An Abstract of the Thesis of

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Abstract approved: ______________________________

Carmo M. Vasconcelos

Five trellis types were compared during 1996 and 1997 for their effect on Pinot noir yield components, fruit composition, fruit set, shoot morphology, leaf gas exchange, and trunk carbohydrate storage. These trellis systems were: upright vertical, cane pruned (double Guyot); upright vertical, spur pruned (bilateral cordon); Scott Henry, cane pruned; Lyre, cane pruned; and Geneva Double Curtain (GDC), cane pruned. In 1996, the double canopy systems had almost double the yield of the single canopy systems. There were no differences in yield or its components in 1997 among the five trellis systems. The bilateral cordon had a higher leaf area index than did the other systems. There were no differences in juice soluble solids, pH, or titratable acidity (TA) among the different trellis systems in either year. Also, there were no differences seen between the two canopies of the double canopy trellis systems in either year.

There were no differences in sugar or starch concentrations in the trunk wood among the five trellis systems at any sample date. Sugar concentration in the trunk was highest during leaf fall and lowest at bloom on a dry weight basis. Starch concentration in the trunk was highest during dormancy and lowest during leaf fall and bud burst. Trunk volume was highest in the GDC and lowest in the Guyot. There was a negative correlation between most yield components and the carbohydrate concentration at bud burst. Leaf photosynthesis was strongly correlated with berry weight and skin anthocyanin content.

In a separate study, yield components, fruit composition and wine quality of fruit generated in both curtains of the Scott Henry system were analyzed. In 1996, the bottom canopy had higher yield, cluster weight, more clusters per shoot and a higher TA than did the top canopy. Must soluble solids were not affected by vine canopy or sun orientation in 1996, but pH was lower and TA was higher in the bottom canopy. In 1997 the top canopy had a higher yield than did the bottom canopy. There were no canopy or orientation effects on leaf gas exchange, leaf area, shoot diameter, or internode length. Wine from the top canopy was found to have more red color than wine from the bottom canopy.

Effect of Trellis Type and Canopy Location on Yield Components, Fruit Composition, Shoot Morphology, Leaf Gas Exchange, and the Dynamics of Storage Carbohydrates in Pinot noir Grapevines

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APPROVED:

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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.

Joey D Ratliff-Peacock, Author

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Contribution Of Authors

Dr Carmo M. Vasconcelos was involved in the design and writing of each manuscript. Dr. Andrew G. Reynolds assisted in the writing and wine evaluations for the Scott Henry trellis trial. Scott Henry Sr. assisted in the design and maintenance of the Scott Henry trial. He also made the wines for the Scott Henry trellis trial.

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Introduction

The cool climate during fruit maturation in Oregon's Willamette Valley dictates the need for good grapevine canopy management practices. Dry summers, cool autumns, spring frosts, and rainy fall harvests make the Willamette Valley a difficult place to grow wine grapes (Brown and Gredler, 1988). A great deal of research has been done on the effects of manipulating a grapevine canopy microclimate in order to produce a better fruit (Archer and Strauss, 1989; Morrison and Noble, 1990; Price *et al.*, 1995; Reynolds and Wardle, 1989; Reynolds *et al.*, 1994; Shaulis and May, 1971; Smart, 1985; Smart, 1973).

Important factors in a grapevine canopy microclimate include light, temperature, humidity, and evaporation. Trellis type has been shown in many instances to play a major role in a grapevine canopy microclimate (Escalera *et al.*, 1996; Howell *et al.*, 1991; Howell *et al.*, 1987; Reynolds and Wardle, 1994; Reynolds *et al.*, 1995; Reynolds *et al.*, 1985; Shaulis and May, 1971). The choice of trellis system depends upon many factors, and is the basis for all other canopy management techniques. These factors include site characteristics, vine vigor, clone, and rootstock. Training systems can either be cane pruned or spur pruned, single canopy or divided canopy. Using trellis system to manipulate shoot position can be a powerful tool in vineyard management (Jackson and Lombard, 1993).

The goals of a properly used trellis system are to maximize leaf exposure to photosynthetically active radiation (PAR), increase bud fruitfulness by increased light within the canopy, and to positively effect fruit composition (Smart, 1985). Trellis systems come in an almost unlimited number of forms. They can be cane-pruned, spur-pruned, or head trained, single canopy or double canopy systems.

Pinot noir has emerged as a leading winegrape cultivar grown in the cool climate region of Oregon's Willamette Valley. This research was initiated with four goals in mind: 1) To determine the influence of trellis type on yield and its components, shoot morphology, and fruit composition in Pinot noir grapevines; 2) To study the impact of canopy location on yield and its components and fruit composition in Pinot noir grapevines; 3) To determine the impact of trellis system on leaf gas exchange and carbohydrate movement in the trunk and to evaluate how these aspects would in turn affect yield and fruit composition of Pinot noir grapevines; 4) To characterize yield components, fruit composition and wine quality of fruit generated in Pinot noir vines in both curtains of the Scott Henry trellis system, and then to investigate if sun exposure had an influence on these variables.

Chapter 1: Literature Review

Trellis impact on vine structure

Trellis design has a large impact on light interception, shoot density, and fruit microclimate in grapevines (Jackson and Lombard, 1993). The total vine structure, which is established through trellis design, also determines the amount of perenniel wood retained. Increasing the amount of perennial wood through increased trunk height, maximized growth and fruit exposure in Seyval blanc vines (Reynolds *et al.*, 1985). In addition they found that systems with high trunks (a large amount of perennial wood) had enhanced vegetative growth. Koblet *et al.* (1994) found that total leaf area at harvest was larger on vines with a larger trunk volume, indicating that vines with a larger trunk volume have a better response to stress.

Within a given trellis system, high yields can be associated with high shoot numbers, but an increased shoot density can lead to more shading in the canopy interior (Smart, 1985). Shaulis and May (1971) demonstrated that one of the main benefits of using a divided canopy trellis system was that it increased the spacing between nodes and thereby improved the microclimate for fruit and leaves.

Using a divided canopy trellis system can maintain a desirable shoot density, while increasing shoots per vine, and therefore increasing yield (Escalera *et al.*, 1996; Kliewer *et al.*, 1991; Reynolds and Wardle, 1994; Reynolds *et al.*, 1995; Shaulis *et al.*, 1966; Shaulis and May, 1971; Smart, 1984). The Geneva double

Curtain (GDC) trellis system consists of a tall trunk with two downward hanging canopies. Smart (1973) found that GDC trained vines can have double the canopy exposure at midday when direct light was incident on four sides of the vine, compared to two sides with a single canopy system. It has also been shown that canopy division in the GDC reduced shading in Gewürztraminer vines (Smart, 1984). Pinot noir vines trained to the Scott Henry system had a reduced canopy density and therefore less leaf shading (Reynolds *et al.*, 1994). The Scott Henry system consists of two curtains, one trained upward, and the other trained to grow toward the ground. Escalera *et al.* (1996) found that Chardonnay vines grown on an Open Lyre trellis had increased pruning weights, as a result of more shoot per vine. The Open Lyre trellis consists of two curtains that are trained to grow upward in a V-shape.

Also related to trellis system is shoot orientation. Shoot orientation has demonstrated an impact on vine performance. Shaulis *et al.* (1966) found that downward shoot positioning can increase the sunlight exposure to the renewal zone. Kliewer *et al.* (1989) found that downward trained shoots on field grown Cabernet Sauvignon vines were less vigorous and had smaller primary leaves, and fewer lateral leaves resulting in a lower leaf area. The downward trained shoots had one-fifth the cane weight of those trained upward as well as a shorter shoot length, a shorter period between bud break and bloom, and slower fruit development. May (1966) working with Sultana vines, found that upward growing shoots had more vigor than shoots that were trained to grow downward. Morsi *et* *al.* (1992) demonstrated that downward-trained shoots produced fruit with a lower pH, and that there were no differences in soluble solids from the fruit of upward and downward-trained shoots. Schubert *et al.* (1995) working with container grown Cortese vines, found that downward trained shoots also had a lower leaf area, due to smaller leaves, rather than fewer leaves. It was also found in this study, that downward trained shoots had a smaller xylem transectional area, and lower hydraulic conductance, which was most noticeable at the point of bending. Schubert *et al.* (1995) also found a reduction in leaf area and a lower shoot diameter when shoots were trained to grow downward. Using a trellis system that includes downward oriented shoots may be a good option for high vigor sites. Since less leaf area and less cane length may result in better sunlight penetration within the canopy and the fruiting zone.

Foliage density and canopy form, which are determined by trellis type, have a impact upon cluster and basal leaf exposure (Smart, 1984). Shaulis and May (1971) found that increasing the spacing between nodes in Concord grapevines resulted in a better bud burst, more fruitfulness, and larger clusters with more berries per cluster. Jackson and Lombard (1993) list several benefits to having properly spaced nodes (i.e. a desirable shoot density): 1) increased air circulation and lower humidity which will lower the incidence of disease; 2) a decreased shading of shoots and developing buds which will increase bud fertility; 3) decrease fruit shading which will increase the quality of the resulting must. Howell *et al.* (1991) found that Vignoles grapevines, as well as Vidal blanc grapevines (Howell *et al.*, 1987) trained to four single canopy systems (high cordon, low cordon, high head, low head) had little difference in overall vine size or nodes retained.

Trellis impact on vine photosynthesis and carbohydrate storage

The method by which a grapevine is trained may affect variables such as light exposure, and therefore photosynthetic capability. A very dense canopy, i.e. a canopy with numerous leaf layers, can have a higher proportion of leaf surface area that only receives transmitted light, or no light at all. Smart (1984, 1985) reviewed light disribution in grapevine canopies and concluded that exterior leaves are responsible for 80-90% of estimated vine photosynthesis, and only about 9% of the photosynthetically active radiation (PAR) is transmitted to leaves within a grapevine canopy interior. Fully shaded leaves found within a grapevine canopy have been shown to contribute little to canopy photosynthesis (Smart, 1985).

Trellis type determines the orientation of shoot growth. The orientation of grapevine canopies influences the radiation and PAR interception of the grapevine leaves and fruit (Smart, 1984). Morsi *et al.* (1992) found that the available PAR was highest for downward-trained shoots and lowest for vertically trained shoots. However, Schubert *et al.* (1995) found that leaves on downward trained shoots had a lower rate of photosynthesis and stomatal conductance, caused by a reduced CO_2 fixation efficiency. Koblet (1975) found that shoot orientation had no impact on the export of photosynthates from leaves to fruit. Koblet (1975) also found that fully shaded leaves did not export any photosynthates, while leaves that were exposed to intermittent light exported photosynthates similar to leaves exposed to full sun. Also important in grapevine photosynthesis in the presence of diffuse light and sunflecks that are utilized by leaves within the grapevine canopy (Kriedemann and Smart, 1971; Kriedemann *et al.*, 1973).

Main leaves and laterals leaves of a grapevine begin exporting photosynthates when they have reached 30% of their final size (Koblet, 1969), and at 50% to 75% of their final size they no longer a sink for photosynthates, but instead are exporting to other parts of the vine (Koblet and Perret, 1979). Stoev *et al.* (1966) found the greatest photosynthetic activity takes place in leaves of the fifteeth to eighteeth nodes. Kriedemann (1968, 1977) found that net photosynthesis and chlorophyll content rose with leaf age, then declined as leaves became older and bronzed. Lateral shoots have been found to behave similarly to young leaves until one or two lateral leaves are mature, at which point no photosynthates move into lateral shoots from the main shoot (Hale and Weaver, 1962). Koblet (1969) found that lateral shoots without clusters exported photosynthates to the main cluster. Candolfi-Vasconcelos and Koblet (1990) found that lateral leaf area also plays an important role in the amount of starch reserves in the wood and the sugar concentration of mature fruit. As mentioned in the previous section, research has shown that trellis system can have a large impact on total leaf area, and may influence the amount lateral shoot growth, thereby having some influence on vine photosynthesis.

The amount of old wood retained is also affected by trellis type (Howell *et al.*, 1987; Koblet and Perret, 1980; Reynolds *et al.*, 1985; Weaver *et al.*, 1984). Reynolds *et al.* (1985) found that trellis systems with high trunks and large amounts of perennial wood serve as reservoirs for carbohydrates, as these systems were found to have a high degree of bud burst. Candolfi-Vasconcelos and Koblet (1990) observed a positive correlation between sugar concentration of must, and the starch concentration of the wood. Caspari *et al.* (1996) found that carbohydrate supply is a major determinant of fruit set.

Trellis impact on yield

The function of a properly used trellis system should be to maintain a balance between vegetative growth and reproductive growth so that the resulting crop will be of good quality. Howell *et al.,* (1991), in working with Vignoles grapevines in Michigan, listed several ways in which trellis system can influence yield: vine size may be increased, and therefore more nodes can be left at pruning; a change in the light microclimate may influence bud fertility; and fruit set or berry weight may be affected. Koblet and Perret (1980) found that vines with larger amounts of old wood had higher yields than vines that had smaller trunks. Archer and Strauss (1989) found that a shaded canopy resulted in a reduction in yield in Cabernet Sauvignon, and Morrison and Noble (1990) found that a shaded canopy decreased berry weights, which would result in a lower yield.

Because grapevine leaves transmit less than 10% of PAR, low light levels are common within the grapevine canopy (Smart, 1985). Bud differentiation has a direct relationship with crop yield for the following season. Anlagen (uncommited primordia) begin their initiation the summer (two weeks before bloom), prior to the year the grapes are actually harvested (Carolus, 1971; Pratt, 1979; Srinivasan and Mullins, 1976; Swanepoel and Archer, 1988). Differentiation is completed by the time the vines lose their leaves and enter dormancy (Mullins, 1992; Pratt, 1979). Bud fertility is determined by sunlight exposure of the leaves that subtended those buds, and therefore those buds, which occupied the best light exposed position, are the most fruitful (Galletta and Himelrick, 1990). Mullins *et al.* (1992) state that direct exposure of latent buds to high intensity light improves fruitfulness in grapevines. With a high shoot density, and multiple leaf layers within the canopy, poor bud differentiation may result, reducing fruitfulness, and therefore reducing yield.

As mentioned above, one way to increase vine size, and the number of potential fruiting sites, but retain a desirable shoot density is by using a multiple canopy trellis system, such as the Scott Henry, GDC, or Lyre systems. Double canopy trellis systems have been shown to effect overall yield by influencing cluster weight, berry weight, and number of berries per cluster (Reynolds and Wardle, 1994; Reynolds *et al.*, 1994). Reynolds *et al.* (1995) found that Chancellor vines grown with divided canopy systems had a 42% increase in yield when compared to single canopy systems.

Smart (1984) found that trellis system had a large impact upon yield, and that the GDC had one of the highest yields and the best fruit composition in field grown Gewürztraminer vines. The GDC has also been shown to increase yield and berries per cluster in Concord grapevines (Cawthon and Morris, 1977). Reynolds *et al.* (1995) also found that Chancellor vines grown with the GDC trellis produced high yields.

Pinot noir vines trained to the Scott Henry system have been found to have a reduced canopy density and therefore less leaf shading, and despite a 31% increase in yield from the Scott Henry trained vines, soluble solids were equal to a vine with half the shoot density per meter of row (Reynolds *et al.*, 1994). Escalera *et al.* (1996) found that the Open Lyre produced the highest Chardonnay yield, due mainly to and increase in the number of clusters per vine, when compared to the GDC and vertical shoot positioned trellis systems.

Trellis impact on fruit composition

As mentioned above, Howell *et al.* (1991) found that trellis system can influence yield by altering the canopy microclimate. In many cases, micrometeorological data has been related to fruit composition (Reynolds *et al.*, 1985). An over-vigorous canopy will have increased shoot density and can lead to excessive shading within the canopy. Excessive shading in grapevines has been shown to adversely impact yield, fruit composition, and ultimately wine quality.

The amount of sugars retained in the fruit of grapevines has been shown too be related to leaf area. The fruit coloration and °brix (% soluble solids) in Carignane and Zinfandel were found to be directly proportional to leaf area retained, sixteen to 20 leaves were considered necessary (Weaver *et al.*, 1963). Kliewer and Ough (1970) found that removal of 20% of Thompson Seedless leaves resulted in a lower °brix. Leaf defoliation in Sultana grapevines was also led to a decrease in fruit °brix, and an increase in TA (Kliewer and Antcliff, 1970). The direct influence of training system on leaf area was demonstrated by Shaulis *et al.* (1966) in their studies of the GDC. These researchers found that °brix decreased in canopies with a short canopy length and an increased amount of interior shoots in Concord grapevines.

