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THROUGH CULTURAL METHODS TO MAXIMIZE SUSTAINABLE
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KASEY WIERZBA

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G. Stanley Howell
Major Professor's Signature

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ACHIEVING GROWTH BALANCE OF NIAGARA GRAPEVINES THROUGH CULTURAL METHODS TO MAXIMIZE SUSTAINABLE YIELDS

By

Kasey Wierzba

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ABSTRACT

ACHIEVING GROWTH BALANCE OF NIAGARA GRAPEVINES THROUGH CULTURAL METHODS TO MAXIMIZE SUSTAINABLE YIELDS

By

Kasey Wierzba

To better understand the achievement of highest sustainable yields Niagara vines were subjected to different node level treatments, including two simulated mechanically pruned treatments, Hedge (H) and Minimally Pruned (MP). Vines were also trained to four training systems, Hudson River Umbrella (HRU), Umbrella Kniffen (UK), Hybrid (HYB) and Geneva Double Curtain (GDC). Nested within the MP treatment were three cluster thinning treatments, control (MP-C) with no cluster thinning, thin 1 (MP-1) with all clusters except the basal removed and thin 2 (MP-2) with clusters removed randomly.

Data suggests that the retention of more than 80 fixed nodes on single curtain vines does not increase yield and contributes to an upset in vine balance. Increased shoot potential did not significantly increase the photosynthetically active leaf area, but contributed to a larger inner canopy as well as canopy shading and crowding. There were no vegetative, reproductive or fruit composition differences among HRU, UK and HYB. Regression analysis suggests that GDC can achieve balance between vegetative and reproductive growth better than single curtain training, if applied to vines with sufficient vigor. The advantage of reduced hand labor with MP was accomplished through the use of MP-2, which helped to increase vegetative and reproductive balance.

Dedicated to
Juice Grape Growers of Michigan

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CHAPTER I:

INTRODUCTION AND LITERATURE REVIEW

Introduction

The Niagara Grape

In 1868, C.L. Hoag and B.W. Clark of Lockport, New York fertilized a Concord (*Vitis labruscana* Bailey) (Bailey 1917) grape flower with pollen from the white grape Cassady. Four years later, the resulting Niagara (*Vitis labruscana* B.) (Bailey 1917) vine fruited for the first time (Hedrick 1908). In 1882, the Niagara Grape Company introduced Niagara to the market and for many years they owned the entire stock, fruiting vines as well as propagative material. In early years, the Niagara Grape Company concentrated on marketing Niagara as a fresh table grape (Hedrick 1908). In 1908, Hedrick (1908) wrote, "Niagara is the leading American green grape, holding rank among grapes of this color that Concord does among black varieties." He further noted that it was similar in vigor, productivity and adaptability to Concord, although it was deemed somewhat less cold hardy than Concord. While early use of Niagara was for table fruit, in Ohio it was used primarily for wine production (Hedrick 1908).

Today Niagara grapes are used primarily for grape juice. According to the USDA (Kleweno 2003), 1,179 metric tons (1,300 tons) of Michigan grapes were grown for wine processing in 2002, while 35,373 metric tons (39,000 tons) were grown for juice processing. Niagara has joined Concord as a key cultivar in unfermented juice production.

The success of unfermented grape juice began in the kitchen of Dr. Thomas Bramwell Welch in 1869. He applied techniques for juice processing and pasteurization, which led to the capability for storage and travel of unfermented juice (http://www.welchs.com).

Niagara Production in Michigan

While Niagara is not a new cultivar to commercial production, practical information concerning optimal cultural methods, training system and crop load are lacking. After the repeal of prohibition, Niagara use in Michigan was primarily for wine. That began to change in the late 1970s as the major processor of juice grapes, the National Grape Cooperative, initiated a planting program that increased acreage. This planting program has emphasized the urgency for better cultural and management understanding, as Michigan's total vineyard acreage has increased significantly as a result of Niagara plantings (Kleweno 1998). From 1995 to 2000, Michigan's Niagara acreage grew from 742 to 1,200 hectares (1,855 to 3,000 acres) (USDA 2000a); a 38% increase for the cultivar. Currently, Michigan produces over 36% of the Niagara grapes in the United States, making the state the leading producer with 1,214 hectares (3,000 acres) that produce 17,233 tonnes/year (19,000 tons/year) (USDA 2000, 2000b). Ninety-seven percent of the Niagara vineyards in Michigan are located in the Southwest corner of the state, primarily in Allegan, Berrien, Cass and Van Buren counties (USDA 2000a). Michigan is also the leading producer of Niagara for Welch's, exceeding the production from Washington and the tri-state region (Ohio, Pennsylvania and New York) (http://www.nationalgrape.com).

Limitations to Commercial Cultivation

There are two major limitations for Michigan Niagara growers. The first is an artificial growing season deadline that is set by processors who desire to schedule Niagara harvest, delivery and processing prior to the Concord harvest. The second limit is related to the cool climate growing conditions (Howell 2001, 2003, Miller and Howell

1996) that influence most Niagara growing regions (Michigan, New York, Ohio, Pennsylvania and Washington). Climatic factors are beyond human control, therefore it is important to understand how the vine can be cultured to survive and thrive in cool climate conditions. Under cool climate conditions, finite and precise leaf area:crop load relationships exist; there is an upper limit of sustainable productivity for ripe grapes cultured under optimum conditions in the best years (Howell 2001). That upper limit requires precise crop level definition before crop adjustment (via thinning) can be carried out when a grower faces conditions that maybe less than optimal (Howell 2001). Conditions like cool, late and cloudy seasons, as well as foliar damage by disease or insects may cause need for vine yield adjustment. Shaulis et al. (1966a) recommended a growing season of at least 165 days to ripen fruit of cool climate cultivars. Michigan's southwest has an average of 160 days (http://www.national grape.com), five less than Shaulis' recommendation. Environmental and climatic limitations are among the most pressing viticultural issues in cool climate regions. These limitations have been the subject of many studies (Bates et al. 2002, Howell 2001, 2003a, 2003b, Koblet et al. 1994, Mansfield and Howell 1981, Miller and Howell 1996, Shaulis et al. 1953, 1966a, Stergios and Howell 1977, Wolpert and Howell 1984, 1985). Miller and Howell (1996) suggested that, "low vine capacity is the result of a combination of environmental factors which limit carbohydrate production in Michigan's vineyards." These cool climate concerns must be addressed if optimum sustainable yields of ripe Niagara grapes are to be achieved.

Literature Review

Sustainability

According to Webster's dictionary, *sustain* means to *hold up and keep from falling* (Suplicki and Molino 1999). Howell (2001) relates sustainability to viticulture as a "collective methodology that produces highest yields of ripe fruit per unit land area with no reduction in vegetative growth and does so over a period of years at a cost which returns a net profit." Accordingly, sustainable production considers both viticulture and economic components, and must not exclude variables such as cultivar value, viticulture management, perceived quality of the crop, production costs and production consistency.

Vine Balance

Both vegetative and reproductive health is crucial to vine sustainability. Achieving a balance between the two is a necessary step to sustainable management of vines. According to Gladstone (1992), balance is achieved "when vegetative vigor and fruit load are in equilibrium and consistent with high fruit quality." The concept of "balance" was first introduced by Ravaz (1911) in the early 1900's, with the Ravaz Index. He related the weight of fruit production to the weight of mature cane production (fruit:vegetative). This tool can be used to understand the ratio between yield and vegetative growth. Smart and Robinson (1991) suggested a ratio of 5:1 to 10:1 as optimal for moderate vigor vines, *vinifera* having a lower and juice grapes having a higher ratio.

A decade after Ravaz, Partridge (1925a) suggested a proactive tool he called the growth-yield relationship. This tool could be used to project fruit productivity for the coming growing season. He reasoned that the amount of vegetative growth could influence the fruiting of the vine the following year. The amount of growth would indicate storage and utilization of the photoassimilates manufactured by the vine that season (Partridge 1925a). The availability of these stored carbohydrates and proteins is now known to be crucial for flower initiation and differentiation (Howell 1988), cold hardiness (Mansfield and Howell 1981), early shoot growth (Howell 1988), fruit set (Edson et al. 1995a, 1995b, Shaulis and Oberle 1948) and support during growing season stress (Miller et al. 1993). Partridge (1925a) used the weight of cane prunings to estimate the fruit load that the vine could support the following growing season. Several studies have shown that strong, vigorous vines could tolerate greater cropping stress than weak, low vigor vines (Koblet et al. 1994, Miller et al. 1993, Petrie et al. 2002a). Partridge (1925a) recognized a stronger linear relationship between growth and yield in smaller, weaker vines compared to larger, vigorous vines where this relationship tends lose significance. This is an example of yield being limited in smaller, weaker vines by inadequate vegetative growth, but in large, vigorous vines yield is not limited by vegetative growth.

In reality, the growth-yield relationship was an allometric means of relating exposed leaf area and crop load. According to Smart and Robinson (1991), the amount of leaf area necessary for vine balance was 7-14 cm^2/g of fresh fruit. The large range can be attributed to differences among cultivars and climatic conditions. Observations in southwest Michigan suggest that while leaf area requirements vary with cultivar and climatic conditions, they commonly fall between 11-14 cm^2/g (Miller and Howell 1996).

Crop load is the amount of fruit that the vine carries to maturation. It can strongly influence vine balance between reproductive and vegetative growth. According to

Winkler (1954), "vines have the capacity to produce only so much fruit and bring it to normal maturity." Over-cropping can result in reduced vine growth (Edson et al. 1995a, 1995b, Edson and Howell 1993, Petrie et al. 2000a, Shaulis et al. 1966a, Winkler 1954), reduced leaf size and area (Edson et al. 1995b, Petrie et al. 2000a), reduced fruit set (Edson et al. 1995a, 1995b), irregular yield production (Winkler 1954), delayed fruit maturation (Edson et al. 1995b, Winkler 1954), reduced percent soluble solids (Edson et al. 1993, Shaulis et al. 1966a, Winkler 1954) and high sugar/acid ratios (Winkler 1954). In an over-cropping situation the fruit is produced not only at the expense of leaf and shoot growth, but root growth as well (Edson et al. 1995b). The negative effects of over-cropping can accumulate year after year and can be reversed only if the vine is allowed to produce a moderate crop (Winkler 1954) and return to balance.

Influence of Pruning on Vine Balance

Balance between fruit and vegetative growth is the foundation on which sustainable grape production stands. Dormant pruning is a highly responsive and common tool used to influence canopy growth and crop load (Howell et al. 1987, 1991, Kimball and Shaulis 1958, Morris et al. 1984a, 1984b, Partridge 1925b, Shaulis et al. 1966a, 1966b, 1953, Shaulis and Oberle 1948, Winkler 1958, Wolpert et al. 1983). Niagara vines in Michigan usually are pruned from the end of December through March, when vines are dormant and most stored reserves are sequestered in perennial wood and the root system.

Several approaches to pruning Niagara have been suggested over the past 125 years, most of which are based on the pruning methods for Concord. One simple approach to pruning is to employ a fixed-node pruning method, in which a specific node number is retained regardless of the vine growth the previous year (Howell et al. 1991). Cultivar, training system and vine capacity all should be considered when deciding the number of nodes to be retained. Fixed-node pruning is often used on *vinifera* cultivars trained to vertical shoot positioning (Smart and Robinson 1991). Currently, Niagara growers in Michigan who employ fixed-node pruning are retaining 90-120 nodes per vine (Howell 2004, personal communication).

The growth-yield relationship was discussed briefly above as a means to estimate the upper limit of fruit that can be supported by a vine the following year. To achieve this upper limit, Partridge (1925b) created *balanced pruning*, a pruning method that would take into consideration vine capacity for ripening fruit. His original protocol for Concord retained 30 nodes for the first pound of prunings, and 8 nodes for every additional pound, and can be expressed as 30+8 (Partridge 1925a). Subsequent evaluation and application by Shaulis, who worked with Partridge, revised the protocol to 30+10 (Shaulis and Jordan 1966, Shaulis et al. 1953, 1966a, Shaulis and Robinson 1953,) and then, finally, to 20+20 (Howell 2004, personal communication). Partridge and Shaulis worked with several cultivars, but the concepts of balanced pruning were defined on Concord grapevines (Partridge 1925a, Shaulis and Jordan 1966). The practice of balanced pruning has been shown to improve vine size (Miller et al 1993), fruitfulness and percent soluble solids at harvest (Miller et al. 1993, Shaulis et al. 1953).

<u>Hand Pruning</u>

Hand pruning has both advantages and limitations that must be considered within cultivar crop value. On the positive side, hand pruning is selective. The pruner can selectively choose reproductive nodes of a desired quality to ensure desired bud characteristics such as fruitfulness, cold hardiness and likelihood of good stored reserves in adjacent vegetative tissue. The pruner can also remove any dead or infected wood and modify undesirable canopy architecture every winter. From a negative prospective, hand pruning is expensive and time consuming when compared to mechanical pruning.

Mechanical Pruning

Unlike hand pruning, mechanical pruning lacks selectivity. Pruning equipment can be set to retain a certain length of cane, but cannot achieve a specific node number nor select superior canes to produce the crop. Some operations prune mechanically to eliminate the bulk of unwanted growth and create uniformity within the vineyard, and then a hand crew selectively removes unwanted wood. This two-step process can be time efficient and affordable, while maintaining some selectivity.

Physiological Impacts of Pruning

The effects of pruning are not limited to the current season, but will cyclically affect future growing seasons as well (Miller et al. 1993, Partridge 1925a). Vines are perennial organisms with a long and productive life if managed with sustainability as a goal. Extensive research on pruning suggests that the current year's pruning will affect vegetative growth (Miller et al. 1996a, 1996b, Miller et al. 1993, Miller and Howell 1996, 1998, Shaulis and Smart 1974), reproductive growth (Miller et al. 1996a, 1993, Miller and Howell 1996, 1998), the growth:yield relationship (Miller and Howell 1996, 1998, Miller et al. 1993, Shaulis and Smart 1974, Stergios and Howell 1977), fruit composition (Miller et al. 1993, Shaulis and Smart 1974), light penetration into the canopy (Shaulis and Smart 1974), photosynthesis (Miller et al. 1996a, Shaulis and Smart 1974), carbon accumulation (Miller et al. 1996a, 1996b, 1993, Miller and Howell 1996, 1998, Shaulis and Smart 1974) and cold hardiness (Shaulis and Smart 1974, Stergios and Howell 1977).

Pruning Severity and Vegetative Growth

Pruning affects vegetative growth directly. Retention of varying node numbers will influence the amount of vegetative and reproductive growth to be obtained. Discussions of pruning method commonly refer to "severity" of pruning. Simply put, increases in pruning severity will reduce node numbers retained (Howell et al. 1987, 1991; Miller et al. 1996a); total shoots per vine similarly will decrease (Miller et al. 1996a). The reciprocal response is also true (Kimball and Shaulis 1958, Shaulis and Oberle 1948, Smithyman et al. 1997). Total shoots per vine decrease with an increase in pruning severity, but shoot number per node increases (Kimball and Shaulis 1958, Smart 1982a), along with leaf area per shoot (Miller et al. 1996a). Increased uniformity of exposure to sunlight encourages these benefits to the vine (Shaulis and Smart 1974). Cane exposure to sunlight will result in increased cold hardiness of canes and buds (Shaulis and Smart 1974), increased vegetativeness (post-season vine size/nodes retained) (Miller et al. 1993, Shaulis and Smart 1974) and increased sugar accumulation (Shaulis and Smart 1974). Furthermore, vines with more severe pruning, tend to have increased vegetative growth, both shoot length and diameter, on the shoots that are produced (Miller et al. 1996a and 1996b). This can increase vine size as measured by winter pruning weight (Howell et al. 1987, 1991; Miller et al. 1993; Morris et al. 1984a). Reducing pruning severity results in greater shoot number, earlier development of leaf area, a denser canopy (Miller and Howell 1998, Smithyman et al. 1997, Sommer and Clingeleffer 1996, Winkler 1958) and increased within-vine competition (Miller et al.

1996b). These results promote a negative influence on distribution and penetration of sunlight into the canopy (Shaulis and Smart 1974, Smart 1985).

Pruning Severity and Reproductive Growth

Pruning affects fruit growth and yield in a manner similar to that of vegetative growth. Initially, increased pruning severity reduces yield (Kimball and Shaulis 1958, Shaulis and Oberle 1948), but after several years, less severely pruned vines may yield less than more severely pruned vines (Howell et al. 1987, Morris et al. 1984a). On such vines, the decrease in yield may be due to a reduction in bud fruitfulness (yield/nodes retained) (Howell et al. 1987, Miller et al. 1993, Morris et al. 1984a, 1980, Shaulis and Smart 1974). Reduced fruitfulness can be the result of poor light penetration into the canopy and/or vine photoassimilate distribution (Koblet et al. 1994, May et al. 1969, Petrie 2000a, 2000b). Yield reduction on less severely pruned vines usually comes from reduced yield components such as reduced cluster weight (Kimball and Shaulis 1958, Miller and Howell 1996, 1998, Smart et al. 1982a), fewer berries per cluster (Kimball and Shaulis 1958, Morris et al. 1984a, Miller and Howell 1996, 1998) and reduced berry weight (Miller and Howell 1996, Morris et al. 1984a, Smart et al. 1982a). On a one-year basis, light pruning can appear to be desirable in producing high yields and accumulating carbohydrates. After several years of insufficient pruning, the detriment of over-cropping becomes apparent (Winkler 1958) in poorer fruit composition, reduced vine growth and reduced cold hardiness (Shaulis and Smart 1974).

Alternatively, vines pruned too severely could accumulate insufficient carbohydrates (Miller et al. 1996a, Smart 1985) to support the vine and result in reduced fruitfulness and fruit set (Shaulis and Oberle 1948). Miller and Howell (1996, 1993, 1998), along with Shaulis et al. (1966a), found that over-pruned, under-cropped vines caused vegetative growth to increase and created a crowded, shaded canopy. Too much vegetative growth can be the result of both insufficient and excessive pruning. In both situations, internal canopy shading can reduce cluster weight, cluster number, delay fruit maturity and reduce cold hardiness (Shaulis et al. 1966a). Both pruning extremes are undesirable in obtaining vine balance and sustainability.

Node position on a cane can influence vine yield. In *V. labruscana* B., the basal node positions 1-3 tend to be less fruitful, while nodes 4-9 are most fruitful (Partridge 1921, Pool et al. 1978). Thus, short or spur pruning (1-3 nodes) can reduce yield, while long cane pruning can increase it. Partridge (1921, 1925b) found that *V. labruscana* B. canes eight to eleven nodes long were more productive than those with two- to three-node spurs.

Pruning Severity and Fruit Maturation

Pruning influences the growth-yield relationship and therefore influences photoassimilate accumulation and partitioning (Shaulis and Smart 1974). Fruit ripening requires carbohydrates and must be included when considering pruning practices. Less severe pruning can cause crop load to increase, resulting in delayed fruit maturity and/or reduced percent soluble solids at harvest (Howell et al. 1987, Kimball and Shaulis 1958, Miller and Howell 1998, Morris et al. 1984a, Shaulis et al. 1966a, Shaulis and Robinson 1953, Smart et al. 1982a, Winkler 1958, Wolpert et al. 1983). Reduced pruning severity also can result in acidity reduction to undesirable lows (Winkler 1958). This acidity decline can result in what the industry refers to as a 'flat' juice composition (Howell et al. 1982). This decrease in acidity causes a higher percent soluble solids:acid ratio (Winkler

1958). Ripening delays for some heavily cropped vines may be due to inadequate leaf and fruit exposure of a large, crowded canopy to sunlight (Kimball and Shaulis 1958, Shaulis and Smart 1974). The profit value of a cultivar must be considered when deciding whether to increase crop or increase sugar accumulation in fruit. A balance between high yields with acceptable fruit composition should be achieved to gain the highest profit possible.

Influence of Crop Thinning on Vine Balance

Vine balance can be accomplished by methods other than pruning. Crop reduction by fruit removal also can be used to balance the leaf area to fruit weight ratio after pruning (Shaulis et al. 1966a). Crop thinning can be accomplished through flower cluster thinning, where flower clusters are removed manually, mechanically or chemically. Thinning also can be accomplished by whole cluster removal, where fruit clusters are manually or mechanically removed. It also can be accomplished via berry thinning where portions of the cluster are removed. Fruit removal can be used to encourage vine balance after unexpected injury occurs to the vine. Spring weather episodes can affect both crop load and/or leaf area. Thinning can be used to adjust crop load after the critical spring period when detrimental weather such as winter damage, spring frost damage or a poor fruit set can severely reduce crop load and/or vegetative growth. Weather conditions can influence many different vineyard situations that change from year to year. Using crop thinning can allow the grower to adjust the vineyard after weather conditions have intervened. In the case of winter damage or spring frost where vegetative growth is reduced, a vineyard can be allowed to retain more buds for vegetative production, while reproductive growth is reduced by yield adjustment.

Thinning and Highest Sustainable Production

Fruit removal is also necessary in an over-cropped year, like 2003 in southwest Michigan. Excessive crop in 2003 was a response to a very low crop load in both 2001 and 2002 resulting from poor fruit set and spring frost damage, respectively. Good management suggested crop adjustment in 2003 if vine balance was to be achieved. Thinning has allowed fruit to accumulate acceptable sugar that would not have been reached otherwise (Howell et al. 1987, Wolpert et al. 1983). Thinning has also been used instead of severe pruning to increase cold hardiness (Stergios and Howell 1977) and improve fruit composition values (Edson and Howell 1993, Edson et al. 1993, Wolpert et al. 1983).

Early on, Partridge (1925b) observed that a balance between pruning and thinning was needed for optimal maintenance of Concord. Crop control through crop thinning can provide greater success to vines with low vigor than severe pruning (Shaulis et al. 1966a). Low-vigor vines are characterized by inadequate leaf area. Retaining sufficient nodes to fill the canopy with leaves while limiting crop via thinning provides a solution for achieving balance in weak vines (Shaulis et al. 1966a).

Thinning also can influence yield by increasing yield components like cluster weight, berry weight and berries per cluster (Edson et al. 1995a, 1995b, Howell et al. 1987, Wolpert et al. 1983). Thinning prior to fruit set will result in more berries retained per cluster, as shown by (Edson et al. 1995a, 1995b) in his cropping study with potted Seyval, which alleviated cropping stress by thinning.

Thinning and Fruit Composition

With regard to fruit composition, Wolpert et al. (1983) found that thinning gave similar results to pruning. For example, Vidal blanc pruned to 15 nodes per pound of pruning weight plus thinning was comparable in fruit composition to vines pruned to 10 nodes per pound without thinning. In the same study, 15-nodes with no thinning was comparable to 20-nodes with thinning (Wolpert et al. 1983). However, pruning could be better for achieving balance in high vigor vines like Niagara (Winkler 1958).

Influence of Training System on Vine Balance

The 'best fit' training system also can contribute to vine balance (leaf area:crop load) and optimal distribution of leaf area to sunlight (Howell 2003a). In Michigan, Niagara commonly is trained to single curtain systems, such as Hudson River Umbrella (HRU) (Figure 1) and Umbrella Kniffen (UK) (Figure 2), or a divided canopy system such as Geneva Double Curtain (GDC) (Figure 3). All three systems support the vine while allowing it to grow with the natural recumbent habit.

Figure 1. Hudson River Umbrella (HRU).

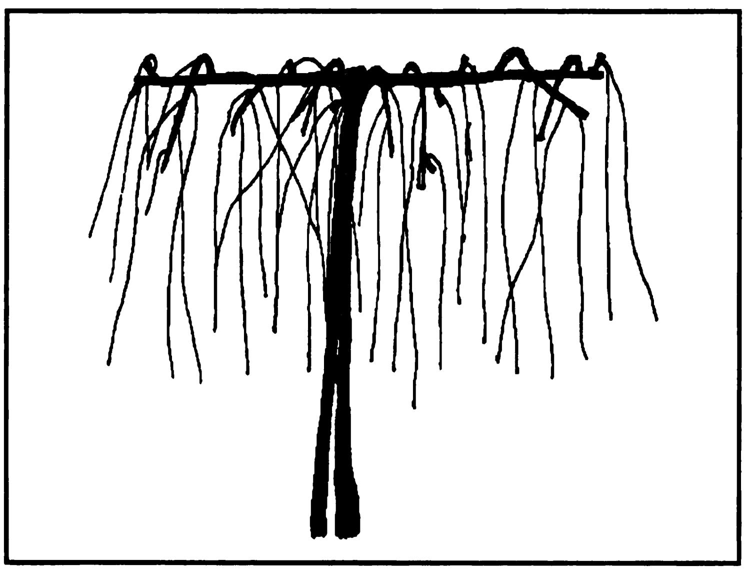
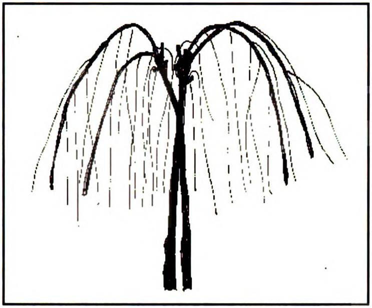
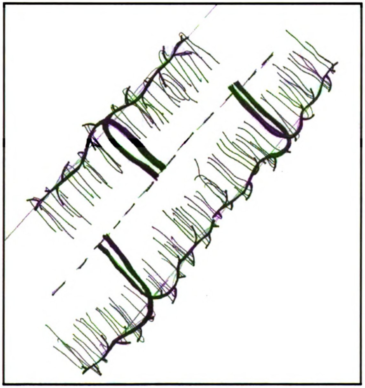


Figure 2. Umbrella Kniffen (UK).



Figures 1and 2 Courtesy of Leah Clearwater

Figure 3. Geneva Double Curtain (GDC) shown in overhead view.



V. labruscana B. cultivars have a recumbent habit due to long internodes and large leaves whose weight on canes and shoots causes them to hang (Howell 2003a). Due to less fruitful basal nodes, node fruitfulness must be considered when choosing a training system for *V. labruscana* B. cultivars (Howell 2003a, Partridge 1921, 1925b; Pool et al. 1978). Therefore a system allowing retention of canes with 5 to 15 nodes each would be desirable for Niagara vines.

HRU is a high, bilateral cordon system with a top wire at 1.8 m (6 feet). Canes of 5-8 nodes are spaced evenly over the cordon length and are designated for fruiting. Spurs 1-3 nodes in length are spaced along the cordon and near the top of the trunks to produce renewal shoots (Figure 1). The UK system is a head system, with the head and top wire at 1.8 m (6 feet). Long canes of 15-20 nodes are trained from the head of the trunk, bent down and tied to the mid-wire to form an arching shape (Figure 2). Two to four renewal spurs are retained at the head of the vine to produce canes for the following year. UK retains less two-year and older wood than the HRU system. Both systems may require tying of the trunks, cordons and canes, but the UK requires more tying attention.

Divided canopy systems, like the GDC (Figure 3), are desirable for accommodating excess vine vigor by spreading canopy over twice the area of a single curtain. According to Howell et al. (2003a), vines that produce more than 0.6 kg/m (0.4 lbs/foot) of prunings may be overly vigorous and can be brought into balance using GDC. GDC is a high cordon system 1.8 m (6 feet) high that horizontally divides the canopy by cordon or two trunks. Cordons are trained 2.4 m (8 feet) long in each direction from the trunk, spanning a total of 4.9 m (16 feet). This system produces the same vine number per hectare as in a 2.4 m (8 feet) spaced single curtain row, but vine division creates more canopy space and therefore the canopy can be spread over twice the cordon length (Shaulis and Shepardson 1965, Shaulis et al. 1966a). Reduced shoot crowding improves light distribution in the GDC canopy that allows more crop to be carried without detrimental impact on fruit composition (Morris et al. 1984a, Morris and Cawthon 1980a and 1980b, Shaulis 1966 and Jordan, Shaulis and Shepardson 1965, Shaulis and Smart 1974). As with HRU, GDC canes of 5-8 nodes are spaced evenly over the cordon length and are designated for fruiting. Spurs 1-3 nodes long are placed along the trunk to produce renewal shoots.

Increased light exposure throughout the GDC canopy can also improve bud development (Morris et al. 1984b). Higher yields on GDC vines are due to increased bud fruitfulness (Morris et al. 1984b, Morris and Cawthon 1980b, Shaulis and Smart 1974), berries per cluster (Morris et al. 1984b) and berry weight (Morris et al. 1984) that can be attributed to enhanced light exposure (Morris et al. 1984b, Shaulis et al. 1966b).

In the case of vigorous vines, a higher trellis, 1.7 vs. 1.2 m (5.5 vs. 4 feet), has been shown to be superior in maturing fruit (Shaulis and Jordan 1966, Shaulis et al. 1953, Shaulis and Robinson 1953), developing renewal buds, increasing vegetative growth (Shaulis et al. 1953), increasing yield and increasing yield components (Howell et al. 1987, 1991, Shaulis et al 1953). Though cordon and head training systems have not been found to result in different fruit quality and yield components (Howell et al. 1987, 1991, Morris et al. 1984a, Wolpert et al. 1983), the source of yield has been different. Cordon training systems, like HRU, produced significantly more two-year and older wood. Non-count nodes, nodes that arise from two-year and older wood as well as from base buds, can provide more crop on cordon-trained vines as opposed to head-trained vines in other cultivars (Howell et al. 1987, 1991, Wolpert et al. 1983). Although clusters from a non-count shoot usually weigh less than those from a count shoot (Smart et al. 1982a, Wolpert et al. 1983), they contribute to valuable production in cases of winter and/or frost damage (Howell et al. 1987). Another advantage of a cordon system is the retention of more 5 to 10-node canes, which according to Partridge (1925b, 1921) are at more fruitful positions than the fewer and longer 15 to 20-node canes from a head system. Because cordon systems have more nodes at prime fruitful positions, they can produce higher yields (Howell et al. 1987). Though HRU, UK and GDC all complement the natural recumbent growth habit of *V. labruscana* B., these training systems may position the fruiting zone under leaf layers shading the fruit (Schultz 1995). Cultural practices such as shoot positioning have evolved to resolve this limitation (Shaulis et al. 1966a).

Minimal Pruning & Hedging

Two methods involving no hand pruning can be administered through mechanical pruning. Machinery can be set to obtain longer or shorter canes. Minimal pruning (MP) involves no pruning except 'skirting' or trimming growth to retain longer canes (~76 cm from cordon wire) while hedging (H) will retain shorter canes (~15 cm radius around cordon wire). As discussed above, mechanical pruning is not selective but it does reduce production cost. Though mechanical pruning reduces labor cost, several studies and observations have found this method to be viticulturally unsustainable (Kliewer and Benz 1992, Lake et al. 1997, 1998, Reynolds and Wardle 1993, Sims et al. 1990, Striegler et al. 1998).

Mechanically pruned vines (MP and H) commonly have more nodes retained and therefore possess many of the same vegetative and reproductive problems as the less severely pruned vines discussed above. More nodes retained and shoots per vine contribute to over-crowding and shading of shoots (Smart 1985). The leaves on shoots located in the interior of the canopy have minimal to no photosynthetic contribution (Shaulis and Jordan 1966, Smart 1985). Smart (1985) suggests, and Howell and Trought (2001, unpublished data) have observed, that interior leaves act as sinks rather than as sources. Stress in MP vines can be expressed through shorter shoot lengths (Kliewer and Benz 1992), reduced pruning weights (Kliewer and Benz 1992, Reynolds and Wardle 1993) and fewer mature nodes per vine (Morris and Cawthon 1980a, Striegler and Berg 1994, Striegler et al. 1998).

Though there are many negative effects on MP vines above ground, Wample et al. (2000) found very few differences in root fresh weight, dry weight, soluble carbohydrates or starch level, between mechanically and balance pruned vines in Washington state. On the other hand, researchers in Michigan have found that increases in crop load, common in mechanically pruned vines, reduce vegetative growth and dry weight, including root growth (Edson et al. 1995b).

A study of MP Cabernet Franc vines found no differences in total carbohydrate accumulation but, rather significant differences in carbohydrate partitioning (Clingeleffer and Krake1992, Rühl and Clingeleffer 1993). Cabernet Franc vines with MP treatments had more carbohydrates in old wood compared to spur pruned vines which had more in canes and roots. On the other hand, nitrogen accumulation in perennial plant parts was 20% less in MP vines compared to the spur pruned vines (Rühl and Clingeleffer 1993). Edson et al. (1995a) found similar results in over-cropped potted vines.

Initially, MP vines tend to produce higher yields compared to hand pruned vines with fewer nodes retained (Lake et al. 1997, 1998, Morris and Cawthon 1980a, Reynolds and Wardle 1993, Striegler and Berg 1994, Striegler et al. 1998, Wample et al. 2000). After several years, however MP vines become unbalanced, which is shown through decreasing yields (Kliewer and Benz 1992, Morris and Cawthon 1980a, Reynolds and Wardle 1993,). Initial increases in yield can be attributed to an increase in clusters per vine (Kliewer and Benz 1992, Lake et al. 1997, 1998, Reynolds and Wardle 1993, Striegler and Berg 1994, Striegler et al. 1998); unfortunately, this is coupled with reduced berry weight (Kliewer and Benz 1992, Lake et al. 1997, 1998, Morris and Cawthon 1980a, Striegler and Berg 1994, Reynolds and Wardle 1993, Striegler et al. 1998) and fewer berries per cluster (Kliewer and Benz 1992, Lake et al. 1997, 1998, Morris and Cawthon 1980a, Reynolds and Wardle 1993, Striegler and Berg 1994, Striegler et al. 1998). This leads to a reduction in yield, yield components, and production of fruit with lower percent soluble solids (Kliewer and Benz 1992, Reynolds and Wardle 1993) caused by delayed ripening (Kliewer and Benz 1992, Lake et al. 1997, 1998, Striegler et al. 1998).

After noticing faults of mechanical pruning, Shaulis et al. (1973) made some suggestions and goals. Mechanically pruned vines should provide a vine size of 1.1-1.5 kg (2.4-3.2 lbs) winter pruning weight per vine, increased yields over time and ripened fruit by an expected date (Shaulis et al. 1973). According to Morris and Cawthon (1980a), hand pruning after mechanical pruning can improve the system by increasing yield, percent soluble solids, vine size and cane maturity. The implementation of hand pruning and/or thinning has potential to elevate mechanically pruned vines to the standards described above.

Canopy Microclimate

According to Smart (1985), canopy microclimate depends on the amount and distribution of leaf area in a space and its interaction with weather conditions. Therefore training system and pruning method are of vital importance when considering the influence of weather conditions on canopy microclimate (Smart 1985). Shoot number, vigor control and trellis system can be used to manipulate microclimate and are equally influential as soil and climatic properties (Smart 1985).

Sunlight incidence in the canopy's interior is reduced significantly to less than 4-10% of the initial incidence on the exterior canopy (Shaulis and Shepardson 1965, Smart 1985) and therefore photosynthesis also is reduced (Shaulis and Smart 1974, Smart 1985). Leaf exposure to sunlight is important not only for the current year's crop but also for the crop of subsequent years. Smart et al. (1982a) found that variations in illuminance at certain leaf positions during one year were associated with variance of crop per node in the next year. During the period prior to bloom, leaf illuminance can explain 37% of the variation in the yield per node, cluster number and berry number for the following year.

Evaporation rates within the interior of the canopy are reduced due to reduction in wind speed and increased humidity, which can lead to increased fungal disease pressure (Smart 1985, Koblet et al. 1994). Reduced shoot and foliage crowding decreases the amount of interior shade and increases the amount of exterior canopy (Shaulis et al. 1966b, Smart et al. 1982b). Crowding can be reduced by decreasing the number of shoots per row length (Miller et al. 1996a), extending cordon length (Shaulis and Smart 1974) or shoot thinning (Smart and Robinson 1991).

Shaulis et al. (1966a) found fruit and shoot maturity to be related closely. He evaluated shoot maturity via periderm color. Dark brown canes with shorter internodes are more mature and fruitful compared to a yellow-brown cane with long internodes. He further suggested that differences in both fruit and shoot maturity were related to sunlight exposure status.

Statement of Objectives

Vine sustainability is an objective with multiple factors, including cultivar, climate, weather conditions, the balance of vegetative and reproductive growth, production cost and profit. In Michigan Niagara grape juice production has several limitations, including cool climate conditions and a harvest deadline set by processors. There are vegetative and reproductive growth relationships within the Niagara grapevine that can produce the highest sustainable yield. Once these relations are identified and understood, a cultural management protocol can be established to help the vine compensate for undesirable growing season conditions or other abiotic or biotic stress conditions.

The objectives of this study are:

1. To investigate training and pruning system techniques that will produce highest sustainable yields with acceptable fruit composition year after year.
2. To investigate the relationship between vegetative and reproductive growth of the Niagara grapevine.
3. To evaluate the effects of cluster thinning on minimally pruned vines.
4. To investigate the interaction of spring weather conditions with different training systems and pruning levels.

LITERATURE CITED

Bailey, L.H. 1917. Vitis. *In* Volume Six of The Standard Cyclopedia of Horticulture. pp. 3481-3492.. The Macmillan Company, New York.

Bates, T.R., R.M. Dunst, and P. Joy. 2002. Seasonal dry matter, starch and nutrient distribution in 'Concord' grapevine roots. HortScience. 37(2):313-316.

Clingeleffer, P.R. and L.R. Krake. 1992. Response of Cabernet Franc grapevines to minimal pruning and virus infection. Am. J. Enol. Vitic. 43:31-37.

Dethier, B.E., N.J. Shaulis. 1964. Minimizing the hazard of cold in New York vineyards. Cornell Extension Bulletin 1127.

Edson, C.E. and G.S. Howell. 1993. A comparison of vine architecture systems at different crop loads: Leaf photosynthesis, vine yield and dry matter partitioning. Vitic. Enol. Sci. 48:90-95.

Edson, C.E., G.S. Howell, and J.A. Flore. 1993. Influence of crop load on photosynthesis and dry matter partitioning of Seyval grapevines. I. Single leaf and whole vine response pre- and post-harvest. Am. J. Enol. Vitic. 44:139-147.

Edson, C.E., G.S. Howell, and J.A. Flore. 1995a. Influence of crop load on photosynthesis and dry matter partitioning of Seyval grapevines. II. Seasonal changes in single leaf and whole vine photosynthesis. Am. J. Enol. Vitic. 46:469-477.

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

Gladstone. J.S. 1992. Viticulture and Environment. Wine Titles, Adelaide, Australia.

Hedrick, U.P. 1908. The Grapes of New York. J. B. Lyon Company, Albany.

Howell, G.S. 1988. Cultural manipulation of vine cold hardiness. *In* Proceedings for the Second International Symposium on Cool Climate Viticulture and. Oenology. pp. 98-102. Auckland, New Zealand.

Howell, G.S. 2000. Grape crop control: Implication for yield, fruit composition and subsequent wine quality, cold hardiness and sustainable production. Wine East Sept-Oct. pp. 12-19, 47-49.

Howell, G.S. 2001. Sustainable grape productivity and the growth-yield relationship: A review. Am. J. Enol. Vitic. 52:165-174.

Howell, G.S. 2003a. Selecting and appropriate trellis/training system based on specific variety characteristics. *In* Proceedings for the Twenty Second Annual Horticulture Industry Show. pp. 121-129. Springdale, Arkansas.

Howell, G.S. 2003b. Factors related to spring frost damage: What are the options. Michigan State University Program of Viticulture and Enology.

Howell, G.S., M. Carmo Candolfi-Vasconcelos, and W. Koblet. 1994. Response of Pinot noir grapevine growth, yield and fruit composition to defoliation the previous growing season. Am. J. Enol. Vitic. 45:188-191.

Howell, G.S., T.K. Mansfield, and J.A. Wolpert. 1987. Influence of training system, pruning severity and thinning on yield, vine size and fruit quality of Vidal blanc grapevines. Am. J. Enol. Vitic. 38:105-112.

Howell, G.S., D.P. Miller, C.E. Edson, and R.K. Striegler. 1991. Influence of training system and pruning severity on yield, vine size and fruit composition of Vignoles grapevines. Am. J. Enol. Vitic. 42:191-198.

