Establishment Technique and Rootstock Impact ‘Chambourcin’ Grapevine Morphology and Production in Missouri

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SUMMARY. An evaluation of establishment techniques and rootstocks for ‘Chambourcin’ hybrid grape (*Vitis* sp.) was conducted 2009–12. Our objective was to evaluate four establishment methods and their interactions with grafted and ungrafted vines in terms of vine morphology and early fruit production under southwest Missouri conditions. The study was established in May 2009, as a factorial experiment comparing four establishment methods (open-trained without protection—two shoots, grow tube protected—two shoots, paperboard carton protected—two shoots, and fan-trained without protection—six shoots) across two vine types (own-rooted and grafted to ‘Couderc 3309’ hybrid grape rootstock). All vines in four of 12 field replications were destructively harvested near the conclusion of the first growing season, with leaf area and total vine dry matter determined. In years 3 and 4, yield, fruit composition, and vegetative growth were determined from the eight remaining replications. The fan training method increased leaf area and total vine dry matter compared with the other methods, but none of the establishment techniques affected fruit yield. Trunks that were tube protected had longer internodes, smaller diameter, and less dry matter, whereas both protection devices reduced glyphosate injury. Vine type (grafted and ungrafted) did not impact total leaf area or dry weight during the establishment year, but grafted vines had increased trunk and root shank dry weights compared with own-rooted vines. Grafted vines produced greater fruit yield in 2012. The fan training method required more labor to execute; although it was successful at increasing leaf area and root dry weight, it increased susceptibility to glyphosate injury and did not promote increased precocity or early fruit yield.

The wine industry in the midwestern United States continues to expand, along with the demand for high-quality, regionally produced grapes. Low winter temperatures, fluctuating spring temperatures, low diurnal temperature ranges during the growing season, and high disease pressure are principal

production challenges in the region. ‘Chambourcin’ is a French–American hybrid grape with a complex pedigree based on Seibel hybrids, developed in France by Joannes Seyve, and released in 1963 (Regents of the University of California, 2017; Robinson et al., 2012). It performs well and yields abundantly with good management in the lower midwestern United States, and produces a wine that is well received by regional consumers (Dami and Ferree, 2005; Dami et al., 2006; Kurtural et al., 2006). Although

successful ‘Chambourcin’ vineyards are increasing in the region, production and quality can be improved through better management, including improved establishment techniques. More efficient establishment may also advance the onset of quality fruit production and economic return. ‘Chambourcin’ establishment techniques, including early vine training methods and the use of vine shelters, have been poorly researched in the midwestern United States. Furthermore, the majority of ‘Chambourcin’ vineyards in the region use ungrafted vines; the potential benefits imparted by use of improved rootstocks with ‘Chambourcin’ are not well understood.

Establishment year management protocols for many producers often fall into two categories, with the shared goal of producing maximal amounts of leaf area and developing a vigorous root system. Depending on site characteristics and other factors, some growers allow new vines to sprawl with little training the initial year, whereas others initiate training the first season by pruning and guiding one or more main shoots toward the cordon wire (Dami et al., 2005; Davidson, 2001; Jacobs, 2001; Whisson, 2001; Wolf, 2008). The decision to train early is often favored by desires to use vine shelters and/or to simplify weed management operations, and a common belief that doing so will result in more rapid vineyard establishment. However, the return on additional investments of labor and resources for the latter system are not well documented with ‘Chambourcin’ under midwestern U.S. conditions, and the typical practice of training to only two shoots initially may restrict the vine’s photosynthetic potential during the establishment year.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
10	%	g·L ⁻¹	0.1
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
6.4516	inch ²	cm ²	0.1550
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
28.3495	oz	g	0.0353
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Interest in increasing early vine leaf area (and potentially, total vine growth) has stimulated development of establishment methods that involve training multiple shoots at variously spaced angles toward the cordon wire to increase overall light interception during the establishment year (Fig. 1). In subsequent years, the strongest canes may be selected and trained vertically as permanent or semipermanent trunks. We characterize this as a “fan” training method for vineyard establishment, which is somewhat different from the fan training system described by Zabadal (2002) employed to retain multiple trunks and fruiting canes to increase the likelihood of winter survival of grapevines in cold climates. During the establishment of ‘Steuben’ hybrid grape in Indiana, unpruned vines trained to four shoots radiating from the vine base toward the top wire produced three times the leaf area, and double the shoot length, top dry weight, and root dry weight compared with vines that were pruned to single shoots and sheltered within tubes (Bordelon and Blume, 2000). However, that study did not evaluate effects of this greater leaf and biomass production on subsequent year growth or eventual fruit production, precocity, or quality. In a greenhouse study, Miller et al. (1996a, 1996b) evaluated potted, grafted ‘Chambourcin’ vines trained to one, three, or six shoots. They found that the individual shoots competed with each other as vegetative sinks, resulting in reduced growth among individual shoots when grown multiply; but as a whole, total leaf area, shoot length,

and overall vine dry weight increased proportionately with shoot number.