Other research has shown that excessive shading can have a negative impact upon fruit quality. Archer and Strauss (1989) found that Cabernet Sauvignon grapes, grown in a dense canopy had a reduction in skin color, pH, and TA. Morrison and Noble (1990) found many impacts resulting from excessive leaf shading in research done on Cabernet Sauvignon grapes. These included a lowering of berry weights at maturity, delayed onset of ripening, higher pH, higher malate and potassium concentrations at maturity (the latter was highly correlated with juice pH), lower anthocyanin concentration, and lower phenols. Reynolds and Wardle (1989), found that shading delayed the accumulation of sugars and the degradation of acids in vertically trained Gewürztraminer. Reynolds *et al.* (1994)

found that an increase in shoot density and clusters per shoot in Pinot noir vines led to a decrease in fruit °brix and pH, and an increase in TA. The findings of Reynolds *et al.* (1995) indicate that Chancellor vines with higher yields also had a decrease in juice soluble solids.

Research indicates that anthocyanin concentration in grape skins is dependent upon cluster exposure to the sun (Archer and Strauss, 1989; Jackson and Lombard, 1993). It was shown that skin anthocyanin concentration was lower in a shaded Cabernet Sauvignon canopy (Morrison and Noble, 1990). In another study on Cabernet Sauvignon grapes it was found that sun-exposed clusters were higher in total phenols per berry than shaded clusters, and that sun exposed clusters had a higher concentration of skin anthocyanins during stage III of berry growth, but concentrations were not different from shaded clusters at harvest (Crippen and Morrison, 1986).

Price *et al.* (1995) investigated the impacts of cluster shading in Pinot noir grapes, and found that both exposed and shaded clusters were smaller than those with moderate exposure. They also found that shaded clusters had fewer berries, lower cluster weights, lower soluble solids, and higher TA (which was attributed to higher malic acid). Exposed clusters had 60% higher anthocyanin concentration than shaded clusters, and fully exposed clusters had 385% higher quercetin levels than the fully shaded clusters.

There is an abundance of literature stating that if an optimal fruit environment can be achieved, good fruit quality can be attained despite high crop levels (Jackson and Lombard, 1993; Reynolds *et al.,* 1996; Smart *et al.*, 1985 (I); Smart *et al.*, 1985 (II); Smart *et al.*, 1990). These authors have demonstrated the impact that double canopy trellis systems can have on achieving an optimal shoot density, which in turn may help to attain a desirable fruit microclimate. Pinot noir vines trained to the Scott Henry system led to increased ethanol and anthocyanin concentrations and reduced TA and pH in the wines relative to non-divided systems (Reynolds *et al.*, 1996). Kliewer *et al.* (1989) while working with Cabernet Sauvignon grapevines, found that the fruit harvested from downward oriented shoots had lower soluble solids than upward oriented shoots. Reynolds *et al.* (1995) indicated that Chancellor vines grown with a GDC trellis had higher yields and a higher berry anthocyanin concentration. Morsi *et al.* (1992) found that fruit harvested from Petite Sirah grapevines had a higher soluble solids when trained to a Tatura trellis (V-shaped). Research has also shown that increasing the amount of perennial wood through increased trunk height, maximized pH, and minimized TA in Seyval blanc vines (Reynolds *et al.*, 1985).

Conclusion

The way in which a grapevine is trained has been shown to influence virtually all aspects of grapevine growth and therefore the resulting fruit production. As illustrated in the above text, trellis type can influence vine structure, vine photosynthetic capacity, yield, and fruit composition. Research has shown that for the production of quality wine grapes, a grapevine canopy should be developed that allows for at least partial sun exposure of fruit and growing shoots, and for maximum sun exposure of the leaves. A grapevine trellis system, when matched with site and vigor, clone and rootstock, can a very important viticultural tool.

Chapter 2: Effect of Trellis Type and Canopy Location on Yield Components, Fruit Composition, Fruit Set, and Shoot Morphology in Pinot noir Grapevines

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Abstract

Five different trellis and training systems were compared in their effect on yield components, fruit composition, fruit set, and shoot morphology in Pinot noir grapevines in 1996 and 1997. This trial was performed on established vines planted on a low-vigor valley floor site, in the Willamette Valley of Oregon. The treatments were: upright vertical, cane pruned (double Guyot); upright vertical, spur pruned (bilateral cordon); Scott Henry, cane pruned; Lyre, cane pruned; and Geneva Double Curtain (GDC), cane pruned. The GDC and the Scott Henry had the highest yield, but were not different from the Lyre or bilateral cordon in 1996. In 1996, the double canopy systems had almost double the yield of the single canopy systems. There were no differences in yield in 1997 among any of the five trellis systems. The GDC, Scott Henry, and Lyre had the highest number of clusters per shoot, the GDC had the highest cluster weight and the GDC and Scott Henry had the most berries per cluster in 1996. These differences were not seen in 1997. The bilateral cordon had a higher leaf area index than did the other systems. In 1996, the GDC and Scott Henry systems had a higher skin anthocyanin concentration than did the other systems. There were no differences in juice soluble solids, pH, or TA among the different trellis systems in either year. The two canopies ot the double canopy trellis systems were also evaluated by canopy to determine differences within the vine. In 1996, there were no differences in yield between the canopies within a vine. In 1997, there were few differences observed

except the top canopy of the Scott Henry had a higher TA and more berries per cluster than did the bottom canopy.

Introduction

A great deal of research has been done on the effects of manipulating a grapevine canopy microclimate (Archer and Strauss, 1989; Morrison and Noble, 1990; Price *et al.*, 1995; Reynolds and Wardle, 1989; Reynolds *et al.*, 1994; Shaulis and May, 1971; Smart, 1985; Smart, 1973). Important factors in a grapevine microclimate include light, temperature, humidity, and evaporation. Trellis type has been shown in many instances to influence a grapevine microclimate (Escalera *et al.*, 1996; Howell *et al.*, 1991; Howell *et al.*, 1987; Reynolds and Wardle, 1994; Reynolds *et a*l., 1995; Reynolds *et al.*, 1985; Shaulis and May, 1971). Trellis systems come in an almost unlimited number of forms. They can be cane-pruned, spur-pruned, or head trained, single canopy or double canopy systems. Howell *et al.,* (1991), working with Vignoles grapevines in Michigan, listed several ways in which trellis system can influence yield: vine size may be increased, and therefore more nodes can be left at pruning; a change in the light microclimate may influence bud fruitfulness; and fruit set or berry weight may be affected.

Within a given trellis system, high yields can be associated with high shoot numbers, but an increased shoot density can lead to more shading in the canopy interior (Smart, 1985). Using a divided canopy trellis system can maintain a desirable shoot density, while increasing shoots per vine, and therefore increasing yield (Escalera *et al.*, 1996; Kliewer *et al.*, 1991; Reynolds and Wardle, 1994; Reynolds *et al.*, 1995; Shaulis *et al.*, 1966; Shaulis and May, 1971; Smart, 1984). Divided canopy systems also have been shown to positively impact Pinot noir and Seyval blanc cluster weights, berry weights, and number of berries per cluster in British Columbia, Canada (Reynolds and Wardle, 1994; Reynolds *et al.*, 1994).

Shoot orientation is determined by trellis type. For example, the Scott Henry system has two canopies, one canopy is trained to grow upwards, while the other is trained to grow downwards. Trellis systems such as the Guyot have an upward growing canopy as compared to the GDC, which has two canopies trained to grow downward. Downward trained shoots are less vigorous, havings smaller primary leaves, fewer lateral leaves, shorter shoots, and a lower cane dry weight in Cabernet Sauvignon grapevines (Kliewer *et al.*, 1989). These researchers also found that the period from bud burst to bloom was shorter when shoots were trained to grow downward. Schubert *et al.* (1995) also found a reduction in leaf area and a smaller shoot diameter when shoots were trained to grow downward. This reduction in leaf area was due to smaller leaves, rather than fewer leaves.

The amount of old wood retained can also be impacted by trellis type. Trellis systems such as the bilateral cordon are spur pruned and so retain more old wood in the perenniel arms of the trellis system, as compared to the Guyot system which is cane pruned leaving less of a permanent structure. Reynolds *et al.* (1985) found that trellis systems with high trunks and large amounts of perenniel wood served as reservoirs for carbohydrates. Koblet and Perret (1980) found that vines with a higher amounts of old wood had higher yields than vines with a smaller permanent structure. In Müller-Thurgau this larger permanent structure resulted in increased cluster weights (Koblet and Perret, 1980). Further, in spite of higher yields, the Pinot noir vines studied had a higher berry sugar concentration when more old wood was retained (Koblet and Perret, 1980). Increasing trunk height (amount of perennial wood), maximized growth, fruit exposure, and pH, and minimized TA in Seyval blanc vines grown on different trellis systems (Reynolds *et al.*, 1985). Retaining more old wood has also been shown to increase yield in Thompson Seedless and Vidal blanc grapevines (Howell *et al.*, 1987; Weaver *et al.*, 1984). Short trunks (less old wood), with long fruiting canes optimized sugar accumulation in Seyval blanc (Reynolds *et al.*, 1985).

Foliage density and canopy form, which are determined by trellis type, have an impact upon cluster and basal leaf exposure (Smart, 1984). Berry growth and sugar accumulation were found to be slower in Cabernet Sauvignon and Gewürztraminer grapevines with shaded leaves and fruit (Archer and Strauss, 1989; Morrison and Noble, 1990; Price *et al.*, 1995). Anthocyanins and total soluble phenols were lower in shaded Cabernet Sauvignon fruit (Morrison and Noble, 1990), and cluster sun exposure was found to be a primary factor in quercetin levels in Pinot noir grapes (Price *et al.*, 1995).

Pinot noir has emerged as the leading cultivar of wine grapes grown in Oregon's Willamette Valley. This study was initiated to determine the influence of trellis type on yield components, shoot morphology, and fruit composition in Pinot noir grapevines. Based on previous research it was hypothesized that yield would be greater in the double canopy systems without compromising fruit quality. It was also hypothesized that leaf area would be greater in the double canopy systems, enabling the double canopy systems to ripen a heavier crop load.

Materials and methods

Own rooted Pinot noir (UCD 4) planted in the Spring of 1984 in a randomized complete block design at the Lewis-Brown Farm (Corvallis, Oregon) was studied. The vines were trained to five trellis systems. These treatments were: upright vertical, cane pruned (double Guyot); upright vertical, spur pruned (Bilateral cordon); Scott Henry, cane pruned; Lyre, cane pruned; and Geneva Double Curtain (GDC), cane pruned. Diagrammatic representations of these trellis systems are shown in Figure 2.1. The two single canopy systems (Guyot and bilateral cordon) were spaced 1.5m x 2.0m (vine x row), and the divided canopy systems (Scott Henry, Lyre, and GDC) were spaced 1.5m x 3.0m (vine x row). Rows were oriented east to west. Each plot consisted of eight vines, two border vines and six data vines. There were a total of 25 plots (the treatments were replicated 5 times). There were guard rows between each replication, and between single and divided canopy systems within replication. The Pinot noir vines were balance pruned to 28 nodes/kg cane prunings in February of 1996 and 1997.

The trial was located on a soil depth gradient, and blocked against the gradient with replications one and two grown on shallower soils than replications

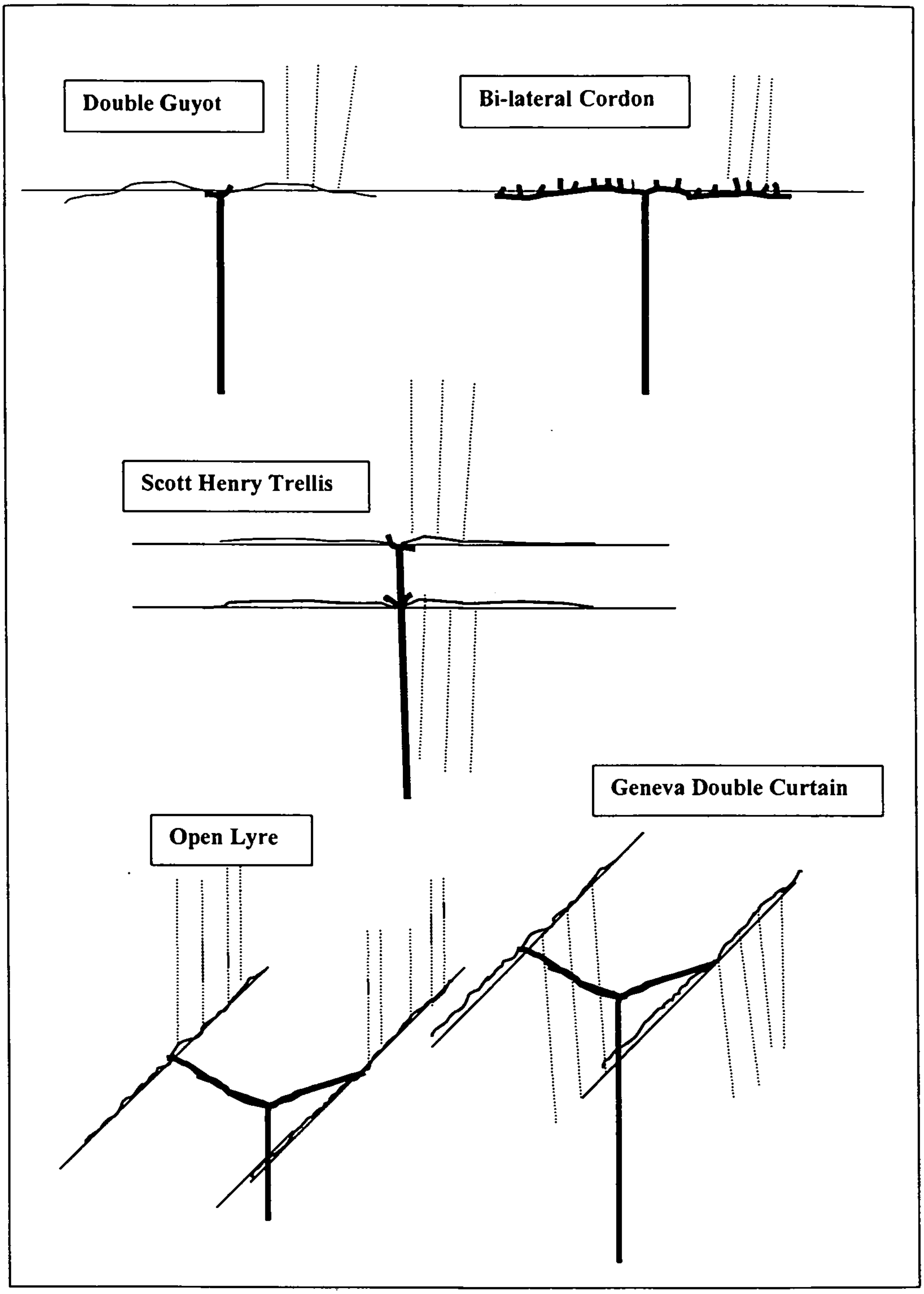

Figure 2.1: Diagrammatic representations of the five training systems observed in this experiment.

three, four and five. Soils in the area of this trial consist of Chehalis and Malabon series. In 1996 no irrigation was applied to the trial. In 1997, drip irrigation was applied to replications one and two during the months of August and September, when the vines appeared to be suffering from drought stress. Vineyard floor management consisted of a natural green cover. Common ground cover species include *Poa annua, Trifolium sp.,* and *Hypochaeris radicatta* (Spotted Cat's Ear). Alternate rows were mowed after resident plant species were allowed to bloom. Pest control was consistant with grower practices for the area (Pscheidt, 1992). The vines were shoot positioned and hedged three times during the growing season.

Shoot morphology

Shoots were hedged above the top wire, and above ground level for the downward hanging canopies. Because the trellis systems were different heights, this resulted in different shoot lengths among the trellis systems. In 1996, immediately post harvest, and in 1997 just prior to harvest, one shoot per vine on the single canopy treatments, and one shoot per canopy on the double canopy treatments were collected. Shoots with a similar diameter, and from mid-cane were selected. Diameter, shoot length, main leaf area and number, and lateral leaf area and number were measured. Shoot diameter was measured on the third internode from the shoot base. Leaf area was measured using a LI-COR area meter (model 3100). Percent of main leaf area to the total leaf area, percent lateral leaf area to the total leaf area, and leaf area index (LAI) were extrapolated from a subsample. LAI was determined using total leaf area and square meter ground surface area. After leaf fall, total shoot number per vine was determined. Pruning weights were recorded at pruning.

Fruit set

Just prior to bloom, in 1996 and 1997 one inflorescence per vine was enclosed in a pollination bag to catch all shed flowers. Four weeks after bloom was completed, the bags were removed, and all shed flowers were counted. At harvest, the same clusters were picked separately, frozen, and then all berries and remaining flowers were counted. Total flower number and percent fruit set were then calculated from the total number of flowers and berries.