Howell, G.S. and N. Shaulis. 1980. Factors influencing within-vine variation in the cold resistance of cane and primary bud tissues. Am. J. Enol. Vitic. 31:158-161.

Howell, G.S., B.G. Stergios, and S.S. Stackhouse. 1978. Interrelation of productivity and cold hardiness of Concord grapevines. Am. J. Enol. Vitic. 29:187-191.

Howell, G.S. and J.A. Wolpert. 1978. Nodes per cane, primary bud phenology, and spring freeze damage to Concord grapevines. A preliminary note. Am. J. Enol. Vitic. 29:229-232.

Howell, G.S., J.A. Wolpert, and T.K. Mansfield. 1982. Pruning Niagara grapevines for top yields and quality fruit. *In* Proceedings for the Michigan Grape Society. 4:1-23.

Johnson, D.E. and G.S. Howell. 1981. Factors influencing critical temperatures for spring freeze damage to developing primary shoots on Concord grapevines. Am. J. Enol. Vitic. 32:144-149.

Kimball, K. and N. Shaulis. 1958. Pruning effects on the growth, yield, and maturity of Concord grapes. J. Am. Soc. Hortic. Sci. 71:167-176.

Kleweno, D.D. 2003. United States Department of Agriculture. Michigan Agricultural Statistics 2002-2003, National Agriculture Statistics Service. www.nass.usda.gov/mi/stats03/fruit.txt

Kleweno, D.D. and S.J. Pscodna. 1998. United States Department of Agriculture, Michigan Agricultural Statistics. Mich. Dept. Agriculture Publ. pp. 148.

Kliewer, W.M. and M. Benz. 1992. Performance of cordon-trained Carbernet sauvignon grapevines grown in the Napa Valley to hedge pruning and minimal pruning. Abstr. ASEV 43rd Ann. Meet. Am. J. Enol. Vitic. 43:300A.

Koblet, W., M. Carmo Candolfi-Vasconcelos, W. Zweifel, and G.S. Howell. 1994. Influence of leaf removal, rootstock and training system on yield and fruit composition of Pinot noir grapevines. Am. J. Enol. Vitic. 45:181-187.

Lake, C., R.K. Striegler, P. Verdegaal, G. Berg, and J.A. Wolpert. 1997. Influence of vine trellis training system on growth, yield, fruit composition and *Eutypa* incidence in Cabernet sauvignon. Abstr. 4th International Symposium of Cool Climate Viticulture and Enology and ASEV Ann. Eastern Meet. Am. J. Enol. Vitic. 48:248A.

Lake, C., R.K. Striegler, P. Verdegaal, G. Berg, J.A. Wolpert and C.A. Ingels. 1998. Effect of training system and soil type on growth, yield, and fruit composition of Cabernet Sauvignon grapevines. Abstr. ASEV Ann. Meet. Am. J. Enol. Vitic. 49:352A.

Loomis, N.H. 1939. Note on grape foliation as affected by time of pruning. J. Amer. Soc. Hort. Sci. 37:653-654.

Mansfield, T. and G.S. Howell. 1981. Response of soluble solids accumulation, fruitfulness, cold resistance and onset of bud growth to differential defoliation stress at veraison in Concord grapevines. Am. J. Enol. Vitic. 32:200-205.

Martinez de Toda, Fernando and Juan Carlos Sancha. 1999. Long-term effects of simulated mechanical pruning on Grenache vines under drought conditions. Am. J. Enol. Vitic. 50:87-90.

May, P., N.J. Shaulis, and A.J. Antcliff. 1969. The effect of controlled defoliation in the Sultana vine. Am. J. Enol. Vitic. 20:237-250.

Miller, D.P. and G.S. Howell. 1996. Influence of vine capacity and crop load on the yield, fruit composition and sugar production per unit land area of Concord grapevines. *In* Proceedings for the Forth International Symposium on Cool Climate Enology and Viticulture. T. Henick-Kling et al. (Eds.), pp. 94-98. N.Y. State Agricultural Experiment Station, Geneva, NY.

Miller, D.P. and G.S. Howell. 1998. Influence of vine capacity and crop load on canopy development, morphology and dry matter partitioning in Concord grapevines. Am. J. Enol. Vitic. 49:183-190.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996a. Effect of shoot number on potted grapevines: I. Canopy development and morphology. Am. J. Enol. Vitic. 47:244-250.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996b. Effect of shoot number on potted grapevines: II. Dry matter accumulation and partitioning. Am. J. Enol. Vitic. 47:251-256.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996c. Influence of shoot number and crop load on potted Chambourcin grapevines. I. Morphology and dry matter Partitioning. Am. J. Enol. Vitic. 47:380-388.

Miller, D.P., G.S. Howell, and J.A. Flore. 1997. Influence of shoot number and crop load on potted Chambourcin grapevines. II. Whole-vine vs. single-leaf photosynthesis. Vitis 36:109-114.

Miller, D.P., G.S. Howell, and R.K. Striegler. 1993. Reproductive and vegetative response of mature grapevines subjected to differential cropping stresses. Am. J. Enol. Vitic. 44:435-440.

Morris, J.R., and D.L. Cawthon. 1980a. Mechanical trimming and node adjustment of cordon-trained 'Concord' grapevines. J. Amer. Soc. Hort. Sci. 105(3):310-313.

Morris, J.R., and D.L. Cawthon. 1980b. Yield and quality response of 'Concord' grapes to training systems and pruning severity in Arkansas. J. Amer. Soc. Hort. Sci. 105(3):307-310.

Morris, J.R., and D.L. Cawthon. 1981. Yield and quality response of Concord grapes (*Vitis labrusca L.*) to mechanized vine pruning. Am. J. Enol. Vitic. 32:280-282.

Morris, J.R., D.L. Cawthon, and C.A. Sims. 1984a. Long-term effects of pruning severity, nodes per bear unit, training system, and shoot positioning on yield and quality of 'Concord' grapes. J. Amer. Soc. Hort. Sci. 109(5):676-683.

Morris, J.R., C.A. Sims, J. E. Bourque, and J.L. Oakes. 1984b. Influence of training system, pruning severity, and spur length on yield and quality of six French-American hybrid grape cultivars. Am. J. Enol. Vitic. 35:23-27.

Morris, J.R., W.A. Sistrunk, J. Junek, and C.A. Sims. 1986. Effects of fruit maturity, juice storage, and juice extraction temperature on quality of 'Concord' grape juice. J. Amer. Soc. Hort. Sci. 111(5):742-746.

Partridge, N.L. 1921. A note on the fruiting habit of the Concord grape. Proc. Amer. Soc. Hort. Sci. 18:193-196.

Partridge, N.L. 1925a. Growth and yield of Concord grape vines. Proc. Amer. Soc. Hort. Sci. 22:84-87.

Partridge, N.L. 1925b. The fruiting habits and pruning of the Concord grape. Michigan Agriculture Experiment Station Tech Bulletin. 69:3-38.

Partridge, N.L. 1925c. The use of the growth-yield relationship in field trials with grapes. Proc. Amer. Soc. Hort. Sci. 23:131-134.

Petrie, P.R., M.C.Trought and G.S. Howell. 2000a. Growth and dry matter partitioning of Pinot noir (*Vitis vinifera* L.) in relation to leaf area and crop load. Austr. J. Grape and Wine Res. 6:40-45.

Petrie, P.R., M.C.Trought and G.S. Howell. 2000b. Fruit composition and ripening of Pinot noir (*Vitis vinifera* L.) in relation to leaf area. Austr. J. Grape and Wine Res. 6:46-51.

Pool, R.M., Charlotte Pratt and H.D. Hubbard. 1978. Structure of base buds in relation to yield of grapes. Am. J. Enol. Vitic. 29:36-41.

Ravaz, M.L. 1911. L effeuellage de la vigne. Annales d L Ecole Nationale d agriculture de Montpellier. 11:216-244.

Reynolds, A.G. and D.A. Wardle. 1993. Yield component path analysis of Okanagan Riesling vines conventionally pruned or subjected to simulated mechanical pruning. Am. J. Enol. Vitic. 44:173-179.

Rühl, E.H. and P.R. Clingeleffer. 1993. Effect of minimal pruning and virus inoculation on the carbohydrate and nitrogen accumulation in Cabernet Franc vines. Am. J. Enol. Vitic. 44:81-85.

Schultz, H.R. 1995. Grape canopy structure, light microclimate and photosynthesis. I. A two-dimensional model of the spatial distribution of surface area densities and leaf ages in two canopy systems. Vitis. 34(4):211-215.

Shaulis, N.J., H. Amberg and D. Crowe. 1966b. Response of Concord grapes to light, exposure and Geneva double curtain training. Amer. Soc. Hort. Sci. 89:268-280.

Shaulis, N.J., J. Einset, and A.B. Pack. 1968. Growing cold-tender grape varieties in New York. New York State Agriculture Experiment Station. Bulletin 821.

Shaulis, N.J., T.D. Jordan, and J. P. Tomkins. 1966a. Cultural practices for New York vineyards. Cornell Extension. Bulletin 805.

Shaulis, N.J., E.S. Shepardson and T.D. Jordan. 1966c. The Geneva Double Curtain for Concord grapes: Vine training and trellis construction. New York State Agriculture Experiment Station. Bulletin 811.

Shaulis, N.J., K. Kimball, and J. Tomkins. 1953. Training and trellising Concord grapes for high yields. Farm Research. 19:11.

Shaulis, N.J. and G.D. Oberle. 1948. Some effects of pruning severity and training on Fredonia and Concord grapes. Proc. Am. Soc. Hort. Sci. 51:263-270.

Shaulis, N.J., J. Pollock, D. Crowe, and E.S. Shepardson. 1973. Mechanical pruning of grapevines: Progress 1968-1972. *In* the New York State Horticultural Proceedings. pp.60-69.

Shaulis, N.J. and W.B. Robinson. 1953. The effects of season, pruning severity, and trellising on some chemical characteristics of Concord and Fredonia grape juice. Proc. Am. Soc. Hort. Sci. 62:214-220.

Shaulis, N.J. and E. Shepardson. 1965. The Geneva Double Curtain-a training system for New York's vigorous grapes. Farm Research. 31:2-4.

Shaulis, N.J. and R. Smart. 1974. Grapevine canopies: Management, microclimate and yield responses. *In* Proceedings for the 19th International Horticultural Congress. pp. 256-262. Warszawa, Poland.

Sims, C.A., R.P. Johnson, and R.P. Bates. 1990. Effects of mechanical pruning on the yield and quality of Muscadine grapes. Am. J. Enol. Vitic. 41:273-276.

Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. Am. J. Enol. Vitic. 36:230-239.

Smart. R.E., and M. Robinson. 1991. Sunlight into Wine. Winetitles, Adelaide.

Smart, R.E., N.J. Shaulis and E.R. Lemon. 1982b. The effect of Concord vineyard microclimate on yield. I. The effects of pruning, training, and shoot positioning on radiation microclimate. Am. J. Enol. Vitic. 33:99-108.

Smart, R.E., N.J. Shaulis and E.R. Lemon. 1982a. The effect of Concord vineyard microclimate on yield. II. The interrelations between microclimate and yield expression. Am. J. Enol. Vitic. 33:109-116.

Smithyman, R.P., G.S. Howell, and D.P. Miller. 1997. Influence of canopy configuration on vegetative development, yield, and fruit composition of Seyval blanc grapevines. Am. J. Enol. Vitic. 48:482-491.

Sommer, K.J. and P.R. Clingeleffer. 1996. Vine canopy development and carbohydrate partitioning as influenced by pruning. *In* Proceedings for the ninth Australian Wine Industry Technical Conference. pp.123-127. Adelaide, Australia.

Stergios, B.G. and G.S. Howell. 1977. Effects of Defoliation, trellis height, and cropping stress on the cold hardiness of Concord grapevines. Am. J. Enol. Vitic. 28:34-42.

Striegler, R.K. and G.T. Berg. 1994. Evaluation of machine and minimal pruning of French Colombard grapevines. Abstr. ASEV 45th Ann. Meet. Am. J. Enol. Vitic. 45:365A.

Striegler, R.K., G.T. Berg, C.B. Lake, and S.G. Graves. 1998. Effect of trellis system on growth, yield, and fruit composition of Sauvignon blanc grapevines grown in the southern San Joaquin Valley. Am. J. Enol. Vitic 49:452A.

Suplicki, Carol and Gina Molino, editors. Webster's Dictionary and Thesaurus. 1991. Nichols Publishing, USA.

United States Department of Agriculture. 2000a. Michigan Agricultural Statistics 2000, National Agricultural Statistics Service. www.nass.usda.gov/mi/stats01/farmecon.txt.

United States Department of Agriculture. 2000b. Michigan Fruit Inventory, National Agricultural Statistics Service www.nass.usda.gov/mi/mi_fruit01/grapes.pdf.

Wample, R.L., L. Mills and A. Kawakami. 2000. Root growth of mechanically pruned grapevines-hypothesis and reality. Abstr. ASEV Ann. Pacific Northwest Meet. Am. J. Enol. Vitic. 51:90A.

Weaver, R. 1963. Effect of leaf to fruit ratio on fruit quality and shoot development in 'Carignane' and 'Zinfandel' wine grapes. Am. J. Enol. Vitic. 14:1-12.

Winkler, A.J. 1954. Effects of overcropping. Amer. J. Enol. Viticult. 5:4-12.

Winkler, A.J. 1958. The relation of leaf area and climate to vine performance and grape quality. Am. J. Enol. Vitic. 9:10-23.

Winkler, A.J., J.A. Cook, W.M. Kliewer, L.A. Lider. 1974. General Viticulture. University of California Press, Berkeley.

Wolpert, J.A. and G.S. Howell. 1984. Effects of cane length and dormant season pruning data on cold hardiness and water content of Concord bud and cane tissues. Am. J. Enol. Vitic. 35:237-241.

Wolpert, J. and G.S. Howell. 1985. Cold acclimation of Concord grapevines. I. Variation in cold hardiness within the canopy. Am. J. Enol. Vitic. 36:185-188.

Wolpert, J.A., G.S. Howell and T.K. Mansfield. 1983. Sampling Vidal blanc grapes. I. Effect of training system, pruning severity, shoot exposure, shoot origin, and cluster thinning on cluster weight and fruit quality. Am. J. Enol. Vitic. 34:72-76.

CHAPTER II:

IMPACT OF NODES RETAINED AND SINGLE CANOPY TRAINING SYSTEMS ON SUSTAINABLE YIELDS, FRUIT COMPOSITION AND VEGETATIVE GROWTH OF NIAGARA GRAPEVINES

Abstract

Under cool climate conditions, there are relationships between grapevine and environment that limit sustainable fruit production. Vine balance between vegetative and reproductive growth is essential to sustain production of high yields and quality fruit, without compromising the health of the vine. To better understand the impacts of nodes retained on Niagara production, vines were subjected to 6 pruning levels: 20, 40, 80 or 120 fixed nodes, along with two simulated mechanically pruned treatments, minimally pruned (MP) and hedge (H). Vines with 20-120 fixed nodes also were subjected to a subplot treatment, single curtain training systems: Hudson River Umbrella (HRU), Umbrella Kniffen (UK) or Hybrid (HYB) which retains a cordon and long canes. There were no differences between HRU, UK and HYB regarding vegetative or reproductive impact, nor in fruit composition. As the number of nodes retained increased, vine size, cluster weight, berry weight, percent soluble solids, pH and fruitfulness decreased, while yield, cluster number, productivity and leaf area at veraison increased. Retaining 80 fixed nodes resulted in sustainable production, while not compromising vine health and long-term vineyard sustainability. The choice of training system, HRU, UK or HYB should be based on specific grower and vineyard needs.

Introduction

Winkler (1954) observed, "Vines have the capacity to produce only so much fruit and bring it to normal maturity." Consistent fruit production reaching the upper limit without compromising vine health is a goal termed highest sustainable yields. Howell (2001) explained that highest sustainable yields cannot be achieved without support of vegetative growth, full maturation of fruit and quality production over a period of years at a cost that returns a net profit. Vine balance between vegetative and reproductive growth is crucial for highest sustainable yields. Gladstone (1992) described vine balance as an equilibrium between vegetative vigor and fruit load that would encourage high fruit quality.

Cool Climate Limitations: Michigan's cool climate must be considered in any cultural program to achieve vine balance and highest sustainable yields. Cool climate conditions limit viticulture in several ways: threat of winter freeze and spring frost injury, limited growing season length, low sunlight intensity and no postharvest recovery period. All four limitations can cause within vine competition. Alleviation of within vine competition should start with promoting vine balance.

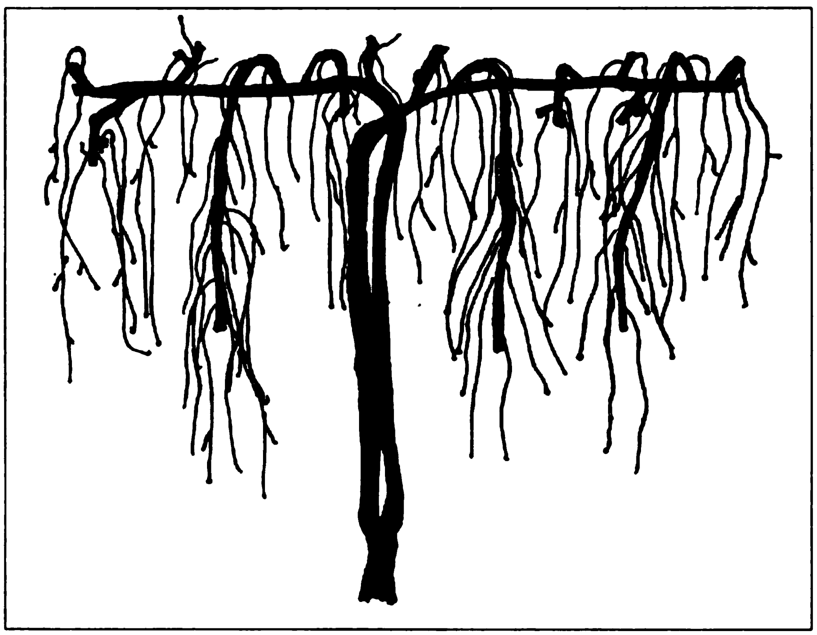
Vine Balance: In the early 1900's, Ravaz (1911) described vine balance as a ratio of fruit:vegetative growth that has since become known as the Ravaz Index. Smart and Robinson (1991) have suggested a 5:1 to 10:1 ratio as optimal for moderate vigor vines. *Vitis labruscana* B. (Bailey 1917), being more vigorous, would fall at the higher end of the Ravaz Index. Viticulturists continued to study vine balance, and a decade later Partridge (1925) suggested the growth-yield relationship. Unlike the Ravaz Index, which evaluated vine balance post-season, the growth-yield relationship was proactive and was proposed as a guideline to predicting vine yield capacity. Partridge (1925) used the vine growth estimated by dormant pruning weight per vine to predict the amount of fruit the vine should be able to produce and ripen the following season. This relationship between growth and yield tends to be very strong in smaller, weaker vines due to a heavy reliance on stored carbohydrates (Partridge 1925).

Training Systems: Training system choice and the number of nodes retained during winter pruning are two methods by which vine balance can be achieved. Hudson River Umbrella (HRU) (Figure 1; Chapter I) is a high cordon system that retains 5- to 8-node canes for fruiting and 1- to 2-node spurs for renewal. Because HRU is cordon trained, vine growth is spaced horizontally, which help can reduce crowding and shading. HRU vines also have more two-year and older wood and have been suggested to stored more carbohydrates and produce higher yields from fruiting non-count positions depending on cultivar (Howell et al. 1987, 1991, Wolpert et al. 1983). Non-count buds arise from nodes on two-year and older wood as well as base buds. Cordon systems, like HRU, also retain 5- to 10-node canes, which according to Partridge (1925, 1921) have greater fruitfulness than 15- to 20-node canes. This also can increase yield (Howell et al. 1987).

Umbrella Kniffen (UK) (Figure 2; Chapter I) also is a common training system for Niagara grapevines. UK is a head trained system that retains 15- to 20-node canes and two to four 2-node renewal spurs at the head. UK requires tying the head and canes to the trellis wires for support. By arching and tying the long canes vigor can be reduced and more yield may also result (Shaulis 1966). Head trained vines also have less two-year and older wood. They may also have less stored carbohydrates and produce smaller yields than cordon trained vines (Howell et al. 1987).

The Hybrid (HYB) (Figure 1) training system was initiated to help alleviate cane breakage effects by mechanical harvesting. HYB is a high cordon system that also retains 1 to 3 long canes as in UK. The long canes and the nodes they carry help to replace nodes that are lost when mechanically harvesting. This system is not as common as the HRU and UK, but holds potential for juice grapes (Howell 2004, personal communication).

Figure 1: The Hybrid (HYB) training system.



Pruning Severity: Winter pruning can be used to manipulate reproductive and vegetative growth. In general, less severely pruned vines have increased yield and leaf layers, but not functional leaf area. Increasing leaf layers is not beneficial to vine balance. According to Smart and Robinson (1991), only 1.5 leaf layers are fully photosynthetically active. Therefore increasing leaf layers beyond 1.5 can be detrimental, due to shading of the inner canopy. Howell and Trought (2001 unpublished data) have observed inner shaded leaves acting as photosynthetic sinks rather than sources, with CO_2 assimilation below the compensation point for photosynthesis. Shaded shoots also suffer from decreased cold hardiness of canes and buds, and reduced percent soluble solids in fruit (Shaulis and Smart 1974).

Higher crop load and canopy shading can increase vine sinks and create problems associated with inadequate carbohydrate levels. Over-cropped and shaded vines tend to decrease yields after several years (Howell et al. 1987, Morris et al. 1984) as a result of reduced bud fruitfulness (yield/nodes retained) (Howell et al. 1987, Miller et al. 1993, Morris et al. 1984, 1980, Shaulis and Smart 1974). Reduced fruitfulness can be due to poor light penetration into the canopy and/or vine photoassimilate distribution (Koblet et al. 1994, May et al. 1969, Petrie et al. 2000a, 2000b). Over-cropped vines also exhibit carbohydrate stress by delayed fruit maturity and/or reduced percent soluble solids (Howell et al. 1987, Kimball and Shaulis 1958, Miller and Howell 1998, Morris 1984, Shaulis and Robinson 1953, Shaulis et al. 1966, Smart et al. 1982, Winkler 1958, Wolpert et al. 1983).

On the other hand, vines pruned too severely also can be out of balance. In this case, vines can have insufficient carbohydrates (Miller et al. 1996, Smart 1985). Miller et al. (1996, 1993) and Shaulis et al. (1966) found that severe pruning can cause under-cropping that results in excessive vegetative growth, which in turn can lead to shading and a further reduction in cluster size, cluster number, cold hardiness and delayed fruit maturity (Shaulis et al. 1966).

Concepts of Methodology: Howell (2001) has expressed three concepts as the basis of methodology for achieving highest sustainable yields. These concepts are based on the environmental limitations of cool climate viticulture.

> **Premise 1.** For any genotype-environmental interaction there is an optimum method of culture to achieve highest yields of ripe grapes over years.
> **Premise 2.** Good viticultural practices must result from the application of sound principles of vine growth and development.
> **Premise 3.** A Sustainable level of highest fruit quality at maximum yield can occur only by achieving vine balance through the application of the growth-yield relationship.

Experimental Objectives:

1. Investigate the differences between head and cordon trained single curtain vines. Does training system affect yield, vegetative growth and fruit composition differently?
2. Investigate the impact of nodes retained per vine on yield, vegetative growth and fruit composition.
3. Investigate the advantages of, and limitations to, retention of high node numbers.

Materials and Methods

Plant Material

The experiment was located in southwest Michigan, about five miles east of Lake Michigan. The treatments were established in May 1999 on vines, in Scottdale, Michigan and measurements were taken for five years. The mature, bearing Niagara grapevines were planted in 1974 on a clay loam. The vines were own-rooted and trained initially to a Four Arm Kniffen and pruned to 70-80 nodes. Vine spacing was 2.4m (8 feet) and row spacing was 3m (10 feet). The trellis height was 1.8m (6 feet) from the vineyard floor to the top wire. Vines were trained with double trunks for insurance to avoid devastating circumstances from winter kill.

The pest management program was based on scouting, experience and weather conditions. A combination of fungicides and insecticides (Appendix I; Table 1) used for control were rotated to avoid resistance. Fertilizing consisted of a post-bloom nitrogen application of 66 kg/hectare (60 lbs/acre) in the form of calcium nitrate or ammonium nitrate. In December 333 kg/hectare (300 lbs/acre) of potash was also applied. There was no irrigation system.

Experimental Design and Treatments

The experimental design was a randomized block/split-plot with multiple factors. Individual vines in eight rows were organized in blocks of three vines each, replicated four times. The whole plot factor was node level establishing 20, 40, 80 and 120 nodes retained during winter pruning. The vines were hand pruned in mid-December during the five years of data collection. In the incidence of a frost, bud mortality was assessed within one month after damage.

The subplot factor consisted of three single curtain training systems, HRU, UK and HYB. Two high node treatments, minimally pruned (MP) and hedge (H), represented mechanical pruning approaches and were also included within the pruning treatment (whole plot factor). MP and H vines were high cordon trained. The MP treatment was established by trimming growth at 76cm (30 inches) from the cordon wire. The H treatment was established by removing all growth up to a 15cm (6-inch) radius around the cordon wire.

Experiment I: Included the HRU, UK and HYB training systems of the subplot factor to determine whether there were reproductive, vegetative and fruit compositions differences among vines trained to different single curtain systems.

Experiment II: The whole plot factor was used to determine differences in reproductive, vegetative and fruit compositions among vines pruned to different node levels.

Data Collected

Node Numbers and Vine Size

Nodes retained were counted at the time of winter pruning. Frost injury was assessed on a node basis, in which viability or mortality was noted for the compound, primary and secondary buds. This data was used to estimate the viable buds that remained, which were called Functional Nodes Retained (FNR) (Appendix I; Figure 2).

The weight of dormant cane prunings from each vine was used to express vine size or vegetative growth in a season. Vegetativeness (post-season vine size/nodes retained) was calculated to express the amount of vine growth related to the number of nodes retained.

Leaf Area

Leaf area was estimated at three stages during the growing season: bloom (LA-bloom), 1200 growing degree days (growing degree days are the accumulation of average temperatures above 50°F) (LA-1200) and veraison (LA-Ver). LA-bloom was estimated first by measuring the length of five modal shoots per vine in the field. Fifteen shoots representing different lengths also were collected from the vineyard and taken back to campus for leaf area measurements using a LI-3100 area meter by Li-Cor, inc. (Lincoln, Nebraska). The leaf area of the shoots was plotted against the length of the shoot to acquire a regression and best-fit equation. This equation was used to estimate leaf area per shoot. Leaf area per shoot was multiplied by the shoot number to obtain leaf area per vine. LA-1200 and LA-Ver were estimated by the measured surface area of the vine's canopy (Appendix I; Figure 1) and multiplied by 1.5 photosynthetic leaf layers (Smart and Robinson 1991).

The treatment comparison analysis for this study was based on LA-Ver. Previous work by Miller et al. (1996b) suggested that vines are not source limited prior to veraison, but can become so post-veraison. Therefore, the amount of leaf area from veraison to harvest was deemed crucial to the maturation of fruit as well as to carbohydrate accumulation and storage.

Reproductive Measurements

Yield and cluster number per vine were measured at harvest. Samples of 50 random berries also were collected and weighed at harvest for each treatment. These were used to calculate cluster weight, berry weight and berries per cluster. Fruitfulness (yield/nodes retained) described the amount of fruit an average node produced and is the reciprocal of vegetativeness. Crop load (yield/pre-season vine size) described the ratio of fruit that was carried to the size of vine it was carried on. Productivity (yield/post-season vine size), also called the Ravaz Index, described the ratio of reproductive to vegetative growth that occurred over the season, thereby providing an assessment of vine balance (Howell 2001).

Fruit Composition Measurements

The chemical composition of fruit was analyzed from the 50-count berry sample taken on the day of harvest and frozen for later date of berry analysis. Grape juice soluble solids were measured using a NAR IT Atago (Kirkland, WA) refractometer. Titratable acidity and pH were measured using a 370 Thermo Orion (Beverly, MA) pH meter. Titratable acidity (TA) was measured by titrating juice with 0.1M sodium hydroxide (NaOH) until a pH of 8.2 and using an equation to yield the TA (g/L).

$$TA\ (g/L) = 75 * \text{Molarity of NAOH} * (\text{titre amount (mL)}/\text{volume of sample})$$

Statistical Methods

Comparisons between treatments were made using SAS statistical computer program (SAS Institute, Cary, NC). Single treatment comparisons for experiments I and II were analyzed using Least Significant Differences, with the proc glm function. Means separation was calculated by t-test (Sasha Kravchenko 2002, personal communication). Significance was taken from the type III p-value. Comparisons for experiment II also were analyzed with regression (Howell 2002, personal communication) using Microsoft Excell (USA).

Results and Discussion

Experiment I: Training System Comparison

There were no significant differences between HRU, UK and HYB in the five year average of seasonal measurements (Table 1). Single season data revealed soluble solids in 2000 and 2001 to be the only significant difference among the treatments in five years (Appendix 1; Tables 2 and 3). Alternatively, the remaining years did not follow similar trends and therefore treatment differences can not be concluded. The difference between soluble solids were 0.70 and 0.99 respectively (Appendix 1; Tables 2 and 3), which was not considered culturally significant since the acceptable range of soluble solids is between 12 to 14 °Brix (Howell et al. 1982). Therefore, these training systems were not considered to produce differences in seasonal growth and maturation, this finding is supported by other reports as well (Howell et al. 1991, Wolpert et al. 1983).

As it was mentioned in above, UK requires arching and tying the long canes of each vine. This can result in more time and labor cost, which the grower should consider before choosing to use UK. UK canopies also tend to be more crowded and confined to a smaller area than HRU, which is able to spread growth out horizontally with the use of a cordon. Because the HRU canopy is trained along a cordon and essentially less compact it would appear to have less fungal incidence, due to more air movement and better spray penetration. Because there is no significant vine response differences among the three training systems, a grower should choose a system based on the needs of the vineyard as well as the equipment used on the vineyard.

Experiment II: Node Level Comparison

Nodes Retained: Unlike the comparison of training systems, node levels were significantly different, statistically and culturally when analyzed by mean separation (Table 2). The higher level of significance found in this experiment was expected. Vines are highly responsive to pruning severity (Howell et al. 1987, 1991, Kimball and Shaulis 1958, Morris et al. 1984, Shaulis et al. 1966, Wolpert et al. 1983).

Reproductive Growth: Regression analysis showed interesting relationships. Yield increased as nodes retained increased, but the polynomial curve suggests that the yield increase slowed and stopped increasing beyond 80 nodes retained (Figure 2). The three highest node levels (120, H and MP) did not produce significantly different yields by regression analysis (Figure 3) or mean separation (Table 2). Yield limits have been reported in other studies, where reduced fruitfulness, berries per cluster and berry weight contributed to the limited yield (Kimball and Shaulis 1958, Miller and Howell 1996, 1998, Morris et al. 1984, Smart et al. 1982). Cluster weight (Figure 3) and berry weight (Figure 4) appeared to contribute to yield loss with increased nodes retained.

Increased yield was the result of more clusters per vine as nodes retained increased (Figure 3). Consequently, the positive linear relationship between nodes retained and cluster number per vine did not result in larger yields, due to the negative relationship with cluster weight (Figure 3). The decrease in yield components (cluster and berry weight) was primarily responsible for limiting the yield as node level increased.

Internal canopy shading in less severely pruned vines, like 120, H and MP, can contribute to a yield loss or lack of yield increase (Howell et al. 1987, Morris et al. 1984) seen in fruitfulness, which decreased also as node numbers increased (Figure 5). This suggests that severe canopy shading was occurring (Koblet et al. 1994, May et al. 1969, Petrie 2000a, 200b). Vines with node levels above 80 did not have significantly higher bud fruitfulness (Figure 2) and between 80 and 90 nodes retained the fruitfulness regression leveled off as the relationship between nodes retained and fruitfulness diminished.

Vegetative Growth: As seen in previous studies, vine size decreased as nodes retained increased (Figure 6) (Howell et al. 1987, 1991, Morris et al. 1984). Vine size also was significantly different in the means separation (Table 2). This relationship was most likely due to within vine competition and partitioning of limited carbohydrates. Vine size was not used to express the vegetative growth of MP and H vines because the amount of growth removed at pruning is minimal and is not a fair representation of the vine growth that season. Leaf area per vine was more appropriate.

Regression analysis showed LA-Ver increased linearly as nodes retained increased (Figure 7). Though leaf area was not shown to increase greatly, it must be remembered that this measurement does not represent the total foliar canopy beyond 1.5 layers. Four to five leaf layers have been observed in Niagara vines possessing high node numbers (Howell 2004, personal communication). In this situation, the ratio of total leaf area:canopy surface area well exceeds the recommended value of less than 1:5 (total leaf area:canopy surface area) (Smart and Robinson 1991).

Fruit Composition: Soluble solids decreased as nodes retained increased (Figure 8), also losing the relationship and leveling off at 80 nodes retained. This helps to show the strong influence of yield on soluble solids. Sugar accumulation at all node levels was above or within processor standards, 12-14 °Brix. Between 12-14 °Brix, Niagara juice has balanced sugar and acid (Howell et al. 1982). It is a possibility that the vines with higher soluble solids (20 and 40 nodes retained) had fruit ripened earlier in the season. Due to processing deadlines to juice Niagara fruit prior to Concord, early ripening could expand the processing window and benefit both grower and processor.

Overall H vines were able to produce the most sugar per vine (Table 2). This was due to the high yield and soluble solids within a "quality" range (12-14 °Brix).

Conclusions

Cordon (HRU), head trained (UK) and HYB vines produced similar vegetative and reproductive growth. Understanding this can help the grower to make training system decisions based on the "best fit" for their operation. Node levels above 80 fixed nodes tend to decrease valuable yield components like cluster and berry weight, but most importantly did not increase yield. Yield limitations above 80 nodes retained can be attributed to a decrease in cluster and berry weight as well as decreased bud fruitfulness. Decreased fruitfulness was probably a result of crowding and shading in the canopy. Unfortunately, leaf layers within the canopy were not estimated. Without this information, only speculative conclusions can be made concerning the negative effects of multiple leaf layers.

Although yield components, vine size and fruitfulness are all exceptional at 40 and 20 nodes retained, these node levels produce unacceptably low yields. At 80 nodes retained, the vine appears to be reproductively efficient, while maintaining sufficient fruit maturity and leaf area. I speculated that vines pruned above 80 nodes retained could be wasting carbohydrates to support a crowded, shaded canopy.

Literature Cited

Bailey, L.H. 1917. Vitis. *In* Volume Six of The Standard Cyclopedia of Horticulture. pp. 3481-3492.. The Macmillan Company, New York.

Gladstone. J.S. 1992. Viticulture and Environment. Wine Titles Adelaide, Australia.

Howell, G.S. 2001. Sustainable grape productivity and the growth-yield relationship: A review. Am. J. Enol. Vitic. 52:165-174.

Howell, G.S., T.K. Mansfield, and J.A. Wolpert. 1987. Influence of training system, pruning severity and thinning on yield, vine size and fruit quality of Vidal blanc grapevines. Am. J. Enol. Vitic. 38:105-112.

Howell, G.S., D.P. Miller, C.E. Edson, and R.K. Striegler. 1991. Influence of training system and pruning severity on yield, vine size and fruit composition of Vignoles grapevines. Am. J. Enol. Vitic. 42:191-198.

Howell, G.S., J.A. Wolpert, and T.K. Mansfield. 1982. Pruning Niagara grapevines for top yields and quality fruit. *In* Proceedings for the Michigan Grape Society. 4:1-23.

Kimball, K. and N. Shaulis. 1958. Pruning effects on the growth, yield, and maturity of Concord grapes. J. Am. Soc. Hortic. Sci. 71:167-176.

Koblet, W., M. Carmo Candolfi-Vasconcelos, W. Zweifel, and G.S. Howell. 1994. Influence of leaf removal, rootstock and training system on yield and fruit composition of Pinot Noir grapevines. Am. J. Enol. Vitic. 45:181-187.

May, P., N.J. Shaulis, and A.J. Antcliff. 1969. The effect of controlled defoliation in the Sultana vine. Am. J. Enol. Vitic. 20:237-250.

Miller, D.P. and G.S. Howell. 1996. Influence of vine capacity and crop load on the yield, fruit composition and sugar production per unit land area of Concord grapevines. *In* Proceedings for the Forth International Symposium on Cool Climate Enology and Viticulture. T. Henick-Kling et al.. (Eds.), pp. 94-98. N.Y. State Agricultural Experiment Station, Geneva, NY.

Miller, D.P. and G.S. Howell. 1998. Influence of vine capacity and crop load on canopy development, morphology and dry matter partitioning in Concord grapevines. Am. J. Enol. Vitic. 49:183-190.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996a. Effect of shoot number on potted grapevines: I. Canopy development and morphology. Am. J. Enol. Vitic. 47:244-250.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996b. Influence of shoot number and crop load on potted Chambourcin grapevines. I. Morphology and dry matter Partitioning. Am. J. Enol. Vitic. 47:380-388.

Miller, D.P., G.S. Howell, and R.K. Striegler. 1993. Reproductive and vegetative response of mature grapevines subjected to differential cropping stress. Am. J. Enol. Vitic. 44:435-440.

Morris, J.R. and D.L. Cawthon. 1980. Yield and quality response of 'Concord' grapes to training systems and pruning severity in Arkansas. J. Amer. Soc. Hort. Sci. 105(3):307-310.

Morris, J.R., D.L. Cawthon, and C.A. Sims. 1984. Long-term effects of pruning severity, nodes per bear unit, training system, and shoot positioning on yield and quality of 'Concord' grapes. J. Amer. Soc. Hort. Sci. 109(5):676-683.

Partridge, N.L. 1921. A note on the fruiting habit of the Concord grape. Proc. Amer. Soc. Hort. Sci. 18:193-196.

Partridge, N.L. 1925. Growth and yield of Concord grape vines. Proc. Amer. Soc. Hort. Sci. 22:84-87.

Petrie, P.R., M.C.Trought and G.S. Howell. 2000a. Growth and dry matter partitioning of Pinot noir (*Vitis vinifera L.*) in relation to leaf area and crop load. Austr. J. Grape and Wine Res. 6:40-45.

Petrie, P.R., M.C.Trought and G.S. Howell. 2000b. Fruit composition and ripening of Pinot noir (*Vitis vinifera L.*) in relation to leaf area. Austr. J. Grape and Wine Res. 6:46-51.

Ravaz, M.L. 1911. L effeuellage de la vigne. Annales L Ecole Nationale agriculture de Montpellier. 11:216-244.

Shaulis, N.J., T.D. Jordan, and J. P.Tomkins. 1966. Cultural practices for New York vineyards. Cornell Extension. Bulletin 805.

Shaulis, N.J. and W.B. Robinson. 1953. The effects of season, pruning severity, and trellising on some chemical characteristics of Concord and Fredonia grape juice. Proc. Am. Soc. Hort. Sci. 62:214-220.

Shaulis, N.J. and R. Smart. 1974. Grapevine canopies: Management, microclimate and yield responses. *In* Proceedings for the 19th International Horticultural Congress. pp. 256-262. Warszawa, Poland.

Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. Am. J. Enol. Vitic. 36:230-239.

Smart. R.E. and M. Robinson. 1991. Sunlight into Wine. Winetitles, Adelaide.

Smart, R.E., N.J. Shaulis and E.R. Lemon. 1982. The effect of Concord vineyard microclimate on yield. II. The interrelations between microclimate and yield expression. Am. J. Enol. Vitic. 33:109-116.

Winkler, A.J. 1954. Effects of overcropping. Amer. J. Enol. Viticult. 5:4-12.

