. The 1999 harvest dates were October 5th for Pinot gris, October 7th for Pinot noir, October 8th for Chardonnay, and October 13th for Merlot. Pruning weights used for the Ravaz Index calculation were collected in January of 2000.

Fruit Composition

Random representative twenty-five cluster samples were taken from the five vine replicates and used for juice analysis. 100 berries were taken out of a separate five-cluster sample and weighed for use in berry weight and berries per cluster calculations.

A digital refractometer (Palette, Atago CO., LTD, 32-10 Honcho, Itabashi-ku Tokyo 173, Japan) was used to measure soluble solids (°Brix). An auto-titrator (Mettler DL21, Mettler-Toledo AG, Analytical, Schwerzenbach) was used to analyze the juice pH and titratable acidity (TA).

Results and discussion

In the first two years of growth, there was no significant difference that could be attributed to the growth phase in which the measurements were taken. The first year when the vines were pruned to two shoots, fruit was removed after bloom to facilitate vegetative growth. The second year the fruit that was set on the four shoots was left, but there was no evidence that the fruit had an effect on growth responses.

There was a measurable difference in vine size attributed to the interaction of rootstock and scion. Shoot lengths and shoot diameters varied depending upon the scion-rootstock combination. Despite the wide range of shoot length and diameter, there was no significant difference in pruning weights. Analysis suggests a correlation between shoot length and diameter to pruning weight (R^2 length = 0.2549 and R^2 diameter = 0.1695). Interestingly, longer shoots tended to have larger diameters, shorter shoots smaller diameters.

Rootstock did not affect gas exchange parameters but cultivar had a marked effect on photosynthesis, transpiration and WUE.

The quantum yield of photosynthesis was not different among the rootstock/scion units, but there were differences depending on the choice of rootstock and on the choice of scionwood.

With the exception of Merlot, the estimates of chlorophyll content in the leaf tissue responded to the rootstock-scionwood combination.

The variety x rootstock interaction was insignificant when measuring yield and, as previously mentioned, pruning weights for the 1999 season. The calculations for the Ravaz Index were also not affected by the rootstock-scion combination. Yield, winter pruning weights and the Ravaz Index varied with rootstocks, and yield and the Ravaz Index were different among varieties.

The first harvest, occurring in the third leaf of this experimental block, showed several yield component and fruit composition effects.

Cluster number per shoot did differ across rootstock and variety but not among the rootstock-scion combinations. Berry weights were affected only by the choice of rootstock.

The number of berries per cluster and cluster weight were dependent upon the interaction between scion and rootstock.

Rootstock effect on fruit composition varied depending on the cultivar, suggesting the affinity of a scion to a rootstock. Juice soluble solids and pH varied more on Chardonnay and Merlot depending on the rootstock than did the two Pinots. Pinot gris was the only cultivar showing a rootstock response on titratable acidity.

Table 4.1: Shoot length (cm) of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks. Data from three measurements in 1998 and three measurements in 1999 were pooled (n = 30).

Vitis Parentage / Rootstock	Chardonnay UCD 95	Merlot UCD 3	Pinot gris Colmar 146	Pinot noir UCD 2A
riparia x berlandieri				
5BB Kober	135 c[a]	137 a	149 a	141 ab
420A Millardet et de Grasset	138 c	132 ab	139 b	138 abc
Selection Oppenheim 4	151 a	123 de	152 a	143 a
riparia x rupestris				
3309 Couderc	125 d	117 ef	127 d	126 ef
101-14 Millardet et de Grasset	144 b	131 ab	134 bc	132 cde
rupestris x berlandieri				
110 Richter	122 d	130 bc	131 cd	130 def
riparia				
Riparia Gloire	123 d	125 cd	133 c	126 f
riparia x rupestris x berlandieri				
Gravesac	137 c	117 ef	148 a	135 bcd
riparia x rupestris x cordifolia				
4453 Malegue	134 c	111 f	135 bc	136 bcd
Significance[b]	***	***	***	***
LSD	6	6	5	6

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of variety x rootstock interaction.

*** = $p < 0.001$.

Table 4.2: Shoot diameter (mm) of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks. Data from three measurements in 1998 and three measurements in 1999 were pooled (n = 30).