Yield and fruit composition

The trial was harvested October 16, 1996 and September 30, 1997. The six treatment vines per plot were harvested and weighed. The fruit from the double canopy systems were harvested by canopy, and weighed separately. A 24 cluster sample was used to determine cluster weight, and was then crushed to determine soluble solids, pH, and TA. A six cluster sample was weighed and then frozen, and later used to determine berry weight. A 100-berry sample was frozen and later processed to determine skin weight and anthocyanin concentration. The skins were removed from all berries in each 100 berry sample. The skin samples were then extracted and decanted three times in a 250 ml jar with different volumes of MeOH/HCl extractant. (The first extracion was done with 70ml, the second with

40ml, and the third with 30ml of 1%MeOH/HCl). After the third extraction, the combined extracts were brought to a final volume of 200 ml. This final extract was frozen and color was determined later with the spectrophotometer at 530nm. Detailed methods used to determine anthocyanin concentration can be found in Candolfi-Vasconcelos and Koblet (1990).

Data analysis

All data were analyzed by ANOVA using the SAS statistical package (SAS Institute, Cary, NC), with mean separation by Waller-Duncan K-ratio T test at $p < 0.05$.

Results and discussion

Shoot morphology

Due to differences in spacing among the divided and single trellis systems, LAI (the ratio between leaf area and ground surface area) was used to describe leaf area among the five trellis systems. There were no differences in LAI among the Guyot, GDC, Lyre, and Scott Henry. However, the LAI for the bilateral cordon was higher than the other systems in 1996 (data not shown) and when the data from both years was combined (Table 2.1). In 1997, LAI did not differ among the trellis systems (data not shown). Overall, LAI was higher in 1997 (Table 2.1).

There was no difference among the five trellis systems in percent main leaf area or percent lateral leaf area during either year (data not shown). Percent main

Table 2.1: Shoot morphology characteristics of Pinot noir grapevines trained to five trellis systems.

	Trellis	LAI	% Main leaf area	% Lateral leaf area	Internode length(cm)	Shoot diam. (mm)	Flower #	Fruit Set (%)
	Main effects							
Trellis	Cordon	1.45 a	69 ab	31 ab	7.8	7.40 b	169 b	44
	GDC	0.84 b	76 a	23 b	8.9	7.91 a	238 a	41
	Guyot	0.89 b	65 b	34 a	9.0	7.79 a	197 ab	46
	Lyre	0.84 b	71 ab	29 ab	9.1	7.83 a	165 b	44
	Scott Henry	1.10 b	74 ab	25 ab	8.9	8.02 a	217 a	42
	Significant F	***	*	*	ns	**	**	ns
Year	1996	0.87 b	64 b	35 a	9.9	7.79	263 a	42
	1997	1.17 a	78 a	21 b	7.6	7.78	130 b	44
	Significant F	***	***	***	***	ns	***	ns
	Interaction							
	trellis x year	ns	ns	ns	ns	ns	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01 and 0.001 levels.
Values followed by the same letters do not differ significantly.

leaf area and percent lateral leaf area were different between the two years of this trial, and can be explained by the droughty conditions in 1997. Percent main leaf area averaged 64% in 1996 and 78% in 1997. Percent lateral leaf area averaged 35% in 1996 and 21% in 1997. Over the two data years, the GDC had a higher percent main leaf area, and a lower percent lateral leaf area than did the Guyot, but did not differ from the other trellis systems (Table 2.1). These trends were in agreement with previous findings (Kliewer *et al.*, 1989; Schubert *et al.*, 1995), where it was shown that downward oriented shoots have a lower leaf area when compared to upward growing shoots.

Internode length and shoot diameter did not differ among the trellis systems during either year (data not shown). The cordon had the shortest internode length and the smallest shoot diameter in both years (Table 2.1). The Scott Henry system had the highest overall shoot diameter, followed by the GDC, but the differences were not large enough to be statistically significant (Table 2.1). The observed trends differ from previous findings, where it was shown that training a shoot to grow downward resulted in a reduction in shoot diameter (Kliewer et al., 1989; Schubert *et al.*, 1995).

Fruit set

Mean fruit set was not affected by year and was 42% in 1996 and 44% in 1997. Fruit set did not differ among the five trellis systems during either year (Table 2.1). Mean flower number per cluster (263 flowers in 1996 and 130 flowers in 1997), was different between the two years of this trial (Table 2.1). Flower number was not affected by trellis system in 1996 (data not shown). However, in 1997 the bilateral cordon had fewer flowers than the GDC (data not shown). Over both data years, the GDC and Scott Henry systems had a higher flower number than the Lyre and bilateral cordon (Table 2.1). These higher flower numbers resulted in a higher number of berries per cluster in the GDC when compared to the Guyot over the two years of this trial (Table 2.2). In 1996, the GDC and Scott Henry systems had a higher number of berries per cluster than the other three trellis systems (Table 2.2). This trend was also seen in 1997, but differences were not significant. These results indicate that trellis system does not influence fruit set, but may influence the total number of flowers produced. The GDC and Scott Henry systems, both of which have downward hanging canopies, produced more flowers resulting in more berries per cluster.

Previous research showed that flower differentiation occured in the early about the time of bud burst, as buds emerge from dormancy (Mullins *et al.*, 1992). During this stage of grapevine growth there is little microclimate difference among trellis systems as the canopy is absent. We speculate that the anlage reach a more advanced stage of development before entering dormancy. Hanging canopies have a reduced apical dominance (Kliewer *et al.*, 1989; Schubert *et al.*, 1995) which may affect competition between shoot growth and bud formation.

Table 2.2: Yield and yield components of Pinot noir grapevines trained to five different trellis systems.

Year	Trellis	Yield (Kg/m^2)	Tons/ Acre	Clusters/ m^2	Clusters/ shoot	Cluster wt. (g)	Berry wt. (g)	Berries/ cluster
	Treatment effects							
1996	Cordon	0.76 ab	3.4 ab	7	1.0 bc	100.67 c	0.94	112 b
	GDC	1.17 a	5.2 a	9	1.6 a	130.67 a	0.91	152 a
	Guyot	0.43 b	1.9 b	6	0.8 c	71.00 d	0.84	88 c
	Lyre	0.77 ab	3.4 ab	7	1.5 ab	111.67 bc	0.93	123 b
	Scott Henry	1.02 a	4.5 a	9	1.6 a	115.67 b	0.91	131 ab
	Significant F	*[1]	*	ns	**	***	ns	***
1997	Cordon	0.66	2.9	6	1.0	99.45	1.13	90
	GDC	0.68	3.0	6	1.3	104.63	1.05	100
	Guyot	0.54	2.4	6	1.3	97.40	1.03	95
	Lyre	0.55	2.5	6	1.1	94.32	1.03	93
	Scott Henry	0.56	2.5	5	1.0	102.43	1.05	99
	Significant F	ns	ns	ns	ns	ns	ns	ns
	Main effects							
Trellis	Cordon	0.71	3.2	7	1.0	100.06	1.04	101 ab
	GDC	0.93	4.1	8	1.5	117.65	0.98	126 a
	Guyot	0.49	2.2	6	1.1	84.20	0.94	92 b
	Lyre	0.66	2.9	6	1.3	102.99	0.98	108 ab
	Scott Henry	0.79	3.6	7	1.3	109.05	0.98	115 ab
	Significant F	ns	ns	ns	ns		ns	*
Year	1996	0.84	3.7	8	1.3	105.93	0.91	122 a
	1997	0.60	2.7	6	1.2	99.65	1.06	96 b
	Significant F	ns	ns	ns	ns		ns	**
	Interaction							
	trellis x year	ns	ns	ns	ns	**	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01 and 0.001 levels.
Values followed by the same letters do not differ significantly.

Yield and fruit composition

The GDC and the Scott Henry systems had the highest yields in 1996, but were not different from the Lyre and bilateral cordon (Table 2.2). The Guyot was lowest yielding at 0.43 kg/m^2 (1.9 tons/acre). The mean yield for the single canopy systems (Guyot and bilateral cordon) in 1996 was 0.6 kg/m^2. Mean yield for the divided canopy systems (Scott Henry, Lyre, and GDC) in 1996 was 1.0 kg/m^2. For the 1996 season, the divided canopy systems nearly doubled yield. In 1997 there were no differences in yield among the five trellis systems (Table 2.2). There were also no differences in clusters per unit of ground surface area in either year. The divided canopy systems had the most clusters per shoot and the Guyot the least in 1996, but in 1997 these differences were not seen (Table 2.2). When the yields for both years were combined, there were no trellis system effect. However, the GDC and Scott Henry systems tended to have higher yields and the Guyot had a lower yield in this trial (Table 2.2). The trends seen in yield were a result of differences in cluster weights, berries per cluster, and the number of clusters per unit of ground surface. Trends also show that yield differences had no effect on fruit composition, and that the GDC and Scott Henry systems had a higher skin anthocyanin concentration than the other trellis systems in this trial. Reynolds *et al.* (1995) also found that Chancellor vines grown in the GDC trellis had higher yields and a higher anthocyanin concentration. The GDC and Scott Henry systems had a lower LAI, which would result in better canopy and cluster exposure. It would appear that although the GDC and Scott Henry trellis systems had higher yields, the increased canopy exposure resulted in an equal or better fruit quality, when compared to the other systems in this trial. Smart (1973) found that GDC vines can have double the canopy exposure at midday when direct light was incident on four sides per vine, compared to two sides with a single canopy system.

From 1996 to 1997 the number of berries per cluster dropped by an average of 34 berries for all the trellis systems except the Guyot system which had an increase of 7 berries per cluster (Table 2.2). In 1996 the GDC had the highest cluster weight and the highest number of berries per cluster at 152 (Table 2.2). The Guyot system, in 1996, had a lower cluster weight and number of berries per cluster than the other trellis systems. For 1996, higher yields were due to more clusters per shoot, higher cluster weight, and more berries per cluster. These results differ from previous findings, where it was found that an increased crop load led to a decrease in berry weights, cluster weights, and the number of berries per cluster (Escalera *et al.*, 1996; Reynolds *et al.*, 1995; Reynolds *et al.*, 1994). These differences in cluster weight and number of berries per cluster were not seen in 1997. When the data from both years were averaged, there was an interaction in cluster weight among trellis system and year (Table 2.2). Berry weight showed a trend toward a slight increase from 1996 to 1997 (Table 2.2). Cluster weight did not increase from 1996 to 1997 due to the overall decrease in number of berries per cluster (Table 2.2).

There were no differences in must soluble solids, pH, or TA among the five training systems (Table 2.3). This suggested that for the 1996 season, the double

Table 2.3: Fruit composition and skin characteristics from Pinot noir grapevines trained to five trellis systems.

Year	Trellis	% Soluble solids (brix)	pH	TA (g/L)	Skin anthocyanins (mg/berry)
	Main effects				
Trellis	Cordon	20.5	3.12	7.95	0.705
	GDC	20.1	3.10	7.87	0.832
	Guyot	20.7	3.11	8.33	0.705
	Lyre	20.3	3.14	7.94	0.745
	Scott Henry	20.2	3.10	7.85	0.822
	Significant F	ns	ns	ns	ns
Year	1996	19.1 b	3.06 b	8.59 a	0.674
	1997	21.6 a	3.17 a	7.39 b	0.850
	Significant F	***	***	***	ns
	Interaction				
	trellis x year	ns	ns	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01 and 0.001 levels. Values followed by the same letters do not differ significantly.

canopy trellis systems had the effect of nearly doubling yield with no detrimental effects on fruit composition. These results agree with the findings of Reynolds *et al.* (1995) where Chancellor vines were grown with divided canopy systems and had a 42% increase in yield when compared to single canopy systems. However, the results in our Pinot noir trial indicated that the increased yields had no affect on soluble solids, while Reynolds *et al.* (1995) indicated that the Chancellor vines with higher yields had a decrease in soluble solids. The mean juice soluble solids across trellis systems at harvest was 19.1 and 21.6 °brix in 1996 and 1997, respectively. Mean pH in 1996 was 3.06 across trellis system and mean TA was 8.59g/l (Table 2.3). Mean pH in 1997 was 3.17 across trellis system and mean TA was 7.39 g/l.

The Lyre had the highest berry skin weight in 1996 (data not shown), although there were no differences in percent skin to berry weight. In 1996, the Scott Henry system had the highest skin anthocyanin concentration per berry weight, although it did not differ from the GDC system (data not shown). In 1997 there were no differences seen in skin anthocyanin concentration per berry weight among the five trellis systems (data not shown). Although the trend was for the GDC and Scott Henry systems to have a higher skin anthocyanin concentration during the two years of this trial (Table 2.3). The skin anthocyanin concentration per unit of berry weight was slightly higher in 1997 (Table 2.3) probably a result of lower yields, cluster weight, and berries per cluster (Table 2.2).

Divided canopy comparison

Geneva double curtain

There were no differences in yield and yield components between the two canopies of the GDC (Table 2.4). There were no differences in berry weight, berries per cluster, juice soluble solids, pH, or TA between the two canopies of the GDC (Table 2.5). Overall, the GDC system had higher juice soluble solids and a higher pH in 1997 (Table 2.5). In 1996 the GDC had a higher percentage of main leaf area (68%) in the north facing canopy and a higher percentage of lateral leaf area (40%) in the south facing canopy (Table 2.6). No differences were observed in leaf area in 1997. Shoot diameter was not different between the two canopies of the GDC (Table 2.6). Although much research has been done on the impacts of training to the GDC trellis system (Escalera *et al.*, 1996; Reynolds and Wardle, 1994; Reynolds *et al.*, 1995; Shaulis and May, 1971; Smart, 1973), there was no research to date on the differences in yield and growth variables between the two canopies of the GDC system.

Open lyre

There were no differences in yield and yield components between the two canopies of the Lyre (Table 2.4). There were no differences in berry weight, berries per cluster, juice soluble solids, pH, or TA between the two canopies in either year (Table 2.5). Overall, the Lyre system had a higher juice soluble solids and a lower TA in 1997. In 1996 the percent of main leaf area was lower and the percent of

Table 2.4: Yield component data for the two canopies of the GDC, Lyre, and Scott Henry trellis systems in 1996 and 1997.

Trellis system	Year	Canopy	Yield (Kg/m^2)	Cluster wt. (g)	Clusters/ m^2	Clusters/ shoot
GDC	**Main effects**					
	Canopy	North	0.35	98.7	3.9	1.4
		South	0.37	101.5	3.6	1.5
		Significant F	ns[1]	ns	ns	ns
	Year	1996	0.44	104.0	4.4 a	1.7
		1997	0.29	96.1	3.1 b	1.3
		Significant F	ns	ns	**	ns
	Interaction	canopy x year	ns	ns	ns	ns
Lyre	**Main effects**					
	Canopy	North	0.44	100.5	4.0	1.6
		South	0.43	104.2	4.1	1.5
		Significant F	ns	ns	ns	ns
	Year	1996	0.53	101.3	4.7	1.8
		1997	0.35	103.4	3.1	1.3
		Significant F	ns	ns	ns	ns
	Interaction	canopy x year	ns	ns	ns	ns
	Main effects					
Scott Henry	Canopy	Bottom	0.44	105.9	3.8	1.5
		Top	0.43	106.5	3.8	1.4
		Significant F	ns	ns	ns	ns
	Year	1996	0.54	105.7	5.0 a	1.8 a
		1997	0.33	106.9	3.1 b	1.0 b
		Significant F	ns	ns	**	**
	Interaction	canopy x year	ns	ns	ns	ns

[1]ns, *, ** indicate not significant and statistically significant at the 0.05 and 0.01 levels.
Values followed by the same letters do not differ significantly.

Table 2.5: Fruit composition data for the two canopies of the GDC Lyre, and Scott Henry trellis systems in 1996 and 1997.

Trellis system	Year	Canopy	Berry wt. (g)	Berries/ cluster	Brix	pH	TA (g/l)
GDC	**Main effects**						
	Canopy	North	0.95	106	19.8	3.09	7.91
		South	0.93	112	20.0	3.10	7.83
		Significant F	ns[1]	ns	ns	ns	ns
	Year	1996	0.91	117	19.0	3.04	8.46
		1997	0.97	101	20.1	3.15	7.28
		Significant F	ns	ns	**	**	ns
	interaction	canopy x year	ns	ns	ns	ns	ns
Lyre	**Main effects**						
	Canopy	North	0.96	106	20.4	3.14	7.86
		South	1.00	105	20.6	3.14	7.72
		Significant F	ns	ns	ns	ns	ns
	Year	1996	0.93	110	19.2	3.10	8.60
		1997	1.02	102	21.7	3.18	6.97
		Significant F	ns	ns	**	ns	**
	interaction	canopy x year	ns	ns	ns	ns	ns
Scott Henry	**Main effects**						
	Canopy	Bottom	0.98	106	19.8	3.11	7.65
		Top	0.97	112	20.2	3.10	8.10
		Significant F	ns	ns	ns	ns	ns
	Year	1996	0.88	116	18.9	3.05	8.55
		1997	1.06	103	21.0	3.16	7.20
		Significant F	ns	ns	**	**	**
	interaction	canopy x year	ns	ns	ns	ns	ns

[1]ns, *, ** indicate not significant and statistically significant at the 0.05 and 0.01 levels. Values followed by the same letters do not differ significantly.