Wolpert, J.A., G.S. Howell and T.K. Mansfield. 1983. Sampling Vidal blanc grapes. I. Effect of training system, pruning severity, shoot exposure, shoot origin, and cluster thinning on cluster weight and fruit quality. Am. J. Enol. Vitic. 34:72-7.

Table 1: Training System Treatments: Reproductive, vegetative and fruit composition measurements and calculations of Niagara grapevines averaged over 1999-2003. Training system treatments were also subjected to node level treatments (20, 40, 80 and 120). The data here represents the effects of training system on Niagara vines in southwest, MI regardless of node level.

Key:

U: Nodes Retained = number of nodes per vine established during dormant pruning.

V: Vine Size = weight of dormant cane prunings per vine.

W: Productivity = yield [kg]/post-season vine size [kg].

X: Fruitfulness = yield [kg]/nodes retained.

Y: Leaf Area Ver. = leaf area at veraison was used to estimate a component of vegetative growth. The amount of leaf area at veraison is important because at this stage the vine is most source limited (Miller et al. 1996b).

Z: LA/Fruit = leaf area per gram of fruit expresses a ratio of vegetative to reproductive growth. In Michigan ~11-14 cm^2/g is optimum (Miller and Howell 1996)

Table 1.

Parameters Measured or Calculated	Training System			
	UK	HRU	HYB	P-value
Nodes Retained[U]	55	54	55	NS
Vine Size (kg)[V]	1.03	1.1	0.99	NS
Yield (kg/vine)	11.2	10.43	11.29	NS
Yield (t/a)	6.73	6.27	6.79	NS
Yield (mt/h)	15.09	14.06	15.22	NS
Clusters/ Vine	116	105	108	NS
Cluster Wt. (g)	108	108	109	NS
Berry Wt. (g)	3.58	3.59	3.6	NS
Berries/ Cluster	30	30	30	NS
SS (°Brix)	14.6	14.5	14.6	NS
Sugar/Vine (kg)	1.55	1.45	1.57	NS
pH	3.31	3.35	3.33	NS
Titratable Acidity (g/L)	6.4	6.42	3.93	NS
Productivity (kg)[W]	23.88	23.82	25.89	NS
Fruitfulness (kg/node)[X]	0.24	0.23	0.25	NS
Leaf Area Ver (m^2)[Y]	10.0	10.7	10.5	NS
LA/Fruit (cm^2/g)[Z]	9.01	10.22	9.31	NS

Table 2: Node Level Treatments: Reproductive, vegetative and fruit composition measurements and calculations of Niagara grapevines averaged over 1999-2003. Node Level treatments were also subjected to training system treatments (HRU, UK and HYB). The data here represents the effects of Node Level or Nodes Retained on Niagara vines in southwest, MI regardless of training system.

Key:

U: **Nodes Retained (NR)** = Number of nodes per vine established during dormant pruning

V: **Vine Size** = Weight of dormant cane prunings per vine

W: **Productivity** = yield [kg]/post-season vine size [kg]

X: **Fruitfulness** = yield [kg]/nodes retained

Y: **Leaf Area Ver.** = leaf area at veraison was used to estimate vegetative growth. The amount of leaf area at veraison is important because it is at this stage the vine is most source limited (Miller et al 1996).

Z: **LA/Fruit** = Leaf are per gram of fruit expresses a ratio of vegetative to reproductive growth. In Michigan ~11-14 cm^2/g (Miller and Howell 1996) is optimum.

Table 2.

Parameters Measured or Calculated	Node Level						
	20	40	80	120	Hedge (12" radius)	MP	P-value
Nodes Retained[U]	19 f	38 e	70 d	92 c	99 b	117 a	0.0001
Vine Size (kg)[V]	1.45 a	1.30 b	0.80 c	0.62 d	---	---	0.0001
Yield (kg/vine)	6.14 d	8.95 c	13.73 b	15.07 ab	15.42 a	14.59 ab	0.0001
Yield (t/a)	3.69 d	5.38 c	8.25 b	9.06 ab	9.27 a	8.77 ab	0.0001
Yield (mt/h)	8.27 d	12.06 c	18.49 b	20.31 ab	20.78 a	19.66 ab	0.0001
Clusters/ Vine	57 d	93 c	134 b	155 a	155 a	166 a	0.0001
Cluster Wt. (g)	113	109	108	104	105	99	NS
Berry Wt. (g)	3.74 a	3.71 a	3.55 b	3.36 cd	3.49 bc	3.28 d	0.0001
Berries/ Cluster	30	29	30	30	30	29	NS
SS (°Brix)	15.62 a	15.04 b	13.82 c	13.79 c	13.54 c	13.71 c	0.0001
Sugar/Vine (kg)	0.94 d	1.32 c	1.84 b	1.99 ab	2.01 a	1.93 ab	0.0001
pH	3.35 ab	3.38 a	3.31 bc	3.29 c	3.27 c	3.27 c	0.0001
Titratable Acidity (g/L)	6.35	6.47	6.41	6.27	6.39	6.19	NS
Productivity (kg)[W]	5.93 d	11.28 d	30.11 c	50.80 b	53.66 b	66.83 a	0.0001
Fruitfulness (kg/node)[X]	0.34 a	0.23 b	0.20 bc	0.17 cd	0.18 cd	0.15 d	0.0001
Leaf Area Ver (m^2)[Y]	9.0 b	10.3 ab	11.0 ab	11.2 ab	10.8 ab	12.1 a	0.0029
LA/Fruit (cm^2/g)[Z]	20.33 a	15.66 b	10.77 c	10.22 c	9.97 c	11.56 c	0.0001

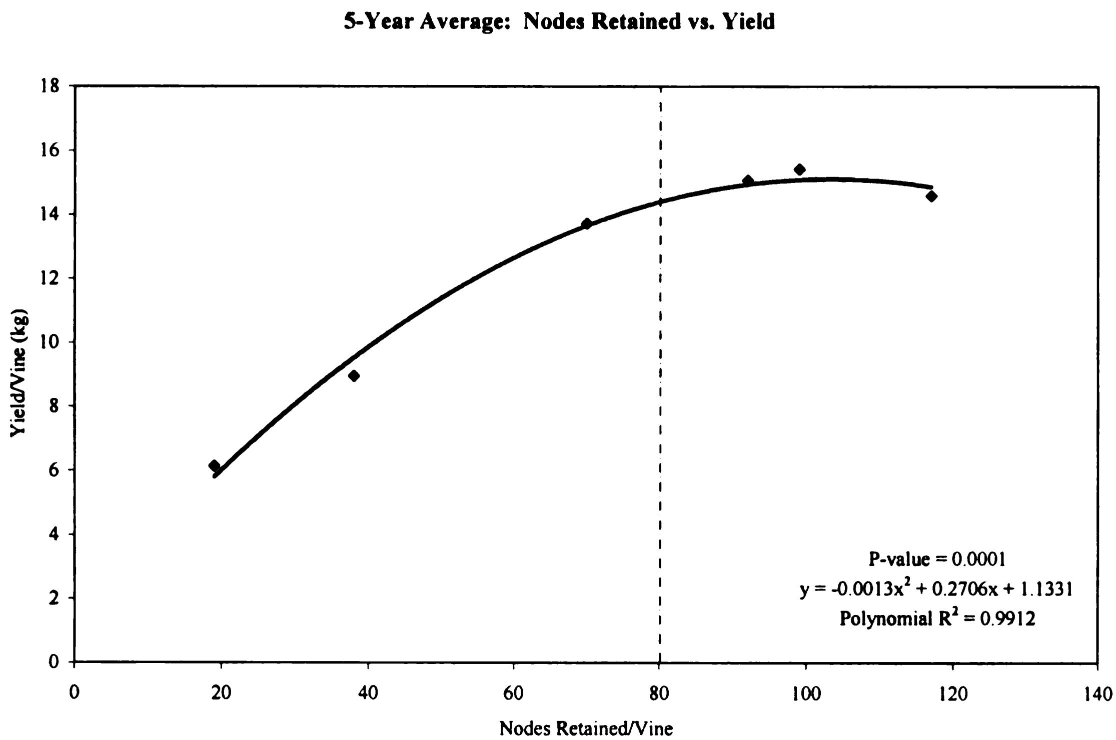


Figure 2. Average yield (1999-2003) for different node level treatments established during winter pruning. The retention of nodes above 80 does not result in statistically significant greater yields.

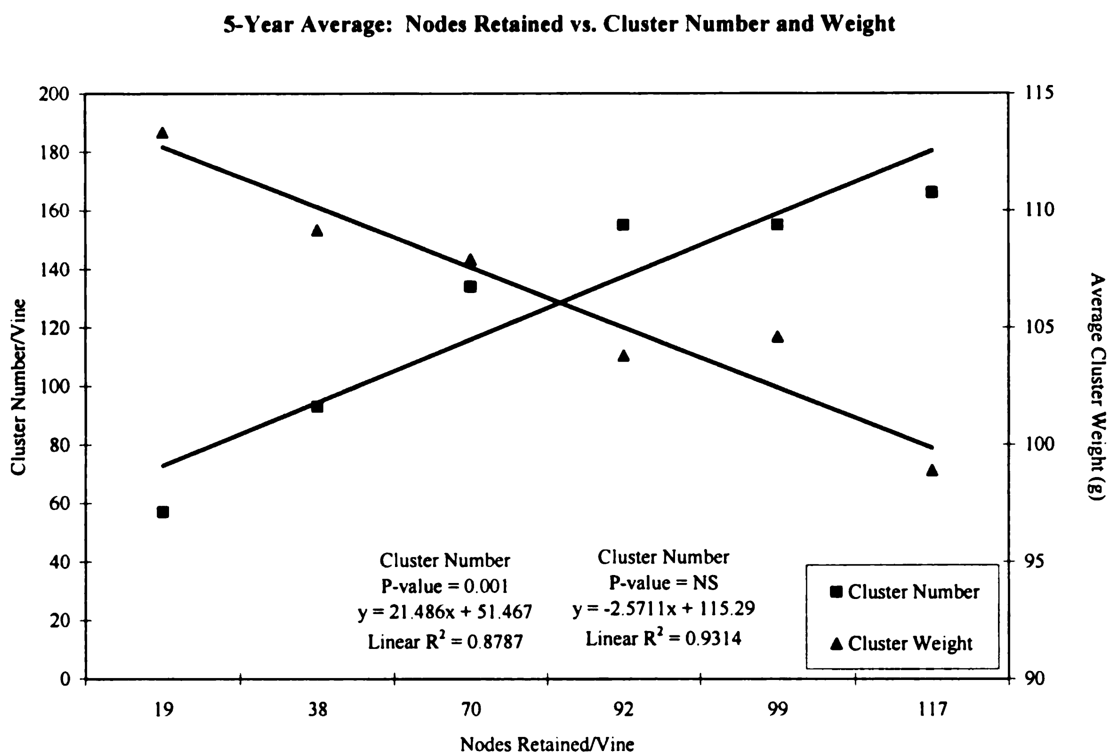


Figure 3. Average clusters per vine and average cluster weight (1999-2003) for different node level treatments established during winter pruning. Cluster number and cluster weight are negatively related. Cluster weight was not statistically significant according to mean separation (P-value=NS), but through regression it is (R^2=0.9314).

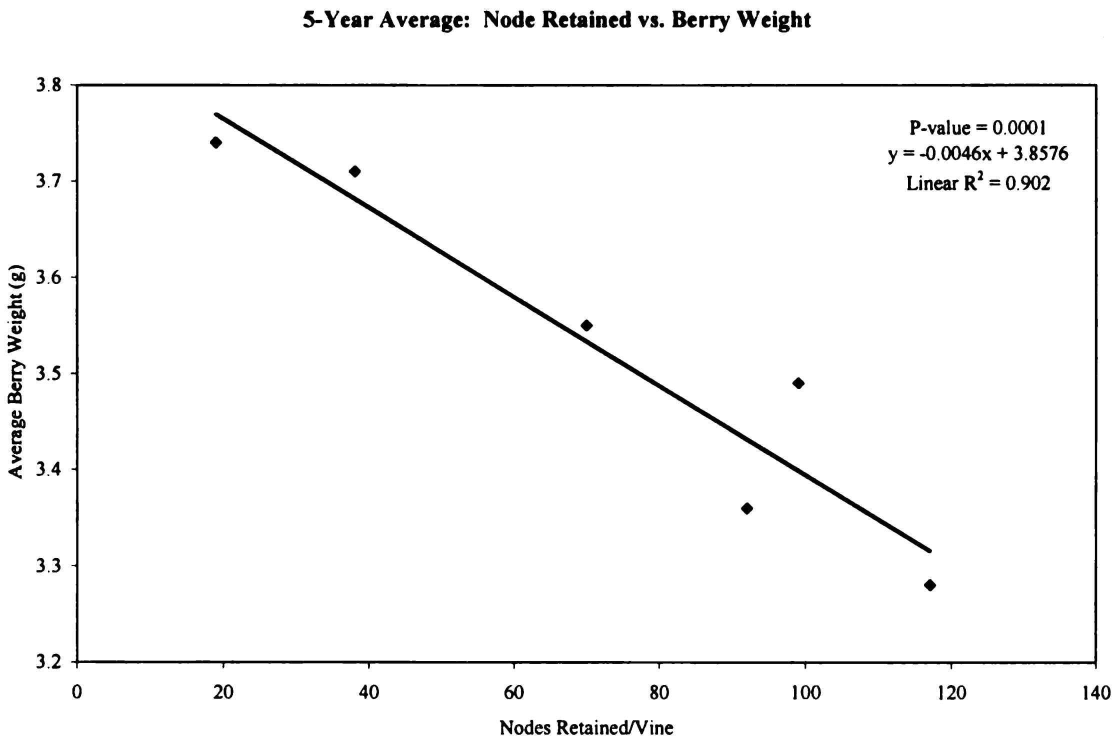


Figure 4. Average berry weight (1999-2003) for different node level treatments established during winter pruning. The loss of berry weight as more nodes are retained directly contributed to loss of cluster weight (Figure 3).

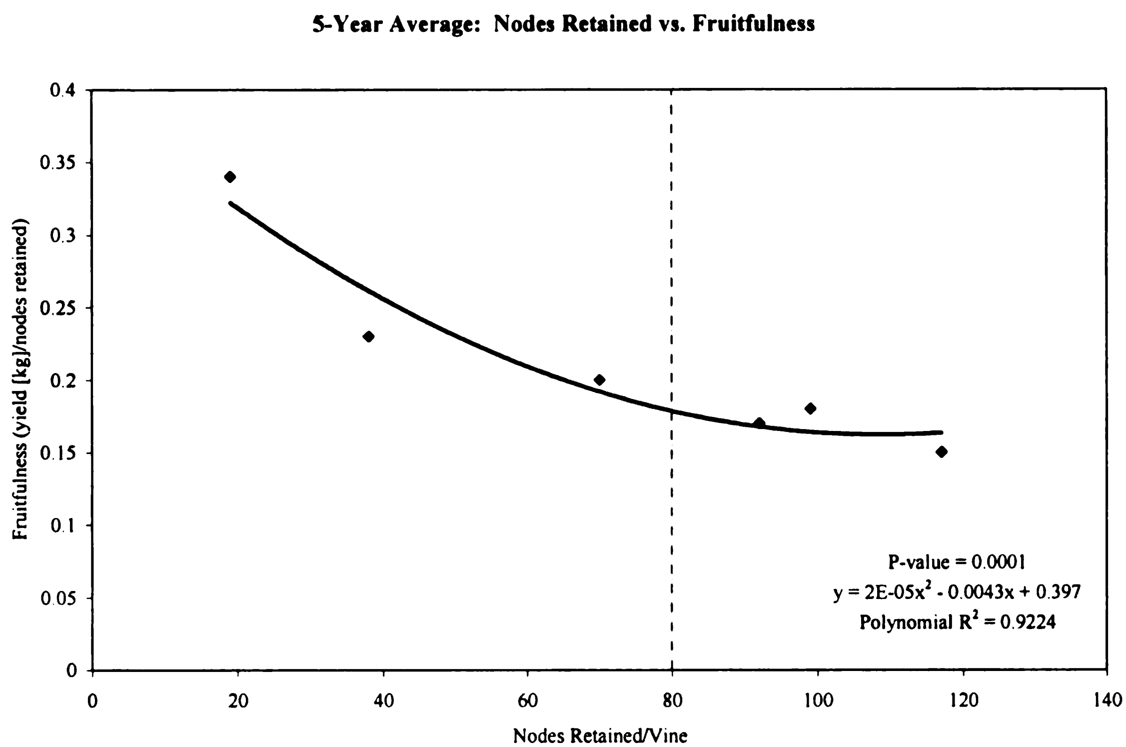


Figure 5. Average node fruitfulness (1999-2003) for different node level treatments established during winter pruning. The relationship starts to diminish above 80 nodes retained.

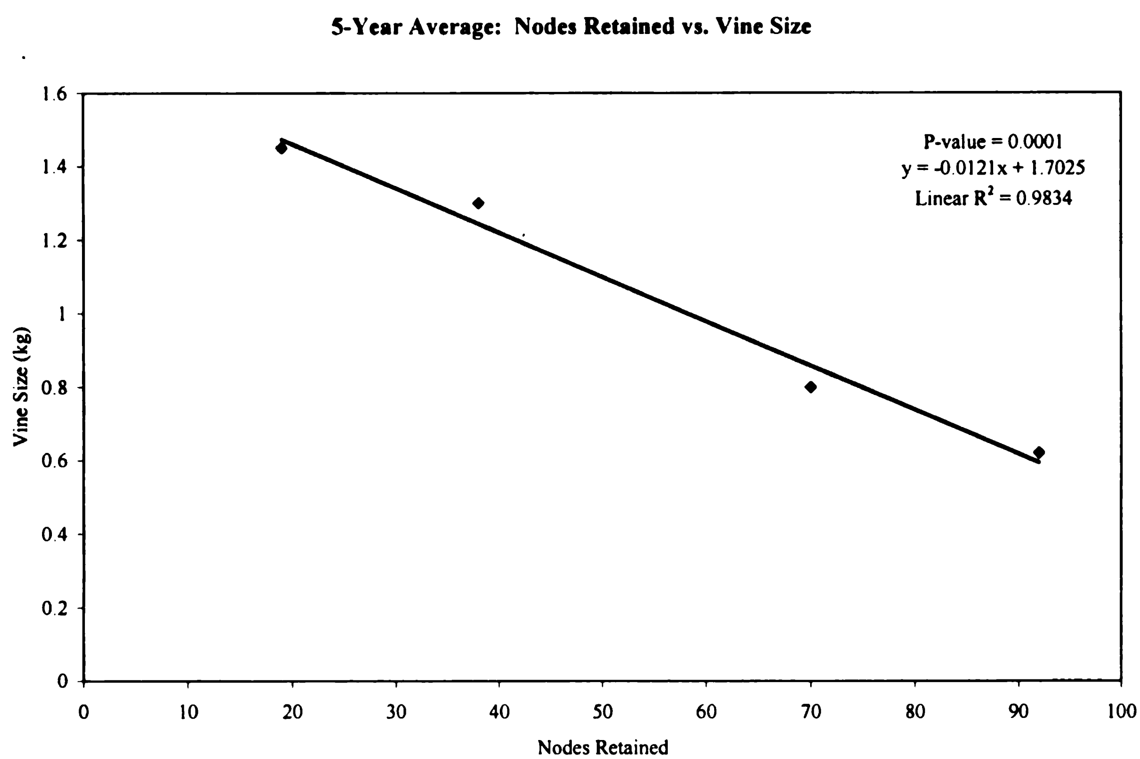


Figure 6. Average vine size (1999-2003) for different node level treatments established during winter pruning. Vine size was measured using dormant cane prunings.

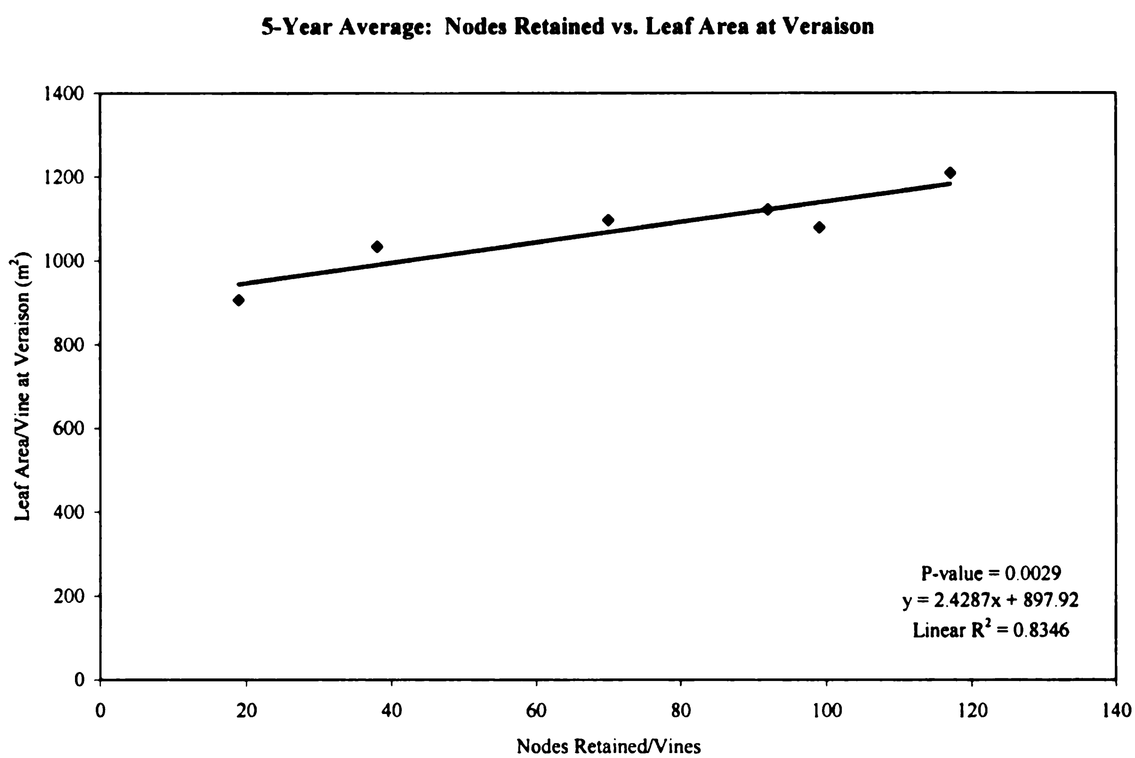


Figure 7. Average leaf area at veraison (1999-2003) for different node level treatments established during winter pruning. Leaf area at veraison was used because it is at this time the vine is source limited (Miller et al. 1996).

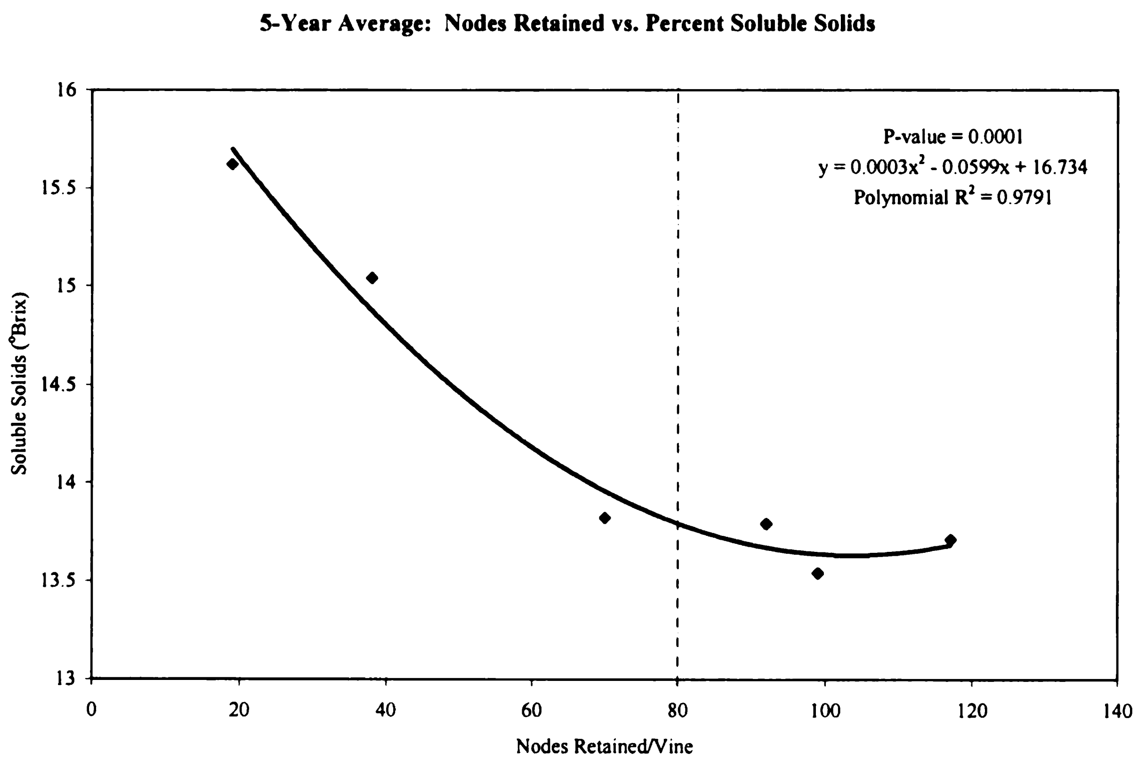


Figure 8. Average soluble solids (1999-2003) for different node level treatments established during winter pruning. The relationship starts to diminish above 80 nodes retained.

CHAPTER III:

COMPARISON OF SINGLE AND DIVIDED CANOPY TRAINED NIAGARA GRAPEVINES WITH REGARD TO SUSTAINABLE YIELD, FRUIT COMPOSITION AND VEGETATIVE GROWTH

Abstract

Niagara grapevines (*Vitis labruscana* B.) were subjected to Single Curtain (SC) and Geneva Double Curtain (GDC) training systems. Vines were also pruned to node level treatments. Over the course of five years, reproductive, vegetative and fruit composition measurements were taken. Regression analysis and means separation suggested differences in the effects of nodes retained on SC and GDC systems. Both systems were evaluated on a per vine and per meter of cordon/canopy basis. Yield and cluster number/vine had positive linear relationships with nodes retained on GDC trained vines. SC vines have positive relationships as well, but curved (polynomial and logarithmic) relationships. This suggests that the yield/vine limit was met at 92 nodes retained for vines trained to SC and not met on to GDC vines. When considering yield data per meter of cordon length, both yield and cluster number of GDC vines does not increase as rapidly as on SC vines. Leaf area/vine also increased with nodes retained; the relationship for GDC trained vines was polynomial, while the relationship for SC vines was linear. On an average GDC produced more surface leaf area per node than SC. However, leaf area/meter cordon was essentially half that of SC, suggesting that with leaf area spread over twice the canopy, shoot crowding and shading could be alleviated. SC vines were able to accumulate more percent soluble solids per node than GDC. Overall, vines did benefit from GDC training, but did not reach full potential due to lack of vigor.

Introduction

The Niagara grape (*Vitis labruscana* B.) (Bailey 1917) is not new to the grape juice industry. However, there is limited information concerning growing practices specific to the cultivar. The practices that have been used thus far are those that are appropriate for Concord (Mansfield and Howell 1981, Miller and Howell 1996, Miller et al. 1993, Shaulis et al. 1966a, 1966b, 1973, Smart et al. 1982a, 1982b, Stergios and Howell 1977). Though similar to Concord, Niagara is less cold hardy (Hedrick 1908, Howell et al. 1982). Therefore, assessment of how to balance vegetative and reproductive growth to ensure high yields, vine health and vine longevity is critical. Such important issues include nodes retained at pruning, training system and optimal distribution of leaf area to sunlight (Howell 2003, Smart and Robinson 1991).

Training Systems: Niagara is commonly trained to single curtain systems, such as the Hudson River Umbrella (HRU) (Figure 1 in Chapter 1) or the Umbrella Kniffen (UK) (Figure 2 in Chapter 1). The HRU retains spurs (~ 2 nodes) and canes (~ 8 nodes). The UK head system retains several spurs at the head and long canes (~ 15 nodes).

Niagara also may be trained to a divided canopy cordon system called Geneva Double Curtain (GDC) (Figure 3 in Chapter 1). The vine is divided horizontally by two trunks from which two cordons 2.4 m (8 feet) long arrive, creating a canopy twice in length, 4.8 m (16 feet) long. GDC training retains 2-node spurs and 5-node canes (Shaulis et al. 1966b). Twice the length of cordon per row alleviates shoot crowding and shading by spreading growth over two curtains as opposed to one (Shaulis 1966c, Shaulis and Shepardson 1965).

All three systems support the vine at the top wire (~1.8 m) while allowing it to grow with the natural recumbent habit. Because *V. labruscana* B. vines are less fruitful at basal nodes (Pool et al. 1997), a training system that retains canes with 5 to 15 nodes maybe advantageous to yielding a sufficient crop on Niagara vines.

Vine Growth: High vigor, as well as large individual leaves, are characteristic of Niagara (Howell 2003) and can lead to several limitations: a) a tendency for many leaf layers, b) reduced photosynthesis of shaded leaves, c) delayed fruit maturity and d) reduced bud fruitfulness. Smart and Robinson (1991) suggest that ~1.5 leaf layers of a canopy are sufficient for photosynthesis. Howell and Trought (2001 unpublished data) observed interior leaves acting as sinks rather than sources due to shading and crowding. Reduced shoot crowding improves canopy light distribution and photosynthesis, thereby allowing more crop to be carried without a detrimental impact on fruit composition (Morris and Cawthon 1980a, 1980b, Morris et al. 1984, Shaulis et al. 1966b, Shaulis and Shepardson 1965, Shaulis and Smart 1974).

Vines that produce more than 0.6 kg of pruning weight per meter (0.4 lbs/foot) of row may be overly vigorous (Howell 2003). GDC training may balance such vigorous vines (Morris et al. 1980a, 1980b, Shaulis et al. 1966a, 1966b). Vine balance is achieved when vegetative and reproductive growth are in equilibrium and support high fruit quality (Gladstone 1992). Miller et al. (1996b) suggested that maximum dry matter production can be gained with a balance between sink and source strength. Ravaz (1911) initially introduced the concept of vine balance by relating the fruit yield and shoot growth of a season. The ratio was called the Ravaz Index. Later, Partridge (1921, 1925a, 1925c) established the growth-yield relationship, which relates the vine growth of the previous season to the amount of fruit the vine can successfully carry during the current season.

A training system should complement not only the cultivar growth habit, but also the vine growth influenced by the environment (Howell 2003, Kimball and Shaulis 1958, Shaulis et al. 1966b, 1966c), if highest sustainable yields are to be achieved. Howell (2001) relates sustainability to viticulture as, "collective methodology that produces highest yields of ripe fruit per unit land area with no reduction in vegetative growth, and does so over a period of years at costs which return a net profit." That philosophy was the cornerstone of the efforts reported here.

Experimental Objective:

1. Investigate the reproductive, vegetative and fruit composition differences between single and divided canopy systems.

Materials and Methods

Plant Material

The experiment was established at two locations in Southwest Michigan. At the Scottdale location treatments were established in May 1999, 5 miles east of Lake Michigan. The mature, bearing Niagara grapevines where planted in 1974 on clay loam. The vines were own-rooted, trained initially to a Four Arm Kniffen and pruned to 70-80 nodes. At the second location, Michigan State University's Southwest Michigan Research and Education Center (SWMREC), treatments were established in the winter of

1996, on six-year-old, own-rooted vines. The vines where planted in Spinks sandy loam soil, and trained initially to a GDC system and pruned to about 65 nodes. SWMREC is located about 7 miles east of Lake Michigan. At both locations vine spacing was 2.4m (8 feet) and row spacing was 3m (10 feet). The trellis height was 1.8m (6 feet) from the vineyard floor to the top wire. Vines were trained with double trunks for insurance to avoid devastating circumstances from winter kill.

The pest management program at both locations was based on scouting, experience and weather conditions. A combination of fungicides and insecticides (Appendix I, Table 1) used for control were rotated to avoid resistance. Fertilizing consisted of a post-bloom nitrogen application of 66 kg/hectare (60 lbs/acre) in the form of calcium nitrate or ammonium nitrate. In December 333 kg/hectare (300 lbs/acre) of potash was also applied at the Scottdale location. Vines at neither location were irrigated.

Single Canopy Vines

The Scottdale location was the site of the single canopy (SC) treatments. It was designed as a randomized block/split-plot with multiple factors (training system and node level). Individual vines from eight rows were placed in blocks of three and replicated four times. The whole plot factor was a pruning treatment establishing 20, 40, 80 and 120 fixed nodes retained along with hedge (H) and minimally pruned (MP) treatments.

H and MP were simulated mechanically pruned treatments, trained to a basic high cordon.. The MP treatment was established by trimming shoot growth at 76 cm (30 inches) from the cordon wire. The H treatment was established by trimming growth up to a 15 cm (6 inch) radius around the cordon wire.

Geneva Double Curtain Vines

The SWMREC location was the site of the GDC training system. This site had a completely randomized block design, with node level treatments as the variable. Four rows of vines established four replications, where each row contained all five node levels. Pruning was conducted during mid-December and treatments of 20+20 balance pruned, 35 fixed nodes, 70 fixed nodes, 105 fixed nodes, MP and H were applied at this time. Here, MP and H where obtained by using the same protocol as above for the SC plot.

Data Collected

Node Numbers and Vine Size

Nodes retained were counted at the time of winter pruning. Frost injury was assessed on a node basis, in which viability or mortality was noted for the compound, primary and secondary buds. This data was used to estimate the viable buds that remained, which were called Functional Nodes Retained (FNR) (Appendix I; Figure 2).

The weight of dormant cane prunings from each vine was used to express vine size or vegetative growth in a season. Vegetativeness (post-season vine size/nodes retained) was calculated to express the amount of vine growth related to the number of nodes retained.

Leaf Area

Leaf area was estimated at three stages during the growing season: bloom (LA-bloom), 1200 growing degree days (growing degree days are the accumulation of average temperatures above 50˚F) (LA-1200) and veraison (LA-Ver). LA-bloom was estimated first by measuring the length of five modal shoots per vine in the field. Fifteen shoots representing different lengths also were collected from the vineyard and taken back to campus for leaf area measurements using a LI-3100 area meter by Li-Cor, inc. (Lincoln, Nebraska). The leaf area of the shoots was plotted against the length of the shoot to acquire a regression and best-fit equation. This equation was used to estimate leaf area per shoot. Leaf area per shoot was multiplied by the shoot number to obtain leaf area per vine. LA-1200 and LA-Ver were estimated by the measured surface area of the vine's canopy (Appendix I; Figure 1) and multiplied by 1.5 photosynthetic leaf layers (Smart and Robinson 1991).

The treatment comparison analysis for this study was based on LA-Ver. Previous work by Miller et al. (1996b) suggested that vines are not source limited prior to veraison, but can become so post-veraison. Therefore, the amount of leaf area from veraison to harvest was deemed crucial to the maturation of fruit as well as to carbohydrate accumulation and storage.

Reproductive Measurements

Yield and cluster number per vine were measured at harvest. Samples of 50 random berries also were collected and weighed at harvest for each treatment. These were used to calculate cluster weight, berry weight and berries per cluster. Fruitfulness (yield/nodes retained) described the average amount of fruit produced per node and is the reciprocal of vegetativeness. Crop load (yield/pre-season vine size) described the ratio of fruit that was carried to the size of vine it was carried on. Productivity (yield/post-season vine size), also called the Ravaz Index, described the ratio of reproductive to vegetative growth that occurred over the season, thereby providing an assessment of vine balance (Howell 2001).

Fruit Composition Measurements

The chemical composition of fruit was analyzed from the 50-count berry sample taken on the day of harvest and frozen for later date of berry analysis. Grape juice soluble solids were measured using a NAR IT Atago (Kirkland, WA) refractometer. Titratable acidity and pH were measured using a 370 Thermo Orion (Beverly, MA) pH meter. Titratable acidity (TA) was measured by titrating juice with 0.1M sodium hydroxide (NaOH) until a pH of 8.2 and using an equation to yield the TA (g/L).

TA (g/L) = 75 * Molarity of NAOH * (titre amount (mL)/volume of sample)

Statistical Methods

Comparisons between treatments were made using SAS statistical computer program (SAS Institute, Cary, NC). Single treatment comparisons were analyzed using Least Significant Differences and the proc glm function, with means separation calculated by t-test (Sasha Kravchenko 2002, personal communication). Significance was taken from the type III p-value. Comparisons also were analyzed with regression using Microsoft Excell (Howell 2002, personal communication).

Results and Discussion

The differences between SC and GDC were shown in the growth trends displayed through regression analysis (Figures 1-15) and mean separations (Table 1-4) both presented on a per vine and per meter of cordon basis.

Reproductive Comparison of Single and Double Canopy Training Systems Pruned to Different Node Levels

Yield: On a per vine basis GDC had linear reproductive growth, while growth for SC systems was expressed best by a polynomial curve (Figure 1). Regression suggests that yield on SC vines was limited and would not continue to increase with more nodes retained per vine (Figure 1). At 92 nodes retained, yield of SC vines ceased to increase. By contrast, GDC displayed an increasing linear trend that suggests further increase in yield as more nodes were retained (Figure 1). The increased yield of GDC training is in agreement with other studies on Concord (Morris and Cawthon 1980b, Shaulis et al. 1966b) and hybrids (Morris et al. 1984).

When looking at the two training systems and their measurements per meter of cordon the results change. Up to the 80 nodes retained on the SC vines the trend is essentially linear like the GDC trend (Figure 2). However, the GDC vines have a much slower increase in yield (Figure 2), which could be attributed to more energy cost for extra perennial wood. It is possible that these vines did not have enough vigor, as estimated by vine size, to support a double canopy system. This suggests that the SC vines at this plot were able to produce more fruit per meter of cordon. However, the SC yield trend remains curved, which again suggests that no further increase in yield will occur with more than 36 nodes per meter of cordon.

Cluster Number: Cluster number increased similarly to yield, in both training systems (Figure 3). Cluster number increased as a logarithmic curve in SC vines, which suggested cluster number, like yield, would cease to increase with the retention of more nodes. This correlation is not unexpected, studies have shown that cluster number is highly related to yield (Edson et al. 1993, Miller and Howell 1996). GDC continued a similar trend to yield as well, where clusters per vine increased linearly with the retention of more nodes retained, suggesting that the upper limit of nodes retained was not achieved in this experiment (Figure 3). If it had been, yield and cluster number regressions should have leveled off. Similar increases in cluster number on GDC trained vines were found in studies on Concord (Morris and Cawthon 1980b, Shaulis et al. 1966a).

However when looking at cluster number per meter of cordon (Figure 4), GDC vines produce fewer clusters than SC trained vines. Again this suggests that reproductive growth of these Niagara vines was being limited by the metabolic cost of maintaining perennial wood and the full potential of the GDC system was not achieved.

Yield Components: Though both training systems (SC and GDC) had different reproductive trends, they both increased in yield and cluster number as nodes retained increased. SC and GDC also had decreased cluster and berry weight as more nodes were retained (Figures 5 and 6). The decrease of cluster and berry weight with increasing nodes retained may have contributed to the decreased fruitfulness found in SC and GDC training (Figure 7 and 8), which can be attributed to increased canopy shading and sink competition as more nodes are retained (Koblet et al. 1994, May et al. 1969, Petrie 2000a, 2000b).

Though bud fruitfulness (yield [kg]/nodes retained) decreased with increasing node levels on a per vine basis as well as per meter of cordon, the two situations express very different results. When considering fruitfulness per vine both systems have nearly identical trend lines (Figure 7). Alternatively, when considering fruitfulness per meter of cordon the GDC trained vines have a much lower fruitfulness at every node level (Figure 8). Lower fruitfulness in GDC vines could be due to crop being spread over twice the amount of canopy and therefore reducing fruitfulness on the account of less fruit per unit of cordon. In this case the vine should be able to produce more fruit to increase fruitfulness, because this is not the case there is reason to speculate that these vines did not hold the vigor necessary to gain full production potential with GDC.

