Vine Management Systems Affect Yield, Fruit Quality, Cluster Compactness, and Fruit Rot of 'Chardonnay' Grape

Thomas J. Zabadal¹ and Thomas W. Dittmer²

Department of Horticulture, Michigan State University, East Lansing, MI 48824-1325

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Abstract. Three vine management systems were evaluated on 'Chardonnay' grapevines under Michigan growing conditions for five growing seasons to determine their influence on yield, fruit quality, cluster compactness, and the incidence and severity of fruit rot. These systems used mid-wire cordon (MWC) vine training, Umbrella Kniffin (UK) vine training, and a combination of those (UK/MWC). Over four growing seasons the UK and UK/MWC treatments had higher fruit soluble solids and higher yields than the MWC treatment. These higher yields were attributed to higher yields per node and the ability to retain more live nodes per vine than was possible with the MWC treatment. The UK and UK/MWC treatments also had less fruit rot than the MWC treatment in some years, which was related to reduced compactness of clusters. The UK and UK/MWC treatments produced greater numbers of mature canes per vine than the MWC treatment, and the locations of the canes allowed full cropping the season following an extremely cold winter.

Mid-wire cordon (MWC) training with spur pruning (Fig. 1A) is a common vine management system for 'Chardonnay' in Michigan, but low fruitfulness at the basal node positions on fruiting spurs can be a problem. The leaf subtending a developing node is the principal source of assimilates for that node (Hale and Weaver, 1962), and the light intensity on both the subtending leaf and the node itself strongly influences flower bud development (May and Antcliff, 1963). Dense canopies, such as those often found around cordons on large vines (May and Antcliff, 1963; Morris et al., 1984; Shaulis et al., 1973), can reduce light interception to as little as 1% of full sunlight (Smart, 1984). Therefore the basal nodes of canes, which are retained for fruiting in spur pruning, can be less fruitful than more distal nodes (Christensen, 1986; Colby and Tucker, 1933; Cooper and Vaile, 1939; Maney and Plagge, 1934; Morris et al., 1984; Partridge, 1921, 1922; Schrader, 1926). Consequently, long-cane pruning is considered preferable to spur pruning in some viticultural applications (Christensen, 1986; Morris et al., 1984; Winkler et al., 1974).

Winter injury makes renewal of cordons of MWC-trained vines difficult (Wolf, 1988).

After severe winter injury, a minimum of 2 years is often required to rebuild cordons and establish full cropping potential of MWC-trained vines. The MWC training system limits the development of canopy early in the growing season to a narrow horizontal zone, making trellis filling less efficient than in some other training systems (Winkler et al., 1974; Zabadal et al., 1997).

Fruit rot is a major obstacle to the production of 'Chardonnay' vineyards in southwest Michigan. Observation of sporulation like that described by Bulit and Dubos (1988) indicates that *Botrytis cinerea* Pers. is the primary causal agent for this rot. *Botrytis* infection is promoted by high humidity (Jarvis, 1977), which often occurs in the congested canopy and fruit zone around the cordon. This may necessitate leaf removal along the cordon to expose fruit for disease control as well as for maturation (Bledsoe et al., 1988).

Physical injury to berries and thinning of the cuticle also increase fruit susceptibility to *Botrytis*, and these characteristics are closely associated with reduced exposure of clusters and increased cluster compactness (Jarvis, 1977; Marois et al., 1986; Percival et al., 1993). Light pruning severity can increase competition among clusters for assimilates (Coombe, 1973; Looney, 1981) and reduce cluster compactness by reducing berry set (Christensen, 1981; Smithyman, 1994). Therefore, a training system that allows light pruning severity without increasing canopy density might help reduce fruit rot caused by *Botrytis*. However, under the cool-climate conditions of Michigan, such a vine management system would risk overcropping and a reduction in fruit quality if not used in conjunction with crop adjustment.

Umbrella Kniffin (UK) is a desirable long-cane training system for varieties susceptible

to winter injury in a cool climate. There are no cordons requiring a costly, 2-year replacement effort after severe winter-injury. A large number of highly fruitful nodes can be retained on very long canes at the time of dormant pruning, and such nodes can be distributed over a wide vertical zone of the trellis (Fig. 1B) to reduce fruit and canopy congestion. The fruiting potential of vines can be immediately re-established after severe winter injury by using long trunk renewal canes, and the trellis can be filled efficiently with canopy early in the growing season (Zabadal et al., 1997).