Vitis Parentage / Rootstock	Chardonnay UCD 95	Merlot UCD 3	Pinot gris Colmar 146	Pinot noir UCD 2A
riparia x berlandieri				
5BB Kober	8.71 cd [a]	9.29 a	8.29 b	9.10 b
420A Millardet et de Grasset	8.80 bc	9.10 abc	8.24 bc	9.42 a
Selection Oppenheim 4	9.09 ab	8.90 bcd	8.69 a	9.20 ab
riparia x rupestris				
3309 Couderc	8.65 cd	9.12 ab	7.91 d	8.97 b
101-14 Millardet et de Grasset	9.15 a	9.32 a	8.38 b	9.37 a
rupestris x berlandieri				
110 Richter	8.47 d	8.80 d	8.03 cd	8.98 b
riparia				
Riparia Gloire	8.16 e	8.82 cd	7.94 d	8.56 c
riparia x rupestris x berlandieri				
Gravesac	8.77 cd	8.84 bcd	8.76 a	9.04 b
riparia x rupestris x cordifolia				
4453 Malegue	8.79 c	8.08 e	7.96 d	9.07 b
Significance [b]	***	***	***	***
LSD	0.31	0.30	0.24	0.26

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of variety x rootstock interaction.

*** = $p < 0.001$.

Table 4.3: Photosynthesis, transpiration and water use efficiency of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks. Data from three measurements in 1998 and three measurements in 1999 were pooled (n = 270).

Vitis Parentage / Rootstock	Photosynthesis (μmol $CO_2/m^{-2}\ s^{-1}$)	Transpiration (mmol $H_2O/m^{-2}\ s^{-1}$)	Water use efficiency (A/E)
Vinifera grafted on all rootstocks			
Chardonnay Dijon 95	9.42 a [a]	3.76 b	2.81 b
Merlot UCD 3	8.81 b	3.56 c	2.88 ab
Pinot gris Colmar 146	9.74 a	3.83 b	2.96 a
Pinot noir UCD 2A	9.67 a	4.26 a	2.59 c
Significance [b]	***	***	***
LSD	0.41	0.16	0.11
Variety x rootstock interaction [c]	ns	ns	ns
Rootstock effect [d]	ns	ns	ns

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the effect of variety. *** = $p < 0.001$.

[c] Significance for interaction. ns = non-significant.

[d] Significance effect of rootstock. ns = non-significant.

Table 4.4: Maximum quantum yield of photosynthesis (Fv/Fm) of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks. Data from three measurements in 1998 and three measurements in 1999 were pooled (n = 30 for rootstock and n = 270 for variety).

Vitis Parentage / Rootstock	Fv/Fm
riparia x berlandieri	
5BB Kober	0.777 bc[a]
420A Millardet et de Grasset	0.782 ab
Selection Oppenheim 4	0.783 ab
riparia x rupestris	
3309 Couderc	0.787 a
101-14 Millardet et de Grasset	0.780 abc
rupestris x berlandieri	
110 Richter	0.773 c
riparia	
Riparia Gloire	0.785 ab
riparia x rupestris x berlandieri	
Gravesac	0.786 a
riparia x rupestris x cordifolia	
4453 Malegue	0.785 ab
Significance[b]	**
LSD	0.008
Vinifera grafted on all rootstocks	
Chardonnay Dijon 95	0.785 a
Merlot UCD 3	0.785 a
Pinot gris Colmar 146	0.785 a
Pinot noir UCD 2A	0.773 b
Significance[c]	***
LSD	0.005
Variety x rootstock interaction[d]	ns

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the effect of rootstock. ** = $p < 0.01$.

[c] Significance effect of variety. *** = $p < 0.001$.

[d] Significance for interaction. ns = non-significant.

Table 4.5: Leaf chlorophyll content (mg/cm^2) of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks. Data from three measurements in 1998 and three measurements in 1999 were pooled (n = 30).