Vegetative Comparison of Single and Double Canopy Training Systems Pruned to Different Node Levels

Vine Size: The vegetative growth trends were the opposite of reproductive trends for SC and GDC. GDC had curved trend lines (polynomial), while SC was expressed with linear trend lines. Both SC and GDC decreased in vine size as nodes retained increased (Figure 9). GDC vine size decreased with a polynomial trend line, suggesting that vine size levels off and does not continue to decrease above 61 nodes retained (Figure 9). On the other hand, the negative linear relationship of nodes retained and vine size for SC vines suggested that vine size would continue to decrease as nodes retained increased (Figure 9). Morris and Cawthon (1980b) also found that GDC training could increase vine size at different pruning levels.

When looking at the vine size per meter of cordon it is apparent that GDC produces less vegetative growth (Figure 10). This is not surprising, since growth is spread over twice that of the SC vines. General observations suggest that the shoots did not grow as long on the GDC vines as they did on the SC vines (data not shown).

Leaf Area: Both training systems had increasing leaf area with increasing nodes retained, but again GDC vines had half the leaf area as the SC vines (Figures 11 and 12). This was most likely a response to twice the length of cordon to spread growth among on GDC training. Though both systems did not reach maximum leaf area, the regressions suggest that with node number increases the SC canopy would continue to increase larger, than the GDC. Spreading leaf area over twice as much canopy space has proved to limit vigor, which can reduce shading and over crowding (Morris et al. 1984, Shaulis et al. 1966a, 1966b, Smart et al. 1982b).

Vegetative support for fruit can be analyzed by looking at the leaf area to fruit weight ratio. Smart and Robinson (1991) suggest that ~12cm^2 per gram of fruit weight is able to sustain the vine and ripen fruit. The data from this study shows that GDC (Table 1) was able to reach ~12cm^2/g, while the SC vines (Table 3) were not.

Fruit Composition Comparison of Single and Double Curtain Training Systems Pruned to Different Node Levels

Percent Soluble Solids: Overall, SC trained vines were able to accumulate more soluble solids per node than GDC (Figure 13). Both systems decreased in soluble solids as nodes retained increased, but all treatments fell between acceptable levels of 12-14 °Brix (Howell et al. 1982). Shaulis et al. (1966b) suggests that GDC shortens time to fruit maturity, while SC training can delay maturity. Unfortunately, percent soluble solids were only measured on the harvest date. It could have been valuable to have measurements of maturation from veraison to harvest. This would have helped in understanding the differences in maturation rate between SC and GDC trained vines.

GDC trained vines were able to produce more sugar per vine than SC trained vines (Figure 14). This was a result of larger yields of GDC vines, as opposed to higher soluble solids. However when looking at sugar accumulation per unit of cordon the SC vines had much more sugar produced (Figure 15). Again this could have resulted from twice the length of cordon on GDC vines which reduced the amount of sugar accumulated to half of that of SC vines.

Conclusions

Regression analysis suggested that on a per vine basis GDC vines can produce more yield with higher soluble solids and a higher leaf area to fruit ratio. However, due to twice the length of cordon in GDC vines; yield, fruitfulness, vine size, leaf area and sugar accumulation per meter of cordon length was nearly half that of SC trained vines. This does not mean that GDC training is less productive than SC training. When GDC is applied to a vineyard the same number of vines per row can be planted as in SC training. Therefore allowing growth to be spread over twice the canopy in SC, which reduces growth on a per unit cordon basis. This can help reduce shading and crowding that leads to cane and fruit maturation problems.

When establishing a training system vine vigor and environmental factors that will effect vigor, like soil fertility and rain fall, must be taken into consideration. GDC training is for vines that have too much vigor or vines that produce more than 0.6 kg of dormant prunnings per meter (0.4 lbs.) (Howell 2003). Vines that do not vegetatively produce at this level may not be able to produce at full potential if trained to GDC.

Literature Cited

Bailey, L.H. 1917. Vitis. *In* Volume Six of The Standard Cyclopedia of Horticulture. pp. 3481-3492.. The Macmillan Company, New York.

Edson, C.E., G.S. Howell, and J.A. Flore. 1993 Influence of crop load on photosynthesis and dry matter partitioning of Seyval grapevines. I. Single leaf and whole vines response pre- and post-harvest. Am. J. Enol. Vitic. 44:139-147.

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

Gladstone. J.S. 1992. Viticulture and Environment. Wine Titles Adelaide, Australia.

Hedrick, U.P. 1908. The Grapes of New York. J. B. Lyon Company, Albany.

Howell, G.S. 2001. Sustainable Grape Productivity and the Growth-Yield Relationship: A Review. Am. J. Enol. Vitic. 52:165-174.

Howell, G.S. 2003. Selecting and appropriate trellis/training system based on specific variety characteristics. *In* Proceedings for the Twenty Second Annual Horticulture Industry Show. pp. 121-129. Springdale, Arkansas.

Howell, G.S., T.K. Mansfield, and J.A. Wolpert. 1987. Influence of training system, pruning severity and thinning on yield, vine size and fruit quality of Vidal blanc grapevines. Am. J. Enol. Vitic. 38:105-112.

Howell, G.S., D.P. Miller, C.E. Edson, and R.K. Striegler. 1991. Influence of training system and pruning severity on yield, vine size and fruit composition of Vignoles grapevines. Am. J. Enol. Vitic. 42:191-198.

Howell, G.S. and J.A. Wolpert. 1978. Nodes per cane, primary bud phenology, and spring freeze damage to Concord grapevines. A preliminary note. Am. J. Enol. Vitic. 29:229-232.

Howell, G.S., J.A. Wolpert, and T.K. Mansfield. 1982. Pruning Niagara grapevines for top yields and quality fruit. *In* Proceedings for the Michigan Grape Society. 4:1-23.

Johnson, D.E. and G.S. Howell. 1981. Factors influencing critical temperatures for spring freeze damage to developing primary shoots on Concord grapevines. Am. J. Enol. Vitic. 32:144-149.

Kimball, K. and N. Shaulis. 1958. Pruning effects on the growth, yield, and maturity of Concord grapes. J. Am. Soc. Hortic. Sci. 71:167-176.

Mansfield, T. and G.S. Howell. 1981. Response of soluble solids accumulation, fruitfulness, cold resistance and onset of bud growth to differential defoliation stress at veraison in Concord grapevines. Am. J. Enol. Vitic. 32:200-205.

Miller, D.P. and G.S. Howell. 1996. Influence of vine capacity and crop load on the yield, fruit composition and sugar production per unit land area of Concord grapevines. *In* Proceedings for the Forth International Symposium on Cool Climate Enology and Viticulture. T. Henick-Kling et al.. (Eds.), pp. 94-98. N.Y. State Agricultural Experiment Station, Geneva, NY.

Miller, D.P. and G.S. Howell. 1998. Influence of vine capacity and crop load on canopy development, morphology and dry matter partitioning in Concord grapevines. Am. J. Enol. Vitic. 49:183-190.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996a. Effect of shoot number on potted grapevines: I. Canopy development and morphology. Am. J. Enol. Vitic. 47:244-250.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996b. Influence of shoot number and crop load on potted Chambourcin grapevines. I. Morphology and dry matter Partitioning. Am. J. Enol. Vitic. 47:380-388.

Miller, D.P., G.S. Howell, and R.K. Striegler. 1993. Reproductive and vegetative response of mature grapevines subjected to differential cropping stress. Am. J. Enol. Vitic. 44:435-440.

Morris, J.R. and D.L. Cawthon. 1980a. Mechanical trimming and node adjustment of cordon-trained 'Concord' grapevines. J. Amer. Soc. Hort. Sci. 105(3):310-313.

Morris, J.R. and D.L. Cawthon. 1980. Yield and quality response of 'Concord' grapes to training systems and pruning severity in Arkansas. J. Amer. Soc. Hort. Sci. 105(3):307-310.

Morris, J.R., C.A. Sims, J. E. Bourque, and J.L. Oakes. 1984b. Influence of training system, pruning severity, and spur length on yield and quality of six French-American hybrid grape cultivars. Am. J. Enol. Vitic. 35:23-27.

Partridge, N.L. 1921. A note on the fruiting habit of the Concord grape. Proc. Amer. Soc. Hort. Sci. 18:193-196.

Partridge, N.L. 1925a. Growth and yield of Concord grape vines. Proc. Amer. Soc. Hort. Sci. 22:84-87.

Partridge, N.L. 1925b. The fruiting habits and pruning of the Concord grape. Michigan Agriculture Experiment Station Tech Bulletin. 69:3-38.

Partridge, N.L. 1925c. The use of the growth-yield relationship in field trials with grapes. Proc. Amer. Soc. Hort. Sci. 23:131-134.

Pool, R.M., Charlotte Pratt and H.D. Hubbard. 1978. Structure of base buds in relation to yield of grapes. Am. J. Enol. Vitic. 29:36-41.

Ravaz, M.L. 1911. L effeuellage de la vigne. Annales d L Ecole Nationale d agriculture de Montpellier. 11:216-244.

Shaulis, N.J., H. Amberg and D. Crowe. 1966a. Response of Concord grapes to light, exposure and Geneva double curtain training. Amer. Soc. Hort. Sci. 89:268-280.

Shaulis, N.J., T.D. Jordan, and J. P.Tomkins. 1966c. Cultural Practices for New York vineyards. Cornell Extension. Bulletin 805.

Shaulis, N.J., E.S. Shepardson and T.D. Jordan. 1966b. The Geneva Double Curtain for Concord grapes: Vine training and trellis construction. New York State Agriculture Experiment Station. Bulletin 811.

Shaulis, N.J., J. Pollock, D. Crowe, and E.S. Shepardson. 1973. Mechanical pruning of grapevines: Progress 1968-1972. *In* the New York State Horticultural Proceedings. pp.60-69.

Shaulis, N.J. and E. Shepardson. 1965. The Geneva Double Curtain-a training system for New York's vigorous grapes. Farm Research. 31:2-4.

Shaulis, N.J. and R. Smart. 1974. Grapevine canopies: Management, microclimate and yield responses. *In* Proceedings for the 19th International Horticultural Congress. pp. 256-262. Warszawa, Poland.

Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. Am. J. Enol. Vitic. 36:230-239.

Smart. R.E. and M. Robinson. 1991. Sunlight into Wine. Winetitles, Adelaide.

Smart, R.E., N.J. Shaulis and E.R. Lemon. 1982b. The effect of Concord vineyard microclimate on yield. I. The effects of pruning, training, and shoot positioning on radiation microclimate. Am. J. Enol. Vitic. 33:99-108.

Smart, R.E., N.J. Shaulis and E.R. Lemon. 1982a. The effect of Concord vineyard microclimate on yield. II. The interrelations between microclimate and yield expression. Am. J. Enol. Vitic. 33:109-116.

Stergios, B.G. and G.S. Howell. 1977. Effects of Defoliation, trellis height, and cropping stress on the cold hardiness of Concord grapevines. Am. J. Enol. Vitic. 28:34-42.

Winkler, A.J., J.A. Cook, W.M. Kliewer, L.A. Lider. 1974. General Viticulture. University of California Press, Berkeley.

Wolpert, J.A., G.S. Howell and T.K. Mansfield. 1983. Sampling Vidal blanc grapes. I. Effect of training system, pruning severity, shoot exposure, shoot origin, and cluster thinning on cluster weight and fruit quality. Am. J. Enol. Vitic. 34:72-76.

Table 1: Reproductive, vegetative and fruit composition measurements of Niagara grapevines averaged over 1999-2003. The data here represents the effects of Node Level or Nodes Retained on Single Curtain (SC) trained Niagara vines.

Key:

U: Nodes Retained = number of nodes per vine established during dormant pruning.

V: Vine Size = weight of dormant cane prunings per vine.

W: Productivity = yield [kg]/post-season vine size [kg].

X: Fruitfulness = yield [kg]/nodes retained.

Y: Leaf Area Ver. = leaf area at veraison was used to estimate a component of vegetative growth. The amount of leaf area at veraison is important because at this stage the vine is most source limited (Miller et al. 1996b).

Z: LA/Fruit = leaf area per gram of fruit expresses a ratio of vegetative to reproductive growth. In Michigan ~11-14 cm^2/g is optimum (Miller and Howell 1996)

Table 1.

Parameters Measured or Calculated	Node Level						
	20	40	80	120	Hedge (12" radius)	MP	P-value
Nodes Retained[U]	19 f	38 e	70 d	92 c	99 b	117 a	0.0001
Vine Size (kg)[V]	1.45 a	1.30 b	0.80 c	0.62 d	---	---	0.0001
Yield (kg/vine)	6.14 d	8.95 c	13.73 b	15.07 ab	15.42 a	14.59 ab	0.0001
Yield (t/a)	3.69 d	5.38 c	8.25 b	9.06 ab	9.27 a	8.77 ab	0.0001
Yield (mt/h)	8.27 d	12.06 c	18.49 b	20.31 ab	20.78 a	19.66 ab	0.0001
Clusters/ Vine	57 d	93 c	134 b	155 a	155 a	166 a	0.0001
Cluster Wt. (g)	113	109	108	104	105	99	NS
Berry Wt. (g)	3.74 a	3.71 a	3.55 b	3.36 cd	3.49 bc	3.28 d	0.0001
Berries/ Cluster	30	29	30	30	30	29	NS
SS (°Brix)	15.62 a	15.04 b	13.82 c	13.79 c	13.54 c	13.71 c	0.0001
Sugar/Vine (kg)	0.94 d	1.32 c	1.84 b	1.99 ab	2.01 a	1.93 ab	0.0001
pH	3.35 ab	3.38 a	3.31 bc	3.29 c	3.27 c	3.27 c	0.0001
Titratable Acidity (g/L)	6.35	6.47	6.41	6.27	6.39	6.19	NS
Productivity (kg)[W]	5.93 d	11.28 d	30.11 c	50.80 b	53.66 b	66.83 a	0.0001
Fruitfulness (kg/node)[X]	0.34 a	0.23 b	0.20 bc	0.17 cd	0.18 cd	0.15 d	0.0001
Leaf Area Ver (m^2)[Y]	9.0 b	10.3 ab	11.0 ab	11.2 ab	10.8 ab	12.1 a	0.0029
LA/Fruit (cm^2/g)[Z]	20.33 a	15.66 b	10.77 c	10.22 c	9.97 c	11.56 c	0.0001

Table 2: Reproductive, vegetative and fruit composition measurements of Niagara grapevines averaged over 1999-2003. The data here represents the effects of Node Level or Nodes Retained per meter of cordon on Single Curtain (SC) trained Niagara vines.

Parameters Measured or Calculated	Node Level						
	20	40	80	120	Hedge (12" radius)	MP	P-value
NR/ meter[V]	8 f	16 e	29 d	38 c	41 b	49 a	0.0001
Vine Size (kg)/ meter[W]	0.60 a	0.54 b	0.33 c	0.26 d	---	---	0.0001
Yield (kg)/ meter	2.56 d	3.73 c	5.72 b	6.28 ab	6.43 a	6.08 ab	0.0001
Clusters/ meter	24 d	39 c	56 b	65 a	65 a	69 a	0.0001
Sugar/ meter (kg)	0.39 d	0.55 c	0.77 b	0.83 ab	0.84 a	0.80 ab	0.0001
Productivity/ meter (kg)[X]	2.47 d	4.70 d	12.55 c	21.17 b	22.36 b	27.85 a	0.0001
Fruitfulness (kg/node/m)[Y]	0.14 a	0.10 b	0.08 bc	0.07 cd	0.08 cd	0.06 d	0.0001
Leaf Area Ver (m^2/m)[Z]	3.8 b	4.3 ab	4.6 ab	4.7 ab	4.5 ab	5.0 a	0.0029

Key:

V: Nodes Retained/meter = number of nodes per meter of cordon established during dormant pruning.

W: Vine Size/meter = weight of dormant cane prunings per meter of cordon.

X: Productivity/meter = yield [kg]/post-season vine size [kg]/meter of cordon.

Y: Fruitfulness/meter = yield [kg]/nodes retained/meter of cordon

Z: Leaf Area Ver. = leaf area at veraison was used to estimate a component of vegetative growth. The amount of leaf area at veraison is important because at this stage the vine is most source limited (Miller et al. 1996b).

Table 3. Reproductive, vegetative and fruit composition measurements of Niagara grapevines averaged over 1999-2003. The data here represents the effects of Node Level or Nodes Retained on Geneva Double Curtain (GDC) trained Niagara vines.

Key:

U: Nodes Retained = number of nodes per vine established during dormant pruning.

V: Vine Size = weight of dormant cane prunings per vine.

W: Productivity = yield [kg]/post-season vine size [kg].

X: Fruitfulness = yield [kg]/nodes retained.

Y: Leaf Area Ver. = leaf area at veraison was used to estimate a component of vegetative growth. The amount of leaf area at veraison is important because at this stage the vine is most source limited (Miller et al. 1996b).

Z: LA/Fruit = leaf area per gram of fruit expresses a ratio of vegetative to reproductive growth. In Michigan ~11-14 cm^2/g is optimum (Miller and Howell 1996).

Table 3.

	Node Level							
Parameters Measured or Calculated		**20+20**	**35**	**70**	**105**	**Hedge (12" radius)**	**MP**	**P-value**
	Nodes Retained[U]	35 f	30 d	61 c	91 b	98 b	164 a	0.0001
	Vine Size (kg)[V]	0.97 b	1.40 a	0.70 c	0.67 cd	---	---	0.0001
	Yield (kg/vine)	10.46 de	8.96 e	11.53 cd	13.00 bc	14.86 b	19.10 a	0.0001
	Yield (t/a)	6.28 de	5.37 e	6.92 cd	7.80 bc	8.92 b	11.49 a	0.0001
	Yield (mt/h)	14.08 de	12.04 e	15.51 cd	17.49 bc	20.00 b	25.76 a	0.0001
	Clusters/ Vine	90 d	76 d	116 c	131 c	157 b	236 a	0.0001
	Cluster Wt. (g)	118 a	116 a	104 b	102 b	99 b	94 b	0.0001
	Berry Wt. (g)	3.98 ab	4.03 a	3.84 b	3.84 b	3.89 ab	3.64 c	0.0002
	Berries/ Cluster	29 a	29 a	27 ab	27 ab	26 b	26 b	0.0206
	SS (°Brix)	12.98 ab	13.46 a	13.41 a	12.86 bc	12.36 cd	12.00 d	0.0001
	Sugar/Vine (kg)	1.30 d	1.18 d	1.53 c	1.63 bc	1.76 b	2.21 a	0.0001
	pH	3.17 c	3.22 b	3.15 c	3.23 ab	3.28 a	3.20 bc	0.0001
	Titratable Acidity (g/L)	6.72	6.78	6.78	6.88	6.96	7.91	NS
	Productivity (kg)[W]	14.48 d	9.18 d	20.56 cd	30.63 bc	42.95 b	103.45 a	0.0001
	Fruitfulness (kg/node)[X]	0.36 a	0.30 ab	0.24 bc	0.15 de	0.20 cd	0.13 e	0.0001
	Leaf Area Ver (m^2)[Y]	9.0 b	9.0 ab	8.7 b	9.3 ab	10.3 ab	11.1 a	0.0001
	LA/Fruit (cm^2/g)[Z]	8.6 b	11.0 a	7.5 bc	7.1 cd	6.9 d	5.8 e	0.0001

Table 4. Reproductive, vegetative and fruit composition measurements of Niagara grapevines averaged over 1999-2003. The data here represents the effects of Node Level or Nodes Retained per meter of cordon on Geneva Double Curtain (GDC) trained Niagara vines.

	Node Level							
		20+20	35	70	105	Hedge (12" radius)	MP	P-value
Parameters Measured or Calculated	NR/ meter[V]	7 f	6 d	13 c	19 b	20 b	34 a	0.0001
	Vine Size (kg)/ meter[W]	0.20 b	0.29 a	0.15 c	0.14 cd	---	---	0.0001
	Yield (kg)/ meter	2.18 de	1.87 e	2.40 cd	2.71 bc	3.10 b	3.98 a	0.0001
	Clusters/ meter	19 d	16 d	24 c	27 c	33 b	49 a	0.0001
	Sugar/ meter (kg)	0.28 d	0.25 d	0.32 c	0.35 bc	0.38 b	0.48 a	0.0001
	Productivity/ meter (kg)[X]	3.02 d	1.91 d	4.28 cd	6.38 bc	8.95 b	21.55 a	0.0001
	Fruitfulness (kg/node/m)[Y]	0.08 a	0.06 ab	0.05 bc	0.03 de	0.04 cd	0.03 e	0.0001
	Leaf Area Ver $(m^2/m)^Z$	1.9 b	2.1 ab	1.8 b	1.9 ab	2.1 ab	2.3 a	0.0001

Key:

V: Nodes Retained/meter = number of nodes per meter of cordon established during dormant pruning.

W: Vine Size/meter = weight of dormant cane prunings per meter of cordon.

X: Productivity/meter = yield [kg]/post-season vine size [kg]/meter of cordon.

Y: Fruitfulness/meter = yield [kg]/nodes retained/meter of cordon

Z: Leaf Area Ver. = leaf area at veraison was used to estimate a component of vegetative growth. The amount of leaf area at veraison is important because at this stage the vine is most source limited (Miller et al. 1996b).

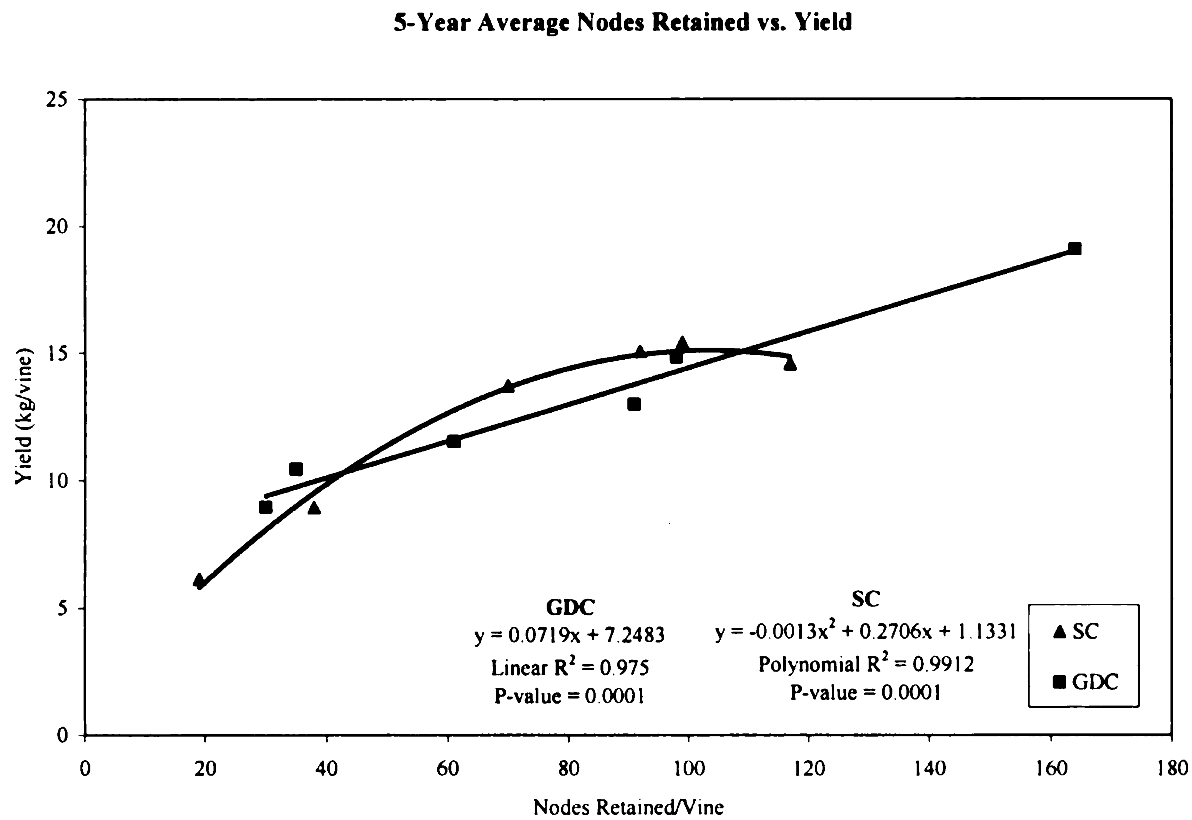


Figure 1. Yield per vine (means; 1999-2003) for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Yield is expressed with relation to nodes retained or node number per vine.

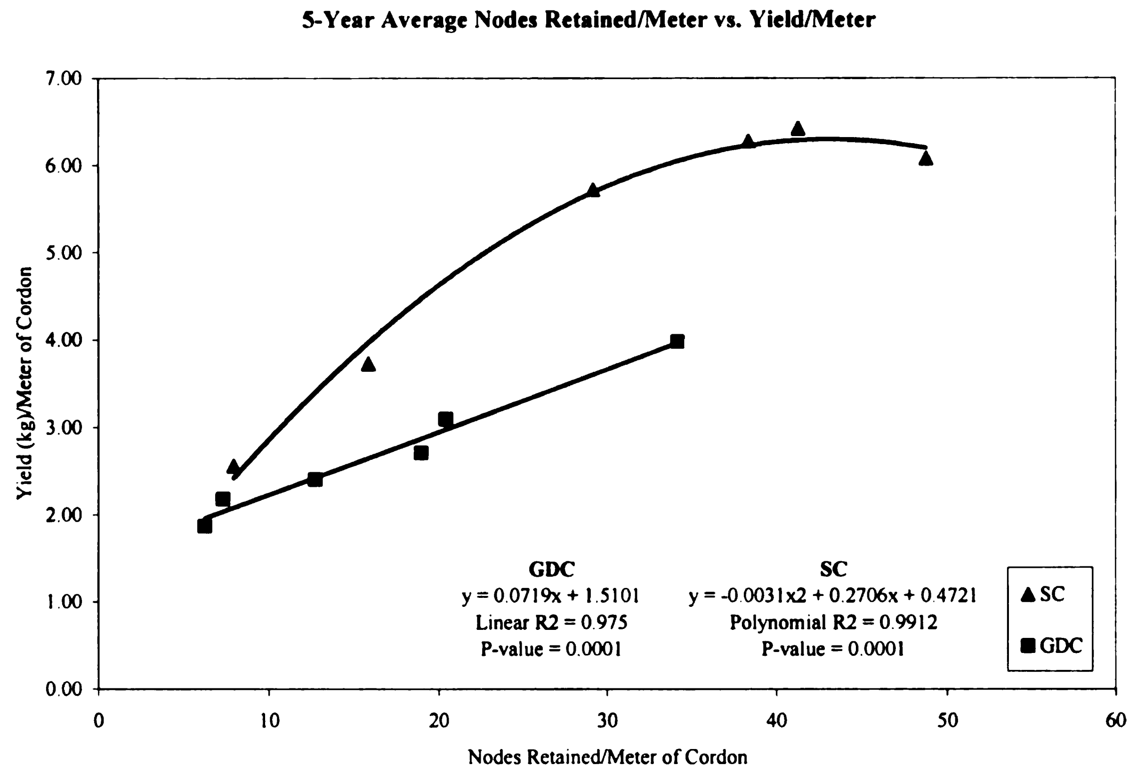


Figure 2. Yield per meter of cordon (means; 1999-2003) for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Yield is expressed with relation to nodes retained or node number per meter of cordon. Because GDC has twice the amount of cordon a visual comparison between systems can be made with greater fairness when analyzing on a per meter basis. The two systems also occur at two different plots.

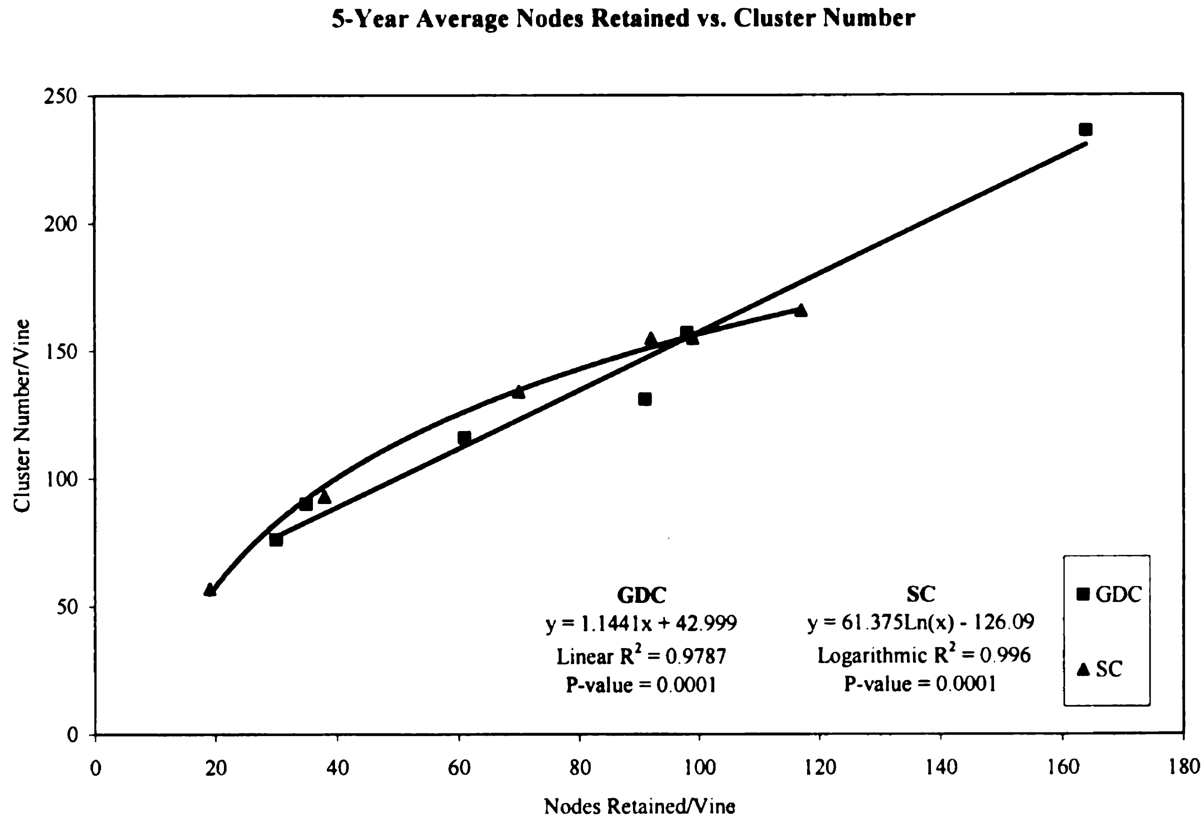


Figure 3. Clusters per vine (means; 1999-2003) for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Cluster number is expressed with relation to nodes retained or node number per vine.

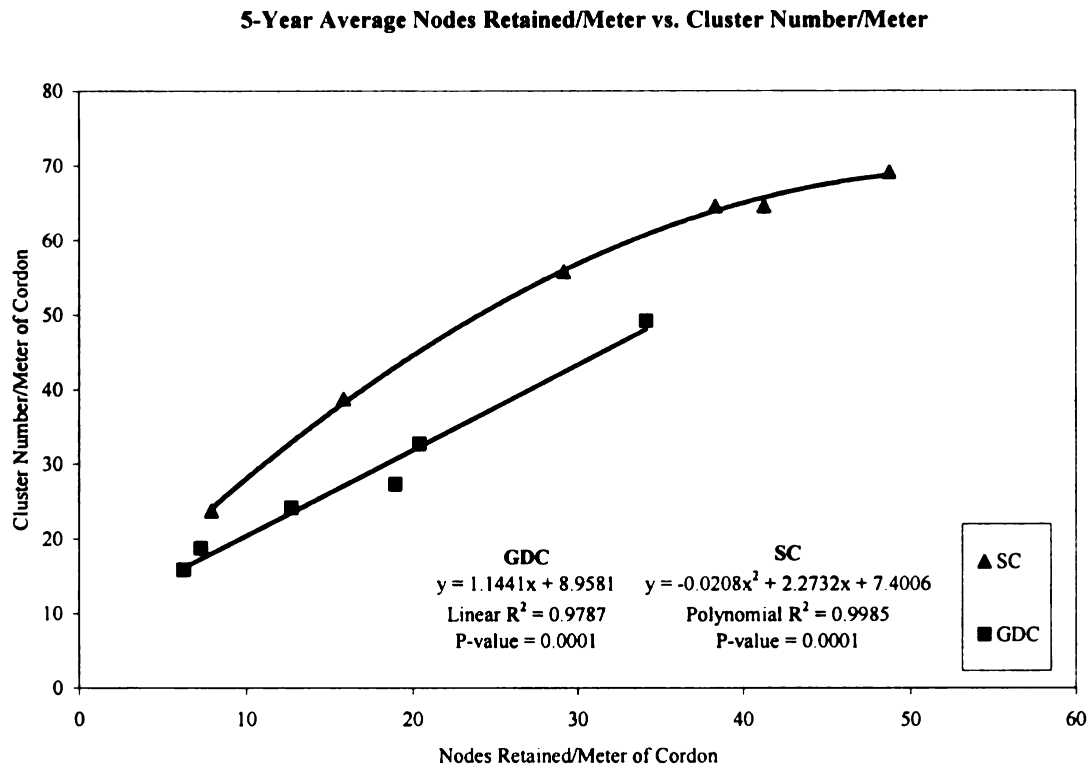


Figure 4. Clusters per meter of cordon (means; 1999-2003) for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Cluster number is expressed with relation to nodes retained or node number per meter of cordon. Because GDC has twice the amount of cordon a visual comparison between systems can be made with greater fairness when analyzing on a per meter basis. The two systems also occur at two different plots

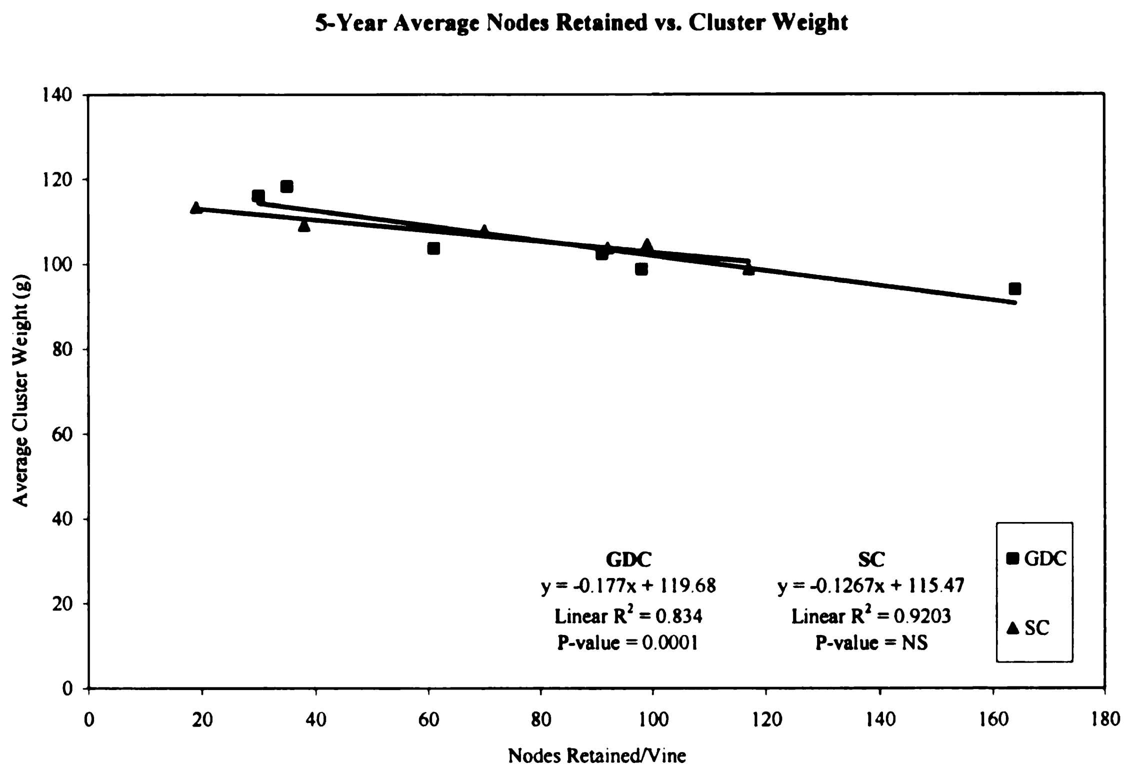


Figure 5. Five-year means (1999-2003) for average cluster weight for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Cluster weight is expressed with relation to nodes retained or node number per vine.

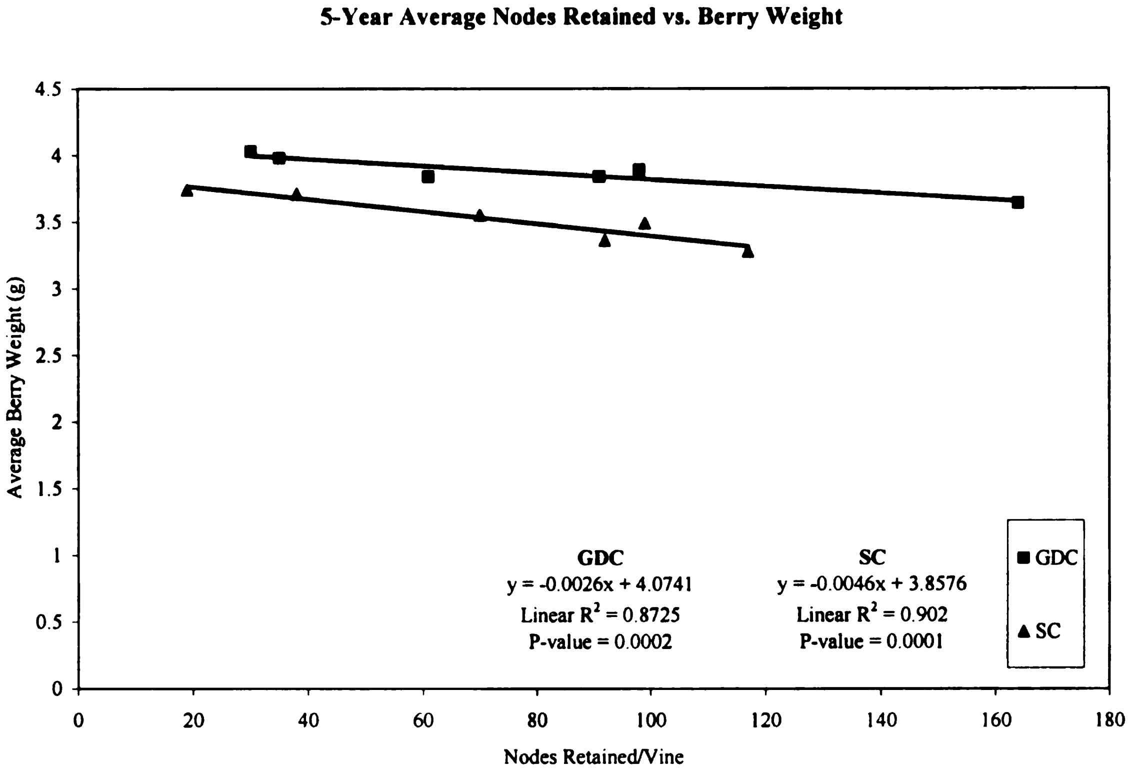


Figure 6. Five-year means (1999-2003) for average berry weight for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Berry weight is expressed with relation to nodes retained or node number per vine.