The advantages of grafting grapevines to rootstocks may include improved root disease, insect [especially phylloxera (*Daktulosphaira vitifoliae*)] and nematode resistance, improved drought or excessive moisture tolerance, soil salinity tolerance, increased or reduced vigor, potassium uptake regulation, improved scion winterhardiness, and improved yield and fruit quality (e.g., Howell, 2005; Krstic et al., 2005; Main et al., 2002; McCraw et al., 2005; Striegler and Howell, 1991; Striegler et al., 2005; Whiting, 2004, 2012). Concurrently, the disadvantages usually focus on greater cost, susceptibility to winter climate vagaries during the establishment years, and increased labor costs in caring for the graft unions. Although rootstocks are widely used with wine grape (*Vitis vinifera*) genotypes in Europe, California, and Australia (Whiting, 2012), the majority of hybrid grapes produced in the midwestern United States are not grafted to rootstocks because the physiological and economic benefits have not been clearly demonstrated. ‘Couderc 3309’ hybrid grape (often and hereafter called 3309C) is a commonly used rootstock worldwide, and performs well in the midwestern United States. It was bred in France by Georges Couderc and released in 1881 (Regents of the University of California, 2017). In several field and greenhouse studies in the midwestern United States, the rootstock 3309C imparted modest degrees of winterhardiness (Gu et al., 2005; Miller et al., 1988; Striegler and Howell,

1991) and flood tolerance (Striegler et al., 1993) to hybrid genotype scions. In a reciprocal grafting study with hybrid grape cultivars Maréchal Foch and Vidal blanc (neither typically used as rootstocks), Sabbatini and Howell (2013) documented significant rootstock effects on vine vigor and yield in Michigan, but attributed most phenological and winterhardiness attributes to scion and environment. Main et al. (2002) found a greater benefit to grafting ‘Chardonnay’ hybrid grape to improved rootstocks in Arkansas compared with California. McCraw et al. (2005) showed that the rootstock 3309C delayed budbreak on ‘Chambourcin’ and other grape cultivars by a few days compared with own-rooted vines in Oklahoma; this delay may be considered potentially beneficial in avoiding damage from late spring freezes. Some studies have found varying degrees of rootstock effect (including minor or no effect) on juice characteristics in hybrid grapes (e.g., Gu et al., 2005; Main et al., 2002; Striegler and Howell, 1991; Striegler et al., 2005), whereas Krstic et al. (2005) documented rootstock effects in finished wines from ‘Chardonnay’ and ‘Shiraz’ wine grape in Australia.

A variety of physical devices or shelters, such as plastic tubes and cardboard enclosures, are sometimes used to protect grapevines during establishment by modifying the microenvironment surrounding the young vines. Their use typically necessitates thinning of early shoot growth to facilitate installation of the units themselves. Some of these devices were rapidly and widely adopted in the 1990s before being thoroughly studied; their general success and rapid adoption resulted in a variety of publications in trade journals (e.g., Davidson, 2001; Due, 1990, 1996; Ker, 2003). The advantages of using such shelters may include protecting young vines from herbicide applications and therefore improved vineyard weed control, reduced herbivory and wind injury, reduced vine-training labor, and more rapid early shoot growth (Bordelon and Blume, 2000; Due, 1990, 1996; Ker, 2003; Lu and Ren, 2001; Olmstead and Tarara, 2001; van Schalkwyk, 2000). Concerns related to their use may include initial cost of the shelters in

Fig. 1. Midseason 2009 illustration of the four ‘Chambourcin’ grapevine establishment and trunk protection techniques used in this study: open, tube, carton, and fan treatments (left to right) (illustration by Linda S. Ellis).

addition to cost of proper installation and off-season storage, possible production of less total photosynthetic leaf area resulting in reduced root growth and etiolated trunks, harboring certain pests and disease inoculum, and possible winterhardiness issues. Lu and Ren (2001) compared early vine growth in muscadine grape (*Vitis rotundifolia*) in Florida when sheltered by either a 3-ft-tall grow tube or a 0.5-gal orange juice carton. They noted increased vine growth and leaf number in tube-protected vines compared with carton-treated, but observed few differences in main stem girth. In a study of 'Cabernet franc' wine grape grafted to 3309C in southeast Ontario (Ker, 2003), 10 different grow tube products generally increased shoot growth, shoot growth rate, and overall vine weight compared with unprotected vines. Hall and Mahaffee (2001) reported reduced incidence of powdery mildew (*Uncinula necator*) on leaves of 'Cabernet Sauvignon' and 'Chardonnay' wine grape within solid-wall grow tubes, attributed to physical exclusion of spores and increased in-tube temperatures; whereas tubes that were designed or installed to increase air flow fostered more in-tube disease development. Shoot length, midshoot diameter, node number, and internode length were all generally increased by various shelters and shelter installations compared with unsheltered vines in that study.