Table 2.6: Shoot morphology data for the two canopies of the GDC, Lyre, and Scott Henry trellis systems in 1996 and 1997.

Trellis system		Canopy	LAI	% Main leaf area	% Lateral leaf area	Shoot diam. (mm)
GDC	**Main effects**					
	Canopy	North	0.40	76	24	8.11
		South	0.39	76	24	7.72
		Significant F	ns[1]			ns
	Year	1996	0.45	64	36	8.04
		1997	0.34	89	11	7.78
		Significant F	ns			ns
	interaction	canopy x year	ns	**	**	ns
Lyre	**Main effects**					
	Canopy	North	0.56	71	29	7.76
		South	0.61	73	27	7.89
		Significant F	ns	ns	ns	ns
	Year	1996	0.59	64	36	7.72
		1997	0.58	80	20	7.93
		Significant F	ns	**	**	ns
	interaction	canopy x year	ns	ns	ns	ns
Scott	**Main effects**					
Henry	Canopy	Bottom	0.48	76	24	8.14
		Top	0.46	76	24	7.88
		Significant F	ns	ns	ns	ns
	Year	1996	0.52	66	34	8.14
		1997	0.43	85	15	7.88
		Significant F	ns	**	**	ns
	interaction	canopy x year	ns	ns	ns	ns

[1]ns, *, ** indicate not significant and statistically significant at the 0.05 and 0.01 levels.

Values followed by the same letters do not differ significantly.

lateral leaf area was higher than in 1997 (Table 2.6). However, within a single year the Lyre had similar main and lateral leaf area percentages between both sides of the canopy (data not shown). Shoot diameter was not different between the two canopies in either year (Table 2.6). Carbonneau and Casteran (1986) did a detailed study of the Lyre system, and although they found the Lyre system to give desirable results in both yield and fruit quality, differences between the two canopies of the Lyre were not studied.

Scott henry trellis

There were no differences in yield and yield components between the two canopies of the Scott Henry system (Table 2.4). Although not significant, in 1996 the bottom canopy had a slightly higher yield ($0.58 kg/m^2$) than did the top canopy ($0.50 kg/m^2$), and in 1997 the opposite trend was seen (data not shown). This was due to changes in cluster weights, which in 1996 were lower in the top canopy, and in 1997 were higher in the top canopy (data not shown). When the data from both years was combined, the yields between the top and bottom canopies of the Scott Henry system were the same. Overall, yields were higher in 1996 than in 1997 (Table 2.4). This was due to a higher number of clusters per shoot in 1996 (Table 2.4). There were no differences in berry weight, berries per cluster, juice soluble solids, pH, or TA between the two canopies in 1996 (Table 2.5). In 1997, the top canopy had more berries per cluster, and a higher TA, while juice soluble solids and pH did not differ between the top and bottom canopies (data not shown). When the data from both years was combined there were no differences seen in fruit composition between the top and bottom canopies of the Scott Henry system (Table 2.5). In 1996, when the overall Scott Henry yields were higher, juice soluble solids and pH was lower, and TA was higher than in 1997 (data not shown). Shoot diameter was not different between the two canopies (Table 2.6). These results differ from previous findings where it was shown that downward trained shoots had less vigor, lower leaf area, and a lower shoot length and diameter (Kliewer *et a*l., 1989; Schubert *et al.*, 1995).

Conclusions

The information derived from this two year study suggests that double canopy trellis systems, such as the GDC, Scott Henry and Lyre systems, can increase overall yield without having detrimental effects on fruit quality. Furthermore, double canopy systems may promote a better canopy microclimate, i.e. reduced leaf and fruit shading, which would explain the higher skin anthocyanin concentrations that were observed in the double canopy systems in 1996. These findings proved our initial hypothesis to be true. These conclusions would also agree with other findings that indicate trellis system has an impact on canopy microclimate (Escalera *et al.*, 1996; Howell *et al.*, 1991; Howell *et al.*, 1987; Reynolds and Wardle, 1994; Reynolds *et al.*, 1995; Reynolds *et al.*, 1985; Shaulis and May, 1971). And, that higher yields can be achieved with divided canopy systems with little to no detrimental effects on fruit quality (Escalera *et al.*, 1996;

Kliewer *et al.*, 1991; Reynolds and Wardle, 1994; Reynolds *et al.*, 1994; Shaulis and May, 1971; Smart, 1985; Smart, 1973).

This trial also demonstrated the general lack of differences between canopies of the divided trellis systems. The two curtains of the GDC, Scott Henry, and Lyre systems showed no differences in yield, fruit quality, or shoot morphology over this two year study. This would indicate that grapevine canopies can be trained to double curtains without creating uneven ripening between the curtains when the rows run east-west.

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Chapter 3: Effect of Trellis Type on Dynamics of Storage Carbohydrates, Leaf Gas Exchange, and Fruit Composition in Pinot noir Grapevines

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Abstract

Five different trellis and training systems were compared for their effect on wood carbohydrate reserves at four different phenological stages in Pinot noir grapevines. These trellis systems were also compared for their effect on leaf gas exchange. This trial was performed on established vines planted on a low-vigor valley floor site, in the Willamette Valley of Oregon. The treatments were: upright vertical, cane pruned (double Guyot); upright vertical, spur pruned (bilateral cordon); Scott Henry, cane pruned; Lyre, cane pruned; and Geneva Double Curtain (GDC), cane pruned. At bud burst, bloom, leaf fall, and dormancy, wood samples were taken from the main trunk of four vines for each trellis system. Sugar concentration in the trunk was highest during leaf fall and lowest at bloom on a dry weight basis. Starch concentration in the trunk was highest during dormancy and lowest during leaf fall and bud burst. There were no differences in sugar or starch concentrations among the five trellis systems at any sample date. There was no net gain in carbohydrates for any trellis system during the study. The Lyre system had the highest concentration on total non-structural carbohydrates at bloom, but was not different from the Guyot system. Trunk volume was highest in the GDC and lowest in the Guyot. Photosynthetic rate was highest in the Guyot system on the first sample date for both years, but was not different on the remaining sample dates. Water use efficiency and maximum quantum efficiency of photosynthesis were highest in the bilateral cordon in 1997. Transpiration rate and chlorophyll

content did not differ among trellis systems. There was a negative correlation among most yield components and the carbohydrate concentration at bud burst. A positive correlation was found between juice soluble solids and carbohydrate concentration at bud burst. Starch concentration at bud burst was correlated with photosynthesis in August and September. There was no correlation found between photosynthesis and sugar concentration in the trunk wood. Photosynthesis was strongly correlated with berry weight and skin anthocyanin. In 1996, photosynthesis was correlated with juice soluble solids and TA.

Introduction

Previous research has demonstrated that trellis type can influence a grapevine microclimate (Escalera *et al.*, 1996; Howell *et al.*, 1991; Howell *et al.*, 1987; Reynolds and Wardle, 1994; Reynolds and Wardle, 1995; Reynolds *et al.*, 1985; Shaulis and May, 1971). Much of the influence in grapevine microclimate is through differences in overall vine size and shoot density (Howell *et al.*, 1991). Changes in shoot density alter light distribution in the canopy, which effects bud fruitfulness, fruit set, and berry weight (Howell *et al.*, 1991). A heavily shaded canopy slows berry growth and sugar accumulation (Archer and Strauss, 1989; Morrison and Noble, 1990; Reynolds and Wardle, 1989). Koblet (1975) found that fully shaded leaves did not export any photosynthates, while leaves that were exposed to intermittent light exported photosynthates similar to leaves exposed to full sun. Kriedemann *et al.* (1970) found that photosynthetic activity in grape leaves increased dramatically during the first 30 to 40 days after leaf unfolding, at which time the leaf reached full size. Main leaves and laterals leaves begin exporting photosynthates when they reach 30% of their final size (Koblet, 1969). At 50% to 75% of their final size they are no longer a sink for photosynthates, but instead export to other parts of the vine (Koblet and Perret, 1979). Lateral shoots have been found to behave similarly to young expanding leaves until one or two lateral leaves are mature, then no photosynthates move into lateral shoots from the main shoot (Hale and Weaver, 1962). Although grape leaves tend to supply photosynthates to nearbly clusters, Koblet (1969) found that lateral shoots without clusters exported photosynthates to clusters on the main shoot.

Divided canopy trellis systems influence cluster weight, berry weight, and number of berries per cluster (Reynolds and Wardle, 1994; Reynolds *et al.*, 1994). Shoot orientation also has an impact on vine performance. Divided canopy systems such as the Scott Henry trellis have shoots that are oriented both upward and downward. Kliewer *et al.* (1989) found downward trained shoots have decreased vigor, smaller primary leaves, fewer lateral leaves, and a less shoot length. Schubert *et al.* (1995) found that downward oriented shoots have a smaller stem diameter. However, Koblet (1975) observed that shoot orientation had no impact on the export of photosynthates from leaves to fruit.

The total vine permanent structure, which is established through trellis type, determines the amount of old wood retained. Koblet and Perret (1980) and Koblet *et al.* (1994) found that vines with larger amounts of old wood had higher yields than vines that were severely pruned. Other research has shown that increasing the amount of perennial wood through increased trunk height, maximized growth, fruit exposure, and pH, and minimized TA in Seyval blanc vines (Reynolds *et al.*, 1985). Koblet *et al.*(1994) found that yield, fruitfulness, cluster weight, number of berries per cluster, juice soluble solids, and juice pH all increased with an increase in trunk volume. Candolfi-Vasconcelos and Koblet (1990) found that lateral leaves play a role in the amount of starch reserves in the wood and the sugar concentration of the fruit. They also found a small correlation between sugar concentration of must, and the starch concentration of the wood. Yang and Hori (1979) found that at pruning time, carbohydrate reserves were higher in the roots than in the trunk and canes.

The goal of this study was to determine the impact of trellis system on leaf gas exchange and carbohydrate movement in the trunk and to evaluate how these aspects would in turn affect yield and fruit composition of Pinot noir grapevines. Previous research has conlcluded that the amount of permant structure retained by a grapevine trellis system has an impact upon yield components and fruit composition. It was hypothesized that this was not due to different carbohydrate concentrations retained in the trunk wood of grapevines trained to different trellis systems.

Materials and methods

Own rooted Pinot noir (UCD 4) planted in the Spring of 1984 in a randomized complete block design at the Lewis-Brown Farm (Corvallis, Oregon) was studied. The vines were trained to five trellis and training systems. These treatments were: upright vertical, cane pruned (double Guyot); upright vertical, spur pruned (bilateral cordon); Scott Henry, cane pruned; Lyre, cane pruned; and Geneva Double Curtain (GDC), cane pruned. The two single canopy systems (Guyot and bilateral cordon) were spaced 1.5m x 2.0m, and the divided canopy systems (Scott Henry, Lyre, and GDC) were spaced 1.5m x 3.0m. Each plot consisted of eight vines, two border vines and six data vines. There were a total of 25 plots (the treatments were replicated 5 times). There were guard rows between each replication, and between single and divided canopy systems within replication. The Pinot noir vines were balance pruned to 28 buds/kg cane prunings in February of 1996 and 1997.

The trial was located on a soil depth gradient, and blocked against the gradient with replications one and two grown on shallower soils than replications three, four and five. Soils in the area of this trial consist of Chehalis and Malabon series. In 1996 no irrigation was applied to the trial. In 1997, drip irrigation was applied to replications one and two during the months of August and September, when the vines appeared to be suffering from drought stress. Vineyard floor management consisted of a natural green cover that was mowed alternately after the resident plant species were allowed to bloom. Common ground cover species include *Poa annua, Trifolium sp.*, and *Hypochaeris radicatta* (Spotted Cat's Ear). Pest control was consistent with grower practices for the area (Pscheidt, 1992). The vines were shoot positioned and hedged three times during the growing season.

Because the trellis systems were different heights, hedging resulted in differing shoot lengths among the trellis systems.

Wood carbohydrate reserves

At bud burst, bloom, and leaf fall in 1996, and during vine winter dormancy in 1997, two wood samples were taken from the main trunk of four vines for each treatment in each of the five replications. The wood samples were taken from the trunk with a hammer and wood chisel, after the outer bark had been stripped from the area. Fresh weight was taken for both trunk samples. One sample was used to find sample volume by water displacement, so sample density could be calculated. The second sample was dried and ground into a fine powder. Soluble sugars and starch were extracted and analyzed from the dried powder sample, using the methods described by Candolfi-Vasconcelos and Koblet (1990). Total trunk volume was estimated twice during the 1996 season by measuring the diameter and length of old wood for each sample vine.

Leaf gas exchange, maximum quantum efficiency of photosynthesis, and chlorophyll content

Leaf gas exchange was measured three times during the 1996 and 1997 growing seasons. Additionally, the ratio of variable to maximum fluorescence (Fv/Fm), and chlorophyll content were measured three times during the 1997 growing season. Measurement dates were July 9, August 1, and September 9 in 1996, and July 22, August 25, and September 25 in 1997. Three leaves per treatment were sampled from the single canopy systems. Six leaves per treatment (three leaves per canopy) were sampled from the double canopy systems. Using previous methodology, leaf gas exchange was measured from one fully exposed tenth leaf (counted from the base of the shoot) in each vine canopy (Candolfi-Vasconcelos *et al,* 1994). Measurements were taken between 10:00 am and 1:00 pm, at photosynthetic flux densities above 1200 umols m^{-2} s^{-1}, and with cloudless skies. Leaf gas exchange was measured with a portable infra-red gas analyzer (Ciras-1, PPSYSTEMS, Hitchin, U.K.). Fv/Fm and chlorophyll content measurements were taken on the same dates using the same leaves that were measured for leaf gas-exchange. Fv/Fm measurements were taken with a portable fluorescence meter (Hansatech Fluorescence monitoring system, Norfolk UK). Leaf greenness was measured with a hand-held chlorophyll meter (SPAD-502, Minolta Co. Ltd., Japan).

Yield and fruit composition

The trial was harvested October 16, 1996 and September 30, 1997. All fruit from the six center vines was harvested and weighed. A 24 cluster sample was used to determine cluster weight, and was then crushed to determine juice composition.

Data analysis

All data was analyzed using an ANOVA with the SAS statistical package (SAS Institute, Cary, NC), with mean separation by Waller-Duncan K-ratio T test at $p < 0.05$. Correlation coeficients between gas-exchange variables, carbohydrate concentration, yield components and fruit composition were also calculated.

Results and discussion

Wood carbohydrate reserves

The starch concentration in the trunks of the Pinot noir vines trained to the five trellis systems was highest during winter dormancy and lowest during bud burst and leaf fall on a dry weight basis (Table 3.1). These data concur with early research which indicates that starch is the main form of storage carbohydrate in grapevines, and that starch content in the perennial parts of a vine decreases until mid-June presumably because the starch reserves are being utilized for early shoot development (Winkler and Williams, 1945). Sugar concentration in the trunk was highest during leaf fall and lowest at bloom on a dry weight basis (Table 3.1). This pattern is frequently observed in grapevines between harvest and leaf fall, when carbon reserves are translocated from the leaves to the permanent structure, sucrose being the main carbohydrate transported in the phloem (Koblet and Perret, 1979).

The concentration of the total non-structural carbohydrates (TNSC) found in the trunk of the five trellis systems was highest during leaf fall and winter dormancy, and lowest during bud burst and bloom (Table 3.1). Early shoot

Table 3.1: Trunk carbohydrate content in Pinot noir grapevines during four phenological stages.