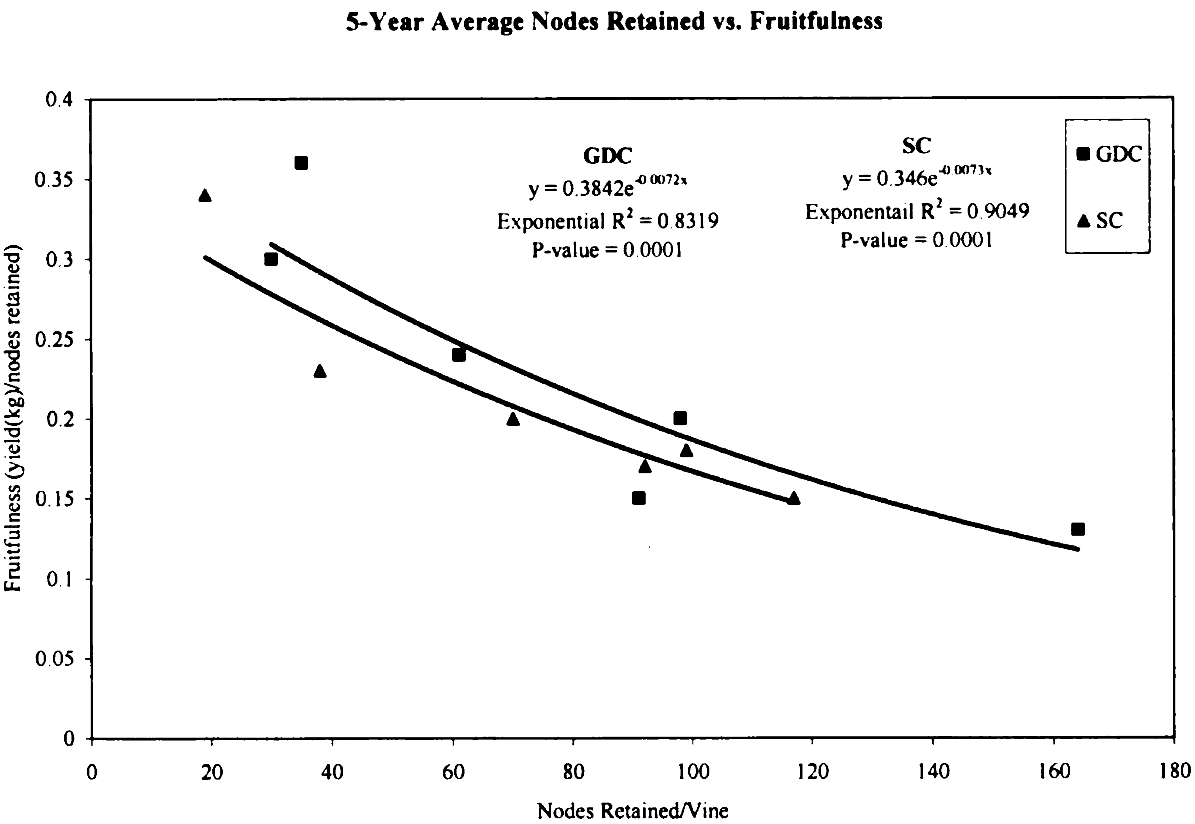


Figure 7. Five-year means (1999-2003) of vine fruitfulness for Niagara grapevines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Fruitfulness is expressed with relation to nodes retained or node number per vine. Fruitfulness describes the yield per node.

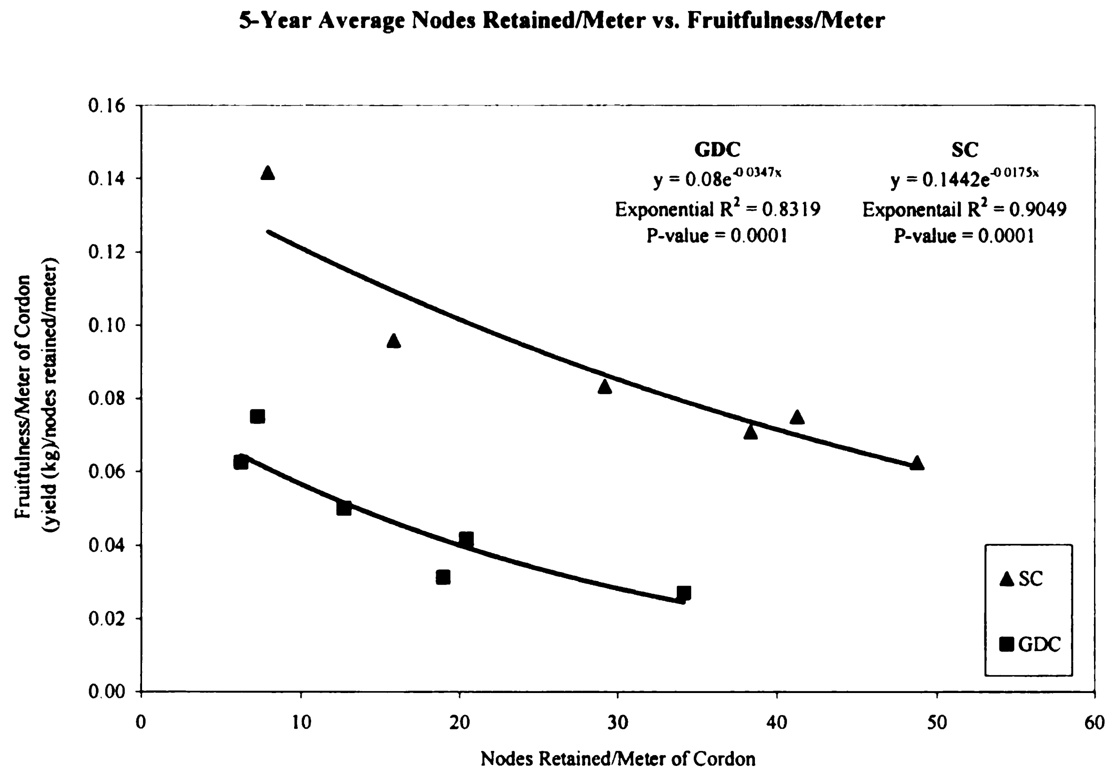


Figure 8. Vine fruitfulness per meter of cordon (means; 1999-2003) for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Fruitfulness is expressed with relation to nodes retained or node number per meter of cordon. Fruitfulness describes the yield per node. Because GDC has twice the amount of cordon a visual comparison between systems can be made with greater fairness when analyzing on a per meter basis. The two systems also occur at two different plots.

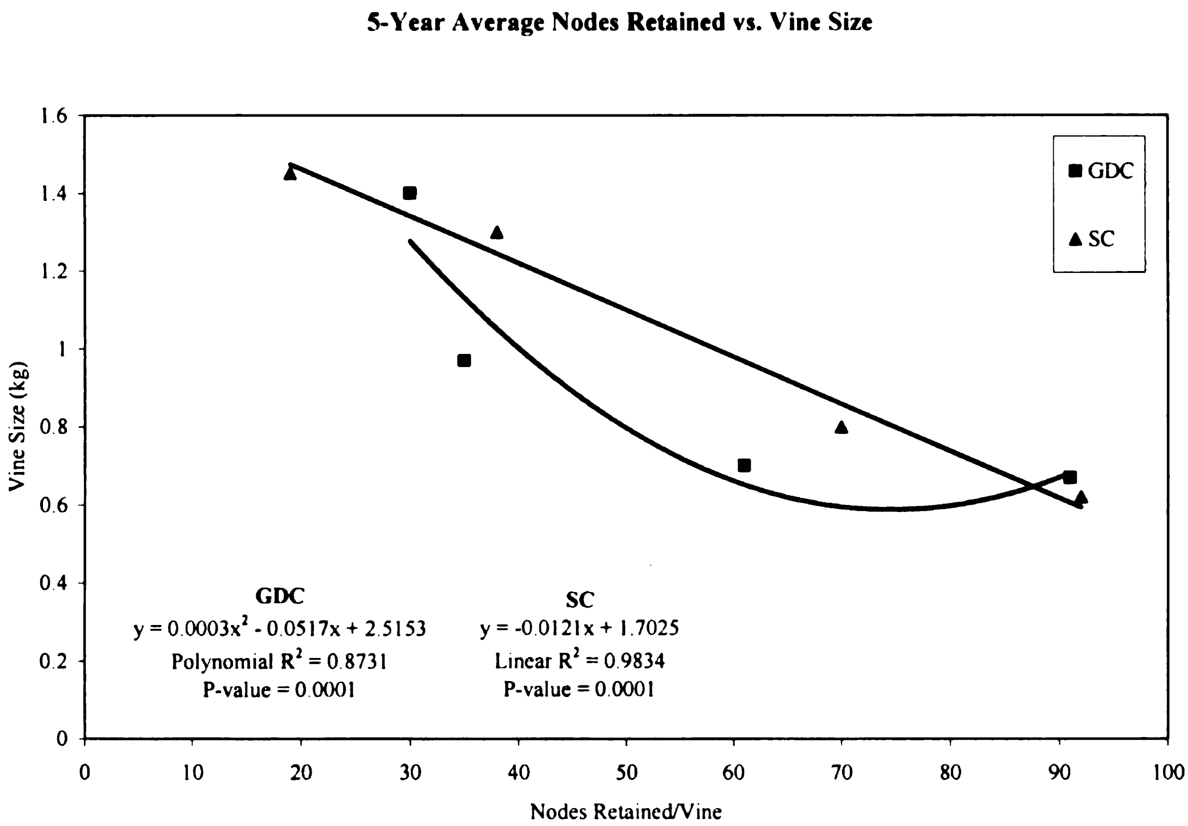


Figure 9. Five-year means (1999-2003) of vine size for Niagara grapevines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Vine size is expressed with relation to nodes retained or node number per vine. Vine size is described by the weight of dormant cane prunings.

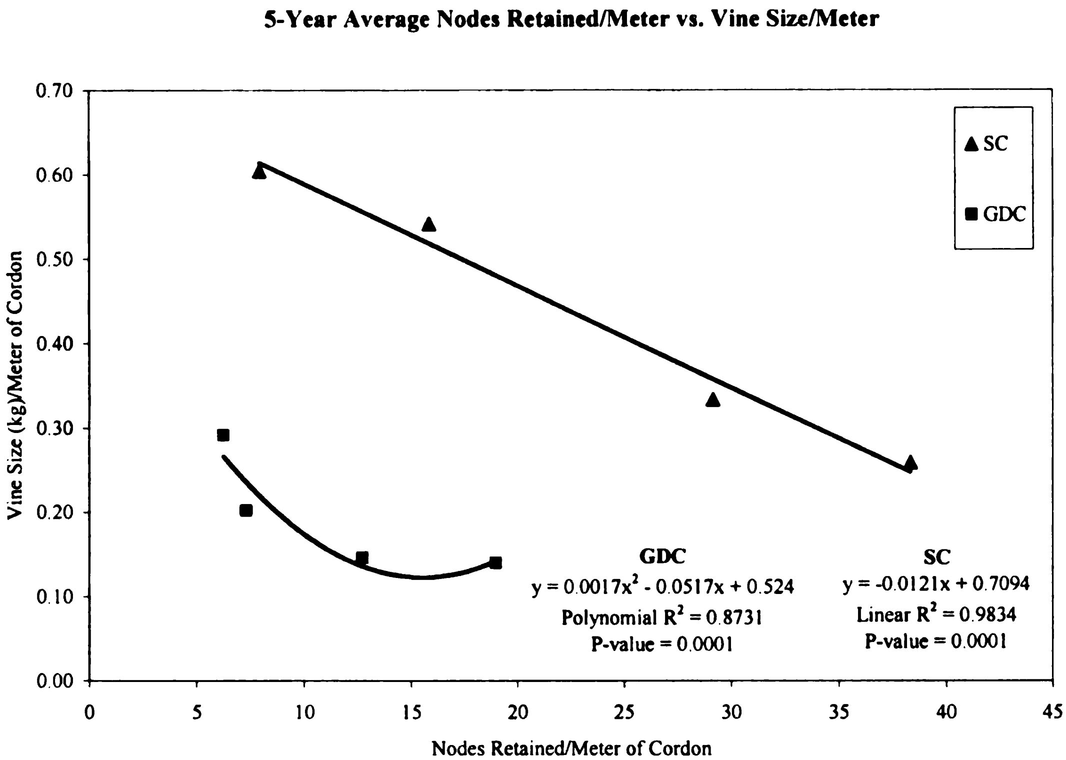


Figure 10. Vine size per meter of cordon (means; 1999-2003) for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain (SC) systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Vine size is expressed with relation to nodes retained or node number per meter of cordon. Vine size is described by the weight of dormant cane prunings. Because GDC has twice the amount of cordon a visual comparison between systems can be made with greater fairness when analyzing on a per meter basis. The two systems also occur at two different plots.

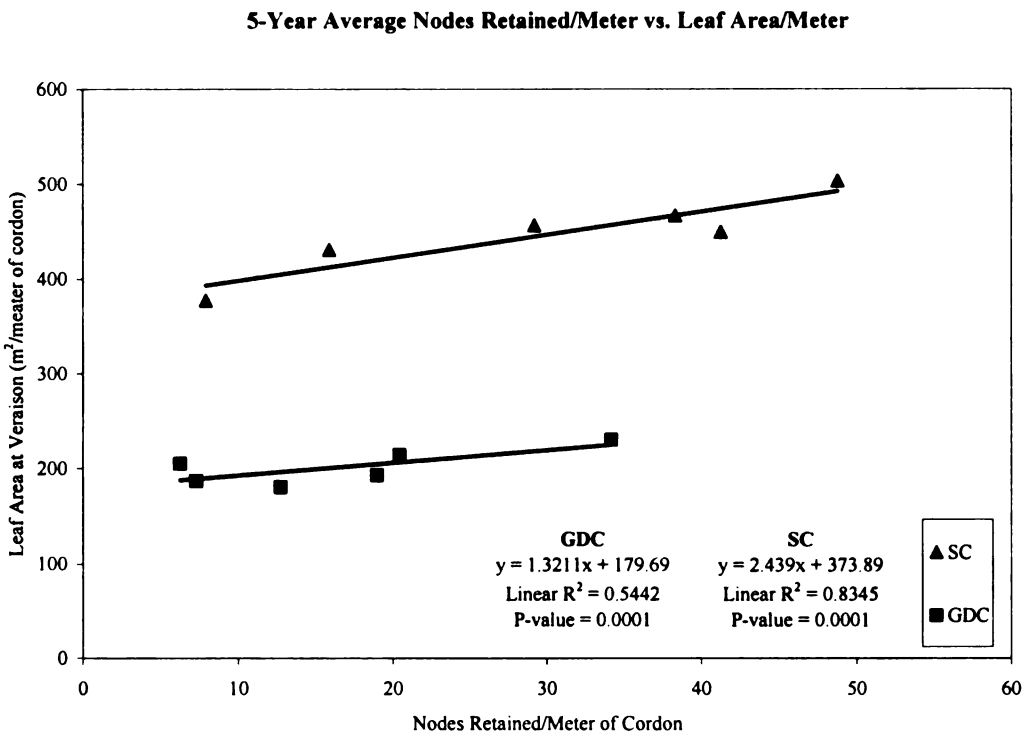


Figure 11. Five-year means (1999-2003) of leaf area per meter at veraison for vines trained to Geneva Double Curtain (GDC) and Single Curtain systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid).

5-Year Average of Leaf Area/Meter

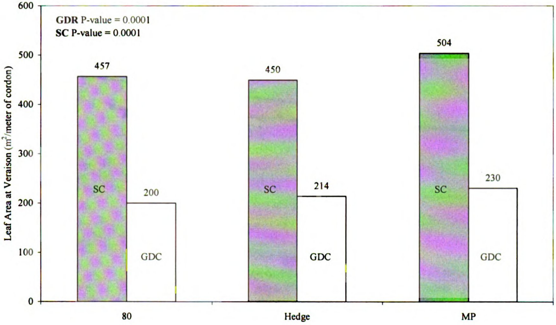


Figure 12. Comparison of leaf area per meter at veraison for 80 fixed nodes, Hedge (H) and Minimally Pruned (MP) vines trained to Geneva Double Curtain or Single Curtain systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). 80 fixed nodes is used as a control for this comparison because it has been shown to have balanced reproductive and vegetative growth (Kasey Weirzba, 2004 submitted for publication). The two training systems are at separate sites and have different cordon lengths, therefore leaf area is expressed by meter of cordon.

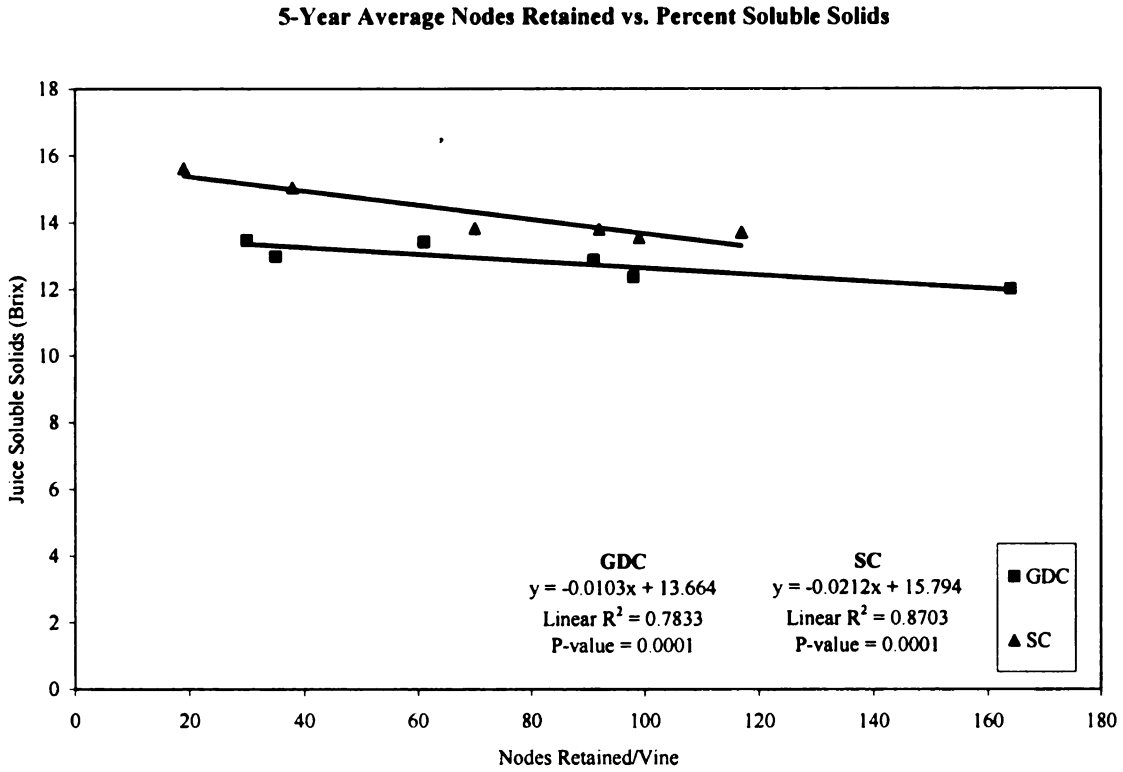


Figure 13. Comparison of soluble solids (°Brix) from vines trained to Geneva Double Curtain or Single Curtain systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). A range of 12-14 °Brix is acceptable to processors.

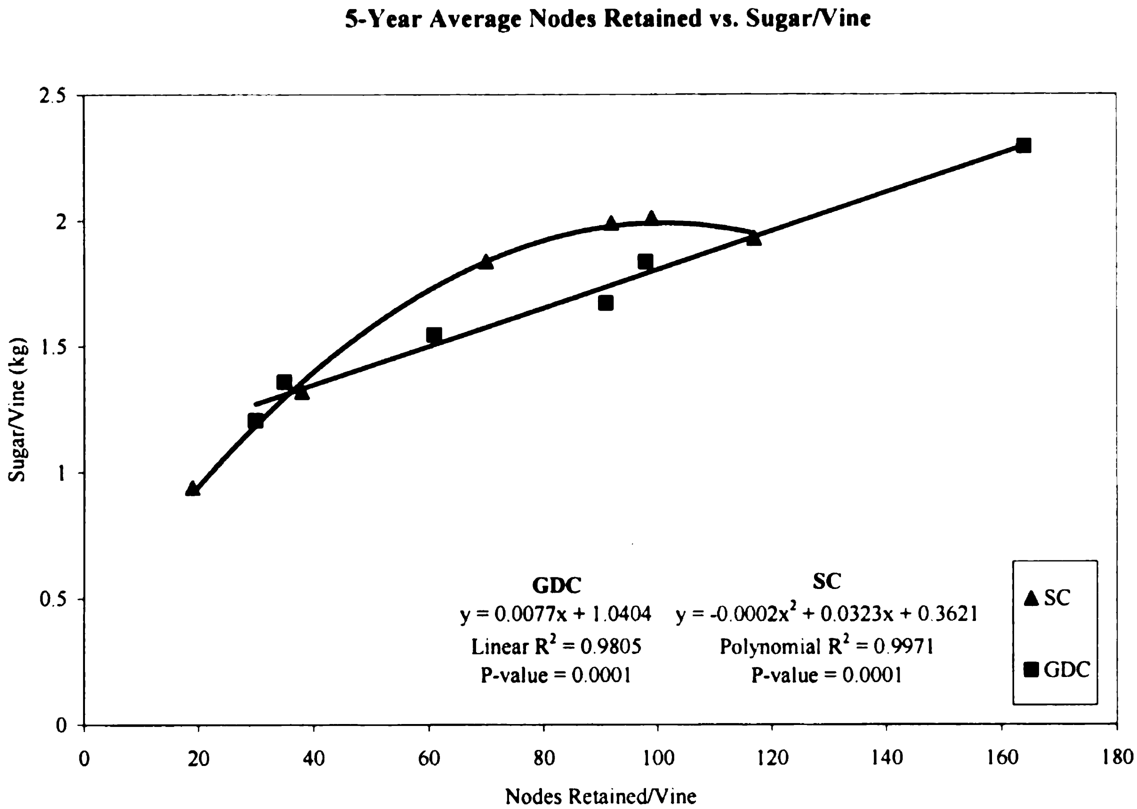


Figure 14. Five-year means (1999-2003) of sugar per vine for vines trained to Geneva Double Curtain (GDC) and Single Curtain systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid). Sugar per vine is the percentage (°Brix) of sugar that makes up the weight of yield.

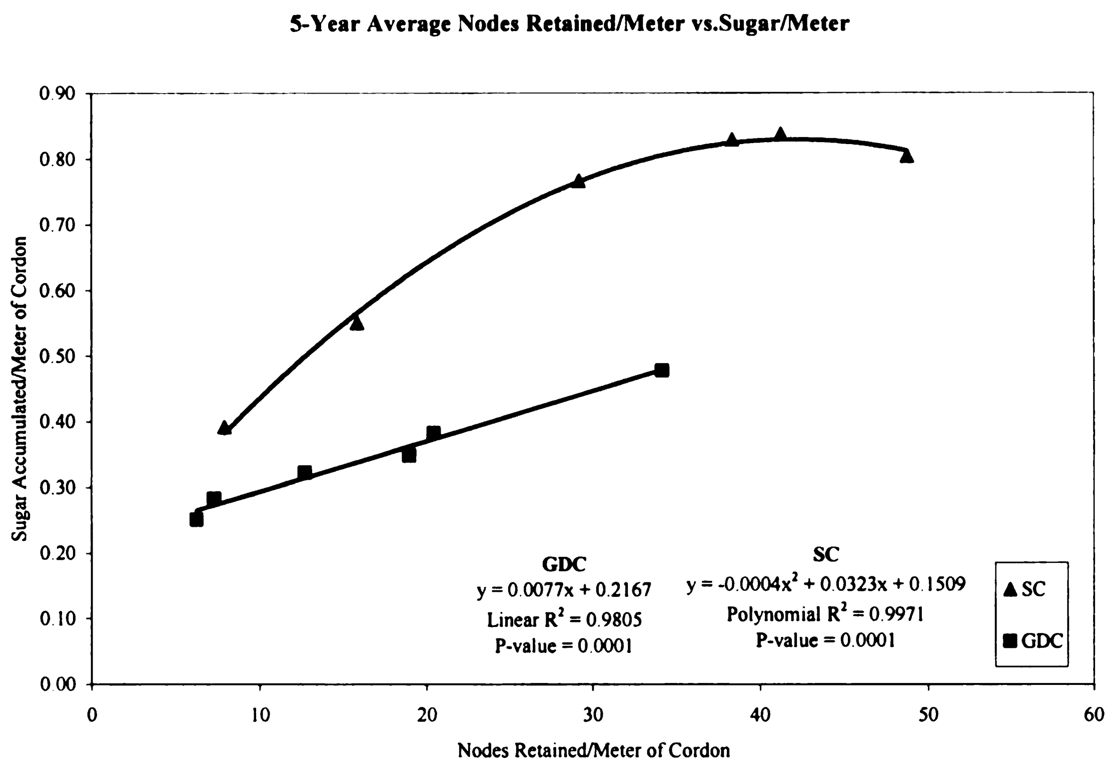


Figure 15. Five-year means (1999-2003) of sugar accumulation per meter of cordon for Niagara vines trained to Geneva Double Curtain (GDC) and Single Curtain systems (Hudson River Umbrella, Umbrella Kniffen and Hybrid).

CHAPTER IV:

ASSESSING THE UTILITY OF MECHANICAL HEDGING AND MINIMAL PRUNING ON SUSTAINABLE YIELD, VEGETATIVE GROWTH AND FRUIT COMPOSITION OF NIAGARA GRAPEVINES

Abstract

Due to the unpredictability and diversity of cool climate viticulture seasons in Michigan, there is a demand for a management protocol in which sustainable vine production can be met. Components of yield, vegetative growth and fruit composition were measured on Niagara vines with high node retention systems, like those acquired through mechanical pruning. In the hedge (H) treatment, all shoot and cane wood was trimmed back to a 15 cm (6-inch) radius around the cordon. In the minimally pruned (MP) treatment, all wood was trimmed to 76 cm (30 inches) below the cordon. Within the MP treatment, three cluster-thinning treatments included control (MP-C), in which no cluster thinning was applied, thin-1 (MP-1), in which all but the basal cluster was removed from every shoot, and thin-2 (MP-2), in which an estimated cluster amount similar to MP-1 was removed randomly. A control treatment was set at 80 fixed nodes. MP-1 and MP-2 retained the most nodes, had more conservative yields and higher soluble solids than MP-C, H and 80 fixed nodes. Overall, the MP-2 vines were the only system with acceptable yield, fruit ripening and vegetative growth attributes among the four simulated mechanically pruned treatments tested.

Introduction

Application of mechanical pruning technology has created an opportunity to conserve time and labor to the juice grape grower. Because juice grapes are of relatively lower raw product value than wine grapes, many growers have adopted mechanical pruning to achieve labor savings. Though mechanical pruning reduces production costs by cutting labor it may not be economically or viticulturally sustainable (Howell et al. 1978, Kliewer and Benz 1992, Morris and Cawthon 1980a, Reynolds and Wardle 1993, Sims et al. 1990, Smithyman et al. 1997, Striegler and Berg 1994, Striegler et al. 1998).

Howell (2001) relates sustainability to viticulture as a "collective methodology that produces highest yields of ripe fruit per unit land area with no reduction in vegetative growth and does so over a period of years at a cost which returns a net profit." Accordingly, sustainable production considers both viticulture and economic components, and must not exclude variables such as cultivar value, viticulture management, perceived quality of the crop, production costs and production consistency.

Mechanically pruned juice grape vines commonly are trained to high cordon systems like Hudson River Umbrella (HRU) (Figure 1 in Chapter I) and Geneva Double Curtain (GDC) (Figure 3 in Chapter I), and are either Minimally Pruned (MP) or Hedged (H). Because this process is non-selective with regard to canes and nodes to be retained, there is concern regarding optimizing the potential for individual canes and/or nodes. Unless hand pruning follows mechanical pruning, selection of node number to be retained, cane quality and removal of dead or infected wood cannot be accomplished (Shaulis et al. 1973). Cane quality (maturity) is commonly based on periderm color (darker is better), internode length and diameter, and location of weak or no lateral growth (Shaulis et al. 1966a).

Mechanically pruned vines commonly retain excess node numbers, resulting in excess shoots per vine (Clingeleffer and Krake 1992, Kliewer and Benz 1992, Lake et al. 1997, Reynolds and Wardle 1993, Striegler and Berg 1994, Striegler et al. 1998). Excess shoot number then contributes to crowding and shading of shoots and foliage (Smart 1985, Smithyman et al. 1997) as well as increased yield and potential for over cropping (Morris and Cawthon 1980b, Winkler 1958).

Crowding and shading can result in sharply reduced photosynthetic activity among shaded leaves (Shaulis et al. 1966b, Smart 1985). Smart (1985) reported, and Howell and Trought have observed (2001 unpublished data) that interior leaves can act as sinks rather than sources, thus using valuable carbohydrate resources. The excess of nodes retained by mechanical pruning can cause vine stresses that ultimately decreases yield, vine size and sugar accumulation (Howell et al. 1978, Kliewer and Benz 1992, Morris and Cawthon 1980a, Reynolds and Wardle 1993, Sims et al. 1990). In some cases, vine death has resulted (Miller et al. 1993).

Less severely pruned vines have a tendency to produce more leaf area early in the season (Martinez de Toda et al. 1999, Smithyman et al. 1997, Sommer and Clingeleffer 1996, Winkler 1958). Some would argue that this is a physiological advantage for early growth and production (Martinez de Toda et al. 1999, Sommer and Clingeleffer 1996). Unfortunately, later in the season shading can cause greater fruit and shoot maturation problems that out-weigh the benefits of early leaf area development (Morris 1980a, Smithyman et al. 1997). It also has been shown by Miller et al. (1996b) that the grapevine is not carbohydrate limited until veraison and it is at this time that sufficient leaf area is crucial. This means that early expression of leaf area is not an advantage with regard to a vine's capacity to ripen a larger crop.

Many studies on vines in cool climate regions suggest that mechanical pruning is unsustainable (Morris and Cawthon 1980a, Reynolds and Wardle 1993, Smithyman et al. 1997), but studies in warm viticultural areas have suggested sustainable benefits (Martinez de Toda et al. 1999, Rühl and Clingeleffer 1993). In an eleven-year study, Martinez de Toda et al. (1999) found that Grenache vines grown in Spain had increased yield, sugar production per vine and dry matter production as a result of mechanical pruning. These vines also had earlier leaf area development and more active leaf area for an extended period of time.

Shaulis et al. (1973) wrote on the need for cultural maintenance in mechanically pruned vines that would encourage increased vine size, increased yield, improved fruit maturity and better fruit positioning that would allow for effective disease and pest control. These goals require manual labor to accompany mechanical pruning. It was suggested that vines should be thinned to an appropriate number of canes, and canes headed back to obtain an appropriate number of count nodes and retention of renewal spurs for cordon replacement (Shaulis et al. 1973). If these goals can be met, there is a possibility that sustainable Niagara production can be accomplished with mechanical pruning.

Experimental Objectives

1. Investigate the sustainability of reproductive and vegetative growth resulting from the nodes retained on Minimally Pruned and Hedged vines.
2. Evaluate the canopy quality resulting from Minimally Pruned and Hedged vines.
3. Evaluate the effects of canopy quality on reproductive and vegetative growth, as well as fruit composition.
4. Evaluate the impacts of cluster thinning on Minimally Pruned vines.

Materials and Methods

Plant Material

The experiment was located in southwest Michigan, about five miles east of Lake Michigan. The treatments were established in May 1999 on vines, in Scottdale, Michigan and measurements were taken for five years. The mature, bearing Niagara grapevines were planted in 1974 on a clay loam soil. The vines were own-rooted and were trained initially to a Four Arm Kniffen and pruned to 70-80 nodes. Vine spacing was 2.4m (8 feet) and row spacing was 3m (10 feet). The trellis height was 1.8m (6 feet) from the vineyard floor to the top wire. Vines were trained with double trunks for insurance to avoid devastating circumstances from winter kill.

The pest management program was based on scouting, experience and weather conditions. A combination of fungicides and insecticides (Appendix I; Table 1) used for control were rotated to avoid resistance. Fertilizing consisted of a post-bloom nitrogen application of 66 kg/hectare (60 lbs/acre) in the form of calcium nitrate or ammonium nitrate. In December 333 kg/hectare (300 lbs/acre) of potash was also applied. There was no irrigation system.

Experimental Design and Treatments

The plot was designed as a randomized block/split-plot. Individual vines from eight rows were placed in blocks of three and replicated four times. Two high node treatments, minimally pruned (MP) and hedge (H), represented mechanically pruned vines. The MP treatment was established by trimming growth at 76cm (30 inches) from the cordon wire. The H treatment was established by removing all growth up to a 15cm (6 inch) radius around the cordon wire. The control treatment was set at 80 nodes retained. At this node level there an acceptable balance between reproductive and vegetative growth as well as fruit maturation and quality on hand pruned, single canopy vines (Wierzba and Howell 2004, Chapter II). All vines where hand pruned in mid-December during the five years of data collection.

Nested within the MP treatment was a cluster thinning experiment that consisted of a control (MP-C), with no thinning and two thinning treatments. The protocol for thin 1 (MP-1) was to remove all clusters from all shoots except the basal cluster, at 1200 growing degree days (GDD). Thin 2 (MP-2) simulated random cluster thinning, similar to what machinery would accomplish, which was also initiated at 1200 GDD. The protocol for MP-2 consisted of first estimating the percent of crop accounted for by the basal cluster for each shoot. This fraction was then applied to the vine on the shoot level, where this fraction of the shoots was retained and the remaining fraction was thinned completely. For example, if the basal cluster represented 2/3 of the total crop on that shoot, then 1/3 of the shoots were de-fruited. In theory, this protocol removed the same amount of fruit as MP-1, but in a manner that would maintain the normal distribution/positions of basal and apical clusters.

Data Collected

Node Numbers and Vine Size

Nodes retained were counted at the time of winter pruning. Frost injury was assessed on a node basis, in which viability or mortality was noted for the compound, primary and secondary buds. This data was used to estimate the viable buds that remained, which were called Functional Nodes Retained (FNR) (Appendix I; Figure 2).

The weight of dormant cane prunings from each vine was used to express vine size or vegetative growth in a season. Vegetativeness (post-season vine size/nodes retained) was calculated to express the amount of vine growth related to the number of nodes retained.

Leaf Area

Leaf area was measured at three stages during the growing season, bloom (LA-bloom), 1200 growing degree days (growing degree days are the accumulation of average temperatures above 50°F) (LA-1200) and veraison (LA-Ver). LA-bloom was estimated first by measuring the length of five modal shoots per vine in the field. Fifteen shoots representing different lengths also were collected from the vineyard and taken back to campus for leaf area measurements using a LI-3100 area meter by Li-Cor, inc. (Lincoln, Nebraska). The leaf area of the shoots was plotted against the length of the shoot to acquire a regression and best-fit equation. This equation was used to estimate leaf area per shoot. Leaf area per shoot was multiplied by the shoot number to obtain leaf area per vine. LA-1200 and LA-Ver were estimated by the measured surface area of the vine's canopy (Appendix I; Figure 1) and multiplied by 1.5 photosynthetic leaf layers (Smart and Robinson 1991).

The treatment comparison analysis for this study was based on LA-Ver. Previous work by Miller et al. (1996b) suggested that vines are not source limited prior to veraison, but can become so post-veraison. Therefore, the amount of leaf area from veraison to harvest was deemed crucial to the maturation of fruit as well as to vine carbohydrate accumulation and storage.

Reproductive Measurements

Yield and cluster number per vine were measured at harvest. Samples of 50 random berries also were collected and weighed at harvest for each treatment. These data were used to calculate cluster weight, berry weight and berries per cluster. Fruitfulness (yield/nodes retained) described the amount of fruit an average node produced and is the reciprocal of vegetativeness. Crop load (yield/pre-season vine size) described the ratio of fruit that was carried to the size of vine it was carried on. Productivity (yield/post-season vine size), also called the Ravaz Index, described the ratio of reproductive to vegetative growth that occurred over the season, thereby providing an assessment of vine balance (Howell 2001).

Fruit Composition Measurements

The chemical composition of fruit was analyzed from the 50-count berry sample taken on the day of harvest and frozen for later date of berry analysis. Grape juice soluble solids were measured using a NAR IT Atago (Kirkland, WA) refractometer. Titratable acidity and pH were measured using a 370 Thermo Orion (Beverly, MA) pH meter. Titratable acidity (TA) was measured by titrating juice with 0.1M sodium hydroxide (NaOH) until a pH of 8.2 and using an equation to yield the TA (g/L).

$$\text{TA (g/L)} = 75 * \text{Molarity of NAOH} * (\text{titre amount (mL)/volume of sample})$$

Statistical Methods

Comparisons between treatments were made using SAS statistical computer program (SAS Institute, Cary, NC). Single treatment comparisons were analyzed using Least Significant Differences and the proc glm function, with means separation calculated by t-test (Sasha Kravchenko 2002, personal communication). Significance was taken from the type III p-value. Regression analysis was done using Microsoft Excel (USA) (Howell 2002, personal communication).

Results and Discussion

Yield: In the five-year average of data, H had the highest yield (Figure 1), which was significantly different from all other treatments except MP-C (Table 1). The large yield was mainly a result of increased cluster number and although not statistically significant, cluster weight and berry weight were also higher than the MP treatments and probably contributed as well (Table 1).

MP-C had the second largest yield, a result of high cluster number (Table 1). Compared to 80 fixed nodes, MP-C had a 20% more in clusters, but only a 6% increase in yield. These data suggest that in a few years MP-C could have reduced production to that of 80 fixed nodes or less. The potential for yield reduction is supported by previous studies on mechanically pruned vines (Howell et al. 1987, Morris and Cawthon 1980a, Reynolds and Wardle 1993, Sims et al. 1990). In many cases, the reduction of total yield is the result of reduced yield components, like cluster weight, berry weight and berries per cluster (Kliewer and Benz 1992, Lake et al. 1998, Miller and Howell 1996, 1998, Morris and Cawthon 1980a, Reynolds and Wardle 1993, Smart et al. 1982, Striegler and Berg 1994, Striegler et al. 1998).

Fruit Composition: Soluble solids over the five-year mean exhibited a polynomial trend when plotted against nodes retained, where the MP thinning treatments accumulated the most sugar (Figure 2). MP-1 gained more soluble solids, than MP-2 because when selecting to keep the basal cluster and remove all others the most ripe or mature fruit was selected for. Cluster thinning, resulting in crop reduction, has improved soluble solids in other studies as well (Edson and Howell 1993, Edson et al. 1993, Howell et al. 1987, Wolpert et al. 1983). This suggests that MP + thinning has the capability to accumulate adequate sugar by the harvest date set by processors.

Hedged vines had the lowest soluble solids for the five-year average (Figure 2). Even though in two of five years H had the lowest soluble solids, this treatment had the greatest ripening variability with a range of 11.8-16.4 °Brix (Table 2). This could be the result of stronger environmental influences on a vine that has most of its energy invested in a high crop load, rather than compensating for unfavorable environmental influences. However, H was able to gain the most sugar per vine in the 5-year mean (Table 1). Considering the large variability of soluble solids, high sugar per vine values were probably a result of high yields.

It is probable that H vines experienced crowding and shading in the fruiting zone, which also could contribute to lower soluble solids (Howell et al. 1978, Kimball and Shaulis 1958, Kliewer and Benz 1992, Lake et al. 1998, Reynolds and Wardle 1993, Shaulis and Smart 1974, Striegler et al. 1998). The H treatment consisted of many three-to four-node canes, causing the production of both leaf area and fruit to be located in the same restricted area. Many short canes also created many leaf layers, which could result in interior leaves with lower photosynthetic production (Shaulis et al. 1966b, Smart 1985) and reduced vine carbohydrates (Howell and Trought 2001, unpublished data). Carbohydrates may have been partitioned to sustain inactive leaf area, which reduced carbohydrate allocation for ripening. Delayed and decreased ripening also has been related to the amount of crop the vine carried previously and/or currently carried (Howell et al. 1987, Kimball and Shaulis 1958, Miller and Howell 1998, Smart et al. 1982, Shaulis et al. 1966a, 1953, Winkler 1958, Wolpert et al. 1983). Importantly, MP and H yields were not increased to the same extent as in the studies noted above and therefore appears to be a problem of inner canopy shading as opposed to excessive crop production.