Vitis Parentage / Rootstock	Chardonnay UCD 95	Merlot UCD 3	Pinot gris Colmar 146	Pinot noir UCD 2A
riparia x berlandieri				
5BB Kober	2.82 bcd [a]	2.48	2.57 cd	2.56 cd
420A Millardet et de Grasset	2.77 cd	2.38	2.41 e	2.79 ab
Selection Oppenheim 4	3.25 a	2.41	2.72 cd	2.54 cde
riparia x rupestris				
3309 Couderc	2.65 d	2.65	2.57 cd	2.46 cde
101-14 Millardet et de Grasset	2.94 bc	2.38	2.61 cd	2.34 e
rupestris x berlandieri				
110 Richter	2.34 e	2.21	2.08 f	2.38 de
riparia				
Riparia Gloire	2.99 abc	2.61	2.84 ab	2.91 a
riparia x rupestris x berlandieri				
Gravesac	3.05 ab	2.36	2.89 a	2.63 bc
riparia x rupestris x cordifolia				
4453 Malegue	3.01 abc	2.47	2.47 de	2.55 cd
Significance [b]	***	ns	***	***
LSD	0.26	na	0.16	0.21

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of variety x rootstock interaction. ns = non-significant, *** = $p < 0.001$.

Table 4.6: Yield and vegetative growth data of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks for the 1999 season (n = 5 for rootstock and (n = 45 for variety).

Vitis Parentage / Rootstock	Yield (kg/m^2)	Pruning weight (kg/m^2)	Ravaz Index
riparia x berlandieri			
5BB Kober	0.107 b [a]	0.089 a	1.267 de
420A Millardet et de Grasset	0.110 b	0.082 ab	1.347 cde
Selection Oppenheim 4	0.118 ab	0.082 ab	1.625 bc
riparia x rupestris			
3309 Couderc	0.132 a	0.067 cd	2.185 a
101-14 Millardet et de Grasset	0.104 b	0.076 bc	1.478 bcd
rupestris x berlandieri			
110 Richter	0.073 c	0.068 cd	1.177 e
riparia			
Riparia Gloire	0.110 b	0.053 e	2.079 a
riparia x rupestris x berlandieri			
Gravesac	0.107 b	0.072 bcd	1.525 bcd
riparia x rupestris x cordifolia			
4453 Malegue	0.107 b	0.061 de	1.717 b
Significance [b]	***	***	***
LSD	0.019	0.012	0.296
Vinifera grafted on all rootstocks			
Chardonnay Dijon 95	0.081 c	0.067	1.270 c
Merlot UCD 3	0.076 c	0.075	1.086 d
Pinot gris Colmar 146	0.108 b	0.077	1.536 b
Pinot noir UCD 2A	0.168 a	0.070	2.521 a
Significance [c]	***	ns	***
LSD	0.011	na	0.168
Variety x rootstock interaction [d]	ns	ns	ns

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the effect of rootstock. *** = $p < 0.001$.

[c] Significance effect of variety. ns = non-significant.

[d] Significance for interaction.

Table 4.7: Yield component data of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks for the 1999 season (n = 5 for rootstock and n = 45 for variety).

Vitis Parentage / Rootstock	Clusters/ shoot	Berry weight (g)
riparia x berlandieri		
5BB Kober	1.3 abc [a]	1.09 a
420A Millardet et de Grasset	1.2 bc	1.02 b
Selection Oppenheim 4	1.3 abc	1.05 ab
riparia x rupestris		
3309 Couderc	1.4 a	1.01 b
101-14 Millardet et de Grasset	1.2 bc	1.00 bc
rupestris x berlandieri		
110 Richter	1.1 c	0.95 c
riparia		
Riparia Gloire	1.3 ab	1.03 bc
riparia x rupestris x berlandieri		
Gravesac	1.3 ab	1.00 bc
riparia x rupestris x cordifolia		
4453 Malegue	1.2 bc	1.04 ab
Significance [b]	*	**
LSD	0.2	0.05
Vinifera grafted on all rootstocks		
Chardonnay Dijon 95	1.2 c	1.00
Merlot UCD 3	0.9 d	1.02
Pinot gris Colmar 146	1.3 b	1.03
Pinot noir UCD 2A	1.6 a	1.04
Significance [c]	***	ns
LSD	0.1	na
Variety x rootstock interaction [d]	ns	ns

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the effect of rootstock. * = $p < 0.05$, ** = $p < 0.01$.

[c] Significance effect of variety. ns = non-significant, *** = $p < 0.001$.