Phenological Stage	Trellis system	% Starch	% Sugar	% TNSC	Trunk Density (mg/cm^3)	% trunk Moisture	g starch /trunk	g sugar /trunk	g TNSC /trunk
Bud Break		9.06 c	1.79 c	10.86 c	548.96	44.93	108.04 b	20.50 c	128.55 b
Bloom		10.27 b	1.44 c	11.71 b	556.81	42.61	121.81 ab	16.89 c	138.71 b
Leaf fall		8.45 c	6.47 a	14.91 a	637.09	44.46	116.08 ab	88.02 a	204.11 a
Dormant		11.05 a	3.37 b	14.42 a	566.15	46.13	136.62 a	42.36 b	178.98 a
Significant F		***[1]	***	***	ns	ns	*	***	***
	Guyot	9.78	3.61	13.39	550.20	44.65	61.29 c	25.15 b	86.45 b
	Cordon	9.50	3.68	13.18	614.50	43.41	118.29 b	53.24 a	171.53 a
	Scott Henry	9.69	3.25	12.94	586.20	43.81	130.55 ab	40.84 ab	171.39 a
	Lyre	10.31	2.79	13.18	552.89	45.64	137.29 ab	38.06 ab	175.36 a
	GDC	9.26	2.93	12.19	584.22	45.14	155.78 a	52.43 a	208.21 a
	Significant F	ns	ns	ns	ns	ns	***	**	***
Interaction									
Trellis x Phenological stage		ns	*	ns	ns	ns	ns	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01 and 0.001 levels.
Values followed by the same letters do not differ significantly.

development in grapevines depends upon retranslocated assimilates, after which assimilates export from the lower leaves as they reach maturity and contribute to shoot growth, fruit development, and to growth of the parent vine (Hale and Weaver, 1962; Koblet and Perret, 1979; Winkler and Williams, 1945; Yang and Hori, 1979). In the present study, there was an interaction in sugar concentration between phenological stage and trellis system (Table 3.1).

Throughout the time when these trunk samples were taken, the Lyre system maintained the highest concentration of starch, but the level was not different from that of the other systems (Table 3.1). The two single canopy systems (Guyot and bilateral cordon) maintained the highest sugar concentrations, but these concentrations were not different from the other trellis systems (Table 3.1). At bud burst and bloom there were no differences in starch or sugar concentrations among the five trellis systems (data not shown). From bud burst to bloom there was an average gain in starch concentration of 1.21%, and an average loss in sugar concentration of 0.35% (Table 3.2). Yang and Hori (1979) found that retranslocation of ^{14}C began with bud burst, was highest at the 6 to 8 leaf stage, and ceased by flowering. Yang *et al.* (1980) found that translocation of current assimilates from the shoots downward began at the tenth leaf stage, and increased rapidly from the flowering stage, and by the time the xylem tissue began to lignify in July, the carbon in the roots was found to be higher than in the canes and trunk. This also seems to have occurred in this experiment, as it appears that the starch reserves in the trunk were being replenished by the time the vines entered the

Table 3.2: The net change in starch and sugar concentration in the trunk of the Pinot noir vines trained to the five trellis systems in 1996.

	Trellis System	Budbreak-Bloom	Bloom-Leaf fall	Leaf fall-Dormancy	Dormancy-Bud break	Year balance
% Sugar	Guyot	-0.779	6.287	-4.635	-0.874	0.0
	Cordon	-0.467	6.452	-4.465	-1.520	0.0
	Scott Henry	-0.555	5.425	-3.271	-1.600	0.0
	Lyre	0.067	3.136	-1.466	-1.737	0.0
	GDC	-0.013	3.806	-1.639	-2.154	0.0
	Significant F	ns[1]	ns	ns	ns	
% Starch	Guyot	1.392	-3.011	3.003	-1.384	0.0
	Cordon	1.466	-2.000	3.606	-3.072	0.0
	Scott Henry	0.790	-1.475	2.890	-2.205	0.0
	Lyre	2.053	-2.420	1.456	-1.088	0.0
	GDC	0.351	-0.229	2.056	-2.178	0.0
	Significant F	ns	ns	ns	ns	

Values followed by the same letters do not differ significantly.

bloom stage, while the sugar concentration in the trunk remained practically unchanged (Table 3.2). Hale and Weaver (1962) also found that by the time a vine reaches bloom, and had 10-12 exporting leaves, half of the photosynthates translocated were going to the parent vine, while the remaining photosynthates were directed acropetally for used by the growing shoot tip and newly developing leaves. The concentrations of starch in the trunks of the Lyre and Guyot systems tended to be 1-2% higher than the other systems during bloom (data not shown). These higher concentrations of starch led to a higher concentration of total non-structural carbohydrates (TNSC) in the Lyre and Guyot systems during bloom (data not shown). It may be a result of the Guyot and Lyre systems having leaves that reach an exporting stage earlier than the other systems. From bloom to leaf fall, there was a net loss of 1.8% in starch concentration in the trunk wood, and a gain of 5.2% in sugar concentration (Table 3.2). Hunter and Visser (1988) found that photosynthates are used mainly by the leaves prior to berry set, but photosynthates were increasingly diverted to fruit development after that. Koblet and Perret (1979) reported that after veraison, assimilates move basipetally into developing clusters and into the parent vine. This would explain the large increase in sugar concentration in the trunk between bloom and leaf fall. At leaf fall, there were no differences in starch or sugar concentrations among the five trellis systems (data not shown), although the two single canopy systems (Guyot and bilateral cordon) had a higher sugar concentration ($\approx 2\%$) in the trunk wood, and a lower starch concentration (≈ 2%) than the double canopy systems (data not shown). From leaf fall to winter dormancy there was a mean gain in starch concentration of 2.6% and a mean loss in sugar concentration of 3.0% (Table 3.2). During winter dormancy, there were no differences in starch or sugar concentration among the five trellis systems (data not shown). From winter dormancy to bud burst there was a mean decrease of 2.0% in starch concentration, and a mean decrease of 1.6% in sugar concentration (Table 3.2). There was no net gain in trunk carbohydrates throughout the growing season, indicating a balance between the produced and consumed carbohydrates (Table 3.2).

The large variation in trunk volume was a good indicator of the differences in the amount of old wood retained with each of the five trellis systems. Trunk volume was highest in the GDC and lowest in the Guyot (data not shown). For this reason, the amount of starch per trunk in the Guyot at bud burst, bloom, and leaf fall was lower than the other four trellis systems (data not shown). Also, the total amount of sugar per trunk in the Guyot at bud burst and bloom was lower than in the GDC and the Scott Henry systems (data not shown). The bilateral cordon, Scott Henry, Lyre, and GDC were not different in starch or sugar per trunk, except during leaf fall (data not shown). Trunk wood density did not differ among the five trellis systems (Table 3.1). Koblet and Perret (1980) found that the amount of old wood retained on a vine had a positive effect on yield, when compared to vines with a smaller permanent structure. This was found to be due to an increase in cluster weight. Koblet and Perret (1980) also found that the variety Pinot noir had an increased yield with more old wood, and a higher berry sugar concentration. Koblet *et al.* (1994) found that vines with higher trunk volumes also has higher yields, fruitfulness, cluster weight and more berries per cluster. In the first year of this trial, the vines with a larger trunk volume also had larger cluster weights, which seemed to impact yield (data not shown). However, there were no differences in fruit soluble solids (data not shown).

Leaf gas exchange

The Guyot system, for both the July 1996 and July 1997 sample dates, had the highest leaf photosynthetic rates (Table 3.3 and 3.4). The photosynthetic rate for the Guyot was higher than that for the Lyre on the July 1996 sample date (Table 3.3), and was higher than those for the Scott Henry and GDC on the July 1997 sample date (Table 3.4). These differences were not seen on any other sample date in 1996 or 1997. Koblet and Perret (1979) found that after veraison, all photosynthates from the 13th leaf downward were moving basipetally into either the cluster or the parent vine. On the first leaf gas exchange sample date in July, it can be assumed that the bulk of the photosynthates being produced by the tenth leaf (the leaf that was measured in this experiment) were moving either into the cluster or into the parent vine. If the Guyot system had higher photosynthesis rates, then in theory, it would gain more sugar in the fruit or in the trunk than the other trellis systems. The Guyot system tended to have the highest fruit soluble solids out of

Table 3.3: Leaf gas exchange measurements taken in 1996 for the five trellis systems.

Date	Trellis system	Photosynthesis (umols CO_2/ m^2s)	Transpiration (mmols H_2O/ m^2s)	WUE (umols CO_2/ mmols H_2O)
7/9/96	Cordon	19.42 ab	5.93	3.31
	GDC	17.93 ab	5.64	3.19
	Guyot	20.10 a	5.78	3.51
	Lyre	17.62 b	5.69	3.10
	Scott Henry	17.75 ab	5.71	3.11
	Significant F	**[1]	ns	ns
8/1/96	Cordon	18.10	3.36	5.58
	GDC	16.30	3.20	5.42
	Guyot	16.90	3.04	5.83
	Lyre	17.18	3.07	5.96
	Scott Henry	17.10	3.20	5.73
	Significant F	ns	ns	ns
9/9/96	Cordon	9.45	2.15	4.64
	GDC	9.69	2.40	4.02
	Guyot	8.39	2.11	3.81
	Lyre	8.23	2.01	4.51
	Scott Henry	9.50	2.13	4.68
	Significant F	ns	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01 and 0.001 levels.

Values followed by the same letters do not differ significantly.

Table 3.4: Leaf gas exchange, fluorescence and chlorophyll measurements taken in 1997 for the five trellis systems.

Date	Trellis system	Photosynthesis (umols CO_2/ m^2s)	Transpiration (mmols H_2O/ m^2s)	WUE (umols CO_2/ mmols H_2O)	Florescense (Fv/Fm)	Chlorophyll content (SPAD values)
7/22/97	Cordon	15.36 ab	4.01	3.89 a	0.77 a	28.60
	GDC	12.61 b	3.85	3.29 ab	0.73 ab	25.32
	Guyot	15.90 a	4.14	3.85 ab	0.75 ab	28.81
	Lyre	14.24 ab	3.99	3.57 ab	0.72 ab	27.34
	Scott Henry	12.34 b	3.79	3.25 b	0.71 b	25.68
	Significant F	***	ns	**	*	ns
8/25/97	Cordon	11.15	2.92	3.75	0.81	33.25
	GDC	11.10	3.11	3.98	0.84	31.28
	Guyot	14.53	3.45	4.39	0.84	34.19
	Lyre	11.33	3.11	3.96	0.82	33.39
	Scott Henry	10.80	3.08	3.54	0.82	30.66
	Significant F	ns	ns	ns	ns	ns
9/25/97	Cordon	10.54	2.83	3.75	0.78	30.48
	GDC	10.82	2.51	4.40	0.80	29.17
	Guyot	10.96	2.96	3.80	0.69	31.74
	Lyre	9.59	2.57	3.58	0.77	28.56
	Scott Henry	9.02	2.46	3.51	0.77	27.18
	Significant F	ns	ns	ns	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01 and 0.001 levels.
Values followed by the same letters do not differ significantly.

the five trellis systems (data not shown). Also, both the Guyot and bilateral cordon systems had the highest gain in trunk sugar concentration between bloom and leaf fall (Table 3.2). Water use efficiency (WUE) was higher for the bilateral cordon as compared to the Scott Henry on the July 1997 sample date. No other differences were observed in WUE (Table 3.3 and 3.4). In 1996, transpiration rate decreased from the July sample date to August sample date, while WUE increased, and then both transpiration and WUE decreased from the August sampling to September sampling (Table 3.3). In 1997, transpiration rate decreased from the July sampling to August sampling, as it did in 1996, but at a much slower rate (Table 3.4). This was most likely due to the differences in sample dates for the two years. Also, in 1997, temperatures were higher in June and July than they were in (data not shown).

Maximum quantum efficiency of photosynthesis and chlorophyll content

On July 22, the ratio of variable to maximum fluorescence (Fv/Fm) was higher in the bilateral cordon than it was in Scott Henry system (Table 3.4). Fv/Fm was not different among any of the trellis systems during the August and September sample dates (Table 3.4). Fv/Fm was highest on the August 25 sample date for all trellis systems (Table 3.4). There were no differences seen in the SPAD values among the five trellis systems on any sample date (Table 3.4). Lange *et al.* (1981) found that chlorophyll content tends to remain relatively constant over a wide range of growth light levels. SPAD values for the leaves of the Pinot noir vines were lowest on the July 22 sample date, and highest on the August 25 sample date (Table 3.4). Kriedemann *et al.* (1970) found that chlorophyll content and photosynthesis reach a maximum when leaves become fully expanded. In this study peak photosynthesis was achieved on the July sample date in 1997, but maximum SPAD values were recorded a month later, on the August 1997 sample date. Candolfi-Vasconcelos and Koblet (1991) found that a higher efficiency of light capturing is needed when chlorophyll content is low, and that reductions in leaf area due to defoliation led to a higher chlorophyll content in the leaves. On the first sampling date, Fv/ Fm was higher in the bilateral cordon than the Scott Henry, but SPAD values were virtually the same. The bilateral cordon had a higher leaf area than the other trellis system for the two years of this trial, so the higher Fv/Fm on the first sample date did not seem to be a result of leaf area or chlorophyll content.

Correlations between carbohydrate concentration and yield components

The starch concentration in the trunk wood at leaf fall was negatively correlated with the yield in 1996 (Table 3.5). This may indicate a competition within the vine between fruit production and carbohydrate storage. The number of clusters per shoot, cluster weight, and the number of berries per cluster were all negatively associated with the concentration of carbohydrates in the trunk wood at bud burst (Table 3.5). The weight of calculated starch and sugar per trunk at bloom was strongly correlated with yield in 1996 (Table 3.5), indicating that the total amount of carbohydrates in the trunk at bloom can have a positive influence over

Table 3.5: Significant correlation coefficients between wood carbohydrate content, trunk volume, yield components and fruit composition during the 1996 season.

1996		Yield (Kg/m^2)	Clusters/ shoot	Cluster weight	Berries/ cluster	Berry weight	Brix	pH	TA (g/l)	Anthocyanins (mg/g berry)
Starch	Bud break		-0.488 *	-0.488 *	-0.579 *	0.514 *	0.632 ***		0.497 **	0.429 *
(% dry	Bloom									
weight)	Leaf fall	-0.421 *[1]				0.600 **				0.587 **
	Dormancy									
Sugar	Bud break		-0.430 *	-0.519 *	-0.579 **			-0.5 *		
(% dry	Bloom					-0.429 *			-0.64 ***	
weight)	Leaf fall			-0.464 *						
	Dormancy									
TNSC	Bud break	-0.401 *	-0.555 *	-0.404 *	-0.691 *	0.501 *	0.645 **	-0.4 *	0.514 **	
(% dry	Bloom									
weight)	Leaf fall	-0.580 *	-0.521 *	-0.420 *	-0.512 **					
	Dormancy									
Starch	Bud break			0.683 ***		0.529 **		-0.4 *		0.542 **
(g/vine)	Bloom	0.642 ***		0.403 *	0.425 *					
	Leaf fall			0.539 **						
	Dormancy			0.605 ***						
Sugar	Bud break			0.402 *		0.538 **		-0.6 **		0.414 *
(g/vine)	Bloom	0.631 ***		0.418 *	0.493 *					
	Leaf fall									
	Dormancy			0.417 *						
TNSC	Bud break			0.651 ***		0.545 **		-0.4 *		0.534 **
(g/vine)	Bloom	0.643 ***		0.406 *	0.436 *					
	Leaf fall									
	Dormancy			0.573 **						

[1]*, **, *** indicate statistically significant at the 0.05, 0.01, and 0.001 levels.

the yield for the same year. Cluster weight was strongly correlated with the total amount of starch in the trunk wood at all phenological stages in 1996 (Table 3.5). Cluster weight, in 1996, was also strongly correlated with the total amount of sugar in the trunk wood at bud burst, bloom, and dormancy (Table 3.5). This may indicate that cluster weight is dependent upon the ability of the vine to produce adequate carbohydrates throughout the growing season. The number of berries per cluster was positively correlated with the total amount of carbohydrate in the trunk wood at bloom, and berry weight was positively correlated with the total amount of carbohydrate in the trunk wood at bud burst in 1996 (Table 3.5). Juice soluble solids and TA were positivly correlated with the concentration of carbohydrates in the trunk wood at bud burst (Table 3.5). Candolfi-Vaconcelos and Koblet (1990) also found a small correlation between sugar concentration of must and starch concentration of wood. Juice pH was negatively correlated with carbohydrate concentration in the trunk wood at bud burst in 1996 (Table 3.5). Skin anthocyanin concentration was positively correlated with starch concentration in the trunk wood at bud burst and leaf fall in 1996 (Table 3.5).

Correlations between photosynthesis and carbohydrate concentration

Photosynthesis in July was negatively correlated with starch concentration at leaf fall, and negatively correlated with the total amount of starch per vine at bud burst, leaf fall, and during winter dormancy (Table 3.6). Photosynthesis in August and September was positively correlated with starch concentration and the total

Table 3.6: Significant correlation coefficients between carbohydrate concentrations at four phenological stages and photosynthesis.