Vegetative Growth: All five high node level treatments had a five-year average vine size (Figure 5) less than the 1.1-1.5 kg pruning weight that was recomended by Shaulis et al. (1973) for mechanically pruned vines. Consequently, due to the lack of cane removal from MP and H vines, vine size from pruning weight was not a fair representation of seasonal vegetative growth for H and MP vines. According to Smart and Robinson (1991), ~12 cm^2 leaf area per gram of fruit is a sufficient amount of leaf area that encourages vegetative and reproductive balance in the vine. However, none of the treatments obtained this level (Table 1), but MP-2 had the most leaf area per unit fruit weight.

The maximum photosynthetically active leaf area per vine was obtained at 80 fixed nodes with 10.2 m^2 (Table 1), although the leaf areas for all five treatments were not statistically different. This suggests that vine imbalance was not a result of insufficient leaf area. In fact, leaf area could have been excessive due to many layers creating a large interior canopy (Shaulis et al. 1966b, Smart 1985), which increased within vine competition (Miller et al. 1996a) and caused shaded leaves to become sinks, competing for available carbohydrates.

Cluster Thinning: Cluster thinning reduced yield, cluster number and crop load (Table 1), while increasing soluble solids (Figure 2). MP-2 had the highest ratio of leaf area per fruit (Table 1), but remained below Smart and Robinson's (1991) suggested value. The ripening success of MP-1 and MP-2 also could be due to unintentional shoot positioning and leaf thinning during application of the cluster thinning treatments. In order to analyze crop and retrieve clusters for thinning it was necessary to pull shoots down and apart. During this process leaves were lost and slight shoot positioning occurred.

Conclusions

Hedging increased yield, due to more clusters per vine and increased berry weight. Unfortunately, with a high crop load, soluble solids were not consistent from year to year. Though not tested in this study for H vines, cluster thinning may increase soluble solids and leaf area per fruit in H vines. MP-C had the highest average yield and cluster number, but suffered from diminishing cluster weight, berry weight and leaf area per fruit. These properties are characteristic of an unsustainable system that will continue to diminish vegetatively and reproductively. Cluster thinning MP vines increased cluster weight, berry weight, soluble solids and leaf area per fruit. Overall, cluster thinning MP vines does promote balance and sustainable yields. Cluster thinning alone may not sustain the vine over an extended period of time, therefore other practices such as renewing cordons and heading back canes are also needed to encourage vine health without the use of full hand labor. An additional study on the effects of cluster thinning H pruned vines would be beneficial. Taking leaf layer measurements also would be helpful in understanding canopy architecture and how it affects microclimate and photosynthesis. Further data on the photosynthetic capabilities of shaded leaves is also desired so that the impact of excess leaf layers can be estimated.

Literature Cited

Clingeleffer, P.R. and L.R. Krake. 1992. Response of Cabernet Franc grapevines to minimal pruning and virus infection. Am. J. Enol. Vitic. 43:31-37.

Edson, C.E. and G.S. Howell. 1993. A comparison of vine architecture systems at different crop loads: Leaf photosynthesis, vine yield and dry matter partitioning. Vitic. Enol. Sci. 48:90-95.

Edson, C.E., G.S. Howell, and J.A. Flore. 1993. Influence of crop load on photosynthesis and dry matter partitioning of Seyval grapevines. I. Single leaf and whole vine response pre- and post-harvest. Am. J. Enol. Vitic. 44:139-147.

Howell, G.S. 2001. Sustainable grape productivity and the growth-yield relationship: A review. Am. J. Enol. Vitic. 52:165-174.

Howell, G.S., T.K. Mansfield, and J.A. Wolpert. 1987. Influence of training system, pruning severity and thinning on yield, vine size and fruit quality of Vidal blanc grapevines. Am. J. Enol. Vitic. 38:105-112.

Howell, G.S., B.G. Stergios, and S.S. Stackhouse. 1978. Interrelation of productivity and cold hardiness of Concord grapevines. Am. J. Enol. Vitic. 29:187-191.

Howell, G.S., J.A. Wolpert, and T.K. Mansfield. 1982. Pruning Niagara grapevines for top yields and quality fruit. *In* Proceedings for the Michigan Grape Society. 4:1-23.

Kimball, K. and N. Shaulis. 1958. Pruning effects on the growth, yield, and maturity of Concord grapes. J. Am. Soc. Hortic. Sci. 71:167-176.

Kliewer, W.M. and M. Benz. 1992. Performance of cordon-trained Carbernet sauvignon grapevines grown in the Napa Valley to hedge pruning and minimal pruning. Abstr. ASEV 43rd Ann. Meet. Am. J. Enol. Vitic. 43:300A.

Lake, C., R.K. Striegler, P. Verdegaal, G. Berg, and J.A. Wolpert. 1997. Influence of vine trellis training system on growth, yield, fruit composition and Eutypa incidence in Cabernet Sauvignon. Abstr. 4th International Symposium of Cool Climate Viticulture and Enology and ASEV Ann. Eastern Meet. Am. J. Enol. Vitic. 48:248A.

Lake, C., R.K. Striegler, P. Verdegaal, G. Berg, J.A. Wolpert and C.A. Ingels. 1998. Effect of training system and soil type on growth, yield, and fruit composition of Cabernet sauvignon grapevines. Abstr. ASEV Ann. Meet. Am. J. Enol. Vitic. 49:352A.

Martinez de Toda, Fernando and Juan Carlos Sancha. 1999. Long-term effects of simulated mechanical pruning on Grenache vines under drought conditions. Am. J. Enol. Vitic. 50:87-90.

Miller, D.P. and G.S. Howell. 1996. Influence of vine capacity and crop load on the yield, fruit composition and sugar production per unit land area of Concord grapevines. *In* Proceedings for the Forth International Symposium on Cool Climate Enology and Viticulture. T. Henick-Kling et al.. (Eds.), pp. 94-98. N.Y. State Agricultural Experiment Station, Geneva, NY.

Miller, D.P. and G.S. Howell. 1998. Influence of vine capacity and crop load on canopy development, morphology and dry matter partitioning in Concord grapevines. Am. J. Enol. Vitic. 49:183-190.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996a. Effect of shoot number on potted grapevines: II. Dry matter accumulation and partitioning. Am. J. Enol. Vitic. 47:251-256.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996b. Influence of shoot number and crop load on potted Chambourcin grapevines. I. Morphology and dry matter Partitioning. Am. J. Enol. Vitic. 47:380-388.

Miller, D.P., G.S. Howell, and R.K. Striegler. 1993. Reproductive and vegetative response of mature grapevines subjected to differential cropping stress. Am. J. Enol. Vitic. 44:435-440.

Morris, J.R. and D.L. Cawthon. 1980a. Mechanical trimming and node adjustment of cordon-trained 'Concord' grapevines. J. Amer. Soc. Hort. Sci. 105(3):310-313.

Morris, J.R. and D.L. Cawthon. 1980b. Yield and quality response of 'Concord' grapes to training systems and pruning severity in Arkansas. J. Amer. Soc. Hort. Sci. 105(3):307-310.

Reynolds, A.G. and D.A. Wardle. 1993. Yield component path analysis of Okanagan Riesling vines conventionally pruned or subjected to simulated mechanical pruning. Am. J. Enol. Vitic. 44:173-179.

Rühl, E.H. and P.R. Clingeleffer. 1993. Effect of minimal pruning and virus inoculation on the carbohydrate and nitrogen accumulation in Cabernet Franc vines. Am. J. Enol. Vitic. 44:81-85.

Shaulis, N.J., H. Amberg and D. Crowe. 1966b. Response of 'Concord' grapes to light, exposure and Geneva double curtain training. J. Amer. Soc. Hort. Sci. 89:268-280.

Shaulis, N.J., T.D. Jordan, and J. P.Tomkins. 1966a. Cultural practices for New York vineyards. Cornell Extension. Bulletin 805.

Shaulis, N.J., K. Kimball, and J. Tomkins. 1953. Training and trellising Concord grapes for high yields. Farm Research. 19:11.

Shaulis, N.J., J. Pollock, D. Crowe, and E.S. Shepardson. 1973. Mechanical pruning of grapevines: Progress 1968-1972. *In* the New York State Horticultural Proceedings. pp.60-69.

Shaulis, N.J. and R. Smart. 1974. Grapevine canopies: Management, microclimate and yield responses. *In* Proceedings for the 19th International Horticultural Congress. pp. 256-262. Warszawa, Poland.

Sims, C.A., R.P. Johnson, and R.P. Bates. 1990. Effects of mechanical pruning on the yield and quality of Muscadine grapes. Am. J. Enol. Vitic. 41:273-276.

Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. Am. J. Enol. Vitic. 36:230-239.

Smart. R.E. and M. Robinson. 1991. Sunlight into Wine. Winetitles, Adelaide.

Smart, R.E., N.J. Shaulis and E.R. Lemon. 1982. The effect of Concord vineyard microclimate on yield. II. The interrelations between microclimate and yield expression. Am. J. Enol. Vitic. 33:109-116.

Smithyman, R.P., G.S. Howell, and D.P. Miller. 1997. Influence of canopy configuration on vegetative development, yield, and fruit composition of Seyval blanc grapevines. Am. J. Enol. Vitic. 48:482-491.

Sommer, K.J. and P.R. Clingeleffer. 1996. Vine canopy development and carbohydrate partitioning as influenced by pruning. *In* Proceedings for the Ninth Australian Wine Industry Technical Conference. pp.123-127. Adelaide, Australia.

Striegler, R.K. and G.T. Berg. 1994. Evaluation of machine and minimal pruning of French Colombard grapevines. Abstr. ASEV 45th Ann. Meet. Am. J. Enol. Vitic. 45:365A.

Striegler, R.K., G.T. Berg, C.B. Lake, and S.G. Graves. 1998. Effect of trellis system on growth, yield, and fruit composition of Sauvignon blanc grapevines grown in the southern San Joaquin Valley. Am. J. Enol. Vitic 49:452A.

Winkler, A.J. 1958. The relation of leaf area and climate to vine performance and grape quality. Am. J. Enol. Vitic. 9:10-23.

Wolpert, J.A., G.S. Howell and T.K. Mansfield. 1983. Sampling Vidal blanc grapes. I. Effect of training system, pruning severity, shoot exposure, shoot origin, and cluster thinning on cluster weight and fruit quality. Am. J. Enol. Vitic. 34:72-76.

Table 1: Reproductive, vegetative and fruit composition measurements and calculations of Niagara grapevines averaged over 1999-2003. The data here represents the effects of simulated mechanical pruning on single canopy vines in southwest Michigan.

Key:

V: Nodes Retained (NR) = number of nodes per vine established during dormant pruning.

W: Vine Size = weight of dormant cane prunings.

X: Fruitfulness = yield [kg]/nodes retained.

Y: Leaf Area Ver. = leaf area at veraison was used to estimate vegetative growth. The amount of leaf area at veraison is important because at this stage the vine is most source limited (Miller et al 1996b).

Z: LA/Fruit = Leaf are per gram of fruit expresses a ratio of vegetative to reproductive growth. In Michigan ~11-14 cm^2/g (Miller and Howell 1996) is optimum.

Table 1.

Parameters Measured or Calculated	Treatments					
	80	Hedge (12" radius)	MP-C	MP-1	MP-2	P-value
Nodes Retained^{V}	70 d	99 c	117 b	144 a	147 a	0.0001
Yield (kg/vine)	13.73 bc	15.42 a	14.59 ab	13.49 bc	12.37 c	0.0001
Yield (t/a)	8.25 bc	9.27 a	8.77 ab	8.11 bc	7.43 c	0.0001
Yield (mt/h)	18.49 bc	20.78 a	19.66 ab	18.18 bc	16.66 c	0.0001
Clusters/ Vine	134 c	155 a	166 a	151 ab	135 bc	0.0001
Cluster Wt. (g)	108	105	99	99	103	NS
Berry Wt. (g)	3.55 a	3.49 ab	3.28 c	3.40 b	3.43 b	0.0001
Berries/ Cluster	30	30	29	28	30	NS
SS (°Brix)	13.8 bc	13.5 c	13.7 c	14.7 a	14.3 ab	0.0001
Sugar/Vine (kg)	1.84 b	2.01 a	1.93 ab	1.92 ab	1.74 c	0.0001
pH	3.31 ab	3.27 bc	3.27 c	3.32 a	3.31 ab	0.0001
Titratable Acidity (g/L)	6.4	6.4	6.2	6.3	5.9	NS
Vine Size (kg)^{W}	0.80 a	0.64 b	0.38 c	0.38 c	0.36 c	0.0001
Fruitfulness (kg/node)^{X}	0.20 a	0.18 a	0.15 b	0.12 c	0.11 c	0.0001
Leaf Area Ver (m^2)^{Y}	10.2	9.5	9.6	10.1	10.1	NS
LA/Fruit (cm^2/g)^{Z}	7.98 ab	5.65 b	6.03 ab	6.62 ab	8.53 a	0.0117

Table 2. Percent soluble solids gained in the Hedge (H) treatment over 5 years.

Year	Percent Soluble Solids (brix)
1999	13.28 b
2000	12.98 bc
2001	16.43 a
2002	13.15 b
2003	11.88 c

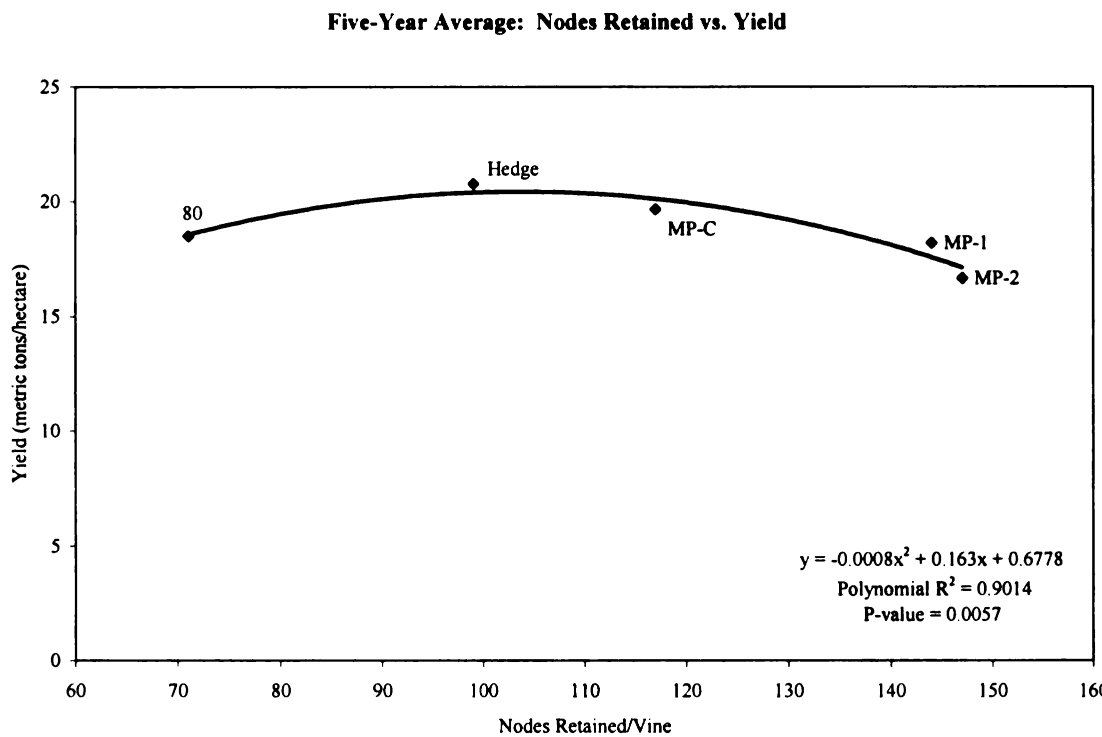


Figure 1. Average yield (1999-2003) of four simulated mechanically pruned treatments and a control treatment (80 nodes). Minimally Pruned Control (MP-C) had no cluster thinning, MP-1 had all clusters except the basal of each shoot removed and MP-2 had random thinning, that in theory had the same amount of fruit removed as MP-1. The Hedge treatment had no cluster thinning and was the only treatment statistically different from the others.

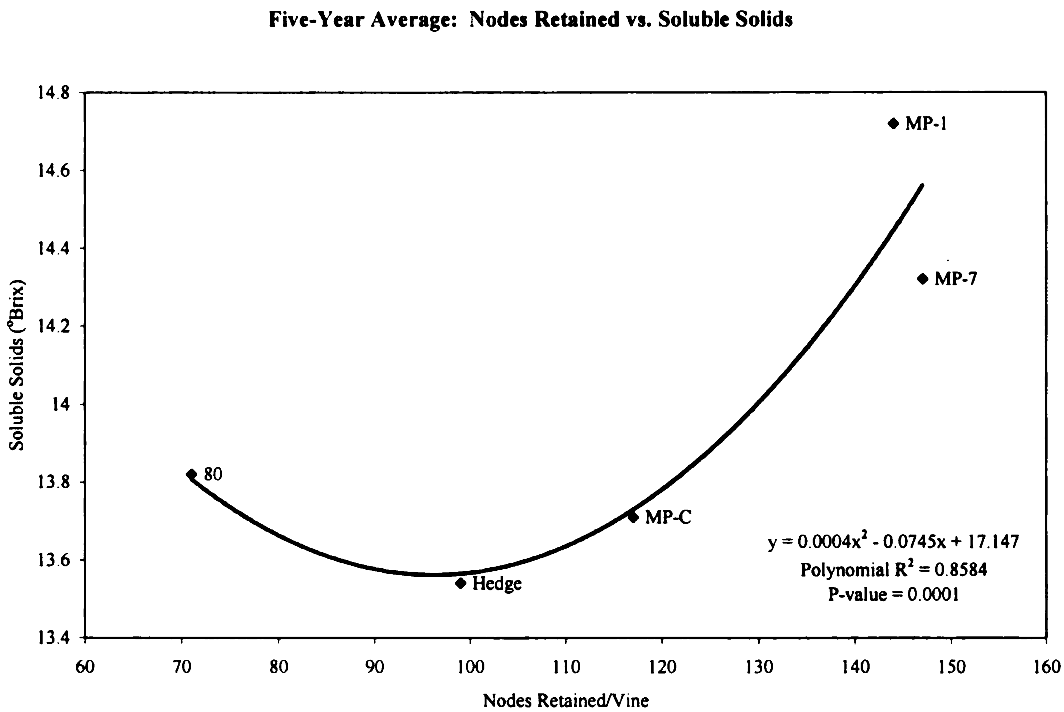


Figure 2. Five-year mean (1999-2003) of soluble solids. MP-C has no cluster thinning, MP-1 has basal cluster thinning and MP-2 has random cluster thinning. All treatments are in the acceptable range of 12-14 °Brix, preferred by processors (Howell et al. 1982).

CHAPTER V:

THE IMPACT OF SPRING FROST ON BUD MORTALITY AND YIELD OF NIAGARA GRAPEVINES

Abstract

There were two freeze episodes in Michigan's grape production region in 2002. Bud mortality, yield, vegetative growth and fruit composition were measured on Niagara vines with freeze injury at two locations. At Scottdale, vines were trained to Umbrella Kniffen (UK), Hudson River Umbrella (HRU) and Hybrid (HYB) which is a HRU system that retains 1-3 long canes similar to UK. Within training systems, node level treatments were applied: 20, 40, 80, 120, Hedge (H) and Minimally Pruned (MP). A method of estimating yield potential of injured vines was evaluated as Functional Nodes Retained (FRN). FNR were statistically similar among UK, HRU and HYB, with no significant differences among percent shootless nodes and percent primary and secondary bud mortality. The 20- and 40-node vines had a higher percent bud and node mortality than vines with greater nodes retained. At SWMREC, vines were trained to Geneva Double Curtain (GDC) with node level treatments of 20+20, 35, 70, 105, H and MP. The 20+20 balanced pruning treatment had significantly more blind nodes than all other treatments. In both locations, MP treatments had the highest yields, but the SWMREC location suffered much more yield reduction. In 2003, higher node treatments suffered from excessive cropping.

Introduction

Seasonally, Michigan's grape industry is subjected to possible severe weather conditions common to cool climate viticulture. Although control of weather episodes is not possible, vine reaction to severe weather may be manipulated by culture.

Niagara, although having slightly less cold hardiness than Concord (Shaulis et al. 1966, 1968), is usually safe from winterkill in Michigan. However, with the tendency for *Vitis labruscana* B. (Bailey 1917) to begin growth early, spring frost damage is a common concern in late April through mid-May. Temperatures between -19 and -18°C (-3° and -1° F) can cause injury and/or damage to buds, shoots and flower clusters (Winkler et al. 1974). The severity of yield reduction is mainly dependent on the number of buds in a developmental stage that is susceptible to frost damage (Johnson and Howell 1981, Winkler et al. 1974), and such developmental differences are influenced by cultivar and weather conditions (Winkler et al. 1974). Johnson and Howell (1981) suggested that more phonologically advanced buds posses more ice nucleation sites as well as more tissue surface area in contact with surface frost. These two factors contribute to decreased freeze resistance as buds become more advanced phenologically (Howell and Wolpert 1978, Johnson and Howell 1981). Hardiness decreases 1.7 °C from scale crack to bud burst (Johnson and Howell 1981). Surface moisture on buds can further increase the threat of injury by causing bud mortality at warmer temperatures than if conditions were dry (Johnson and Howell 1981).

During the same season, buds more apical on a canes were found to suffer 28% more frost kill than those at basal positions (Wolpert and Howell 1984). This is because buds at apical positions were more phenologically advanced. Howell and Wolpert (1978) found that increasing the number of apical nodes after count node one and two would delay basal bud growth. Vine maturity is independent of injury caused by frost. Johnson and Howell (1981) found that buds on mature bearing vines, on young bearing vines and also on cuttings all experienced the same amount and level of injury when the buds were at the same phenological status.

Several choices can a facilitate reduction in frost damage; these include cultivar choice (Shaulis et al. 1968, Winkler et al. 1974), vineyard topography (Winkler et al. 1974), double pruning (Howell and Wolpert 1978, Shaulis et al. 1968, Winkler et al. 1974), late pruning (Shaulis et al. 1968, Loomis 1939, Winkler et al. 1974), spare parts (double trunks) (Shaulis et al. 1966), reduction of cover crop height (Dethier and Shaulis 1964), no-tillage cultivation (Howel 2003) and frost protection systems like overhead sprinkler irrigation (Winkler et al. 1974). Factors that increase the likelihood of winter and/or frost damage that cannot be controlled include short growing seasons (Shaulis et al. 1966) and warm weather prior to a frost (Howell 1988).

The industry is concerned mainly with frosts that cause economic loss. Evidence to date suggests that bud losses of 10% or less will have no measurable yield impact (Shaulis 1975, personal communication). Minimal bud mortality can be considered a crop thinning event and the vine may compensate for cluster number loss with increased cluster weight (Howell 2003). On the other hand, a large loss like 60% dead primary buds will decrease crop considerably. For example, consider a vineyard has 60% loss or dead primary buds. The remaining live secondary buds will produce 35% of what the primary would. Therefore the estimated crop will be, 40% + (60% * .35) = 61% of the initial crop.

The concept of sustainable yields is focused on gaining highest possible yields that will not hinder fruit ripening or vegetative growth and will do so over a period of years, returning a net profit (Howell 2001). Without the consideration of frost damage, net returns, perennial vine health and sustainability are at risk in cool climate. Negative impacts of frost injury are not limited to the frost season. Seasons following those with frost damage and injury have the potential for excessive cropping, due to substantial decreases in crop the previous year. This creates a situation where vine balance is not at equilibrium and extra management efforts, such as thinning, may be needed to bring the crop to an acceptable crop load. Extreme fluctuation in production is a challenge to processors also, creating a situation where either fruit is in excess or not sufficient for their processing capacity (Howell and Wolpert 1978).

In 2002, southwest Michigan's juice grape industry suffered two frosts occurring on 23 April and 21 May. These frosts had the greatest impact on juice grapes, Concord and Niagara. The first frost, being most detrimental, was evaluated for the purpose of this study. The week of warm summer-like weather prior to the frost initiated rapid shoot emergence that in turn increased injury to vines. The warm temperatures were then followed by two days of cold, wet and rainy weather, with day temperatures near 4°C (39°F) and night lows near freezing. A break in cloud cover created conditions optimal for a radiation frost. In the early morning on 23 April, temperatures dipped to -6°C (22°F).

Radiation frost occurs when the ground cools by heat lost to an open sky. When the air is still the layer of cold air becomes thicker and colder. As the cold air accumulates it can reach the budding area of the vine causing damage (Westwood 1993).

If vine tissue begins to radiate, its temperature can become less then that of the ambient air (Howell 2003).

Experimental Objectives:

1. Evaluate the interactions of different pruning and training methods with the occurrence of an early spring frost, in the season of the frost (year 1) and the subsequent season (year 2).
2. Determine pruning and training methods that result in the highest yields with acceptable sugar accumulation and vegetative growth in a season where there is economically significant frost damage.

Materials and Methods

Plant Material

The experiment was located in Michigan's Southwest corner, at two locations. The treatments were established in May 1999 at the Scottdale, Michigan location. The mature, bearing Niagara grapevines were planted in 1974 on a clay loam soil, were trained initially to Four Arm Kniffen and pruned to 70-80 nodes. The experimental treatments at the Benton Harbor location were established in the winter of 1996, on six-year-old vines, at the Michigan State University Southwest Michigan Research and Education Center (SWMREC). The vines were planted in Spinks sandy loam soil, trained initially to a high cordon system and pruned to about 65 nodes. At both locations vine spacing was 2.4m (8 feet) and row spacing was 3m (10 feet). The trellis height was 1.8m (6 feet) from the vineyard floor to the top wire. Vines were trained with double trunks for insurance to avoid devastating circumstances from winter kill.

The pest management program at both locations was based on scouting, experience and weather conditions. A combination of fungicides and insecticides (Appendix I, Table 1) used for control were rotated to avoid resistance. Fertilizing consisted of a post-bloom nitrogen application of 66 kg/hectare (60 lbs/acre) in the form of calcium nitrate or ammonium nitrate. In December 333 kg/hectare (300 lbs/acre) of potash was also applied at the Scottdale location. Vines at neither location were irrigated.

Dongvillo: Experimental Design and Treatments

The Scottdale location was the site of the single curtain (SC) treatments. It was designed as a randomized block/split-plot with multiple factors (training system and node level). Individual vines from eight rows were placed in blocks of three and replicated four times. The whole plot factor was a pruning treatment establishing 20, 40, 80 and 120 fixed nodes retained. The vines where hand pruned in mid December during the five years of data collection.

The subplot factor consisted of three, SC training systems, Hudson River Umbrella (HRU) (Figure 1 in Chapter I), Umbrella Kniffen (UK) (Figure 2 in Chapter I) and Hybrid (HYB) (Figure 1 in Chapter II). HRU and UK are familiar training systems to grape growers while HYB is a HRU system that retains 1-3 long canes similar to UK. This system was established in response to grower concern of cane breakage during mechanical harvesting of HRU trained vines.

Two treatments represented mechanical pruning methods, Minimally Pruned (MP) and Hedge (H). Trained to a basic high cordon system, these vines received simulated mechanical pruning every December. The MP treatment was established by trimming shoot growth at 76 cm (30") from the cordon wire. The H treatment was established by trimming growth up to a 15 cm (6") radius around the cordon wire.

SWMREC: Experimental Design and Treatments

The SWMREC location was the site of the Geneva Double Curtain (GDC) system (Figure 3 in Chapter I). This site had a completely randomized block design, with node level treatments as the variable. Four rows of vines established four replications, where each row contained all five nodes level treatments. Pruning was conducted during mid December and treatments of 20+20 balance pruned, 35 fixed nodes, 70 fixed nodes, 105 fixed nodes, minimally pruned (MP) and hedge (H) were applied at this time. Here, MP and H where obtained by using the same protocol administered at the Scottdale location.

Data Collected

Frost Evaluation

Frost injury was assessed on a node basis, in which viability or mortality was noted for the compound, primary and secondary buds. Shootless nodes (blind) had no growth. Nodes with dead primary buds were estimated to have 65% less production potential and those with dead primary and secondary buds were estimated to have 100% production loss. This data was used to estimate the viable buds that remained, which were called Functional Nodes Retained (FNR) (Appendix I; Figure 2).

$$FRN = \text{Initial Nodes Retained} - (\text{dead } 1^\circ + 2^\circ \text{ buds}) + ([\text{dead } 1^\circ - \text{dead } 2^\circ] * 0.35)$$

Node Numbers and Vine Size

Nodes retained were counted at the time of winter pruning. The weight of dormant cane prunings from each vine was used to express vine size or vegetative growth in a season. Vegetativeness (post-season vine size/nodes retained) was calculated to express the amount of vine growth related to the number of nodes retained.

Leaf Area

Leaf area was measured at three stages during the growing season, bloom (LA-bloom), 1200 growing degree days (growing degree days are the accumulation of average temperatures above 50°F) (LA-1200) and veraison (LA-Ver). LA-bloom was estimated first by measuring the length of five modal shoots per vine in the field. Fifteen shoots representing different lengths also were collected from the vineyard and taken back to campus for leaf area measurements using a LI-3100 area meter by Li-Cor, inc. (Lincoln, Nebraska). The leaf area of the shoots was plotted against the length of the shoot to acquire a regression and best-fit equation. This equation was used to estimate leaf area per shoot. Leaf area per shoot was multiplied by the shoot number to obtain leaf area per vine. LA-1200 and LA-Ver were estimated by the measured surface area of the vine's canopy (Appendix 1; Figure 1) and multiplied by 1.5 photosynthetic leaf layers (Smart and Robinson 1991).

The treatment comparison analysis for this study was based on LA-Ver. Previous work by Miller et al.. (1996) suggested that vines are not source limited prior to veraison, but can become so post-veraison. Therefore, the amount of leaf area from veraison to harvest was deemed crucial to the maturation of fruit as well as to carbohydrate accumulation and storage.

Reproductive Measurements

Yield and cluster number per vine were measured at harvest. Samples of 50 random berries also were collected and weighed at harvest for each treatment. These were used to calculate cluster weight, berry weight and berries per cluster. Fruitfulness (yield/nodes retained) described the amount of fruit an average node produced and is the reciprocal of vegetativeness. Crop load (yield/pre-season vine size) described the ratio of fruit that was carried to the size of vine it was carried on. Productivity (yield/post-season vine size), also called the Ravaz Index, described the ratio of reproductive to vegetative growth that occurred over the season, thereby providing an assessment of vine balance (Howell 2001).

Fruit Composition Measurements

The chemical composition of fruit was analyzed from the 50-count berry sample taken on the day of harvest and frozen for later date of berry analysis. Grape juice soluble solids were measured using a NAR IT Atago (Kirkland, WA) refractometer. Titratable acidity and pH were measured using a 370 Thermo Orion (Beverly, MA) pH meter. Titratable acidity (TA) was measured by titrating juice with 0.1M sodium hydroxide (NaOH) until a pH of 8.2 and using an equation to yield the TA (g/L).

TA (g/L) = 75 * Molarity of NAOH * (titre amount (mL)/volume of sample)

Statistical Methods

Comparisons between treatments were made using SAS statistical computer program (SAS Institute, Cary, NC). Single treatment comparisons for experiments I and II were analyzed using Least Significant Differences, with the proc glm function. Means separation was calculated by t-test (Sasha Kravchenko 2002, personal communication). Significance was taken from the type III p-value. Comparisons for experiment II also were analyzed with regression (Howell 2002, personal communication) using Microsoft Excell (USA).

Results and Discussion

Bud Mortality: Both locations suffered from loss of shootless nodes. SWMREC, with GDC trained vines, had up to 58% loss of primary and secondary shoots (Table 1). Scottdale vines were SC trained and had up to 53% total node loss for node level analysis (Table 2). Among the SC training systems at Scottdale there were no significant differences in total bud loss (Appendix II; Table 4).

Loss of 1° and 2° buds at a node was equated to a blind node, and was considered to have no reproductive potential. Vines with high node level treatments had the least percent total node loss and blind node loss, which is not surprising. These vines had the greatest initial nodes retained, which helped alleviate frost damage. This is the similar response expected when applying double pruning, where long canes are retained and then adjusted accordingly after the threat of frost (Howell and Wolpert 1978, Shaulis et al. 1968, Winkler et al. 1974). Concord plots at the same locations both received similar damage (Leah Clearwater 2004, personal communication).

Yield Loss and Location: There were large differences in injury between the two locations, which are obvious when comparing yield. The SWMREC location suffered greater losses, with 67% yield reduction in the MP treatment compared to year 2000 (Table 3). Year 2000 was considered a "normal" growing season without severe weather or pest damage; therefore it was used for comparison with the frost season. Scottdale suffered less with a maximum yield reduction of 25% in the 80 nodes retained treatment (Table 4). Interestingly, the Scottdale MP treatment had a 5.52-metric ton per hectare increase from the yield of 2000 (Table 4).

Differences in injury and yield reduction could be explained by mesoclimate or vineyard site (Westwood 1993, Winkler et al. 1974). The SWMREC vineyard was located at the bottom of a grade, creating a pocket where warm air radiates quickly and cold air slips down the slopes freely, and continues to accumulate. The Scottdale Niagara vineyard had higher elevation compared to the surrounding land, with good air drainage (Westwood 1995, Winkler et al. 1974).

Yield Loss and Training System: Canopy training system could also be a factor, affecting the amount of frost injury. The vines at SWMREC were trained to GDC with different node number levels, while those at Dongvillo had three different SC training systems and different node levels. Two of these training systems, HYB and HRU were significantly different in yield during the 2002 frost year. In all other growing season these treatments did not have significant yield differences (Table 5). At Scottdale, HYB (including all node level treatments) gained the highest yield despite the frost, with 14.77 metric tons per hectare (Table 5).

There are two physiological hypotheses why HYB was able to produce more yield after the injury of a radiation frost the morning of April 23, 2002. The first advantage that HYB had over the UK system was the retention of a cordon and therefore more two year and older wood. It has been suggested that with the retention of more perennial wood vines have the capacity to store more carbohydrates (Howell 2003a). When stressed, vines rely on stored carbohydrates to help compensate for stress induced losses. Healthy cordon trained (HRU) vines of other cultivars have also been shown to compensate for yield loss by growing fruitful, non-count shoots (Howell et al. 1987, 1991, Wolpert et al. 1983). Although clusters from non-count shoots tend to be weigh less (Smart et al. 1982a, Wolpert et al. 1983), they can still contribute valuable yield in a frost injury situation (Howell et al. 1987).

The HYB treatment also had a physiological advantage over the HRU system with the retention of 1-3 long 15-node canes. Longer canes have a tendency to express delayed bud development and therefore could be both less advanced phenologically and less susceptible to frost injury (Howell and Wolpert 1978). However, there were no significant node injury differences among the three SC treatments (see Appendix II Table 4). Therefore the increased yield cannot be contributed to less phenologically developed buds on the HBY.

The SWMREC vineyard had over a 50% reduction in yield for each node level treatment (Table 3), which suggests that nodes retained had minimal effect on the amount of injury caused. Rather the training system or the mesoclimate (site location) influenced the injury.

Effects in Year 2: In 2003 both locations experienced over cropping (Appendix II; Tables 5 and 10), which lead to difficulties in vine balance and ripening. Smart and Robinson (1991) suggest a yield:pruning weight ratio of 5:1 to 10:1. Over cropping, expressed through crop load, occurred in treatments with node levels above 70 fixed nodes at both locations (Appendix II; Tables 5 and 10). Although vegetative measurements suggest over cropping in 2003, the fruit at both locations ripened to processing standards (Appendix II; Tables 5 and 10).

Conclusions

Since the SC and GDC trained vines evaluated in this study were at different locations (Scottdale and SWMREC), the major impact on amount of bud mortality sustained must be attributed to meso climate (site). The SC site was characterized by higher elevation with regard to surrounding land as compared to the GDC site. This is the likely reason for greater percent primary, secondary and total bud loss of GDC vines pruned to similar node numbers as SC vines. This also lead to more functional nodes retained on SC vines. This difference was also the key component to higher yields from SC vines, nearly twice as much, as the GDC.

During 2002 there were statistical differences among yield from SC training systems (HRU, UK and HYB), which did not occur in the other five years. The yield from HYB was the best, while HRU was the poorest and UK intermediate. More data would help to fully understand if there was a yield advantage to the HYB system in the incidence of a frost. Among all treatments, minimally pruning provided the highest yield in 2002 in spite of buds lost to spring frost. The potential to use MP was coupled with mechanical crop reduction, which provided a means to overcome limits of frost and excess production in poor growing seasons.

Literature Cited

Bailey, L.H. 1917. Vitis. *In* Volume Six of The Standard Cyclopedia of Horticulture. pp. 3481-3492.. The Macmillan Company, New York.

Dethier, B.E., N.J. Shaulis. 1964. Minimizing the hazard of cold in New York vineyards. Cornell Extension Bulletin 1127.

Howell, G.S. 2001. Sustainable grape productivity and the growth-yield relationship: A review. Am. J. Enol. Vitic. 52:165-174.

Howell, G.S. 2003. Factors related to spring frost damage: What are the options. Michigan State University Program of Viticulture and Enology.

Howell, G.S., T.K. Mansfield, and J.A. Wolpert. 1987. Influence of training system, pruning severity and thinning on yield, vine size and fruit quality of Vidal blanc grapevines. Am. J. Enol. Vitic. 38:105-112.

Howell, G.S., D.P. Miller, C.E. Edson, and R.K. Striegler. 1991. Influence of training system and pruning severity on yield, vine size and fruit composition of Vignoles grapevines. Am. J. Enol. Vitic. 42:191-198.

Howell, G.S. and J.A. Wolpert. 1978. Nodes per cane, primary bud phenology, and spring freeze damage to Concord grapevines. A preliminary note. Am. J. Enol. Vitic. 29:229-232.

Howell, G.S., J.A. Wolpert, and T.K. Mansfield. 1982. Pruning Niagara grapevines for top yields and quality fruit. *In* Proceedings for the Michigan Grape Society. 4:1-23.

Johnson, D.E. and G.S. Howell. 1981. Factors influencing critical temperatures for spring freeze damage to developing primary shoots on Concord grapevines. Am. J. Enol. Vitic. 32:144-149.

Loomis, N.H. 1939. Note on grape foliation as affected by time of pruning. J. Amer. Soc. Hort. Sci. 37:653-654.

Miller, D.P., G.S. Howell, and J.A. Flore. 1996. Influence of shoot number and crop load on potted Chambourcin grapevines. I. Morphology and dry matter Partitioning. Am. J. Enol. Vitic. 47:380-388.

Shaulis, N.J., T.D. Jordan, and J. P.Tomkins. 1966. Cultural practices for New York vineyards. Cornell Extension. Bulletin 805.

Smart. R.E. and M. Robinson. 1991. Sunlight into Wine. Winetitles, Adelaide.

Smart, R.E., N.J. Shaulis and E.R. Lemon. 1982. The effect of Concord vineyard microclimate on yield. II. The interrelations between microclimate and yield expression. Am. J. Enol. Vitic. 33:109-116.

Winkler, A.J., J.A. Cook, W.M. Kliewer, L.A. Lider. 1974. General Viticulture. University of California Press, Berkeley.

Wolpert, J.A. and G.S. Howell. 1984. Effects of cane length and dormant season pruning data on cold hardiness and water content of Concord bud and cane tissues. Am. J. Enol. Vitic. 35:237-241.

Wolpert, J.A., G.S. Howell and T.K. Mansfield. 1983. Sampling Vidal blanc grapes. I. Effect of training system, pruning severity, shoot exposure, shoot origin, and cluster thinning on cluster weight and fruit quality. Am. J. Enol. Vitic. 34:72-76.

Table 1. 2002 Bud Mortality at Southwest Michigan Research and Extension Center (SWMREC) after a spring frost. The Niagara vines were trained to Geneva Double Curtain (GDC) and were subjected to different node level treatments, 20+20, 35. 70, 105, Hedge (H) and Minimally Pruned (MP).