[d] Significance for interaction.

Table 4.8: Berries per cluster of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks for the 1999 season (n = 5).

Vitis Parentage / Rootstock	Chardonnay UCD 95	Merlot UCD 3	Pinot gris Colmar 146	Pinot noir UCD 2A
riparia x berlandieri				
5BB Kober	39 de [a]	51 abc	49 def	63 cd
420A Millardet et de Grasset	42 cde	62 a	52 bcde	85 a
Selection Oppenheim 4	47 bc	56 abc	50 cdef	70 bcd
riparia x rupestris				
3309 Couderc	52 ab	59 ab	61 a	72 abc
101-14 Millardet et de Grasset	57 a	50 abc	55 abcd	66 bcd
rupestris x berlandieri				
110 Richter	37 e	40 c	44 f	59 d
riparia				
Riparia Gloire	45 cd	43 bc	57 ab	65 bcd
riparia x rupestris x berlandieri				
Gravesac	42 cde	52 abc	56 abc	76 ab
riparia x rupestris x cordifolia				
4453 Malegue	46 bcd	48 abc	47 ef	66 bcd
Significance [b]	***	*	***	**
LSD	7	17	6	13

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of variety x rootstock interaction.
* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Table 4.9: Cluster weight of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks for the 1999 season (n = 5).

Vitis Parentage / Rootstock	Chardonnay UCD 95	Merlot UCD 3	Pinot gris Colmar 146	Pinot noir UCD 2A
riparia x berlandieri				
5BB Kober	42.2 bc [a]	56.8 ab	54.8 bcd	67.5 b
420A Millardet et de Grasset	42.4 bc	63.3 a	52.8 cd	88.4 a
Selection Oppenheim 4	48.4 ab	63.2 a	51.1 d	74.3 b
riparia x rupestris				
3309 Couderc	50.5 ab	62.4 a	60.6 ab	73.5 b
101-14 Millardet et de Grasset	56.7 a	45.6 b	58.1 abc	68.6 b
rupestris x berlandieri				
110 Richter	35.8 c	40.6 b	40.5 e	54.7 c
riparia				
Riparia Gloire	45.1 bc	44.8 b	62.0 a	66.0 b
riparia x rupestris x berlandieri				
Gravesac	42.2 bc	49.1 ab	55.0 bcd	74.8 b
riparia x rupestris x cordifolia				
4453 Malegue	46.0 b	49.4 ab	50.0 d	71.8 b
Significance [b]	**	*	***	***
LSD	9.6	16.5	6.3	10.8

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of variety x rootstock interaction.

* = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Table 4.10: Juice soluble solids (°Brix) of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks for the 1999 season (n = 5).

Vitis Parentage / Rootstock	Chardonnay UCD 95	Merlot UCD 3	Pinot gris Colmar 146	Pinot noir UCD 2A
riparia x berlandieri				
5BB Kober	22.6 a	23.3 ab	23.0	22.8
420A Millardet et de Grasset	22.4 abc	23.7 a	23.5	23.1
Selection Oppenheim 4	22.6 a	23.2 b	23.2	22.9
riparia x rupestris				
3309 Couderc	22.0 d	22.7 c	23.2	22.6
101-14 Millardet et de Grasset	22.1 cd	22.8 c	23.5	22.9
rupestris x berlandieri				
110 Richter	22.2 bcd	22.6 c	23.5	23.0
riparia				
Riparia Gloire	22.5 abc	23.6 ab	23.1	22.7
riparia x rupestris x berlandieri				
Gravesac	22.5 ab	23.3 ab	23.3	22.7
riparia x rupestris x cordifolia				
4453 Malegue	22.6 ab	23.4 ab	23.5	22.9
Significance [b]	**	***	ns	ns
LSD	0.4	0.4	na	na

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of variety x rootstock interaction. ns = non-significant, ** = $p < 0.01$, *** = $p < 0.001$.

Table 4.11: Juice pH of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks for the 1999 season (n = 5).