Materials and Methods

'Chardonnay' grapevines (Colmar clone) on C3309 rootstock were grown in Spinks loamy fine sand soil at the Southwest Michigan Research and Extension Center near Benton Harbor, Mich. Vines were planted in 1990 with a spacing of 1.8 m in rows and 3.0 m between rows. Rows were oriented north-south on a site with an eastern aspect and 10° slope.

The three vine management systems evaluated were: (a) mid-wire cordon (MWC) training with cordons placed 0.8 m above ground and pruned to 2- to 3-node fruiting spurs (Fig. 1A); (b) UK training with a head region ≈15 cm below a trellis wire that was 1.8 m above ground (Fig. 1B), and (c) a combination of Umbrella Kniffin and mid-wire cordon training (UK/MWC) (Fig. 1C). In system (b), vines were pruned to long (15- to 20-node) canes, which were tied over one trellis wire (1.8 m) to a lower wire (1.1 m). Vines in systems (a) and (b) had two trunks (Figs. 1A and B); those in system (c) had four (Fig. 1C).

A randomized complete-block design was used with six blocks, and two experimental units of seven vines each in each block. Data were analyzed with SAS statistical software (SAS Institute, 1987) for analysis of variance followed by Fisher's test for least significant difference.

MWC-trained vines were pruned to retain a maximum of three live nodes per fruiting spur on all canes arising from the cordon; UK- and UK/MWC-trained vines were pruned to retain four 20-node canes. Cane pruning mass was recorded at the time of dormant pruning. When shoots were 10 to 15 cm long, the number of live nodes per vine on the MWC, UK, and UK portions of the UK/MWC treatment was adjusted to retain 44 live nodes/kg of cane prunings with a maximum of 40 live nodes per vine. In UK/MWC vines, 30 additional live nodes were retained on the MWC portion of the vine to reduce pruning severity, thereby reducing cluster compactness and susceptibility to fruit rot. Clusters that developed from these additional nodes were counted after fruit set, and that number of clusters was then removed from the entire vine so that crop load would approximate that on vines balance-pruned to 44 live nodes/kg of cane prunings. Preference for removing clusters was given to areas with a high concentration of clusters and shaded clusters.

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¹Associate Professor.

²Research Technician.

Fig. 1. Diagrams illustrating the three vine training systems used: (A) Mid-wire cordon training; (B) Umbrella Kniffin training with 15- to 20-node long fruiting canes; (C) a training system utilizing a combination of the Umbrella Kniffin and mid-wire cordon training systems.

For each year, all treatments were harvested on the same date. Yield, clusters per vine, number of clusters with fruit rot, and total mass of decayed fruit were recorded for each vine at harvest in 1992, 1993, 1995, and 1996. These, together with cane pruning mass and live-node data, were used to calculate average cluster mass, yield per node, and crop load. Severity of fruit rot for each vine was obtained by separating all berries with fruit rot from the sound fruit, weighing the rotten fruit and then calculating the percentage of rotten fruit by mass. Fruit from each vine was subsampled and analyzed for soluble solids, pH and titratable acidity (Amerine and Ough,

1980). Values for all vines in each experimental unit were averaged to obtain vine value per unit. Three vines from each experimental unit were randomly chosen and evaluated for cluster compactness. Six clusters from each vine were rated using a visual scale (R.M. Pool, personal communication) as follows: 1 = rigid, unable to move berries; 2 = some movement of berries; 3 = able to manually separate berries; 4 = occasional berries not touching; 5 = uniformly loose, many berries not touching, some gaps; and 6 = large gaps in the cluster. Inter-berry spacing was measured with a series of wooden wedges 1 cm in thickness and with a 7° taper (Zabada and Dittmer, 1992). The

narrow end of individual wedges ranged from 1 to 25 mm in width. Inter-berry spacing measured the maximum width of the narrow end of a wedge that could be inserted between randomly chosen pairs of berries. One random measurement was made in the top, middle, and bottom portions of each cluster.

The graft unions of vines were protected against winter injury by hilling soil around them in the fall and removing the soil in the spring. Vines were managed with permanent ryegrass row middles, no irrigation, and a complete pesticide program to control powdery mildew, downy mildew, black rot, and insects. No fungicides were applied for the specific control of *Botrytis*. There was no crop in 1994 because a winter temperature of -28 °C on 19 Jan. 1994 killed all buds of fruiting nodes. This provided an opportunity to measure the dramatic differences among treatments in this experiment relative to their ability to produce mature fruiting canes from basal buds at the base of canes (Pool et al., 1978) or latent basal buds on two-year-old or older wood on the vine. Vines were lightly hedged in May 1994, removing only canes extending out into row middles. The distribution of mature canes that developed from basal buds during the 1994 growing season was evaluated in Apr. 1995.