		Node Level						
		20+20	35	70	105	Hedge	MP	P-value
Bud Mortality	Initial Nodes Retained	45 d	35 d	70 c	95 b	85 bc	171 a	0.0001
	Functional Nodes Retained[A]	23 d	19 d	34 cd	60 b	45 bc	114 a	0.0001
	% Total Node Loss	58 a	47 ab	51 ab	37 b	52 a	37 b	0.034
	% Blind Nodes[B]	14 a	7 b	5 b	5 b	5 b	4 b	0.0022
	% Dead 1° Buds	60	56	63	45	67	44	NS
	% Dead 2° Buds	11	9	11	6	8	10	NS

Key:
20+20=Balance Pruned (leave 20 nodes for the first pound of pruning weight and 20 nodes for every pound after)
H=Hedge (15cm radius)
MP=Minimally Pruned (76cm from top wire)
A: Functional Nodes Retained=A calculated node number that more accurately represents viable nodes retained in the instance of damaging weather episodes, like spring frost or winter kill.
FRN = Initial Nodes Retained - (dead 1° + 2° buds) + ([dead 1° - dead 2°] * 0.35)
B: Blind Nodes=Nodes that produce no shoot(s)

Table 2. 2002 Bud Mortality at Scottdale, MI location after a spring frost. The Niagara vines were trained to single canopy (SC) systems, Hudson River Umbrella (HRU), Umbrella Kniffen (UK) and Hybrid (H). The vines were also pruned to different node level treatments, 20, 40, 80, 120, Hedge (H) and Minimally Pruned (MP).

		Node Level						
		20	**40**	**80**	**120**	**Hedge**	**MP-C**	**P-value**
Bud Mortality	**Initial Nodes Retained**	20 f	40 e	78 d	107 c	124 b	181 a	0.0001
	Functional Nodes Retained[A]	9 e	24 d	50 c	74 b	77 b	134 a	0.0001
	% Total Node Loss	53 a	39 b	36 bc	31 bc	38 b	27 c	0.0001
	% Blind Nodes[B]	11 ab	12 a	7 bc	4 c	6 bc	6 c	0.0010
	% Dead 1° Buds	50 a	34 bc	37 bc	33 bc	42 a	28 c	0.0002
	% Dead 2° Buds	27 a	12 b	14 b	12 b	12 b	7 b	0.0001

Key:
H=Hedge (15cm radius)
MP-C=Minimally Pruned (76cm from top wire), without cluster thinning applied
HRU=Hudson River Umbrella (single canopy, cordon training system)
UK=Umbrella Kniffen (single canopy, head training system)
HYB=Hybrid (single canopy, cordon system with long canes)
A: Functional Nodes Retained=A calculated node number that more accurately represents viable nodes retained in the instance of damaging weather episodes, like spring frost or winter kill. FRN = Initial Nodes Retained - (dead 1° + 2° buds) + ([dead 1° - dead 2°] * 0.35)
B: Blind Nodes=Nodes that produce no shoot(s)

Table 3. Yield differences between 2000 and 2002 at the Southwest Michigan Research and Extension Center (SWMREC). A comparison between a "normal" Michigan season (2000) and a season suffering from frost injury (2002). The Niagara vines were trained to Geneva Double Curtain (GDC) and were subjected to different node level treatments, 20+20, 35. 70, 105, Hedge (H) and Minimally Pruned (MP).

	Node Level						
	20+20	**35**	**70**	**105**	**Hedge**	**MP**	**P-value**
Yield (mt/h) 2000	18.43 c	13.85 d	17.80 cd	19.26 bc	23.16 b	32.68 a	0.0001
Yield (mt/h) 2002	7.60 b	6.70 b	7.38 b	7.33 b	8.23 ab	10.65 a	0.0333
Yield Difference	10.83 bcd	7.15 d	10.42 cd	11.93 bc	14.93 b	22.03 a	0.0001
% Yield Reduction	59%	52%	59%	62%	64%	67%	NS

Key:
20+20=Balance Pruned (leave 20 nodes for the first pound of pruning weight and 20 nodes for every pound after)
H=Hedge (15cm radius)
MP=Minimally Pruned (76cm from top wire)

Table 4. Yield differences between 2000 and 2002 at the Scottdale location. A comparison between a "normal" Michigan season (2000) and a season suffering from frost injury (2002).. The Niagara vines were trained to single canopy (SC) systems, Hudson River Umbrella (HRU), Umbrella Kniffen (UK) and Hybrid (H). The vines were also pruned to different node level treatments, 20, 40, 80, 120, Hedge (H) and Minimally Pruned (MP).

	Node Level						
	20	**40**	**80**	**120**	**Hedge**	**MP-C**	**P-value**
Yield (mt/h) 2000	8.20 c	12.02 bc	20.60 a	20.35 a	20.98 a	15.80 b	0.0001
Yield (mt/h) 2002	7.33 d	9.73 d	15.36 c	18.72 b	18.83 b	21.32 a	0.0001
Yield Difference	0.87 b	2.29 b	5.24 b	1.63 b	2.15 b	+5.52 a	0.0130
% Yield Reduction	11%	19%	25%	8%	10%	0%	0.0019

Key:
H=Hedge (15cm radius)
MP-C=Minimally Pruned (76cm from top wire), without cluster thinning applied

Table 5: Yield for single curtain training system at the Scottdale location for 1999-2003. Significant yield differences between HRU and HYB only occurred in the frost year, 2002.

Training Systems	**Yield**				
	1999 mt/h	**2000 mt/h**	**2001 mt/h**	**2002 mt/h**	**2003 mt/h**
Umbrella Kniffen	19.82	17.53	6.99	12.26 bc	18.81
Hudson River Umbrella	18.99	13.05	7.6	11.32 c	19.01
Hybrid	24.17	15.31	7.69	14.77 b	18.49
ANOVA Significance	NS	NS	NS	0.0001	NS

Key:
H=Hedge (15cm radius)
MP control=Minimally Pruned (76cm from top wire with no cluster thinning applied)
HRU=Hudson River Umbrella (single curtain, cordon)
UK=Umbrella Kniffen (single curtain, head)
HYB=Hybrid (single curtain, cordon with long canes)

Table 6a and 6b. Scottdale measurements and calculations for 2002. Displayed as node level treatments in 6a and training system treatments in 6b.

Key:

MP=Minimally Pruned (76cm from top wire)

HRU=Hudson River Umbrella (single curtain, cordon)

UK=Umbrella Kniffen (single curtain, head)

HYB=Hybrid (single curtain, cordon with long canes)

T:FNR = Functional Nodes Retained, a calculated node number that more accurately represents viable nodes retained in the instance of damaging weather episodes, like spring frost or winter kill. Equation: Nodes Retained-Blind-2°-(1°-2°)+(0.333*(1°-2°))

U: **Nodes Retained (NR)** = Number of nodes per vine established during dormant pruning

V: Vine Size = Weight of dormant cane prunings per vine

W: Productivity = yield [kg]/post-season vine size [kg]

X: Fruitfulness = yield [kg]/nodes retained

Y: Crop Load=Yield (kg)/Pre-harvest Vine Size (kg)

Z: Leaf Area Ver. = leaf area at veraison was used to estimate vegetative growth. The amount of leaf area at veraison is important because it is at this stage the vine is most source limited (Miller et al 1996).

Table 6a. Scottdale measurements and calculations for node level treatments in 2002.

Parameters Measured or Calculated	Node Level						
	20	40	80	120	Hedge (12" radius)	MP	P-value
Functional Nodes Retained[T]	9 e	24 d	50 c	74 b	77 b	134 a	0.0001
Nodes Retained[U]	20 f	40 e	78 d	107 c	124 b	181 a	0.0001
Vine Size (kg)[V]	1.82 a	1.61 a	1.04 b	0.76 c	0.47 d	0.13 e	0.0001
Yield (kg/vine)	5.46 d	7.24 d	11.43 c	13.93 b	14.02 b	15.86 a	0.0001
Yield (mt/h)	7.33 d	9.73 d	15.36 c	18.72 b	18.83 b	21.32 a	0.0001
Clusters/ Vine	38 d	54 d	88 c	116 b	114 b	151 a	0.0001
Cluster Wt. (g)	148 a	137 ab	132 bc	121 cd	125 bc	108 d	0.0001
Berry Wt. (g)	4.37 a	4.38 a	4.16 bc	4.02 c	4.30 ab	3.69 d	0.0001
Berries/ Cluster	34 a	32 ab	31 ab	30 b	29 b	30 b	0.0417
SS (°Brix)	15.7 a	15.28 ab	15.12 bc	14.85 bc	13.15 c	14.84 c	0.0001
Sugar/Vine (kg)	0.86 d	1.10 d	1.72 c	2.04 b	1.86 bc	2.34 a	0.0001
pH	3.46 ab	3.47 a	3.12 bc	3.43 abc	3.40 c	3.38 c	0.0006
Titratable Acidity (g/L)	6.3 a	5.9 ab	6.2 a	5.7 b	5.7 b	6.0 ab	0.0061
Productivity (kg)[W]	3.58 c	5.39 c	13.08 c	33.35 b	46.86 b	99.48 a	0.0001
Fruitfulness (kg/node)[X]	0.452 a	0.228 b	0.171 bc	0.147 bc	0.146 bc	0.103 c	0.0001
Crop Load (kg)[Y]	4.57 c	5.92 c	16.29 bc	26.54 b	25.20 b	83.20 a	0.0001
Leaf Area Ver (m^2)[Z]	8.9	9.3	10.6	10.2	99.0	10.0	NS

Table 6b. Scottdale measurements and calculations for training system treatments in 2002.

		Training System			
		UK	HRU	HYB	P-value
Parameters Measured or Calculated	Functional Nodes Retained[T]	40	38	40	NS
	Nodes Retained[U]	60	60	63	NS
	Vine Size (kg)[V]	1.22	1.4	1.29	NS
	Yield (kg/vine)	9.12 bc	8.42 c	10.99 b	0.0001
	Yield (mt/h)	12.26 bc	11.36 c	14.77 b	0.0001
	Clusters/ Vine	71	67	83	NS
	Cluster Wt. (g)	134	135	134	NS
	Berry Wt. (g)	4.22	4.22	4.26	NS
	Berries/ Cluster	32	32	32	NS
	SS (°Brix)	15.29	15.36	15.06	NS
	Sugar/Vine (kg)	1.38	1.28	1.62	NS
	pH	3.43	3.44	3.46	NS
	Titratable Acidity (g/L)	6.0 ab	6.3 a	5.8 b	0.0316
	Productivity (kg)[W]	10.64	13.65	17.26	NS
	Fruitfulness (kg/node)[X]	0.227	0.243	0.277	NS
	Crop Load (kg)[Y]	11.86	11.19	16.92	NS
	Leaf Area Ver (m^2)[Y]	9.0	9.7	10.6	NS

Table 7. SWMREC measurements and calculations for 2002.
Key:
MP=Minimally Pruned (76cm from top wire)
20+20=Balance Pruned (20 nodes first lb and 20 nodes for every lb after)
T:FNR = Functional Nodes Retained, a calculated node number that more accurately represents viable nodes retained in the instance of damaging weather episodes, like spring frost or winter kill. Equation: Nodes Retained-Blind-2°-(1°-2°)+(0.333*(1°-2°))
U: Nodes Retained (NR) = Number of nodes per vine established during dormant pruning
V: Vine Size = Weight of dormant cane prunings per vine
W: Productivity = yield [kg]/post-season vine size [kg]
X: Fruitfulness = yield [kg]/nodes retained
Y: Crop Load=Yield (kg)/Pre-harvest Vine Size (kg)
Z: Leaf Area Ver. = leaf area at veraison was used to estimate vegetative growth. The amount of leaf area at veraison is important because it is at this stage the vine is most source limited (Miller et al 1996).

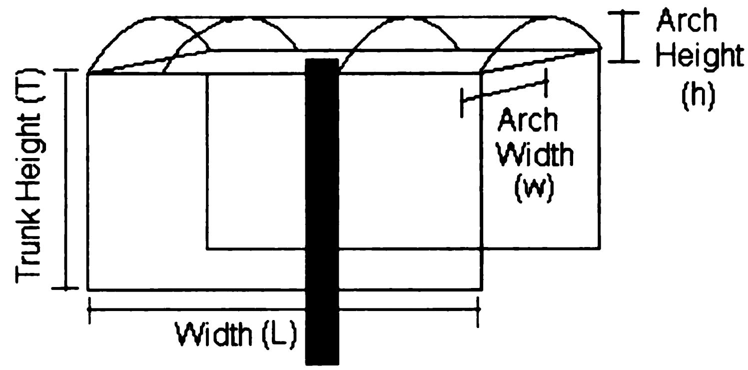
Table 7. SWMREC measurements and calculations for 2002.

	Node Level							
Parameters Measured or Calculated		**20+20**	**35**	**70**	**105**	**Hedge (12" radius)**	**MP**	**P-value**
	Functional Nodes Retained[T]	23 d	19 d	34 cd	60 b	45 bc	114 a	0.0001
	Nodes Retained[U]	45 d	35 d	70 c	95 b	85 bc	171 a	0.0001
	Vine Size (kg)[V]	1.04 b	1.62 a	0.77 b	0.70 bc	0.39 cd	0.21 d	0.0001
	Yield (kg/vine)	5.65 b	4.98 b	5.48 b	5.45 b	6.13 ab	7.92 a	0.0333
	Yield (mt/h)	7.60 b	6.70 b	7.38 b	7.33 b	8.23 ab	10.65 a	0.0333
	Clusters/ Vine	38 bc	34 c	45 bc	44 bc	50 ab	64 a	0.0021
	Cluster Wt. (g)	155 a	142 ab	123 b	124 b	123 b	125 b	0.003
	Berry Wt. (g)	4.51 a	4.63 a	4.23 b	4.54 a	4.56 a	4.12 b	0.0001
	Berries/ Cluster	35 a	31 ab	29 b	27 b	27 b	30 ab	0.0001
	SS (°Brix)	13.75 b	14.23 a	13.63 b	13.80 b	13.45 b	12.93 c	0.0001
	Sugar/Vine (kg)	0.77 ab	0.71 b	0.74 b	0.75 ab	0.01 a	0.83 ab	0.05
	pH	3.2	3.2	3.2	3.2	3.2	3.2	NS
	Titratable Acidity (g/L)	7.68 b	7.60 b	7.75 b	7.55 b	7.95 b	8.86 a	0.0002
	Productivity (kg)[W]	7.23 c	4.05 c	9.04 bc	13.34 bc	20.12 b	58.17 a	0.0001
	Fruitfulness (kg/node)[X]	0.436	0.384	0.462	0.18	0.316	0.106	NS
	Crop Load (kg)[Y]	9.57 c	4.31 c	10.07 c	11.07 c	23.00 b	54.99 a	0.0001
	Leaf Area Ver (m^2)[Z]	7.2 abc	7.2 abc	6.2 c	6.8 bc	7.8 ab	8.0 a	0.0076

APPENDIX I:
TABLES AND FIGURES REFERENCED IN TEXT

Table 1. Pesticides and rate used to manage Niagara vines at Southwest Michigan Research Extension Center and Scottdale.

Product	**Metric**	**English**
Abound	9.6 L/ha	12.8 oz/acre
Copper 65	11 mt/ha	2 lbs/acre
Daniton 2.4 EC	7.5 L/ha	10 oz/acre
Elite 45DF	22mt/ha	4 lbs/acre
Guthion 50WP	5.5mt/ha	1 lbs/acre
Imidan 70WP	9.6 mt/ha	1.8 lbs/acre
Penncozeb 75DF	22 mt/ha	4 lbs/acre
Ridomil Gold MZ68	8.25 mt/ha	1.5 lbs/acrs



$$SA\ bottom = 2(T*L)$$
$$SA\ arch = (\sqrt{[w^2+h^2]})*2*L$$

Figure 1. Grapevine surface area (SA), measurements and equation. Maximum leaf SA for SWMREC was approximately 15.6 m^2 and for Scottdale approximately 16.7 m^2.

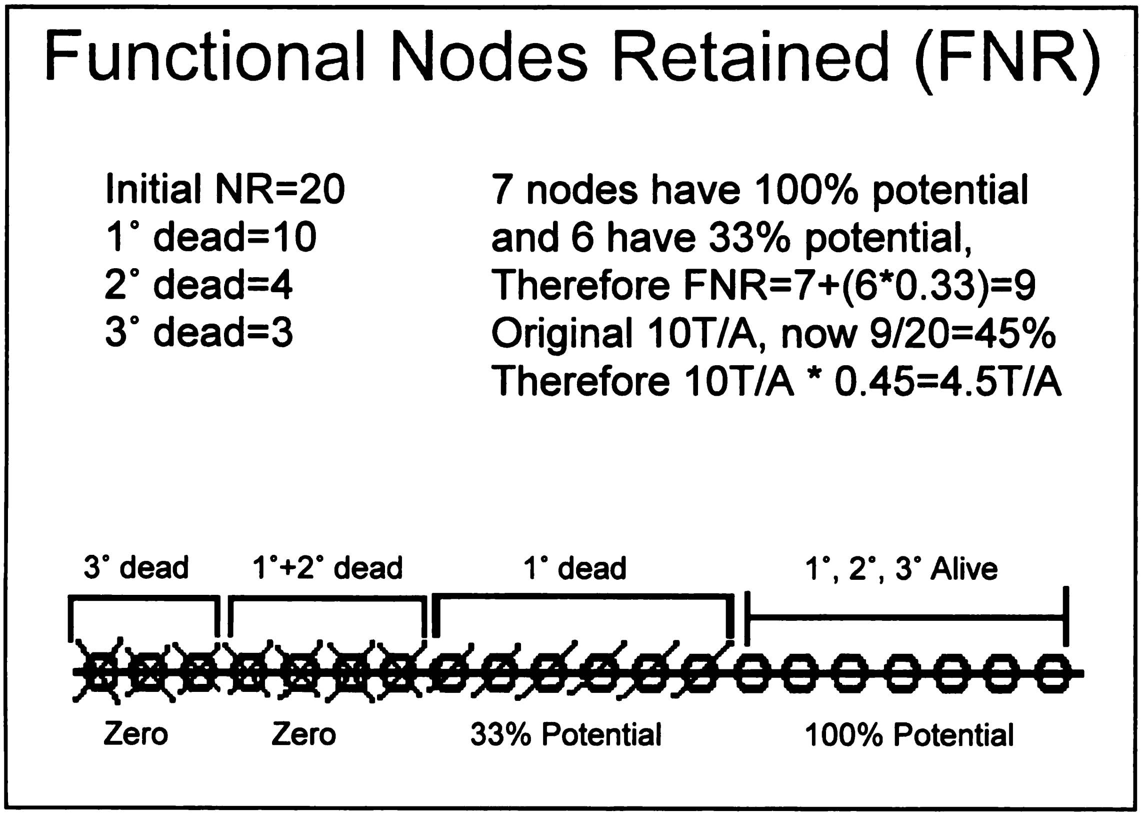


Figure 2. Example for calculating Functional Nodes Retained (FNR).

APPENDIX II:
SUMMARY OF ANNUAL PRODUCTION AND GROWTH AT SWMREC AND SCOTTDALE

Table 1.

Scottdale Niagara 1999 Growing Season Summary

Treatment	Nodes Retained	Yield/Vine (kg)	Yield Tons/Acre	Yield MTons/Hectare	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster	% Soluble Solids (brix)	pH	Titratable Acidity (g/L)
Training Systems											
Umbrella Kniffen	46 b	14.75	8.84	19.82	103	145	3.6	41	13.8 a	3.32	6.1
Hudson River Umbrella	49 b	14.12	8.47	18.99	100	144	3.6	41	13.8 a	3.35	6.0
Hybrid	49 b	17.98	10.78	24.17	105	164	3.6	46	13.6 a	3.31	5.7
Hedge (12" radius)	66 a	17.53	10.51	23.56	125	141	3.6	39	13.3 a	3.26	5.8
Minimally Pruned (control)	58 ab	16.07	9.63	21.59	114	144	3.6	41	12.2 b	3.27	5.9
P-value	0.0461	NS	NS	NS	NS	NS	NS	NS	0.0001	NS	NS
Node Level											
20 Nodes	20 d	10.12 c	6.07 c	13.61 c	68 c	149	3.7 a	40	15.2 a	3.34 b	5.9
40 Nodes	39 c	12.64 bc	7.58 bc	16.99 bc	86 b	147	3.7 a	40	14.7 a	3.44 a	5.9
80 Nodes	65 a	17.00 abc	10.19 abc	22.34 abc	125 a	137	3.5 b	39	12.8 bc	3.30 bc	5.7
120 Nodes	68 a	22.71 a	13.62 a	30.53 a	131 a	171	3.5 b	51	12.4 cd	3.23 d	6.3
Hedge (12" radius)	66 a	17.53 ab	10.51 ab	23.56 ab	125 a	141	3.6 ab	39	13.3 b	3.26 cd	5.8
Minimally Pruned (control)	58 b	16.07 abc	9.63 abc	21.54 abc	114 a	144	3.6 b	41	12.2 d	3.28 cd	6.0
P-value	0.0001	0.0031	0.0031	0.00	0.0001	NS	0.0005	NS	0.0001	0.0001	NS
Minimally Pruned Thinning Treatments											
Control	58	15.68	9.4	21.07	112	145	3.5	12	11.9	3.27	5.6 b
Thin 1	65	18.3	10.97	24.59	132	144	3.6	41	12.2	3.31	6.5 a
Thin 2	60	14.22	8.53	19.12	99	145	3.6	40	12.8	3.24	5.7 b
P-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0004
Training * Pruning											
Hybrid * 20	20 d	11.78 bc	7.06 bc	15.83 bc	79 bc	149	3.8 ab	39	15.8 a	3.34 ab	5.7 ab
Hybrid * 40	38 c	12.38 bc	7.42 bc	16.63 bc	89 bc	139	3.8 a	36	14.6 b	3.44 a	5.8 ab
Hybrid * 80	68 ab	16.01 ab	9.60 ab	21.52 ab	113 ab	142	3.6 b	39	12.6 d	3.33 ab	5.0 b
Hybrid * 120	69 a	17.45 a	10.45 a	23.43 a	133 a	142	3.4 b	42	11.9 d	3.14 c	6.3 a
HRU * 20	20 d	9.38 c	5.62 c	12.60 c	62 c	149	3.6 ab	42	15.3 ab	3.37 ab	5.7 ab
HRU * 40	40 c	11.17 bc	6.70 bc	15.02 bc	76 bc	146	3.6 b	40	14.7 b	3.44 a	6.1 a
HRU * 80	67 ab	17.04 a	10.22 a	22.91 a	129 a	135	3.4 b	40	12.4 d	3.30 b	6.0 a
HRU * 120	71 a	18.34 a	10.99 a	24.64 a	132 a	141	3.6 b	39	12.6 cd	3.28 b	6.3 a
UK * 20	20 d	8.90 c	5.34 c	11.97 c	62 c	143	3.7 ab	39	14.6 bc	3.32 ab	6.3 a
UK * 40	40 c	13.98 b	8.33 b	18.67 b	94 b	151	3.6 b	42	14.7 b	3.44 a	5.7 ab
UK * 80	61 b	18.05 a	10.82 a	24.26 a	133 a	136	3.6 b	38	13.5 c	3.26 bc	6.0 a
UK * 120	64 ab	17.49 a	10.49 a	23.52 a	125 a	145	3.4 b	43	12.5 d	3.27 b	6.3 a
Alpha Level	0.001	0.05	0.05	0.05	0.05	NS	0.05	NS	0.05	0.05	0.0.5

All letter groupings are significant = or < 0.05

Table 1 continued.

Scottdale 1999 Continued

Treatment	Post-Harvest Vine Size (kg)	Fruitfullness	Productivity	Vegetativness
Training Systems				
Umbrella Kniffen	1.17	0.346 ab	23.63	0.035
Hudson River Umbrella	1.27	0.323 ab	17.4	0.037
Hybrid	0.97	0.395 a	33.69	0.029
Hedge (12" radius)	1.13	0.266 b	19.04	0.017
Minimally Pruned (control)	0.93	0.267 b	22.99	0.016
P-value	NS	0.0353	NS	NS
Node Level				
20 Nodes	1.51 a	0.506 a	8.91 b	0.075 a
40 Nodes	1.37 ab	0.318 b	13.40 b	0.034 b
80 Nodes	0.92 cd	0.275 b	28.42 ab	0.014 c
120 Nodes	0.76 d	0.322 b	48.91 a	0.012 c
Hedge (12" radius)	1.13 bc	0.266 b	19.04 b	0.016 c
Minimally Pruned (control)	0.93 cd	0.267 b	22.99 b	0.016 c
P-value	0.0001	0.0001	0.0021	0.0001
Minimally Pruned Thinning Treatments				
Control	0.9	0.276	24.66	0.016
Thin 1	0.93	0.275	26.98	0.015
Thin 2	0.95	0.251	17.34	0.015
P-value	NS	NS	NS	NS
Training * Pruning				
Hybrid * 20	1.31 ab	0.59 a	10.20 bc	0.065 b
Hybrid * 40	1.17 b	0.32 cd	14.39 bc	0.030 cd
Hybrid * 80	0.75 bc	0.25 cd	30.68 ab	0.011 d
Hybrid * 120	0.66 c	0.25 cd	37.27 ab	0.010 d
HRU * 20	1.71 a	0.47 b	5.98 c	0.086 a
HRU * 40	1.26 ab	0.28 cd	16.51 bc	0.031 cd
HRU * 80	1.16 bc	0.24 d	21.39 bc	0.018 d
HRU * 120	0.95 bc	0.26 cd	25.03 b	0.014 d
UK * 20	1.51 ab	0.44 bc	10.29 bc	0.075 ab
UK * 40	1.67 a	0.35 c	8.88 bc	0.042 c
UK * 80	0.84 bc	0.30 cd	33.03 ab	0.014 d
UK * 120	0.67 bc	0.28 cd	41.39 a	0.011 d
Alpha Level	0.05	0.05	0.05	0.01

All letter groupings are significant = or < 0.05

Table 2.

Scottdale Niagara 2000 Growing Season Summary

Treatment	Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/Hectare	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster	% Soluble Solids (brix)	pH
Training Systems											
Umbrella Kniffen	55 b	1.17	13.05 ab	7.82 ab	17.53 ab	141	41.4 ab	3.9	32	13.0 b	3.22
Hudson River Umbrella	48 b	1.27	9.70 b	5.82 b	13.05 b	80	42.1 ab	3.8	32	13.7 a	3.22
Hybrid	51 b	0.97	11.39 b	6.83 b	15.31 b	75	44.6 a	3.8	33	13.3 ab	3.22
Hedge (12" radius)	72 a	1.13	15.61 a	9.36 a	20.98 a	128	45.0 a	3.7	33	13.0 b	3.2
Minimally Pruned (control)	77 a	0.93	11.76 b	7.05 b	15.80 b	109	37.34 b	3.8	30	13.8 a	3.19
P-value	0.0041	NS	0.0348	0.0348	0.0348	NS	0.0188	NS	NS	0.0017	NS
Node Level											
20 Nodes	20 d	1.51 a	6.11 c	3.66 c	8.20 c	45 b	40.7 ab	4.0 a	33	14.0 a	3.25 a
40 Nodes	40 c	1.37 ab	8.93 bc	5.36 bc	12.02 bc	112 a	43.9 a	3.9 ab	30	14.0 a	3.25 a
80 Nodes	67 b	0.92 cd	15.33 a	9.19 a	20.60 a	126 a	44.4 a	3.7 cd	33	12.9 b	3.23 ab
120 Nodes	79 a	0.76 d	15.14 a	9.08 a	20.35 a	141 a	41.7 ab	3.6 d	32	12.6 b	3.15 c
Hedge (12" radius)	72 ab	1.13 bc	15.61 a	9.36 a	20.98 a	128 a	44.7 a	3.7 cd	33	13.0 b	3.20 b
Minimally Pruned (control)	72 ab	0.93 cd	11.76 b	7.05 b	15.80 b	109 a	37.3 b	3.8 bc	30	13.8 a	3.19 bc
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0139	0.0302	0.0001	NS	0.0001	0.0001
Minimally Pruned Thinning Treatments											
Control	72 b	0.9	13.7	8.22	18.43	126	35.7	3.5	30	13.4	3.21
Thin 1	81 b	0.93	10.58	6.59	14.77	90	38	3.8	31	14.6	3.17
Thin 2	106 a	0.95	10.99	6.34	14.21	112	38.3	4	29	13.4	3.19
P-value	0.0206	NS	NS	NS	NS	NS	NS	0.0148	NS	0.0001	NS
Training * Pruning											
Hybrid * 20	20 e	1.31 ab	6.16 c	3.70 c	8.29 c	45 b	36.6 b	4.1 a	33 ab	14.1 ab	3.27 ab
Hybrid * 40	40 d	1.17 b	9.46 bc	5.67 bc	12.71 bc	68 b	50.6 a	3.7 bc	35 a	14.3 ab	3.23 bc
Hybrid * 80	67 bc	0.75 b	16.06 ab	9.63 ab	21.59 ab	132 ab	48.4 ab	3.7 bc	33 ab	12.3 cd	3.17 c
Hybrid * 120	77 b	0.66 b	13.85 b	8.31 b	18.63 b	138 ab	44.8 ab	3.6 bc	31 ab	12.7 cd	3.20 bc
HRU * 20	20 e	1.71 a	13.85 a	8.31 b	18.63 b	43 b	43.2 ab	4.0 ab	30 ab	14.0 ab	3.23 bc
HRU * 40	39 d	1.26 ab	7.84 c	4.70 c	10.54 c	70 b	39.3 b	3.8 b	29 ab	14.5 a	3.28 ab
HRU * 80	64 c	1.16 b	12.38 bc	7.42 bc	16.63 bc	97 ab	43.2	3.8 bc	33 ab	13.6 b	3.30 a
HRU * 120	68 bc	0.95 b	13.09 b	7.85 b	17.60 b	109 ab	42.6 ab	3.7 bc	33 ab	12.8 c	3.09 d
UK * 20	20 e	1.51 ab	6.67 c	4.00 c	8.97 c	47 b	42.2 ab	4.0 ab	37 a	14.0 ab	3.25 ab
UK * 40	40 d	1.69 a	9.25 bc	5.55 bc	12.44 bc	195 a	42.0 b	4.2 a	25 b	13.4 bc	3.24 b
UK * 80	69 bc	0.84 b	17.50 ab	10.49 ab	23.52 ab	148 ab	43.7 ab	3.8 bc	31 ab	12.6 cd	3.22 bc
UK * 120	92 a	0.66 b	18.49 a	11.08 a	24.84 a	176 ab	37.8 b	3.6 c	33 ab	12.1 d	3.16 c
Alpha Level	0.01	0.05	0.05	0.05	0.05	0.05	0.05	0.0001	0.05	0.05	0.05

All letter groupings are significant = or < 0.05

Table 2 continued.

Scottdale 2000 Continued

Treatment	Titratable Acidity (g/L)	Post-Harvest Vine Size (kg)	Fruitfulness	Crop-load	Vegetativeness	Productivity	Leaf Area Bloom (m^2)	Leaf Area 1200 (m^2)	Leaf Area Veraison (m^2)
Training Systems									
Umbrella Kniffen	7.4 a	0.62 a	0.257 a	22.99	0.019	42.48 ab	2.9	13.5	14.9
Hudson River Umbrella	7.3 a	0.69 a	0.216 a	16.54	0.023	32.75 b	2.6	11.7	13.0
Hybrid	7.3 a	0.62 a	0.244 a	18.61	0.02	37.92 b	2.6	12.6	13.5
Hedge (12" radius)	7.5 a	0.40 b	0.235 a	17.15	0.008	62.11 a	3.5	15.3	16.4
Minimally Pruned (control)	6.7 b	0.29 b	0.140 b	16.68	0.007	62.65 a	3.5	14.7	16.1
P-value	0.0066	0.0001	0.0001	NS	NS	0.0167	NS	NS	NS
Node Level									
20 Nodes	6.9 c	1.00 a	0.306 a	6.00 c	0.050 a	7.76 b	1.5 c	8.8 b	9.5 c
40 Nodes	7.8 a	0.82 a	0.224 b	11.48 c	0.021 b	17.78 b	2.6 b	12.8 a	13.6 b
80 Nodes	7.5 ab	0.39 b	0.229 b	26.93 ab	0.006 c	55.62 a	3.1 ab	13.6 a	14.9 ab
120 Nodes	7.2 bc	0.36 b	0.197 bc	33.12 a	0.006 c	71.61 a	3.6 a	15.2 a	16.7 a
Hedge (12" radius)	7.5 ab	0.40 b	0.235 b	17.15 bc	0.008 c	62.11 a	3.5 a	15.3 a	16.3 ab
Minimally Pruned (control)	7.1	0.29 b	0.140 c	16.68 bc	0.007 c	62.65 a	3.3 a	13.9 a	15.3 ab
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Minimally Pruned									
Thinning Treatments									
Control	7.1	0.33	0.176	19.64	0.007	70.96	3.3	13.9	15.3
Thin 1	6.8	0.28	0.133	14.2	0.004	51.57	3.9	16.3	18.6
Thin 2	6.3	0.26	0.110	16.21	0.003	65.42	4.2	15.2	17.8
P-value	NS	NS	NS	NS	NS	NS	NS	NS	NS
Training * Pruning									
Hybrid * 20	6.8 b	1.06 a	0.308	5.25 b	0.053 ab	6.72 c	1.5 d	9.1 c	9.9 c
Hybrid * 40	7.3 b	0.67 b	0.237	12.85 b	0.017 cd	18.00 c	2.4 c	12.9 bc	13.1 bc
Hybrid * 80	7.8 ab	0.46 bc	0.241	30.09 ab	0.007 d	61.48 bc	3.2 bc	13.4 b	13.9 bc
Hybrid * 120	7.2 bc	0.27 c	0.190	26.25 ab	0.004 d	65.48 b	3.4 b	14.8 ab	17.0 ab
HRU * 20	7.2 bc	1.07 a	0.275	3.51 b	0.054 a	6.85 c	1.8 cd	9.6 c	10.2 c
HRU * 40	7.6 b	0.86 ab	0.198	15.35 b	0.022 c	22.47 c	2.6 bc	11.6 bc	13.0 bc
HRU * 80	7.2 bc	0.27 c	0.191	16..19 b	0.004 d	44.22 bc	2.9 bc	13.1 bc	14.6 b
HRU * 120	7.4 b	0.55 bc	0.198	31.12 ab	0.010 d	54.98 bc	3.0 bc	12.5 bc	14.4 b
UK * 20	6.6 b	0.86 ab	0.333	9.25 b	0.043 b	9.72 c	1.3 d	7.7 c	8.4 c
UK * 40	8.4 a	0.96 a	0.230	5.89 b	0.024 c	11.37 c	2.6 bc	13.9 b	14.6 b
UK * 80	7.6 ab	0.49 bc	0.250	35.29 ab	0.007 d	47.29 bc	3.2 bc	14.3 b	16.3 b
UK * 120	7.0 bc	0.24 c	0.200	42.98 a	0.003 d	100.10 a	4.4 a	18.3 a	20.3 a
Alpha Level	0.001	0.01	NS	0.05	0.001	0.05	0.05	0.05	0.01

All letter groupings are significant = or < 0.05

Table 3.

Scottdale Niagara 2001 Growing Season Summary

Treatment	Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/Hectare	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster	% Soluble Solids (brix)	pH
Training Systems											
Umbrella Kniffen	57 c	0.62 a	5.21 b	3.12 b	6.99 b	122 c	41.4 ab	2.6 a	16	16.8 ab	3.53 bc
Hudson River Umbrella	59 c	0.69 a	5.65 ab	3.39 ab	7.60 ab	131 cb	42.8 ab	2.7 a	16	16.0 b	3.60 ab
Hybrid	60 c	0.62 a	5.72 ab	3.43 ab	7.69 ab	125 cb	44.6 a	2.6 a	17	17.0 a	3.54 abc
Hedge (12" radius)	93 b	0.40 b	7.05 a	4.23 a	9.48 a	153 b	45.0 a	2.7 a	16	16.4 ab	3.49 c
Minimally Pruned (control)	141 a	0.29 b	7.07 a	4.24 a	9.50 a	190 a	37.3 b	2.4 b	16	17.0 a	3.58 ab
P-value	0.0001	0.0001	0.0197	0.0197	0.0197	0.001	0.0188	0.0032	NS	0.0335	0.016
Node Level											
20 Nodes	20 e	1.00 a	3.01 c	1.81 c	4.06 c	71 d	40.7 ab	3.8 a	14.94	17.2 a	3.52 bc
40 Nodes	40 d	0.81 a	4.75 b	2.85 b	6.39 b	105 c	43.9 a	2.6 bc	17.12	16.7 a	3.60 ab
80 Nodes	76 c	0.39 b	7.01 a	4.20 a	9.42 a	157 b	44.4 a	2.7 ab	16.52	15.7 b	3.56 abc
120 Nodes	100 b	0.36 b	7.33 a	4.39 a	9.84 a	171 ab	41.7 ab	2.4 cd	17.39	16.9 a	3.56 ab
Hedge (12" radius)	93 b	0.40 b	7.05 a	4.23 a	9.48 a	157 b	44.7 a	2.7 ab	16.64	16.4 ab	3.49 c
Minimally Pruned (control)	141 a	0.29 b	7.07 a	4.24 a	9.50 a	189 a	37.3 b	2.4 d	14.94	17.0 a	3.58 ab
P-value	0.001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0302	0.0001	NS	0.0035	0.0372
Minimally Pruned Thinning Treatments											
Control	141	0.28	7.07	4.24	9.5	199	35.7	2.5	14.58	17.1	3.63 a
Thin 1	199	0.26	6.38	3.83	8.54	166	38	2.3	16.42	17.1	3.58 ab
Thin 2	174	0.33	7.77	4.66	10.45	204	38.3	2.4	16.01	16.7	3.54 b
P-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.0431
Training * Pruning											
Hybrid * 20	20 d	10.6 a	2.58 c	1.54 c	3.45 c	69 c	36.6 b	2.5 b	15 b	17.4 a	3.51 b
Hybrid * 40	40 c	0.67 b	5.44 b	3.26 b	7.31 b	105 bc	50.6 a	2.8 ab	18 ab	16.8 a	3.65 ab
Hybrid * 80	78 b	0.46 bc	7.50 a	4.50 a	10.09 a	166 a	48.4 ab	2.7 ab	17 ab	16.8 a	3.46 b
Hybrid * 120	102 a	0.29 c	7.36 ab	4.41 ab	9.89 ab	161 a	44.8 ab	2.3 b	19 a	16.8 a	3.56 ab
HRU * 20	20 d	10.7 a	4.12 bc	2.47 bc	5.54 bc	91 bc	43.2 ab	2.9 ab	16 ab	17.0 a	3.52 b
HRU * 40	39 c	0.86 ab	4.11 bc	2.46 bc	5.51 bc	101 bc	39.3 b	2.6 b	16 ab	16.6 a	3.66 ab
HRU * 80	75 b	0.27 c	6.84 ab	4.10 ab	9.91 ab	152 a	43.2	2.8 ab	16 b	13.6	3.71 a
HRU * 120	103 a	0.55 bc	7.52 a	4.51 a	10.11 a	180 a	42.6 ab	2.4 b	18 ab	16.9 a	3.51 b
UK * 20	20 d	0.83 ab	2.34 c	1.40 c	3.14 c	54 c	42.2 ab	3.0 a	14 b	17.2 a	3.53 b
UK * 40	40 c	0.92 ab	4.72 b	2.83 b	6.34 b	110 b	42.0 b	2.4 b	18 ab	16.6 a	3.49 b
UK * 80	74 b	0.45 bc	6.69	4.01 ab	8.99 ab	154 a	43.7 ab	2.6 b	17 ab	16.7 a	3.50 b
UK * 120	95 a	0.25 c	7.10 ab	4.26 ab	9.55 ab	171 a	37.8 b	2.5 b	15 b	17.0 a	3.60 ab
Alpha Level	0.001	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

All letter groupings are significant = or < 0.05

Table 3 continued.