Vitis Parentage / Rootstock	Chardonnay UCD 95	Merlot UCD 3	Pinot gris Colmar 146	Pinot noir UCD 2A
riparia x berlandieri				
5BB Kober	3.15 abcd [a]	3.33 abcd	3.19	3.03
420A Millardet et de Grasset	3.10 d	3.34 abcd	3.19	3.01
Selection Oppenheim 4	3.13 abcd	3.34 abc	3.19	2.98
riparia x rupestris				
3309 Couderc	3.15 abc	3.28 d	3.21	2.99
101-14 Millardet et de Grasset	3.17 ab	3.30 bcd	3.23	3.05
rupestris x berlandieri				
110 Richter	3.11 cd	3.29 cd	3.16	3.04
riparia				
Riparia Gloire	3.12 bcd	3.40 a	3.20	3.04
riparia x rupestris x berlandieri				
Gravesac	3.17 ab	3.35 abc	3.22	3.03
riparia x rupestris x cordifolia				
4453 Malegue	3.13 abcd	3.36 ab	3.20	3.02
Significance [b]	*	**	ns	ns
LSD	0.05	0.07	na	na

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of variety x rootstock interaction. ns = non-significant, * = $p < 0.05$, ** = $p < 0.01$.

Table 4.12: Juice titratable acid of Chardonnay, Merlot, Pinot gris and Pinot noir grafted to nine rootstocks for the 1999 season (n = 5).

Vitis Parentage / Rootstock	Chardonnay UCD 95	Merlot UCD 3	Pinot gris Colmar 146	Pinot noir UCD 2A
riparia x berlandieri				
5BB Kober	6.09	6.22	5.60 a [a]	6.82
420A Millardet et de Grasset	6.01	5.96	5.30 ab	6.80
Selection Oppenheim 4	6.19	6.26	5.60 a	7.12
riparia x rupestris				
3309 Couderc	5.73	6.58	5.07 b	6.86
101-14 Millardet et de Grasset	5.86	6.87	5.02 b	6.47
rupestris x berlandieri				
110 Richter	5.60	6.65	5.52 a	6.53
riparia				
Riparia Gloire	6.43	6.02	5.47 a	6.91
riparia x rupestris x berlandieri				
Gravesac	5.70	6.00	5.10 b	6.59
riparia x rupestris x cordifolia				
4453 Malegue	6.33	5.93	5.37 ab	6.61
Significance [b]	ns	ns	*	ns
LSD	na	na	0.35	na

[a] Means followed by the same letter were not significantly different according to the Waller–Duncan K-ratio t test.

[b] Significance for the main effect of variety x rootstock interaction. ns = non-significant, * = $p < 0.05$.

Interaction between rootstock and scion is apparent in the differences in vegetative growth of Chardonnay, Merlot, Pinot gris and Pinot noir. Although this difference in affinity did not affect pruning weight at the end of the 1999 season (Table 4.6), there was an interaction between scion and rootstock on shoot lengths and shoot diameters that were measured in 1998 and 1999 (Tables 4.1 and 4.2). Several trends seem to be apparent and the observations deserve noting. The vegetative growth of Merlot was the most affected by rootstock, with 19% variability in shoot length and 13% variability in diameter. Gravesac-Merlot combinations grew short shoots and Gravesac-Pinot gris vines grew longer shoots. When grafted to 3309 Couderc all four varieties yielded shorter shoots but shoot diameter varied from large to small by 13%. *V. riparia x V. berlandieri* crosses, when grafted to all varieties, originated larger vines measured by shoot length, shoot diameter and pruning weights. 3309 Couderc, Riparia Gloire and 4453 Malegue yielded small vines regardless of scion. The Chardonnay vines grafted to Selection Oppenheim 4 had longer and larger diameter shoots.

Leaf chlorophyll content varied from a high of 3.25 mg/cm^2 for the Selection Oppenheim 4-Chardonnay to 2.08 mg/cm^2 for Pinot gris grafted to 110 Richter (Table 4.5). Along with the lighter colored leaves, 110 Richter-Pinot gris exhibited smaller shoots. According to Pongracz [8], a symptom of the lack of grafting affinity shows up when the vines are young as yellowed (low chlorophyll content) leaves and poor growth. The observation of greener vines occuring in larger vines is consistent with the correlation in the previous chapter (page 37) suggesting that higher chlorophyll contents in leaves are associated with longer shoots of larger diameter. 110 Richter grafted to all scions resulted in lower leaf chlorophyll estimates. Riparia Gloire imparted higher chlorophyll contents in all combinations. 420A Millardet et de Grasset in combination with Pinot gris yielded low chlorophyll contents, when grafted to Pinot noir, yielded high chlorophyll contents. Similar variability in affinity could be seen in the 3309 Couderc vines. When 3309 Couderc is grafted to Merlot, the result is high chlorophyll content leaves. When 3309 Couderc is grafted to Chardonnay, the leaves of the vines contain low chlorophyll levels.