1996		Photosynthesis			
		July	August	September	Year mean
Starch (% dry weight)	Bud break		0.610 **	0.471 *	0.584 **
	Bloom				
	Leaf fall	-0.519 **[1]		0.461 *	
	Dormancy				
Sugar (% dry weight)	Bud break				
	Bloom				
	Leaf fall				
	Dormancy				
TNSC (% dry weight)	Bud break		0.631 **	0.474 *	0.618 ***
	Bloom				
	Leaf fall				
	Dormancy				
Starch (g/vine)	Bud break	-0.483 *	0.409 *	0.551 **	0.461 *
	Bloom				
	Leaf fall	-0.448 *			
	Dormancy	-0.498 **		0.482 *	
Sugar (g/vine)	Bud break		0.472 *	0.583 **	0.545 **
	Bloom				
	Leaf fall				
	Dormancy				
TNSC (g/vine)	Bud break	-0.471 *	0.432 *	0.573 **	0.489 *
	Bloom				
	Leaf fall				
	Dormancy	-0.441 *		0.417 *	

[1]*, **, *** indicate statistically significant at the 0.05, 0.01, and 0.001 levels.

amount of starch per vine at bud burst (Table 3.6). The correlations between photosynthesis and carbohydrate concentration were negative in July and positive afterwards. The vines with low reserves were forced to reach higher photosythesis rates to meet the carbohydrate demands of the growing canopy. There were no correlations between photosynthesis and sugar concentration in the trunk wood at any sample date, although photosynthesis in August and September was found to be positively correlated to the total sugar per vine at bud burst (Table 3.6). This reflects the amount of carbohydrate immediately available for early growth. The year mean for photosynthesis was positively correlated to carbohydrate concentration and total carbohydrates per vine at bud burst (Table 3.6). Carbohydrates at bud break were best related with photosynthesis for all forms of carbohdrates.

Correlations between leaf gas exchange and fruit composition

Photosynthesis and transpiration in both the 1996 and 1997 seasons were strongly correlated to berry weight (Table 3.7). Water use effeciency in both years was negatively correlated to berry weight (Table 3.7). Photosynthesis and transpiration during the 1996 season was positively correlated to juice soluble solids and titratible acidity (Table 3.7).

In 1997, no correlations were seen between photosynthesis and juice soluble solids, but there was a correlation between titratible acidity and photosynthesis in August. Water use efficiency in August of 1996 was negatively correlated to juice

Table 3.7: Significant correlation coefficients between leaf gas exchange parameters and fruit composition.

		Berry weight	Brix	pH	TA (g/l)	Anthocyanins (mg/g berry)
Photosynthesis	**1996**					
	July					-0.425 *
	August	0.674 **	0.658 **	-0.520 **	0.443 *	0.420 *
	September	0.727 **	0.464 *		0.633 **	0.471 *
	Year mean	0.717 **	0.609 **	-0.480 *	0.582 **	0.416 *
	1997					
	July					0.428 *
	August	0.714 ***		-0.673 **	0.595 **	0.585 **
	September					
	Year mean	0.460 *				0.481 *
Transpiration	**1996**					
	July		0.435 *			
	August	0.792 **	0.627 **	-0.611 **	0.631 **	0.525 **
	September	0.738 **	0.457 *	-0.416 *	0.672 **	0.486 *
	Year mean	0.780 **	0.612 **	-0.501 **	0.612 **	0.506 **
	1997					
	July	0.676 ***		-0.614 ***		0.725 ***
	August	0.788 ***		-0.792 **	0.451 *	0.735 ***
	September	0.619 ***		-0.397 *		
	Year mean	0.791 ***		-0.728 **	0.445 *	0.745 ***
Water Use Efficiency	**1996**					
	July	-0.538 **				-0.468 *
	August	-0.729 **	-0.593 **	0.653 **	-0.602 **	-0.492 *
	September					
	Year mean	-0.716 **	-0.600 **	0.623 **	-0.583 **	-0.516 **
	1997					
	July	-0.617 ***		0.654 **	-0.482 *	-0.642 ***
	August	-0.450 *		0.498 **		-0.591 **
	September	-0.551 **		0.627 ***		-0.535 **
	Year mean	-0.651 ***		0.703 ***		-0.689 ***

[1]*, **, *** indicate statistically significant at the 0.05, 0.01, and 0.001 levels.

soluble solids and titratible acidity (Table 3.7). Similar correlations were seen in July of 1997. Water use efficiency was positively correlated with juice pH in both 1996 and 1997 (Table 3.7). For the majority of the sample dates in 1996 and 1997, skin anthocyanin concentration was positively correlated to photosynthesis and transpiration and negatively correlated to water use efficiency (Table 3.7).

Conclusions

The concentrations of starch and sugar found in the trunks of the Pinot noir vines were not affected by trellis system, except during bloom, when differences were seen in the concentration of total non-structural carbohydrates. These findings would agree with our initial hypothesis. The largest difference found among the five studied trellis systems was in trunk volume. The changes in starch concentration and sugar concentration throughout the growing season followed predictable patterns based upon data from previous experiments (Hale and Weaver, 1962; Hunter and Visser, 1988; Koblet and Perret, 1979; Winkler and Williams, 1945; Yang and Hori, 1979; Yang *et al.*,1980). The sum of the increasing and decreasing carbohydrate concentrations in the trunk of the vines throughout the growing season was zero for each trellis system (i.e. there was no net gain or loss of carbohydrates in the trunk wood). This would indicate a balance between the carbohydrates produced and used by the vine. Leaf gas exchange seemed to be affected by trellis system early in the season (July), but did not seem to be related to maximum quantum efficiency of photosynthesis or chlorophyll content.

The carbohydrate concentration at bud burst was negatively correlated with most yield components and positively correlated with juice soluble solids. The starch concentration at bud burst was correlated with photosynthesis in August and September, but there was no correlation found between photosynthesis and sugar concentration in the trunk of the vines. Photosynthesis was strongly correlated to berry weight and skin anthocyanin concentration.

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Chapter 4: Effect of Canopy Location on Yield Components, Fruit Composition, Shoot Morphology and Leaf Gas Exchange in Pinot noir Grapevines Trained to the Scott Henry Trellis System

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Abstract

In 1996 and 1997 sixteen own-rooted Pinot noir vines trained to the Scott Henry trellising system were separated into four different quadrants, determined by shoot orientation: The four quadrants were bottom-east, top-east, bottom-west, top-west. In the bottom canopy, the shoots were trained toward the ground, and the top canopy had shoots trained upwards. The east oriented canopy had shoots receiving direct morning sunlight, and the west oriented canopy had shoots receiving direct afternoon sunlight. In 1996, the bottom canopy had higher yield, cluster weight, more clusters per shoot and a higher TA than did the top canopy. The east oriented canopy, in 1996, had a higher yield, cluster weight, and skin anthocyanin concentration than did the west oriented canopy. Must soluble solids were not affected by vine canopy or orientation in 1996, but pH was lower and TA was higher in the bottom canopy. The bottom-east quadrant had a higher yield than did the other three quadrants in 1996. In 1997 the top canopy had a higher yield than did the bottom canopy. The west oriented canopy, in 1997, had a higher yield, soluble solids, pH, lower TA, and a lower anthocyanin concentration than the east oriented canopy. There were no differences seen in quadrant yields in 1997. There were no canopy or orientation effects on leaf gas exchange, leaf area, shoot diameter, or internode length. Two year means indicated no differences in yield or fruit quality between the top and bottom canopies, but the bottom canopy had more

clusters per shoot than the top canopy. Two year means also indicated a difference in fruit quality and cluster weight between the east and west orientations. Wine made from the top two quadrants were found to have more red color than wine made from the two bottom quadrants. Differences among quadrants were also seen in aroma intensity, flavor intensity, berry flavor, and finish.

Introduction

The Scott Henry trellis was developed in the Umpqua Valley of Oregon by Scott Henry at Henry Estate Vineyards. This training system consists of two divided canopies, one trained up, and the other trained towards the ground. Shaulis *et al.* (1966) found that downward shoot positioning can increase the sunlight exposure to the renewel zone. It has also been shown that downward shoot positioning decreases shoot vigor (May, 1966; Shaulis *et al.,* 1966; Shaulis and May, 1971). With the Scott Henry system, a window is left between the two canopies to allow sunlight to reach the renewal zone, aid in air circulation and spray penetration in the fruiting area, and to increase the number of leaves receiving direct sunlight.

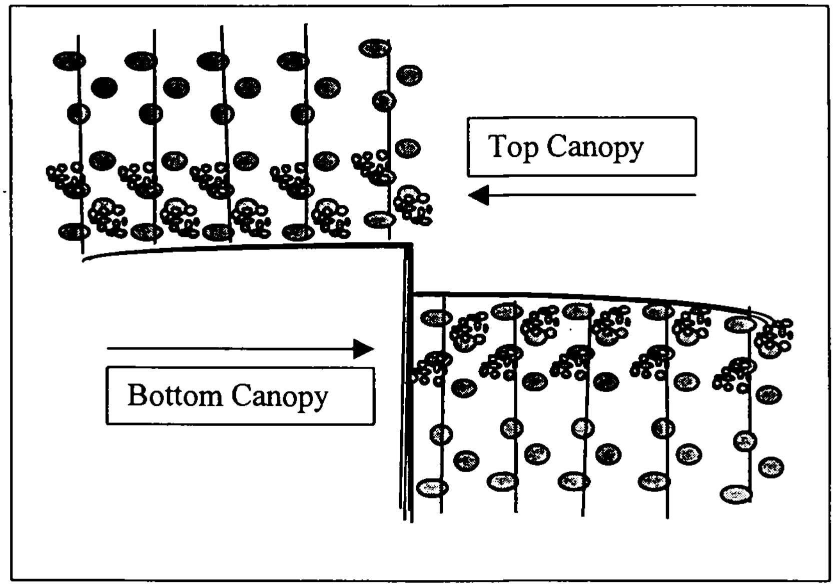
Using trellis system to manipulate shoot position can be a powerful tool in vineyard management (Jackson and Lombard, 1993). Kliewer *et al.* (1989) compared downward and upward trained shoots on field grown Cabernet Sauvignon vines. The downward trained shoots were less vigorous, had smaller primary leaves, fewer lateral leaves resulting in a lower leaf area, had one-fifth the cane weight of upward trained shoots, and had slower fruit development. Morsi *et al.* (1992) found that downward trained shoots produced fruit with a lower pH, and that there were no differences in soluble solids from the fruit of upward and downward trained shoots. Schubert *et al.* (16) found that downward trained Cortese shoots had a lower leaf area, and a lower rate of photosynthesis and stomatal conductance, caused by a reduced CO_2 fixation efficiency. It was also found, that downward trained shoots had a smaller xylem transectional area, and lower hydraulic conductance.

The Scott Henry trellis and training system is being used in many wine grape regions, particularly in the New World. Pinot noir vines trained to the Scott Henry system have been found to have increased wine ethanol and anthocyanin concentration and reduce wine TA and pH when compared to non-divided systems (Reynolds *et al.*, 1996). Pinot noir vines trained to the Scott Henry system had a reduced canopy density and therefore less leaf shading, and despite a 31% increase in yield from the Scott Henry trained vines, soluble solids were equal to a vine with half the shoot density per meter of row (Reynolds *et al.*, 1994). The Scott Henry system is a promising trellis option for vineyards planted on high vigor sites. If an optimal fruit environment can be achieved, good fruit quality can be attained despite high crop levels (Jackson and Lombard, 1993; Reynolds *et al.*, 1994; Reynolds *et al.*, 1996; Smart *et al.*, 1985 (I); Smart *et al.*, 1985 (II); Smart *et al.*, 1990). With the growing popularity of this trellis system, and the unique opportunity of having in close proximity, both the inventor of, and the original site the system was developed for, it seemed important to study the potentials of this trellis system. The goal of this study was to thoroughly characterize yield components, fruit composition and wine quality of fruit generated in both curtains of the Scott Henry system, and to additionally investigate if sun exposure played a role on these variables. Because previous research has demonstrated that shoot orientation can impact fruit exposure to the sun, leaf area, pruning weights, and fruit composition, it was hypothesized that the fruit produced in the four quadrants of the Scott Henry trained vines would be of differing quality at harvest.

Materials and methods

This trial was conducted at Henry Estate Vineyards in the Umpqua Valley, Oregon in 1996 and 1997. Two rows of own-rooted Pinot noir vines, running north-south, were selected from the vineyard in a high vigor area. Sixteen vines were randomly picked from two rows. All 16 vines were trained in the S-shaped Scott Henry system (Figure 4.1). The vine spacing was 1.9m x 3.7m (6ft. x 12ft.). The vines in this trial were grown on deep, clay loam soils. A soil survey of this area has not yet been published. Vineyard floor management consisted of a natural species green cover that was kept mowed throughout the season. Common ground cover species include *Poa annua, Trifolium sp.,* and *Hypochaeris radicatta* (Spotted Cat's Ear). Pest control was consistent with grower practices for the area (Pscheidt, 1992). No irrigation was applied during this trial. The bottom and top canopies of the Scott Henry were separated, and the bottom canopy positioned to

Figure 4.1: A diagrammatic representation of the two canopies of a vine trained to an S-shaped Scott Henry trellis system.

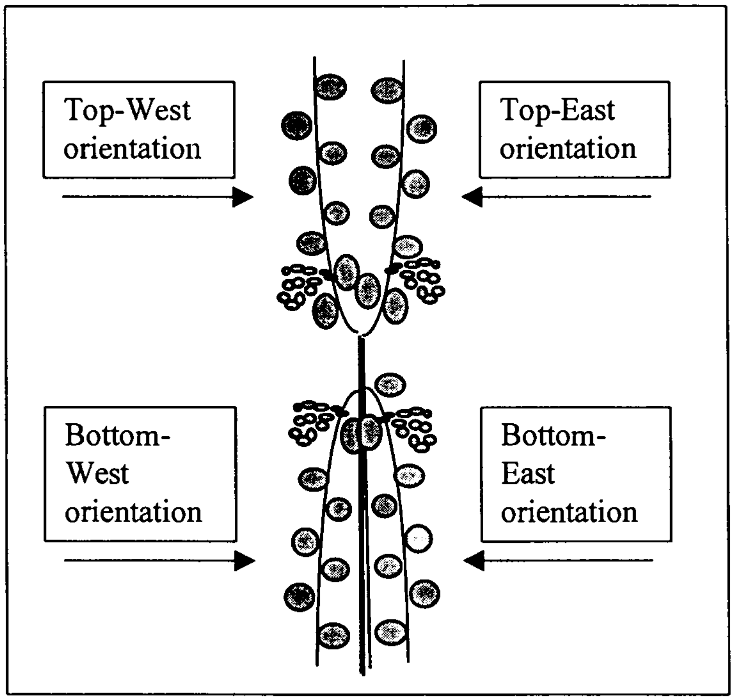


grow downward approximately two weeks before bloom. Vines were shoot positioned and hedged two to three times during the growing season. Each vine was analyzed by canopy (Figure 4.1), by vine orientation to the sun (Figure 4.2), and by the four quadrants of the vine (Figure 4.2). All yield component and gas exchange data were analyzed using an ANOVA with the SAS statistical package (SAS Institute, Cary, NC), with mean separation by Waller-Duncan K-ratio T test at $p<0.05$. Data from the four quadrants were analyzed using a pairwise comparison test.

Leaf gas exchange

Leaf gas exchange, maximum quantum efficiency of photosynthesis (Fv/Fm), and chlorophyll content measurements were conducted three times during

Figure 4.2: A diagrammatic representation of the four quadrants of a vine trained to the Scott Henry trellis.



the 1997 growing season. Using previous metnodology, leaf gas exchange was measured on the east side of each vine from one fully exposed tenth leaf (counted from the base of the shoot) in the top canopy, and one fully exposed tenth leaf in the bottom canopy (Candolfi-Vasconcelos *et al,* 1994). Measurements were taken between 10:00 am and 1:00 PM, at photosynthetic flux densities above 1200 umols m^{-2} s^{-1}, and with cloudless skies. Leaf gas exchange was measured with a portable infrared gas analyzer (Ciras-1, PPSYSTEMS, Hitchin, U.K.).

Chlorophyll content and Fv/Fm measurements were taken on the same leaf and date. Fluorescence measurements were taken with a portable fluorescence meter (Hansatech Fluorescence monitoring system, Norfolk, U.K.), and chlorophyll content was estimated with a hand-held leaf-greenness meter (SPAD-502, Minolta Co. Ltd., Japan), using the technique described by Candolfi-Vasconcelos *et al.* (1994).

Fruit set

Just prior to bloom in 1997, one inflorescence from each quadrant of the 16 research vines was labeled and enclosed in a pollination bag to catch all shed flowers. After bloom was completed, the bags were removed, and all shed flowers were counted. At harvest, the labeled clusters were harvested separately, frozen, and then all berries and remaining flowers were counted. Total flower number and percent fruit set were then calculated.