Results and Discussion

Yield differences between the UK and UK/MWC treatments were inconsistent, but yields of both were consistently higher than those of the MWC treatment (Table 1). The lower yields per live node (Table 1) for MWC-trained vines than for other treatments are consistent with previous reports of reduced fruitfulness of basal nodes along cordons (Christensen, 1986; Morris et al., 1984). To compensate for the reduced fruiting potential of spur-pruned MWC vines, long "kicker" fruiting canes have at times been retained along the cordon (Phillips et al., 1990). However, such a strategy violates the definition of a spur-pruned, MWC training system. Though MWC vines became larger than vines in other systems, as measured by cane mass per vine (Table 1), they retained fewer live nodes (Table 1). The discrepancy between vine size and live nodes retained was a result of winter injury, which necessitated frequent cordon renewal and limited the availability of live fruiting nodes, contributing to reduced yields. In contrast, numerous live, long fruiting canes on all vines of the UK and UK/MWC treatments allowed the retention of more than adequate live nodes, according to the pruning formula, in all years except the year of severe winter injury. Therefore, the MWC treatment, with fruiting spurs, was easier to prune and required less pruning skill and annual tying, but retention of adequate fruiting capacity was more difficult than in the other treatments. The lower yields and larger vine size of MWC-trained vines reduced calculated crop loads relative to other treatments (Table 1), indicating an inability to achieve full productive potential (Winkler et al., 1974). Pool et al.

Table 1. Yield parameters for 'Chardonnay' grapes grown with three vine management systems.

Year	Treatment ²	Yield (t·ha ⁻¹)	Clusters/vine	Mass per cluster (g)	Live nodes/vine	Yield/node (g)	Cane mass/vine (kg)	Crop load ³
1992	MWC	5.80 c ^a	41 c	75 b	24.0 a	138 b	0.82 a	4.8 c
	UK	10.84 a	60 a	102 a	23.9 a	265 a	0.45 b	10.5 a
	UK/MWC	9.41 b	51 b	105 a	22.3 a	244 a	0.64 b	9.1 b
	LSD _{0.05}	1.25	6	8	2.5	27	0.10	1.2
1993	MWC	8.20 c	67 c	70 b	28.9 b	163 b	1.19 a	4.5 c
	UK	10.12 b	76 b	75 a	36.7 a	158 b	1.14 a	5.3 b
	UK/MWC	13.33 a	100 a	76 a	36.3 a	215 a	1.21 a	6.8 a
	LSD _{0.05}	0.96	7	4	2.8	18	0.14	0.7
1995	MWC	4.64 c	32 b	85 a	21.3 c	123 b	1.56 a	2.2 b
	UK	11.45 a	83 a	79 b	36.0 a	180 a	1.32 b	5.8 a
	UK/MWC	10.21 b	79 a	75 b	33.9 b	173 a	1.23 b	5.4 a
	LSD _{0.05}	0.38	5	5	1.8	12	0.16	1.0
1996	MWC	7.21 c	51 c	77 b	25.8 b	157 c	1.58 a	3.4 b
	UK	12.66 b	73 b	103 a	29.9 a	237 b	0.85 b	10.2 a
	UK/MWC	13.96 a	82 a	96 a	28.9 a	271 a	0.95 b	10.7 a
	LSD _{0.05}	1.30	7	11	2.1	23	0.16	1.6
4-year avg.	MWC	6.43 b	47 c	77 b	24.9 b	145 c	1.28 a	3.7 b
	UK	11.27 a	73 b	90 a	31.5 a	211 b	0.98 b	8.0 a
	UK/MWC	11.67 a	77 a	88 a	30.2 a	226 a	1.00 b	8.0 a
	LSD _{0.05}	0.60	4	4	1.4	12	0.08	0.7

^aMWC = Mid-wire cordon; UK = Umbrella Kniffin; UK/MWC = Umbrella Kniffin and mid-wire cordon with cluster thinning.

³Crop load = kg fruit/kg cane prunings.

²Mean separation within years or averages over years and within columns by ANOVA and Fisher's test for least significance, $P \leq 0.05$.