Scottdale 2001 Continued

Treatment	Titratable Acidity (g/L)	Post-Harvest Vine Size (kg)	Fruitfullness	Crop-load	Vegetativeness	Productivity	Leaf Area Bloom (m^2)	Leaf Area 1200 (m^2)	Leaf Area Veraison (m^2)
Training Systems									
Umbrella Kniffen	4.83	1.33 a	0.100 ab	17.15 b	0.039 a	7.60 b	4.3 b	12.2 b	12.0 b
Hudson River Umbrella	4.63	1.31 a	0.118 a	15.43 b	0.037 a	6.86 b	4.4 b	13.2 b	12.5 b
Hybrid	4.75	1.17 ab	0.108 a	17.16 b	0.034 a	8.39 b	4.4 b	11.9 b	11.2 b
Hedge (12" radius)	4.88	0.90 b	0.077 b	27.89 a	0.011 b	12.60 b	5.3 ab	14.0 b	13.4 b
Minimally Pruned (control)	4.56	0.29 c	0.045 c	35.31 a	0.002 b	34.74 a	6.6 a	16.7a	16.7 a
P-value	NS	0.0001	0.0001	0.0001	0.0017	0.0001	0.01	0.01	0.001
Node Level									
20 Nodes	4.67	1.69 a	0.151 a	3.58 c	0.084 a	2.34 d	3.1 d	9.7d	9.0 c
40 Nodes	5.03	1.54 a	0.120 b	8.35 c	0.039 b	4.07 cd	4.1 dc	12.2 c	11.9 b
80 Nodes	4.73	1.01 b	0.092 c	25.21 b	0.013 c	10.72 bc	4.8 bc	13.2 bc	12.5 b
120 Nodes	4.57	0.84 b	0.072 cd	29.99 ab	0.009 cd	13.35 b	5.5 ab	14.7 ab	14.0 b
Hedge (12" radius)	4.88	0.90 b	0.078 c	27.89 ab	0.011 cd	12.60 b	5.3 b	14.0 bc	13.4 b
Minimally Pruned (control)	4.56	0.29 c	0.045 d	35.31 a	0.002 d	34.74 a	6.6 a	16.7 a	16.7 a
P-value	NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.001	0.001	0.001
Minimally Pruned Thinning Treatments									
Control	3.98 b	0.35	0.038	35.94	0.002	27.21	6.6	16.7	16.7
Thin 1	4.75 a	0.23	0.039	34.02	0.002	43.04	7.8	16.7	18.0
Thin 2	4.95 a	0.29	0.059	35.98	0.001	33.97	8.0	16.7	18.0
P-value	0.262	NS	NS	NS	NS	NS	NS	NS	NS
Training * Pruning									
Hybrid * 20	4.67 b	1.66 ab	0.129 b	2.72 c	0.083 a	1.67	3.3 fg	Not Available	16.1 de
Hybrid * 40	4.36 b	1.30 bc	0.137 b	9.23 c	0.033 c	4.76 b	4.0 def	"	20.8 cd
Hybrid * 80	5.20 ab	0.91 bc	0.096 bc	28.37 b	0.011 d	12.89 a	4.9 bcde	"	23.1 bc
Hybrid * 120	4.76 b	0.80 c	0.070 c	31.33 ab	0.008 d	14.24 a	5.4 abc	"	25.2 bc
HRU * 20	4.89 ab	1.74 ab	0.206 a	4.70 c	0.087 a	3.82 b	3.5 f	"	21.3 cd
HRU * 40	4.89 b	1.43 b	0.104 bc	9.72 c	0.036 bc	4.04 b	3.9 ef	"	20.6 cd
HRU * 80	4.07 b	1.13 bc	0.090 bc	30.73 ab	0.015 d	8.03 ab	4.6 bcdef	"	24.7 bc
HRU * 120	4.86 b	0.93 bc	0.072 c	18.98	0.009 d	11.54 a	5.6 ab	"	24.7 ab
UK * 20	4.45 b	1.67 ab	0.117 bc	3.32 c	0.083 a	1.51 b	2.4 g	"	14.1 e
UK * 40	5.85 a	1.88 a	0.119 bc	6.11 c	0.048 b	3.40 b	4.2 cdef	"	25.8 bc
UK * 80	4.94 ab	0.98 bc	0.091 bc	19.52 bc	0.013 d	11.24 ab	5.0 bcde	"	23.8 bc
UK * 120	4.11 b	0.80 c	0.073 c	31.33 ab	0.011 d	14.26 a	5.6 ab	"	27.0 ab
Alpha Level	0.05	0.05	0.05	0.05	0.001	0.05	0.01	"	0.01

All letter groupings are significant = or < 0.05

Table 4.

Scottdale Niagara 2002 Growing Season Summary

Treatment	Initial Nodes Retained	Functional Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/H	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster
Training Systems										
Umbrella Kniffen	60 c	40 c	1.33 a	9.12 bc	5.47bc	12.26 bc	71 c	134.2 a	4.2 a	32
Hudson River Umbrella	60 c	38 c	1.31 a	8.42 c	5.05 c	11.36 c	97 c	135.1 a	4.2 a	32
Hybrid	63 c	40 c	1.17 ab	10.99 b	6.59 b	14.77 b	83 c	134.3 a	4.3 a	32
Hedge (12" radius)	124 b	77 b	0.90 b	14.02 a	8.40 a	18.83 a	114 b	124.9 a	4.3 a	29
Minimally Pruned (control)	181 a	134 a	0.29 c	15.67 a	9.51 a	21.32 a	151 a	108.4 b	3.7 b	29
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	NS
Node Level										
20 Nodes	20 f	9 e	1.69 a	5.46 d	3.27 d	7.33 d	37.69 d	148.3 a	4.4 a	34 a
40 Nodes	40 e	24 d	1.54 a	7.24 d	4.34 d	9.73 d	53.83 d	136.8 ab	4.4 a	32 ab
80 Nodes	78 d	50 c	1.01 b	11.43 c	6.85 c	15.36 c	87.78 c	131.7 bc	4.2 bc	31 ab
120 Nodes	107 c	74 b	0.84 b	13.93 b	8.35 b	18.72 b	115.69 b	121.2 cd	4.0 c	30 b
Hedge (12" radius)	124 b	77 b	0.90 b	14.02 b	8.40 b	18.83 b	114.25 b	124.9 bc	4.3 ab	29 b
Minimally Pruned (control)	181 a	134 a	0.29 c	15.86 a	9.51 a	21.32 a	151.14 a	108.4 d	3.7 d	30 b
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0417
Minimally Pruned										
Thinning Treatments										
Control	181	134	0.29	17.02	10.2	22.87	170.58 a	106.8	3.7	29.14
Thin 1	223	173	0.35	14.53	8.71	19.53	128.42 b	113.4	3.7	30.63
Thin 2	250	177	0.23	16.05	9.62	21.57	154.42 ab	105	3.7	28.36
P-value	NS	NS	NS	NS	NS	NS	0.0218	NS	NS	NS
Training * Pruning										
Hybrid * 20	Not Available	16 c	1.66 ab	7.13 d	4.27 d	9.57 d	51 de	141.8 ab	4.5 a	31.56 b
Hybrid * 40	"	34 d	1.30 bc	8.35 cd	5.01 cd	11.23 cd	68 cd	122.2 b	4.4 ab	28.03 b
Hybrid * 80	"	66 c	0.91 bc	12.49 b	7.49 b	16.79 b	82 c	142.6 ab	4.2 b	33.80 ab
Hybrid * 120	"	105 a	0.80 c	15.99 a	9.59 a	21.50 a	125 a	130.7 ab	3.9 c	33.25 ab
HRU * 20	"	12 c	1.74 ab	5.03 d	3.01 de	6.75 de	33 e	153.4 a	4.2 b	36.32 a
HRU * 40	"	32 d	1.43 b	4.91 d	2.94 de	6.59 de	35 e	145.0 ab	4.5 ab	32.14 ab
HRU * 80	"	67 c	1.13 bc	10.10 c	6.06 c	13.58 c	89 bc	125.3 b	4.2 bc	30.11 b
HRU * 120	"	98 ab	0.93 bc	13.66 b	8.19 b	18.36 b	119 ab	116.6 b	4.0 c	29.44 b
UK * 20	"	14 c	1.67 ab	4.22 e	2.53 e	5.67 e	29 e	149.9 ab	4.3 b	34.72 ab
UK * 40	"	34 d	1.88 a	8.48 cd	5.08 cd	11.39 cd	59 d	143.4 ab	4.3 b	33.60 ab
UK * 80	"	70 bc	0.98 bc	11.69 bc	7.01 bc	15.71 bc	93 bc	127.4 b	4.1 bc	30.99 b
UK * 120	"	89 b	0.80 c	12.13 bc	7.27 bc	16.30 bc	103 b	116.4 b	4.2 b	28.04 b
Alpha Level	"	0.001	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

All letter groupings are significant = or < 0.05

Table 4 continued.

Scottdale 2002 Continued

Treatment	% Soluble Solids (brix)	pH	Tiratable Acidity (g/L)	Post-Harvest Vine Size (kg)	Fruitfull-ness	Crop-load	Vegeta-tiveness	Produc-tivity	Leaf Area Bloom (m^2)	Leaf Area 1200 (m^2)	Leaf Area Veraison (m^2)
Training Systems											
Umbrella Kniffen	15.3 a	3.43 abc	6.01 ab	1.22 a	0.227 ab	11.86 b	0.052 ab	10.64 c	3.1 b	9.0 c	9.0
Hudson River Umbrella	15.4 a	3.44 ab	6.25 a	1.40 a	0.243 ab	11.19 b	0.075 a	13.65 c	3.3 b	9.7 bc	9.7
Hybrid	15.1 ab	3.46 a	5.78 b	1.29 a	0.277 a	16.92 b	0.048 ab	17.26 c	3.4 b	10.4 ab	10.6
Hedge (12" radius)	13.2 c	3.40 bc	5.70 b	0.47 b	0.146 bc	25.20 b	0.006 b	46.86 b	4.6 ab	10.4 ab	99.9
Minimally Pruned (control)	14.7 b	3.38 c	5.97 ab	0.13 c	0.103 c	81.20 a	0.001 b	99.48 a	5.6 a	11.0 a	10.0
P-value	0.0001	0.0026	0.0316	0.0001	0.047	0.0001	0.0251	0.0001	0.05	0.05	NS
Node Level											
20 Nodes	15.7 a	3.46 ab	6.29 a	1.82 a	0.452 a	4.57 c	0.158 a	3.58 c	2.2 b	8.6 c	8.9
40 Nodes	15.3 ab	3.47 a	5.89 ab	1.61 a	0.228 b	5.92 c	0.052 b	5.39 c	2.6 b	9.2 bc	9.3
80 Nodes	15.1 bc	3.12 bc	6.19 a	1.04 b	0.171 bc	16.29 bc	0.016 bc	13.08 c	3.8 b	10.3 ab	10.7
120 Nodes	14.9 bc	3.43 abc	5.68 b	0.76 c	0.147 bc	26.54 b	0.009 c	33.35 b	4.5 b	10.2 ab	10.2
Hedge (12" radius)	13.2 c	3.40 c	5.70 b	0.47 d	0.146 bc	25.20 b	0.006 c	46.86 b	4.6 b	10.4 ab	9.9
Minimally Pruned (control)	14.8 c	3.38 c	5.97 ab	0.13 e	0.103 c	83.20 a	0.001 c	99.48 a	5.6 a	11.0 a	10.0
P-value	0.0001	0.0006	0.0061	0.0001	0.0001	0.0001	0.0001	0.0001	0.001	0.001	NS
Minimally Pruned Thinning Treatments											
Control	13.9 b	3.33 b	6.1	0.14	0.103 a	78.52 ab	0.0010	104.76	9.3 a	11.3	9.6
Thin 1	15.1 a	3.43 a	6.05	0.09	0.073 b	53.08 b	0.0004	99.58	3.8 b	11.0	10.1
Thin 2	15.1 a	3.40 a	5.75	0.16	0.072 b	112.01 a	0.0007	94.13	4.7 b	10.8	10.2
P-value	0.0001	0.0088	NS	NS	0.0027	0.011	NS	NS	0.05	NS	NS
Training * Pruning											
Hybrid * 20	15.6 b	3.48 ab	6.05 b	1.75 ab	0.494 a	4.58 c	0.116 bc	4.65 b	2.2 ab	8.9 b	9.7 b
Hybrid * 40	15.2 bc	3.50 a	5.80 b	1.73 ab	0.270 bc	7.68 c	0.0555 c	5.36 b	2.2 ab	8.9 bc	9.0 ab
Hybrid * 80	14.9 c	3.43 ab	5.75 b	1.08 c	0.192 bc	20.50 b	0.0168 c	13.00 b	3.9 ab	10.5 c	9.8 b
Hybrid * 120	14.6 c	3.43 ab	5.48 b	0.61 d	0.154 c	34.94 a	0.0058 c	46.03 a	5.1 bc	10.3 c	10.3 b
HRU * 20	15.4 bc	3.45 ab	6.68 ab	2.08 a	0.523 a	6.33 c	0.218 a	2.84 b	2.6 ab	9.7 bc	9.3 ab
HRU * 40	15.4 bc	3.50 a	6.20 ab	1.64 ab	0.155 c	4.78 c	0.0561 c	3.68 b	2.5 ab	10.7 c	10.4 b
HRU * 80	15.8 ab	3.43 ab	6.10 b	1.15 c	0.150 c	11.21 bc	0.0175 c	9.50 b	4.0 ab	10.4 c	12.8 c
HRU * 120	14.9 bc	3.40 b	6.03 b	0.75 cd	0.145 c	22.45 b	0.0091 c	38.60 ab	4.4 ab	9.9 bc	9.9 b
UK * 20	16.2 a	3.45 ab	6.15 ab	1.62 b	0.337 b	2.76 c	0.141 b	3.26 b	1.7 a	7.3 a	7.5 a
UK * 40	15.2 bc	3.40 b	5.68 b	1.46 bc	0.260 bc	5.30 c	0.0435 c	7.14 b	3.1 ab	8.0 ab	8.6 ab
UK * 80	14.7 c	3.40 b	6.73 a	0.89 cd	0.170 bc	17.16 bc	0.0128 c	16.75 b	3.9 ab	10.2 bc	9.6 ab
UK * 120	15.1 bc	3.45 ab	5.53 b	0.93 cd	0.142 c	22.23 b	0.0106 c	15.42 b	3.8 ab	10.4 c	10.3 b
Alpha Level	0.05	0.05	0.05	0.05	0.01	0.05	0.01	0.05	0.01	0.05	0.05

All letter groupings are significant = or < 0.05

Table 5.

Scottdale Niagara 2003 Growing Season Summary

Treatment	Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/Hectare	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster	% Soluble Solids (brix)	pH
Training Systems											
Umbrella Kniffen	65 b	1.22 a	14.00 b	8.39 b	18.81 b	142 b	100.6	3.7 a	30	14.0 a	3.78 ab
Hudson River Umbrella	62 b	1.4 a	14.14 b	8.48 b	19.01 b	145 b	101.1	3.7 a	28	13.6 ab	3.13 a
Hybrid	62 b	1.29 a	13.75 b	8.25 b	18.49 b	135 b	100.8	3.7 a	28	13.9 a	3.13 a
Hedge (12" radius)	151 a	0.47 b	23.07 a	13.83 a	31.00 a	256 a	92.2	3.1 b	30	11.9 c	3.02 b
Minimally Pruned (control)	145 a	0.18 b	18.96 a	11.37 a	25.49 a	218 a	100.7	3.3 b	31	12.7 bc	3.01 b
P-value	0.0001	0.0001	0.0002	0.0002	0.0002	0.0001	NS	0.0001	NS	0.001	0.0007
Node Level											
20 Nodes	20 e	1.82 a	6.09 e	3.65 e	8.18 e	62 e	97.4	3.8 a	25	15.9 a	3.17 a
40 Nodes	40 d	1.61 a	10.96 d	6.57 d	14.73 d	105 d	104.1	4.0 a	26	14.5 b	3.14 ab
80 Nodes	77 c	1.04 b	17.87 c	10.71 c	24.01 c	174 c	104.1	3.6 b	29	12.7 c	3.05 cd
120 Nodes	115 b	0.76 bc	20.93 ab	12.55 ab	28.13 ab	221 b	97.7	3.2 cd	31	12.3 cd	3.10 bc
Hedge (12" radius)	145 a	0.47 cd	23.07 a	13.82 a	30.98 a	256 a	92.2	3.1 d	30	11.9 d	3.02 d
Minimally Pruned (control)	151 a	0.18 d	18.96 bc	11.37 bc	25.49 bc	218 b	100.6	3.3 c	31	12.7 c	3.01 d
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	NS	0.0001	NS	0.0001	0.0001
Minimally Pruned											
Thinning Treatments											
Control	138	0.155	18.12 a	10.86 a	24.34 a	204 a	102.8	3.3	31	12.7 bc	3.01 b
Thin 1	169	0.142	17.16 a	10.29 a	23.07 a	208 a	83.6	3.4	24	14.6 a	3.06 b
Thin 2	162	0.199	13.09 b	7.85 b	17.60 b	143 b	94.4	3.5	27	13.2 b	3.14 a
P-value	NS	NS	0.0268	0.0268	0.0268	0.036	NS	NS	NS	0.0087	0.0004
Training * Pruning											
Hybrid * 20	20 f	1.75 ab	5.27 d	3.16 d	7.08 d	54 e	91.5	3.9 b	24	16.1 a	3.12 bc
Hybrid * 40	40 e	1.73 a	11.72 c	7.03 c	15.76 c	114 d	102.9	4.1 a	25	15.0 b	3.15 b
Hybrid * 80	73 d	1.08 c	17.47 b	10.47 b	23.47 b	166 c	105.1	3.6 bc	30	12.4 d	3.06 bc
Hybrid * 120	115 b	0.61 c	20.55 ab	12.32 ab	27.62 ab	205 b	103.8	3.3 c	32	12.2 d	3.18 ab
HRU * 20	20 f	2.08 a	3.47 d	3.88 d	8.70 d	68 e	102	3.8 b	27	15.5 b	3.28 a
HRU * 40	40 e	1.64 a	11.84 c	7.10 c	15.92 c	109 d	107.6	3.9 b	28	13.6 c	3.13 bc
HRU * 80	80 c	1.45 b	17.70 b	10.61 b	23.78 b	185 bc	96.5	3.7 b	26	12.8 cd	3.04 bc
HRU * 120	110 b	0.75 c	20.56 ab	12.32 ab	27.62 ab	218 ab	98.4	3.3 c	31	12.7 cd	3.08 bc
UK * 20	19 f	1.62 b	6.53 d	3.92 d	8.79 d	66 e	98.6	3.8 b	26	16.2 a	3.11 bc
UK * 40	40 e	1.46 b	9.33 cd	5.59 cd	12.53 cd	92 de	101.9	4.0 ab	26	15.0 b	3.13 bc
UK * 80	79 c	0.89 c	18.45 ab	11.06 ab	24.79 ab	171 bc	110.7	3.6 bc	31	12.9 c	3.04 bc
UK * 120	120 a	0.93 c	21.70 a	13.01 a	29.16 a	241 a	91	3.2 c	30	12.1 d	3.03 c
Alpha Level	0.001	0.05	0.01	0.01	0.01	0.01	NS	0.01	NS	0.001	0.05

All letter groupings are significant = or < 0.05

Table 5 continued.

Scottdale Niagara 2003 Continued

Treatment	Titratable Acidity (g/L)	Post-Harvest Vine Size (kg)	Fruitfull-ness	Crop-load	Vegeta-tiveness	Produc-tivity	Leaf Area Bloom (m^2)	Leaf Area 1200 (m^2)	Leaf Area Veraison (m^2)
Training Systems									
Umbrella Kniffen	7.67	0.78 a	0.251 ab	11.46 c	0.023 a	35.25 b	5.7 c	7.7	9.2
Hudson River Umbrella	7.94	0.85 a	0.259 a	10.10 c	0.026 a	50.47 b	5.2 c	8.3	9.7
Hybrid	7.81	0.91 a	0.247 ab	10.66 c	0.028 a	41.92 b	5.2 c	9.3	9.7
Hedge (12" radius)	8.05	0.29	0.184 bc	49.09 b	0.002 b	127.91	9.0 a	12.6	9.0
Minimally Pruned (control)	7.85	0.26	0.136 c	105.33 a	0.002 b	134.95 a	8.8 b	10.4	9.5
P-value	NS	0.0004	0.0045	0.0001	0.003	0.0001	0.0001	NS	NS
Node Level									
20 Nodes	8.00 a	1.23 a	0.314 a	3.35 d	0.063 a	7.15 d	1.7 e	7.0 b	9.3
40 Nodes	7.72 ab	1.15 a	0.274 ab	6.81 d	0.029 b	15.64 d	3.6 d	7.7 ab	9.8
80 Nodes	7.92 ab	0.65 b	0.237 bc	17.18 d	0.008 c	47.40 c	6.7 c	8.7 ab	9.6
120 Nodes	7.59 b	0.37 c	0.184 cd	27.53 c	0.003 c	100 b	9.4 b	10.2 a	9.4
Hedge (12" radius)	8.05 a	0.29 c	0.184 cd	49.09 b	0.002 c	127.91 ab	9.0 ab	12.6 a	9.1
Minimally Pruned (control)	7.85 ab	0.26 c	0.136 d	105.33 a	0.002 c	134.95 a	8.8 ab	10.5 b	9.5
P-value	0.0356	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.05	NS
Minimally Pruned Thinning Treatments									
Control	7.84 a	0.27	0.137 a	105.33 a	0.002	124.67	8.8 a	10.5	10.0
Thin 1	7.35 b	0.17	0.108 ab	120.80 a	0.003	125.38	8.8 a	12.5	10.4
Thin 2	6.64 c	0.33	0.085 b	65.78 b	0.002	82.83	3.3 b	12.6	9.5
P-value	0.0001	NS	0.0066	0.0057	NS	NS	0.0001	NS	NS
Training * Pruning									
Hybrid * 20	7.99 ab	1.34 ab	0.263 b	3.50 c	0.068 a	4.79 c	1.7 e	7.5 c	10.1 a
Hybrid * 40	7.86 ab	1.21 ab	0.293 ab	7.58 bc	0.033 c	12.24 c	3.4 d	8.25 bc	9.9 a
Hybrid * 80	7.56 b	0.74 bc	0.257 b	18.00 bc	0.010 d	28.40 c	6.7 c	8.7 b	10.0 a
Hybrid * 120	7.48 ab	0.26 c	0.177 b	55.29 a	0.002 d	122.80 a	9.0 b	12.9 a	9.1 a
HRU * 20	8.04 a	1.37 a	0.323 ab	3.17 c	0.069 a	6.25 c	1.7 e	7.6 c	9.6 a
HRU * 40	7.79 ab	0.96 bc	0.296 ab	8.88 bc	0.024 cd	12.24 c	3.6 d	7.8 bc	10.0 a
HRU * 80	8.20 a	0.63 bc	0.221 b	16.63 bc	0.008 d	69.11 b	6.3 c	8.8 b	9.6 a
HRU * 120	7.74 ab	0.45 c	0.194 b	53.74 a	0.004 d	104.84 ab	9.1 b	8.9 b	9.6 a
UK * 20	7.98 ab	0.98 b	0.356 a	5.27 c	0.053 b	10.41 c	1.8 e	5.9 d	8.3 b
UK * 40	7.52 b	1.20 ab	0.233 b	7.33 bc	0.029 c	13.81 c	3.8 d	7.2 c	9.6 a
UK * 80	8.00 a	0.59 c	0.233 b	27.89 b	0.007 d	44.22 bc	7.1 c	8.7 b	9.4 a
UK * 120	7.18 b	0.40 c	0.181 b	27.08 bc	0.003 d	72.37 b	10.1 a	8.9 b	9.5 a
Alpha Level	0.01	0.05	0.05	0.05	0.01	0.01	0.05	0.05	0.01

All letter groupings are significant = or < 0.05

Table 6.

SWMREC Niagara 1999 Growing Season Summary

Treatment	Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/Hectare	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster
Node Level									
20+20 (control)	38 c	0.60 b	15.95	9.57	21.45	115 c	137.8 ab	3.9 a	36
35 Nodes	35 c	0.88 a	15.52	9.32	20.84	107 c	145.9 a	3.8 a	38
70 Nodes	70 b	0.52 bc	15.49	9.3	20.85	122 bc	127.3 bc	3.7 b	35
105 Nodes	97 a	0.39 bcd	18.1	10.87	24.37	149 ab	123.7 c	3.5 c	36
Hedge (12" radius)	85 ab	0.26 cd	18.42	11.05	24.77	153 a	121.4 c	3.6 b	34
Minimally Pruned	79 b	0.25 d	16.69	10.01	22.44	132 abc	129.2 bc	3.7 b	35
P-value	0.001	0.0001	NS	NS	NS	0.0036	0.0002	0.0001	NS

Treatment	% Soluble Solids (brix)	Titratable Acidity (g/L)	Post-Harvest Vine Size (kg)	Fruitfull-ness	Crop-load	Vegeta-tiveness	Produc-tivity
Node Level							
20+20 (control)	11.4 d	5.90 d	0.88 ab	0.485 a	43.22 cd	0.0220 a	27.40 c
35 Nodes	13.2 bc	6.20 cd	1.00 a	0.443 a	25.16 d	0.0285 a	19.17 c
70 Nodes	14.1 a	6.40 cd	0.65 bcd	0.221 b	46.08 cd	0.0093 b	27.34 c
105 Nodes	12.5 c	6.70 bc	0.50 cd	0.189 b	65.24 bc	0.0052 b	64.44 ab
Hedge (12" radius)	13.5 ab	7.20 ab	0.70 abc	0.256 b	94.06 ab	0.0106 b	39.71 bc
Minimally Pruned	13.0 bc	7.60 a	0.36 d	0.225 b	110.46 a	0.0049 b	73.41 a
P-value	0.0001	0.0001	0.001	0.0001	0.001	0.0001	0.0001

Table 7.
SWMREC Niagara 2000 Growing Season Summary

Treatment	Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/Hectare	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster
Node Level									
20+20 (control)	46 cd	0.88 ab	13.70 c	8.22 c	18.43 c	121 c	114.1 ab	4.0 a	28 b
35 Nodes	35 d	1.00 a	10.30 d	6.18 d	13.85 d	84 d	124.1 a	3.9 b	32 a
70 Nodes	69 c	0.65 bcd	13.23 cd	7.94 cd	17.80 cd	129 c	103.9 bc	3.6 c	29 b
105 Nodes	105 b	0.50 cd	14.31 bc	8.59 bc	19.26 bc	146 c	97.7 c	3.7 c	26 bc
Hedge (12" radius)	117 b	0.70 abc	17.21 b	10.33 b	23.16 b	183 b	96.6 c	3.5 d	28 b
Minimally Pruned	215 a	0.36 d	24.29 a	14.58 a	32.68 a	306 a	81.1 d	3.4 d	24 c
P-value	0.0001	0.001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002

Treatment	% Soluble Solids (brix)	Titratable Acidity (g/L)	Post-Harvest Vine Size (kg)	Fruitfull-ness	Crop-load	Vegeta-tiveness	Produc-tivity
Node Level							
20+20 (control)	10.9 c	7.30 b	1.06 b	0.336 a	24.09 bc	0.0231 b	14.68 cd
35 Nodes	12.3 a	6.70 cd	1.45 a	0.294 a	13.77 c	0.0413 a	8.85 d
70 Nodes	12.0 ab	6.10 d	0.82 bc	0.190 b	23.30 bc	0.0119 c	22.16 bcd
105 Nodes	11.4 bc	6.90 bc	0.74 bc	0.136 bc	46.10 b	0.0070 cd	27.23 bc
Hedge (12" radius)	9.3 d	6.60 cd	0.73 bc	0.175 bc	42.00 b	0.0068 cd	30.92 b
Minimally Pruned	8.5 d	9.10 a	0.68 c	0.124 c	108.18 a	0.0035 d	54.19 a
P-value	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001

Table 8.

SWMREC Niagara 2001 Growing Season Summary

Treatment	Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/Hectare	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster	% Soluble Solids (brix)	pH
Pruning Systems											
20+20 (control)	38 d	1.06 b	4.13 c	2.48 c	5.56 c	76 c	56.7 a	3.4 b	17 a	14.4 a	3.24 d
35 Nodes	35 d	1.45 a	3.27 c	1.96 c	4.39 c	68 c	48.6 b	3.6 a	14 bc	14.2 a	3.31 c
70 Nodes	70 c	0.82 bc	7.12 b	4.27 b	9.57 b	136 b	51.5 ab	2.9 c	18 a	14.2 ab	3.26 d
105 Nodes	101 b	0.74 bc	7.58 b	4.55 b	10.20 b	148 b	51.1 ab	3.6 a	14 bc	13.6 c	3.36 b
Hedge (12" radius)	101 b	0.73 bc	8.05 b	4.83 b	10.83 b	147 b	54.9 a	3.5 a	16 ab	14.1 ab	3.46 a
Minimally Pruned	171 a	0.68 c	12.94 a	7.94 a	17.80 a	284 a	48.0 b	3.4 b	14 bc	13.8 bc	3.27 c
P-value	0.0001	0.0002	0.0001	0.0001	0.0001	0.0001	0.0461	0.0001	0.0006	0.0065	0.0001

Treatment	Titratable Acidity (g/L)	Post-Harvest Vine Size (kg)	Fruitfull-ness	Crop-load	Vegeta-tiveness	Produc-tivity	Leaf Area Bloom (m^2)	Leaf Area 1200 (m^2)	Leaf Area Veraision (m^2)
Pruning Systems									
20+20 (control)	5.98 d	0.87 b	0.135 a	5.03 c	0.021 b	7.48 cd	3.9 c	9.8 cb	10.0 b
35 Nodes	6.60 ab	1.38 a	0.093 b	3.17 c	0.039 a	3.10 d	4.5 c	11.5 cb	12.0 b
70 Nodes	6.85 a	0.65 bc	0.102 ab	12.28 b	0.009 c	14.70 cd	4.6 c	9.4 c	10.5 b
105 Nodes	6.35 bc	0.67 b	0.076 b	15.95 b	0.008 c	17.96 c	6.4 b	12.5 b	11.7 b
Hedge (12" radius)	6.10 cd	0.37 cd	0.096 b	12.60 b	0.004 cd	33.01 b	6.3 b	12.2 b	13.0 ab
Minimally Pruned	6.07 cd	0.16 d	0.077 b	26.83 a	0.001 d	93.78 a	8.1 a	15.6 a	15.6 a
P-value	0.0001	0.0001	0.0232	0.0001	0.0001	0.0001	0.005	0.005	0.01

Table 9.

SWMREC Niagara 2002 Growing Season Summary

Treatment	Initail Nodes Retained	Functional Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/ Hectare	Cluster Number/ Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster
Node Level										
20+20 (control)	45 d	23 d	0.87 b	5.65 b	3.39 b	7.60 b	38 bc	154.7 a	4.5 a	35 a
35 Nodes	35 d	19 d	1.3 a	4.98 b	2.99 b	6.70 b	34 c	142.2 ab	4.6 a	31 ab
70 Nodes	70 c	34 cd	0.65 bc	5.48 b	3.29 b	7.38 b	45 bc	123.3 b	4.2 b	29 b
105 Nodes	95 b	60 b	0.67 b	5.45 b	3.27 b	7.33 b	44 bc	123.7 b	4.5 a	27 b
Hedge (12" radius)	85 bc	45 bc	0.16 d	6.13 ab	3.67 ab	8.23 ab	50 ab	122.6 b	4.6 a	27 b
Minimally Pruned	171 a	114 a	0.37 cd	7.92 a	4.75 a	10.65 a	64 a	124.8 b	4.1 b	30 ab
P-value	0.0001	0.0001	0.0001	0.0333	0.0333	0.0333	0.0021	0.003	0.0001	0.0001

Treatment	% Soluble Solids (brix)	pH	Titratable Acidity (g/L)	Post-Harvest Vine Size (kg)	Fruitfull-ness	Crop-load	Vegeta-tiveness	Produc-tivity	Leaf Area Bloom (m^2)	Leaf Area 1200 (m^2)	Leaf Area Veraision (m^2)
Node Level											
20+20 (control)	13.8 b	3.23	7.68 b	1.04 b	0.436	9.57 c	0.057 bc	7.23 c	4.1 c	14.0	7.1 abc
35 Nodes	14.2 a	3.2	7.60 b	1.62 a	0.384	4.31 c	0.106 a	4.05 c	4.0 c	13.5	7.2 abc
70 Nodes	13.6 b	3.18	7.75 b	0.77 b	0.462	10.07 c	0.073 ab	9.04 bc	5.0 bc	13.5	6.2 c
105 Nodes	13.8 b	3.23	7.55 b	0.70 bc	0.18	11.07 c	0.016 cd	13.34 bc	5.6 b	14.5	6.8 bc
Hedge (12" radius)	13.5 b	3.23	7.95 b	0.39 cd	0.316	23.00 b	0.017 cd	20.12 b	6.1 b	13.7	7.7 ab
Minimally Pruned	12.9 c	3.19	8.86 a	0.21 d	0.106	54.99 a	0.002 d	58.17 a	9.8 a	14.1	8.0 a
P-value	0.0001	NS	0.0002	0.0001	NS	0.0001	0.0001	0.0001	0.0001	NS	0.0076

Table 10.
SWMREC Niagara 2003 Growing Season Summary

Treatment	Nodes Retained	Pre-Harvest Vine Size (kg)	Yield (kg)	Yield Tons/Acre	Yield Mtons/Hectare	Cluster Number/Vine	Cluster Wt. (g)	Berry Wt. (g)	Berries/ Cluster	% Soluble Solids (brix)
Node Level										
20+20 (control)	37 e	0.87 ab	7.68 e	4.61 e	10.33 e	101 d	74.0 c	4.2 b	31 a	14.5 a
35 Nodes	35 e	1.09 a	7.23 e	4.34 e	9.73 e	88 d	95.1 bc	4.2 b	29 ab	13.4 b
70 Nodes	70 d	0.71 bc	14.46 d	8.67 d	19.44 d	146 c	106.9 b	4.7 a	25 bc	13.1 b
105 Nodes	104 c	0.64 bc	21.50 c	12.89 c	28.90 c	167 c	136.4 a	3.9 bc	30 a	13.1 b
Hedge (12" radius)	158 b	0.51 cd	32.54 b	19.51 b	43.74 b	252 b	134.8 a	4.3 ab	23 c	11.5 c
Minimally Pruned	259 a	0.23 d	53.58 a	32.12 a	72.00 a	393 a	144.0 a	3.7 c	24c	11.8 c
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001

Treatment	pH	Post-Harvest Vine Size (kg)	Fruitfull-ness	Crop-load	Vegeta-tiveness	Produc-tivity	Leaf Area Bloom (cm^2)	Leaf Area 1200 (m^2)	Leaf Area Veraision (m^2)
Node Level									
20+20 (control)	3.00 b	1.01 b	0.392 a	8.83 c	0.336 a	15.58 c	Not Available	10.2	9.8
35 Nodes	3.13 a	1.55 a	0.306 b	6.63 c	0.044 c	10.75 c	"	9.9	10.3
70 Nodes	2.94 b	0.63 c	0.233 c	20.37 c	0.009 c	29.57 c	"	10.4	9.3
105 Nodes	3.02 b	0.75 bc	0.188 cd	33.59 bc	0.007 c	30.16 c	"	10.3	9.3
Hedge (12" radius)	3.20 a	0.47 cd	0.161 d	63.80 b	0.234 b	91.01 b	"	11.7	10.1
Minimally Pruned	2.92 b	0.21 d	0.137 d	232.96 a	0.213 b	237.74 a	"	10.9	9.5
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	NA	NS	NS

	Row						
Vine #	2	3	4	5	6	7	8
1	g	g	g	g	g	g	g
2	HRU-20 Rep 1	g	UK-80 Rep 2	g	Hedge Rep 2	g	UK-40 Rep 4
3		Hybrid-80 Rep 2		g		g	
4				HRU-20 Rep 3		Hybrid-40 Rep 4	
5	UK-20 Rep1		HRU-80 Rep 2		MP-C Rep 3		Hedge Rep 4
6		MP-Th2 Rep 2					
7				g		HRU-40 Rep 4	
8	Hybrid-20 Rep1		MP-Th1 Rep 2	MP-Th2 Rep 3	HRU-80 Rep 3		UK-80 Rep 4
9		Hybrid-120 Rep 2					
10						MP-Th2 Rep 4	
11	UK-120 Rep 1		UK-20 Rep 2	Hybrid-120 Rep 3	MP-Th1 Rep 4		Hybrid-80 Rep 4
12		HRU-120 Rep 2					
13						g	
14	HRU-120 Rep 1		Hybrid-20 Rep 2	g	UK-20 Rep 3	g	MP-C Rep 4
15		UK-120 Rep 2		g		g	
16				Hybrid-20 Rep 4		UK-20 Rep 4	
17	Hybrid-120 Rep 1		HRU-20 Rep 2		Htbrid-20 Rep 3		g
18		MP-Th2 Rep 1					g
19				g		Hybrid-120 Rep 4	g
20	Hedge Rep 1		g	g	HRU-20 Rep 4		g
21		MP-Th1 Rep 1	UK-40 Rep 2	HRU-120 Rep 3			g
22						HRU-120 Rep 4	g
23	UK-40 Rep1				UK-80 Rep 3		g
24		Hybrid-80 Rep 1	MP-Th1 Rep 3	UK-120 Rep 3			g
25						UK-120 Rep 4	g
26	HRU-40 Rep1				Hybrid-80 Rep 3		g
27		UK-80 Rep 1	HRU-40 Rep 2	UK-40 Rep 3			g
28						Hedge Rep 3	g
29	Hybrid-40 Rep1				HRU-80 Rep 4		g
30		g	Hybrid-40 Rep 2	Hybrid-40 Rep 3			g
31		g				g	g
32	MP-C Rep 1	g			g	g	g
33		HRU-80 Rep 1	MP-C Rep 2	HRU-40 Rep 3	g	g	g
34					g	g	g
35	g				g	g	g
36	g	g	g	g	g	g	g

Figure 1. Scottdale vineyard map, showing applied pruning, training and thinning treatments.
KEY:
g=Guard Vine
HRU=Hudson River Umbrella
UK=Umbrella Kniffen
MP=Minimally Pruned
MP-C=No Thinning
MP-Th1=Thin 1
MP-Th2=Thin2

	Row			
Vine #	65	66	67	68
1	g	g	g	g
2	g	g	g	g
3	g	g	g	g
4	g	g	g	g
5	105	20+20	35	70
6	105	20+20	35	70
7	105	20+20	35	70
8	105	20+20	35	70
9	g	g	g	g
10	g	g	g	g
11	70	105	Hedge	20+20
12	70	105	Hedge	20+20
13	70	105	Hedge	20+20
14	70	105	Hedge	20+20
15	g	g	g	g
16	g	g	g	g
17	MP	35	70	Hedge
18	MP	35	70	Hedge
19	MP	35	70	Hedge
20	MP	35	70	Hedge
21	g	g	g	g
22	g	g	g	g
23	Hedge	70	105	35
24	Hedge	70	105	35
25	Hedge	70	105	35
26	Hedge	70	105	35
27	g	g	g	g
28	g	g	g	g
29	35	MP	20+20	MP
30	35	MP	20+20	MP
31	35	MP	20+20	MP
32	35	MP	20+20	MP
33	g	g	g	g
34	g	g	g	g
35	20+20	Hedge	MP	105
36	20+20	Hedge	MP	105
37	20+20	Hedge	MP	105
38	20+20	Hedge	MP	105
39	g	g	g	g
40	g	g	g	g
41	g	g	g	g
42	g	g	g	g

Figure 2. SWMREC vineyard map, showing applied pruning treatments.
KEY:
g=guard vine
MP=minimally Pruned