Shoot morphology

In 1996 and 1997, just prior to harvest, one shoot per canopy was collected. All shoots were selected with a similar diameter from mid-cane. Shoot length, shoot diameter, main leaf area and number, and lateral leaf area and number were determined for both the top and bottom canopies. Leaf area was measured using a LI-COR area meter (model 3100). Post harvest in 1996, shoot number was determined for each canopy. In 1997, shoot number was determined for each quadrant.

Fruit maturity sampling

Maturity samples were taken on September 1, September 15, and September 22, 1997. On each sample date, 40 clusters (10 from each quadrant) were harvested from vines adjacent to the trial vines. The fruit from the maturity samples were weighed and processed to determine juice soluble solids (°brix), pH, and TA, using standard methods.

Yield and fruit composition

The vines were harvested October 5, 1996 and September 29, 1997. The clusters in each of the four quadrants of each vine (top-east, top-west, bottom-east, bottom-west) were harvested and clusters from each vine location were couned and weighed separately. A subsample of ten clusters was then removed from each harvested quadrant and crushed to determine must soluble solids (°brix), pH, and TA. A 100-berry sample was frozen and later processed to determine skin weight and anthocyanin concentration. The skins were removed from all berries in each 100 berry sample. The skin samples were then extracted and decanted three times in a 250 ml jar with different volumes of MeOH/HCl extractant. (The first extracion was done with 70ml, the second with 40ml, and the third with 30ml of 1%MeOH/HCl). After the third extraction, the combined extracts were brought to a final volume of 200 ml. This final extract was frozen and color was determined later with the spectrophotometer at 530nm. Detailed methods used to determine anthocyanin concentration can be found in Candolfi-Vasconcelos and Koblet (1990).

Winemaking and sensory evaluation

In 1996, the harvested fruit from the two research rows was combined by quadrant, and divided randomly into three fermentation replicates. The wine was made at Henry Estate Winery. Winemaking procedures were taken from Reynolds *et al.* (1996). The grapes from each treatment replicate (12 total) were crushed, destemmed, sulfited, and fermented in 75.7L plastic food-grade pails. The must was inoculated with PDM yeast, and fermented at approximately 75F. Caps were submerged two to three times daily by punching down. The wines were fermented 10 days on the skins, and then pressed off and put into 18.9L glass carboys. A total of 24 glass carboys were used, 2 carboys per treatment replicate. At the end of fermentation, wines were racked and sulfited. The wine was bottled March 13, 1996. The wines were bench tested to determine appropriated descriptors. The descriptors used were berry/cherry aroma, overall aroma intensity, red color, berry flavor, flavor intensity, and overall finish/aftertaste. The wines were then submitted to sensory evaluation at the Pacific Agri-Food Research Center in Summerland, BC. A triangle test was used to determine differences between replications. Paired comparison tests were used to evaluate differences in the specified wine attributes for all treatments.

Results and discussion

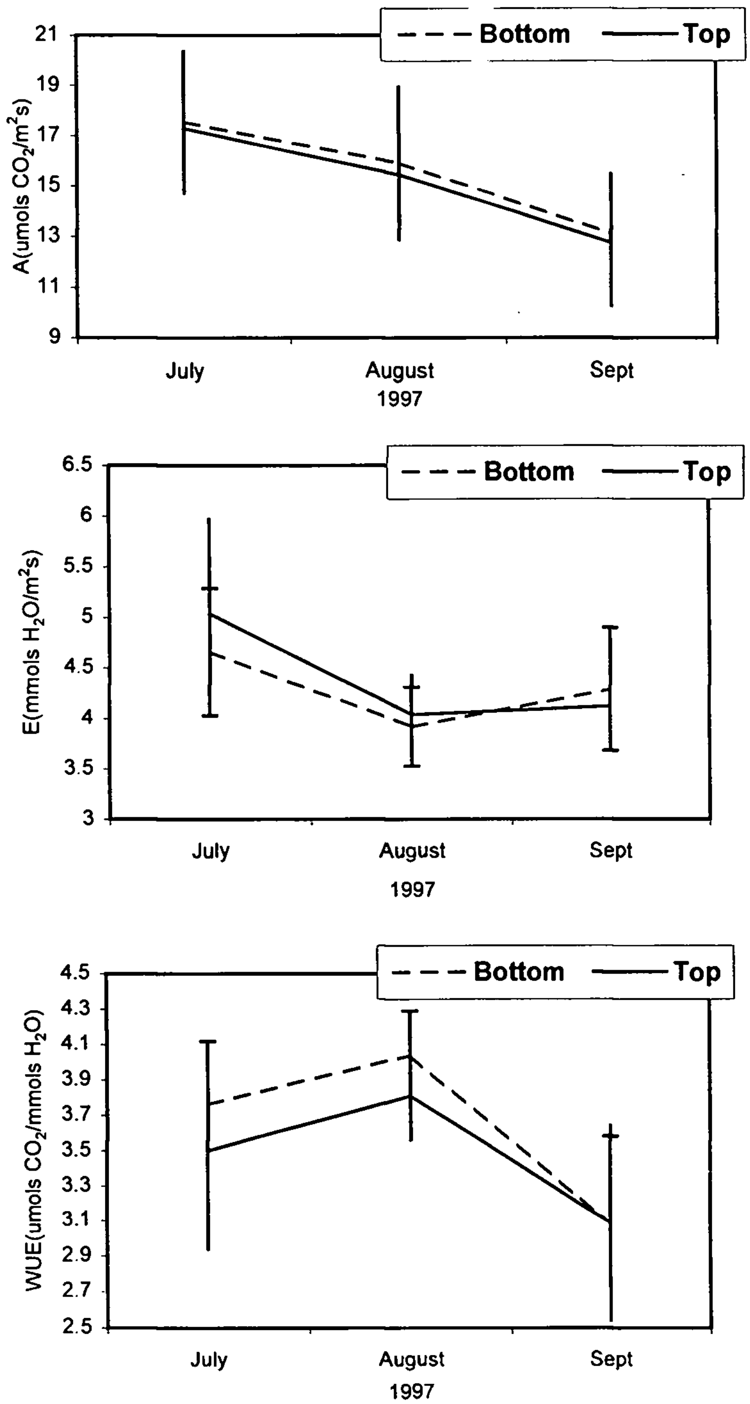
Leaf gas exchange

Photosynthetic rate, transpiration rate, and water use efficiency were measured on July 16, August 01, and September 24, 1997. Photosynthesis averaged 17.35 μmols CO_2 m^{-2} s^{-1} on the July 16 sample date, and decreased to an average of 12.91 μmols CO_2 m^{-2} s^{-1} on the September 24 sample date (Figure 4.3). Photosynthetic rate, transpiration rate, and water use efficiency were not different between the top and bottom canopies of the Scott Henry system at any sample date (Figure 4.3). These results differ from those observed by Schubert *et al.* (1995), where downward orientation reduced photosynthesis. From the July 16 sampling to August 01 sampling photosynthetic and transpiration rates decreased, but water use efficiency increased (Figure 4.3). Between the August 1 sample date and September 24 sample date, photosythetic rate continued to decrease, transpiration rate did not change, and water use efficiency began to decrease (Figure 4.3).

Maximum quantum efficiency of photosynthesis

On the July 16 sample date, the ratio of variable to maximum fluorescence (Fv/Fm) was found to be higher on the east side of the vine, the side that received direct morning sun, when compared to the west side of the vine (data not shown). Fv/Fm was not different between canopies or among the four quadrants of the vine on the July 16 sample date. On the August 01 and September 24 sample dates,

Figure 4.3: Photosynthetic rates, transpiration rates, and water use effeciency measured on July 1 6, August 1, and Sept. 24, 1997 for the canopies of vines trained to the Scott Henry trellis. Error bars indicate standard error.



there were no differences found between vine canopy, orientation, or quadrant of the Scott Henry trained vines (data not shown).

Chlorophyll content

Chlorophyll content, as estimated by SPAD values, was not different between the canopies, shoot orientation to the sun, or by quadrant on the first two sample dates (data not shown). Five days prior to harvest (September 24), leaves on the east vs west sides of the vine had a different chlorophyll content; east was higher (data not shown). However, as with the gas-exchange data, this did not affect leaf photosynthesis.

Shoot morphology

In 1996, the bottom canopy had fewer shoots per unit of ground surface, but had more clusters per shoot than did the top canopy (Table 4.1a). In 1997, both canopies had the same number of clusters per shoot and the same number shoots per unit of ground surface (Table 4.1b). When data from both years was averaged the bottom canopy of the Scott Henry system had a tendency for higher bud fertility (more clusters/shoot). The inflorescence primordia (anlage) for the next season begin development during the current season, two weeks before bloom (Carolus, 1971; Pratt, 1979; Srinivasan and Mullins, 1976; Swanepoel and Archer, 1988). Anlagen appear progressively in latent buds, moving towards the growing tip (Mullins *et al.*, 1992). The number of inflorescence primordia are determined before the bud enters dormancy (Mullins *et al.*, 1992; Pratt, 1979). The bottom

Table 4.1a: Yield and yield components as affected by canopy and orientation of the Scott Henry trellis in 1996.

Year			Shoots/ m^2	Clusters/ shoot	Berries/ Cluster	Berry wt.(g)	Cluster wt.(g)	Clusters/ m^2	Yield (Kg/m^2)
1996	**Main effects**								
	Canopy	Bottom	2.2 b	2.4 a	138	1.19	163.55 a	6	0.88
		Top	2.6 a	1.8 b	129	1.15	147.92 b	4	0.66
			**[1]	**	ns	ns[1]	**	ns	**
	Orientation	West			129	1.13	145.32 b	4	0.66
		East			138	1.21	166.16 a	6	0.88
					ns	ns	***	ns	**
	Treatment effects								
	Canopy x Orientation								
	Bottom-east				147	1.20	175.68	3	0.54 a
	Bottom-west				130	1.18	151.43	2	0.34 b
	Top-east				129	1.22	156.64	2	0.34 b
	Top-west				129	1.08	139.21	2	0.33 b
					ns	ns	ns	ns	**
	Interaction								
	Canopy x Orientation				ns	ns	ns	ns	**

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels.
Values followed by the same letters do not differ significantly.

Table 4.1b: Yield and yield components as affected by canopy and orientation of the Scott Henry trellis in 1997 and year averages.

Year			Shoots/ m^2	Clusters/ shoot	Flower #	% Fruit set	Berries/ Cluster	Berry wt.(g)	Cluster wt.(g)	Clusters /m^2	Yield (Kg/m^2)
1997	**Main effects**										
	Canopy	Bottom	2.2	1.9	144	55	111	1.44	159.82	4	0.68 b
		Top	2.9	2.0	158	53	114	1.50	169.88	6	0.96 a
			ns	ns	ns	ns	ns	ns	ns	**	**
	Orientation	West	2.7 b	2.1	130	56	106 b	1.48	154.61 b	6	0.89 a
		East	2.3 a	1.8	171	51	119 a	1.47	175.08 a	4	0.75 b
			***	ns	*	ns	**	ns	**	***	**
	Treatment effects										
	Canopy x Orientation										
	Bottom-east		1.0	1.8 b	180 a	48 b	115	1.43	164.27	2 b	0.33
	Bottom-west		1.2	1.9 b	108 b	62 a	108	1.46	155.36	2 b	0.35
	Top-east		1.3	1.5 b	163 a	54 b	124	1.50	185.88	2 b	0.42
	Top-west		1.6	2.3 a	154 a	51 b	104	1.49	153.86	3 a	0.54
			ns	*	*	**	ns	ns	ns	*	ns
Year x Location	**Main effects**										
	Bottom		2.2 b	2.1 a			125	1.32	161.68	5	0.78
	Top		2.8 a	1.8 b			122	1.33	158.90	5	0.81
			***	*			ns	ns	ns	ns	ns
	West						118 b	1.30	149.97 b	5	0.78
	East						129 a	1.34	170.61 a	5	0.82
							**	ns	***	ns	ns
	1996		2.4	2.1			134 a	1.17 b	155.73	10	1.55
	1997		2.6	1.9			113 b	1.47 a	164.85	10	1.64
			ns	ns			***	***	ns	ns	ns
	Interactions										
	Year x Canopy		ns	**			ns	ns	*	***	***
	Year x Orientation						ns	ns	ns	***	**

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels.
Values followed by the same letters do not differ significantly.

canopy of the Scott Henry system is trained to grow downward approximately two weeks prior to bloom (Smart and Robinson, 1991). This practice of turning the bottom canopy towards the ground coincides with the development of anlage in the latent buds of the growing shoot. It is at this time that one or more factors may influence the inflorescence development in the latent buds of the bottom canopy. Pouget (1981) showed that temperature following bud burst played an important role in bud fertility (clusters per shoot), and Mullins *et al.* (1992) state that mid-June to mid-July temperatures have a positive relation on the number of inflorescence appearing the following season. When the bottom canopy of the Scott Henry system is trained towards the ground, the orientation of the expanding leaves toward the direct sunlight is altered. During the time that it takes the vine to reorient its leaves to the sun, direct sunlight may be hitting some of the latent buds therefore increasing the amount of heat each bud receives from direct exposure to sunlight. Mullins *et al.* (1992) state that direct exposure of latent buds to high intensity light improves fruitfulness.

There were no differences found in either year for main leaf area per shoot or main leaf number per shoot between the top and bottom canopies of the Scott Henry system (Table 4.2). However, the trend for both 1996 and 1997 indicates that the top canopy had a higher main leaf area than the bottom canopy. This trend is consistent with the results found by both Kliewer *et al.* (1989) and Schubert *et al.* (1995). There were also no differences found in either year for lateral leaf area and leaf number per shoot between the two Scott Henry canopies (Table 4.2). The

Table 4.2: Shoot morphology data as affected by canopy and orientation in the Scott Henry trellis system.

Year			Main Leaf area /shoot(cm^2)	Main leaf # /shoot(cm^2)	Lateral Leaf area /shoot	Lateral leaf # /shoot	Shoot diameter (mm)	Internode length (cm)
1996	Canopy	Bottom	1789	17	1655	41	7.99	10.39
		Top	2031	21	1293	41	8.63	7.22
			ns[1]	ns	ns	ns	ns	ns
1997	Canopy	Bottom	1800	20	1585	49	7.21	9.16
		Top	2008	19	1218	37	7.42	8.96
			ns	ns	ns	ns	ns	ns
	Main effects							
	Bottom		1795	18	1620	45	7.60	9.78
	Top		2019	20	1255	39	8.03	8.10
			ns	ns	ns	ns	ns	ns
	1996		1910	19	1474	41	8.31 a	8.81
	1997		1904	20	1401	43	7.32 b	9.06
			ns	ns	ns	ns	**	ns
	Interaction							
	Canopy x Year		ns	ns	ns	ns	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels.
Values followed by the same letters do not differ significantly.

trend, however, was for the bottom canopy to have a higher lateral leaf area and to have the same or greater number of lateral leaves than the top canopy. These observations differ from the Kliewer *et al.* (1989) results, in that they found downward oriented shoots had fewer lateral leaves and a lower main leaf area when compared to upward growing shoots. Although there were no differences found in shoot diameter between either canopy in either year, the trend was for the bottom canopy to have a smaller shoot diameter than the top canopy (Table 4.2). This trend was consistent with the results seen by Schubert *et al.* (1995). The bottom canopy tended to have a longer internode length than the top canopy. Apical dominance appeared to be affected by the training of shoots to grow downward. This could have led to possible changes in competition between growing tips and inflorescence development. Fournioux (1997) found that before flowering occurs, vegetative growth is predominant over reproductive growth for assimilates and carbohydrate reserves in Pinot noir.

Shoot morphology data was not taken for vine orientation in 1996. The east oriented side of the vine had fewer shoots and clusters per unit of ground surface in 1997, when compared to the west side of the vine (Table 4.1b). In 1997, the top-west quadrant had more clusters per shoot than did the other three quadrants (Table 4.1b). This would indicate that during bud differentiation in 1996 (around bloom) the buds in the top-west quadrant were either surrounded by a more favorable microclimate or were being influenced by a greater number of growth factors, leading to a larger number of clusters per shoot in 1997. Bud fertility has been shown to be related to light exposure (Mullins *et al.*, 1992).

Fruit set

In 1997, the clusters sampled from the bottom-west quadrant of the vine had a higher percent fruit set (62%), but had a lower number of flowers than the samples from the other three quadrants (Table 4.1b). This resulted in no differences in the number of berries per cluster among the four quadrants.