Table 2. Fruit quality, fruit rot, and cluster compactness of 'Chardonnay' grapes grown with three vine management systems.

Year	Treatment ²	Fruit quality			Fruit rot			
		°Brix	pH	Titrate acidity (g·L ⁻¹)	Incidence (%)	Severity (%)	Visual cluster compactness ³	Inter-berry spacing (mm) ³
1992	MWC	20.2 b ^w	3.48 a	0.94 a	17.5 a	0.70 a	3.40 b	7.90 b
	UK	21.5 a	3.50 a	0.89 a	15.8 a	0.58 a	3.97 a	10.16 a
	UK/MWC	21.3 a	3.48 a	0.88 a	15.4 a	0.53 a	3.89 a	9.75 a
	LSD _{0.05}	0.5	0.06	0.14	4.1	0.24	0.18	0.57
1993	MWC	18.8 c	3.40 a	0.94 a	92.5 a	64.69 a	3.39 c	7.60 c
	UK	19.3 b	3.36 a	0.90 a	94.4 a	65.57 a	3.67 b	8.56 b
	UK/MWC	19.7 a	3.38 a	0.82 b	94.2 a	58.19 b	3.94 a	9.92 a
	LSD _{0.05}	0.4	0.03	0.07	3.3	6.24	0.16	0.61
1995	MWC	22.1 a	3.39 a	1.07 a	1.0 a	0.08 a	2.77 c	8.42 c
	UK	21.3 c	3.39 a	1.13 a	0.4 a	0.02 b	3.42 b	10.24 b
	UK/MWC	21.6 b	3.37 a	1.12 a	0.3 a	0.02 b	3.85 a	11.58 a
	LSD _{0.05}	0.3	0.08	0.14	0.8	0.06	0.16	0.51
1996	MWC	19.9 b	3.39 a	1.12 a	52.4 a	6.64 a	2.95 b	6.45 b
	UK	20.0 ab	3.42 a	0.96 b	42.6 b	3.86 b	3.20 a	6.93 ab
	UK/MWC	20.2 a	3.40 a	0.90 b	42.7 b	3.24 b	3.39 a	7.30 a
	LSD _{0.05}	0.2	0.07	0.12	5.3	1.28	0.21	0.57
4-year avg.	MWC	20.2 b	3.41 a	1.02 a	40.1 a	17.47 a	3.11 c	7.56 c
	UK	20.5 a	3.42 a	0.97 ab	37.5 a	16.95 a	3.54 b	8.90 b
	UK/MWC	20.7 a	3.41 a	0.93 b	37.4 a	15.00 a	3.75 a	9.59 a
	LSD _{0.05}	0.2	0.04	0.07	5.9	4.48	0.10	0.31

^aMWC = mid-wire cordon; UK = Umbrella Kniffin; UK/MWC = Umbrella Kniffin and mid-wire cordon with cluster thinning.

³Evaluation based on the following criteria: 1 = rigid—unable to move berries on cluster; 2 = some movement of berries; 3 = able to manually separate berries; 4 = loose—occasional berries not touching others; 5 = uniformly loose with many berries not touching each other—able to see some gaps through the cluster; 6 = large holes or gaps visible in the cluster.

²Measurements were taken at the top, middle, and bottom of clusters to determine the space in millimeters capable of being made between berries.

²Mean separation within years or averages over years and within columns by Fisher's test for least significance, $P \leq 0.05$.

(1989) reported a similar trend of low-to-moderate productivity, combined with increasing vine size in 'Chardonnay' and several other *Vitis vinifera* cultivars.

The greater yields in the UK and UK/

MWC treatments vs. the MWC treatment would not be desirable if they reduced fruit soluble solids. However, soluble solids were as high as or higher than those in the MWC treatments in most years (Table 2). Soluble

solids accumulation is highly related to functional leaf area (Winkler, 1958). The high yields and acceptable fruit soluble solids of the UK and UK/MWC treatments can partially be explained by the more efficient trellis fill in those treatments (Zabada et al., 1997). The 30 additional nodes per vine retained on the MWC portion of the UK/MWC-trained vines contributed to that efficiency. Field observations suggested that the UK/MWC treatment also distributed and exposed fruit well over the height of the trellis. The lower titratable acidity of fruit from the UK/MWC treatment relative to the MWC treatment in some years (Table 2) supports these observations relative to fruit exposure (Kliwer and Linder, 1968; Reynolds et al., 1986).