Interactions between scion and rootstock resulted in differences in berry count per cluster (Table 4.8), and these counts were strongly associated with cluster weight (Table 4.9; $R^2 = 0.91$ for Chardonnay, $R^2 = 0.81$ for Merlot, $R^2 = 0.80$ for Pinot gris and $R^2 = 0.88$ for Pinot noir). Evidence of the variability of affinity can be seen in cluster weight data for Riparia Gloire grafted onto Merlot and Pinot gris. Riparia Gloire-Merlot vines set clusters with low berry counts and low cluster weights and Riparia Gloire-Pinot gris vines had high berry numbers and cluster weights. 110 Richter in all combinations resulted in low berry counts and cluster weights.

Rootstock effect on fruit composition varied depending on cultivar. Chardonnay grafted to 5BB Kober and Selection Oppenheim 4 produced fruit with higher soluble solid accumulations where fruit from Merlot grafted to these two rootstocks did not (Table 4.10). Fruit from 101-14 Millardet et de Grasset-Chardonnay and Gravesac-Chardonnay vines had higher pH musts where Riparia Gloire-Merlot and 4453 Malegue-Merlot ripened quicker as judged by pH readings (Table 4.11). Pinot gris grafted to 3309 Couderc, 101-14 Millardet et de Grasset, and Gravesac accounted for the lowest titratable acidity measurements in 1999 (Table 4.12).

Conclusions

The use of rootstocks in commercial winegrape vineyards is made necessary by factors such as phylloxera, nematodes, soil pH and soil salinity. Grafting to rootstocks can also have a desirable effect on canopy size, fruit composition and a number of other criteria. While these desirable attributes are not necessary for the physical survival and longevity of the vineyard, they can be important to the grower.

The extreme variability of vineyard sites and situations points us to the conclusion that there is no one-size-fits-all rootstock. Fortunately, there is a large selection of rootstocks to choose from, and in that selection, a variety of effects to the scion physiology and resulting harvest.

Differences in rootstock-scionwood affinity have been demonstrated in several studies, but the extreme variability of site, grapevine variety and rootstock warrant more trials to address regional issues. This factorial experiment was created to examine Willamette Valley options.

Certain traits are important in marginal growing areas such as Oregon, where the season can be short due to precipitation or temperature. Quicker ripening vineyards lead to earlier harvests. Earlier harvests would be helpful in avoiding bunch rot pressure or under-ripe fruit brought on by fall rains. Higher soluble solid levels were observed in three experimental combinations. In two combinations, 5BB Kober grafted to Chardonnay and Gravesac grafted to Merlot, the higher level of ripening was coupled with a smaller canopy. Shorter shoot growth would decrease the need for hedging and tipping, giving greater sun exposure to the fruit. A rootstock-scion combination meeting the two criteria of early ripening, small vines would be helpful in growing quality Chardonnay and Merlot in cool climates.

The differences observed in leaf chlorophyll content may indicate rootstock-scion efficiencies in the uptake of water or nutrient utilization. Further study is warrented. Petiole analysis and plant water status in conjunction with the physiological measurements similar to this experiment may shed some light on favorable plant combinations.

Although there was no seasonal or year to year differences observed in this factorial experiment, statistical analysis of the four scions separate of each other might reveal differences not detected by this analysis.

The establishment period of commercial vineyards is commonly defined as the first four to five years of a vineyards life, a period where vegatative growth is promoted for vine structure and root development.

Fruit yield components and composition data is preliminary and can be used in further understanding the changes that a vine goes through during establishment.

It is anticipated that along with future data collection and analysis, this experimental vineyard will act as a reference on cool climate scion-rootstock combinations appropriate for commercial farming.

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