Fruit maturity

Berry weights averaged 1.43g, 1.47g, and 1.54g on September 1, September 15, and September 22, respectively (data not shown). On the first sampling date, 28 days prior to harvest, the top canopy had a higher berry weight than the bottom canopy, and the east oriented canopy, which received direct morning sunlight, had a higher berry weight than the west canopy (data not shown). On the other two sampling dates, as the fruit matured, there were no differences in berry weight between canopy, orientation, or quadrant of the vines trained to the Scott Henry system. There were no differences in cluster weight between canopy or orientation on any of the sampling dates.

Figure 4.4 shows the increase in soluble solids (°brix) and pH, and the decline in TA over the three sampling dates for the canopy and orientation of the Scott Henry trained vines. Archer and Strauss (1989) found that juice pH and TA

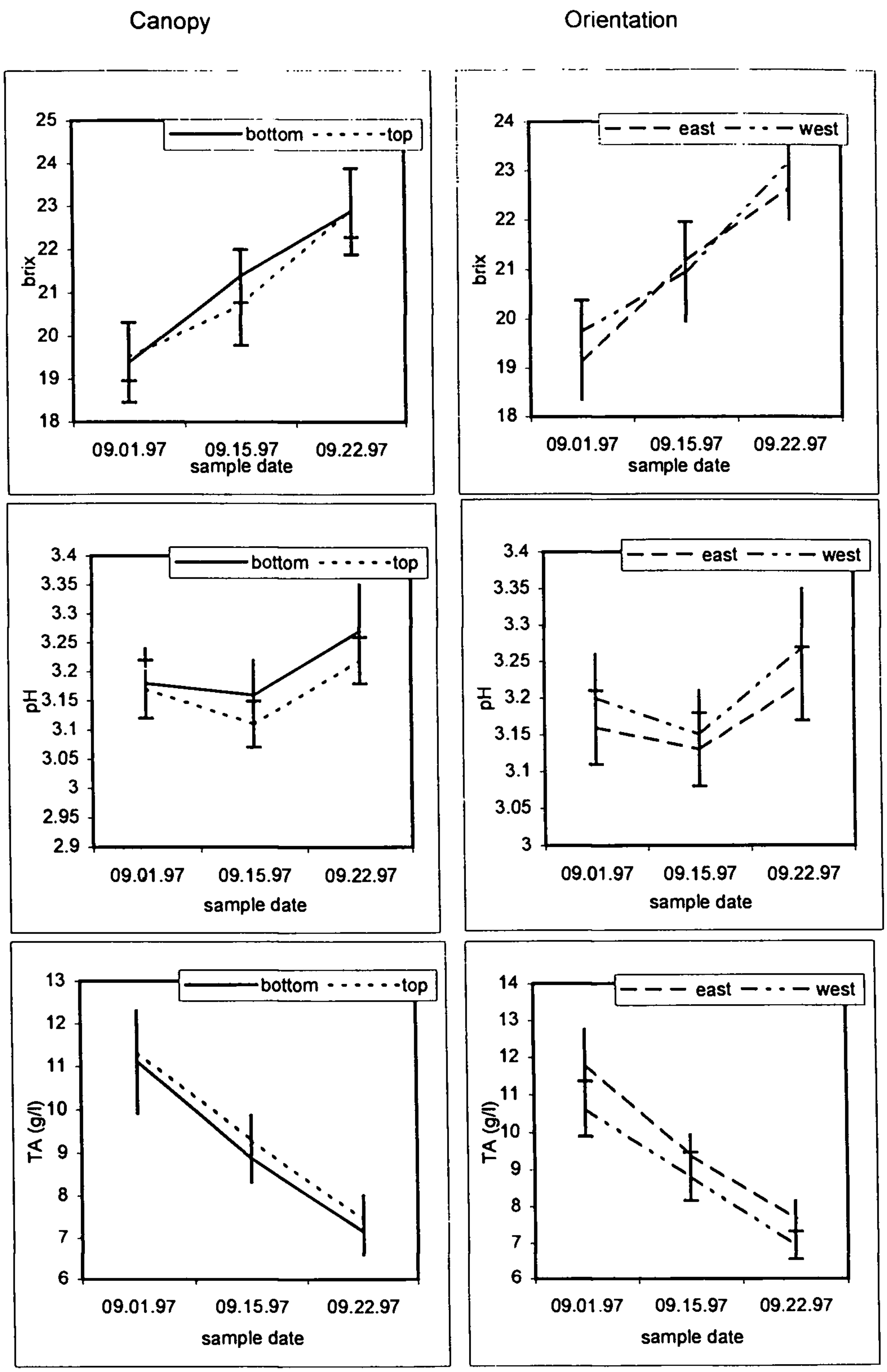


Figure 4.4: The changes in % soluble solids, pH, and titratable acidity in the canopy and orientation of vines trained to the Scott Henry trellis. Error bars indicated standard error.

were lower when Cabernet Sauvignon fruit were grown in a dense canopy. Morrison and Noble (1990) found that leaf shading resulted in a higher pH. Increased shading delayed the degredation of acids in Gewürtztraminer (Reynolds and Wardle, 1989). Price *et al.* (1995) also found that fruit shading resulted in a higher TA in Pinot noir.

Yield and yield components

In 1996 the bottom canopy had a higher yield when compared to the top canopy (Table 4.1a). This was due to higher cluster weights and more clusters per shoot (Table 4.1a). The east oriented canopy had a higher yield and a higher cluster weight than did the west canopy, and the bottom-east quadrant had a higher yield when compared to the other three quadrants (Table 4.1a). These higher yields in the bottom-east part of the canopy were a result of the higher cluster weights, and the higher number of clusters per shoot. In 1996, the top canopy had more shoots m^2 ground surface, but had a lower yield (Table 4.1a). This would seem to indicate that in 1996 the shoots in the bottom canopy had buds that were more fruitful, resulting in more clusters per shoot. There were no differences in berry weight or berries per cluster seen in 1996 (Table 4.1a).

In 1997 the top canopy had a higher yield than the bottom canopy (Table 4.1b). Cluster weight, berry weight, berries per cluster, and clusters per shoot were not affected by canopy (Table 4.1b). In 1997, the higher yields in the top canopy can be accounted for by a higher number of shoots per m^2 in the top canopy. There were no differences in yield, berry weight, or berries per cluster between the two orientations or the four quadrants in 1997 (Table 4.1b). The top-west quadrant did have more clusters per unit of ground surface in 1997, when compared to the other three quadrants (Table 4.1b).

The two year averages for this trial indicate no differences between the bottom and top canopies in yield, cluster weight, berry weight, or number of berries per cluster in the Scott Henry system (Table 4.1b). However, the east oriented side of the vine had higher cluster weights, and more berries per cluster when compared to the west side of the vine for the two growing seasons (Table 4.1b).

Fruit composition

In 1996, the bottom canopy, which had a higher yield, also had a lower juice pH and a higher juice TA when compared to the top canopy (Table 4.3a). However no differences were seen in juice soluble solids (Table 4.3a). Kliewer *et al.* (1989) while working with Cabernet Sauvignon grapevines, found that the fruit harvested from downward oriented shoots had lower soluble solids than upward oriented shoots. This effect of shoot orientation on soluble solids was not observed in either year in this study. The east oriented canopy, in 1996, had a higher yield and a lower TA then the west canopy (Table 4.3a). In 1996 and 1997, the east canopy had higher skin anthocyanin concentration per berry than did the west canopy (Table 4.3b). Also in 1997 the east oriented canopy had a higher anthocyanin concentration per unit of skin weight than did the west side of the canopy (Table

Table 4.3a: Fruit composition as affected by canopy and orientation of the Scott Henry trellis in 1996.

Year			Soluble solids (brix)	pH	TA (g/l)	Skin wt. (g)	% Skin/ Berry wt.	Anthocyanins (mg/berry wt)
1996	**Main effects**							
	Canopy	Bottom	23.1	3.11	8.62	0.139	12	0.553
		Top	23.3	3.15	8.07	0.140	12	0.545
			ns[1]	**	**	ns	ns	ns
	Orientation	West	23.2	3.12	8.58	0.132	12	0.517
		East	23.2	3.14	8.11	0.147	12	0.580
			ns	ns	**	ns	ns	**
	Treatment effects							
	Canopy x Orientation							
	Bottom-east		23.0	3.10	8.36	0.150	12	0.568
	Bottom-west		23.2	3.11	8.88	0.130	11	0.538
	Top-east		23.4	3.17	7.86	0.150	12	0.592
	Top-west		23.3	3.14	8.28	0.130	12	0.498
			ns	ns	ns	ns	ns	ns
	Interaction							
	Canopy x Orientation		ns	ns	ns	ns	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels.
Values followed by the same letters do not differ significantly.

Table 4.3b: Fruit as affected by canopy and orientation of the Scott Henry trellis in 1997 and year averages.

Year			Soluble solids (brix)	pH	TA (g/l)	Skin wt. (g)	% Skin/ berry wt.	anthocyanins (mg/berry wt)
1997	**Main effects**							
	Canopy	Bottom	24.2	3.29	5.53	0.202	14	0.579
		Top	24.2	3.25	5.82	0.213	14	0.600
			ns	*	ns	ns	ns	ns
	Orientation	West	24.6	3.31	5.32	0.208	14	0.552
		East	23.8	3.22	6.02	0.207	14	0.628
			***	***	***	ns	ns	**
	Treatment effects							
	Canopy x Orientation							
	Bottom-east		23.8	3.23	5.85	0.198	14	0.601
	Bottom-west		24.5	3.34	5.15	0.207	14	0.557
	Top-east		23.8	3.21	6.15	0.216	14	0.654
	Top-west		24.5	3.27	5.44	0.209	14	0.547
			ns	ns	ns	ns	ns	ns
Year x Location	**Main effects**							
	Bottom		23.6	3.19	7.07	0.170	13	0.565
	Top		23.8	3.20	6.94	0.177	13	0.573
			ns	ns	ns	ns	ns	ns
	West		23.9	3.22	6.95	0.170	13	0.532
	East		23.5	3.18	7.06	0.177	13	0.605
			**	**	ns	ns	ns	***
	1996		23.2	3.13	8.33	0.139	12	0.547
	1997		24.2	3.27	5.64	0.208	14	0.59
			ns	***	***	***	***	ns
	Interactions							
	Year x Canopy		ns	**	***	ns	ns	ns
	Year x Orientation		*	**	***	*	ns	ns

[1]ns, *, **, *** indicate not significant and statistically significant at the 0.05, 0.01, and 0.001 levels.
Values followed by the same letters do not differ significantly.

4.3b). Previous research indicates that anthocyanin concentration in grape skins is dependent upon cluster exposure to the sun (Archer and Strauss, 1989; Crippen and Morrison, 1986; Jackson and Lombard, 1993). In 1997, there were no differences in fruit composition between the bottom and top canopies. However, in 1997 the west oriented canopy had higher soluble solids, pH, and a lower TA when compared to the east canopy (Table 4.3b). There were no differences in fruit composition among the four quadrants in either year. This trend may indicate that poorer fruit quality may be found in the bottom canopy when bottom canopy yields are higher than the yields in the top canopy, as observed in 1996. Increasing yield in the top canopy, by leaving more buds at pruning in the top canopy, may compensate for fruit quality differences between the two canopies, as was observed in 1997.

When the two years are averaged, the east oriented canopy had a higher cluster weight due to having more berries per cluster (Table 4.1b) and a higher anthocyanin concentration (Table 4.3b) when compared to the west canopy. The west oriented canopy had more shoots per unit ground surface area (Table 4.1b), higher soluble solids, and a higher pH (Table 4.3b) when compared to the east canopy.

Winemaking and sensory analysis

A triangle test indicated no differences between replications. There were no differences found in the berry/cherry aroma among the four quadrants (Table 4.4).

Table 4.4: Paired comparison test on 1996 Pinot noir wines from each vine quadrant of the Scott Henry trellis.

Berry/cherry aroma			**Berry flavor**		
Comparison[1]	times selected[2]	times selected	Comparison	times selected	times selected
TW vs TE	10	8	TW vs TE	11	7
TW vs BW	11	7	TW vs BW	8	10
TW vs BE	8	10	TW vs BE	13*	5
TE vs BW	7	11	TE vs BW	10	8
TE vs BE	7	11	TE vs BE	14*	4
BW vs BE	7	11	BW vs BE	11	7
Overall aroma intensity			**Flavor intensity**		
Comparison	times selected	times selected	Comparison	times selected	times selected
TW vs TE	14*	4	TW vs TE	12	6
TW vs BW	10	8	TW vs BW	6	12
TW vs BE	11	7	TW vs BE	11	7
TE vs BW	11	7	TE vs BW	7	11
TE vs BE	9	9	TE vs BE	9	9
BW vs BE	10	8	BW vs BE	8	10
Red color			**Overall finish/aftertaste**		
Comparison	times selected	times selected	Comparison	times selected	times selected
TW vs TE	8	10	TW vs TE	8	10
TW vs BW	17***	1	TW vs BW	7	11
TW vs BE	18***	0	TW vs BE	7	10
TE vs BW	17***	1	TE vs BW	11	7
TE vs BE	17***	1	TE vs BE	15**	3
BW vs BE	4	14*	BW vs BE	11	7

[1]TW (Top west), TE (Top east), BW (Bottom west), BE (Bottom east)

[2] *, **,*** indicate not significant and statistically significant at the 0.05, 0.01 and 0.001 levels.

The top-west quadrant had a higher aroma intensity when compared to the top-east quadrant (Table 4.4). The top quadrants had more red color than the bottom quadrants (Table 4.4). Decreasing crop load has been shown to increase color in Pinot noir wines (Reynolds *et al.*, 1996). Morrison and Noble (1990) found that anthocyanin concentration was higher in exposed fruit. This may indicate that the top canopy had better cluster exposure than the bottom canopy. Both top quadrants were found to have more berry flavor than the bottom-east quadrant. Morrison and Noble (1990) found no flavor differences in Cabernet Sauvignon wines made from different fruit exposure treatments. There were no differences among the four quadrants in overall flavor intensity. The top-east quadrant had a better finish (aftertaste) than the bottom-east quadrant. Archer and Strauss (1989) found that decreasing the amount of cluster exposure decreased the quality of Cabernet Sauvignon wines.

Conclusions

Manipulating bud number per cane and shoot positioning during the growing season seems to create differences in several yield components and shoot morphology aspects in vines trained to the Scott Henry system. In 1996, when the bottom canopy had a higher yield, fruit quality decreased in the bottom canopy. In 1997, when more buds were retained and a higher yield was produced in the top canopy, there were no differences seen in fruit quality between the two canopies. In 1997 there were also differences seen in fruit composition between the east and west oriented sides of the vines. These differences observed in the Scott Henry trellis were large enough to impact some aspects of wine aroma, color, flavor, and finish. Wine made from fruit produced in the top canopy of the Scott Henry trellis had a better color and more berry flavor than wines made from the bottom canopy. The differences observed in the two seasons suggest that the Scott Henry trellis should be managed to take advantage of the changes that occur in sun exposure and apical dominance when the bottom canopy is trained to grow downward. To obtain even ripening a slightly heavier crop load should be left on the top canopy.

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Conclusion

The way in which a grapevine is trained has been shown by previous research to influence virtually all aspects of grapevine growth and therefore the resulting fruit production. The information derived from this two year study suggests that double canopy trellis systems, such as the GDC, Scott Henry and Lyre systems, can increase overall yield without having detrimental effects on fruit quality. Furthermore, double canopy systems may promote a better canopy microclimate, i.e. reduced leaf and fruit shading. Previous trellis research have resulted in similar findings.

The study of the Scott Henry system indicated that manipulating bud number per cane and shoot positioning during the growing season could create differences in yield components and shoot morphology. Our Scott Henry trellis research also demonstrated the influence of shoot and cluster orientation to the sun when vine rows run north-south. These differences observed in the Scott Henry trellis were large enough to impact some aspects of wine aroma, color, flavor, and finish. Further research is needed on the Scott Henry trellis to determine the exact impact of canopy location and orientation on wine quality.

The concentrations of starch and sugar found in the trunks of the Pinot noir vines were not affected by trellis system, except during bloom, when differences were seen in the concentration of total non-structural carbohydrates. Leaf gas exchange was affected by trellis system early in the season (July sampling date), but did not seem to be related to maximum quantum efficiency of photosynthesis or chlorophyll content. The largest difference found among the five studied trellis systems was in trunk volume. The sum of the increasing and decreasing carbohydrate concentrations in the trunk of the vines throughout the growing season was zero for each trellis system (i.e. there was no net gain or loss of carbohydrates), indicating a balance between the carbohydrates produced and used by the vine. To follow more precisely the movement of carbohydrates in a grapevine, the root systems should also be analyzed.

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