Incidence of fruit rot (percentage of clusters with fruit rot) varied greatly year-to-year and differed significantly among treatments only for the 1996 crop (Table 2). The four-year average for all treatments ranged from 37% to 40% of the clusters with fruit rot.

Severity of fruit rot (percentage damaged fruit) also exhibited a large year-to-year variation, with values for the UK and UK/MWC treatments being significantly lower than those for the MWC treatment in 2 and 3 years out of 4, respectively (Table 2). Fruit rot was especially severe in 1993 (Table 2) when precipitation occurred in 13 out of the 24 days prior to harvest. A significant reduction in the severity of fruit rot in that year was associated with decreased cluster compactness and inter-berry spacing between the UK and UK/MWC treatments (Table 2). Therefore, under intense disease pressure, the strategy of maintaining an excessive number of clusters on UK/MWC vines through fruit set to reduce the compactness of clusters (Christensen, 1981; Smithyman, 1994) was successful in reducing fruit rot. Further evaluation would be required to determine the economic advantage of such a cultural practice for controlling fruit rot in 'Chardonnay'.

In 1994, 90% of the canes on MWC vines developed from the base near the graft union. Because few mature canes were available along the cordon, extensive cordon replacement was required. This did not allow retention of a full complement of fruiting nodes according to the pruning formula for 1995. Therefore, the 1995 production of these vines was relatively low (Table 1). In contrast, the greater survival of semi-permanent trunk and arm portions on UK and UK/MWC vines promoted the development of more mature canes per vine from basal buds, and more than 50% of them were situated high on the trellis (Table 3). These canes provided ample opportunity to retain a full complement of fruiting nodes during pruning for the 1995 growing season.

The applicability of the results of this experiment to the viticulture of a cool climate like Michigan will depend upon vine size, variety, and canopy management. Small, open vines will not exhibit canopy congestion, reduced node fruitfulness and increased susceptibility to fruit rot around the cordon of MWC-trained vines. Large vines of *Vitis vinifera* and *Vitis labrusca* L. varieties, which generally

Table 3. Number and distribution of mature canes which developed from basal buds² in 1994 on 'Chardonnay' grapevines grown with three vine management systems.

Vine management system ^y	Canes per meter of row								Mature canes/vine	
	Origin of canes by height above ground (cm)									
	<60	60–75	75–90	90–105	105–120	120–135	135–150	150+		
MWC	6.2 a ^x	0.3 b	0.0 b	0.0 a	0.0 b	0.3 b	0.0 b	0.0 b	6.8 b	12.7 b
UK	4.9 a	0.3 b	0.0 ab	0.0 a	0.7 a	1.3 a	1.3 a	2.6 a	11.1 a	19.8 a
UK/MWC	4.9 a	1.0 a	0.3 a	0.3 a	0.7 a	1.0 ab	2.0 a	2.3 a	12.5 a	22.9 a

¹Basal buds are all sources of shoot growth on vines other than count nodes on canes. Includes locations at the base of canes and two-year-old or older wood.

²MWC = mid-wire cordon; UK = Umbrella Kniffin; UK/MWC = Umbrella Kniffin and mid-wire cordon with cluster thinning.

³Mean separation within columns by Fisher's test for least significance, $P \leq 0.05$.

have nonfruitful basal buds (Pool et al., 1978), are likely to respond as does 'Chardonnay'. The productivity of large vines of varieties with relatively high levels of basal bud fruitfulness (Pool et al., 1978) and greater hardiness than 'Chardonnay', such as several of the interspecific hybrids, is less likely to be depressed by MWC training. Nevertheless, without the canopy management techniques of shoot positioning and leaf removal, the development of a congested canopy and fruit zone around a mid-wire cordon could create a problem for any variety susceptible to fruit rot.

In summary, the UK and UK/MWC treatments were superior to the MWC treatment for the production of 'Chardonnay' grapes under the conditions of this experiment. These treatments produced greater yields in all years, higher fruit soluble solids in most years, and lower titratable acidity and less incidence and severity of fruit rot in some years. Moreover, these two treatments afforded better opportunity than did the MWC treatment to restructure and crop vines after severe winter injury. Although the UK/MWC treatment incurs the additional expense of post-bloom cluster thinning, it was superior to the UK treatment in a year of high disease pressure for fruit rot by creating less compact clusters that were significantly less susceptible to fruit rot.

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