The objective of this study was to compare four grapevine establishment methods incorporating both grafted and ungrafted vines for 'Chambourcin' under southern Missouri growing conditions. The establishment systems included the use of two trunk protection devices, unprotected training to two shoots per vine, and a vine training technique designed to increase photosynthetic leaf area during the establishment year.

Materials and methods

SITE AND ESTABLISHMENT. This experiment was established as a new planting in 2009 within a larger 1-ha research vineyard at the University of Missouri's Southwest Research Center near Mount Vernon (lat. 37.074297°N, long. 93.879708°W, U.S. Department of Agriculture Plant Hardiness Zone 6a). The climate is

temperate, with cold winters (average minimum winter temperature 4.5 °C) and hot summers (average maximum summer temperature 30.7 °C), and precipitation averaging 1175 mm annually with frequent summer droughts [National Oceanic and Atmospheric Administration (NOAA), 2015]. The soil was a Hoberg silt loam (fine loamy, siliceous, mesic Mollic Fragiudalfs) described as upland, deep, gently sloping, and moderately well drained to a fragipan at 40 to 90 cm (Hughes, 1982). After soil analyses in 2008, amendments of lime, phosphorous (P), potassium (K), and zinc were applied and incorporated into the soil according to recommendation for wine grape production (Dami et al., 2005). To improve soil drainage and root-penetrable soil depth over the fragipan, soil was mechanically pushed from the alleys to form raised berms of ≈25 cm height on which vines were planted. The alleys were then sown to 'Houndog' tall fescue (*Festuca arundinacea*) and kept mowed. The vineyard design incorporated row spacing of 9 ft 8 inches, interrow vine spacing of 8 ft, and training to high bilateral cordons (single curtain) established at an average height of 5.8 ft above the berms. Dormant, bare-root planting materials were obtained from Vintage Nurseries (Wasco, CA) and planted on 5 May 2009, established either as own-rooted 'Chambourcin' vines or 'Chambourcin' grafted to 3309C rootstock according to the experimental design. Graft unions were positioned ≈5 inches above soil level to prevent scion rooting.

VINEYARD AND PROJECT MANAGEMENT. Drip irrigation (emitters rated 0.42 gal/h spaced 36 inches; Netafim, Fresno, CA) was established and operated as needed to provide 1 inch of water per week during the growing seasons. Each vine was fertilized in 2009 with applications of 65 g urea [46% nitrogen (N), about 30 lb/acre N; Feed Products South, St. Louis, MO] in May and July, and 65 g of a commercial 13N–5.7P–10.8K fertilizer [about 20 lb/acre N (Green Country Fertilizer; Chouteau Lime Co., Pryor, OK) in June, applied by hand under irrigation emitters. In subsequent years, each vine was fertilized five times (late April to mid-August) with 65 g of the same N–P–K product in a similar

manner. Standard applications of fungicides and insecticides were used to manage diseases and insect pests according to recommendation and label (Bordelon et al., 2015; Byers et al., 2003; Wolf, 2008). No significant diseases were observed during the study, and insect pests were kept at or below threshold levels. During the establishment year, weeds in the vineyard rows were managed with a banded application of oryzalin + isoxaben + glyphosate 13 d after planting but before bud swell, all according to label. This was followed 90 d later (mid-August) with a meticulous application of glyphosate to kill weeds, but also to evaluate the susceptibility of the variously treated vines to glyphosate injury. In subsequent years, weeds were managed similarly as needed and according to label. Vine training was conducted on 3-week intervals. Shoots were tied according to experimental protocols using medium gauge plastic tie tape and sisal twine. In late autumn, during the first 3 years, graft unions were protected from extreme winter temperatures with an application of municipal and/or mushroom compost (City of Monett, MO and J-M Farms, Miami, OK, respectively) held in place around and above the unions with a cylindrical hardware mesh. An equivalent amount of compost was also applied to nongrafted vines but without a hardware mesh.

Following the 2009 establishment season, vines were pruned and tied to establish a double-trunk vine form. Cordon development was completed during the 2010 season as needed. No fruit was allowed to develop during the first two growing seasons (2009 and 2010). Vines were individually balance-pruned following the 2010 growing season and in all subsequent seasons during the dormant period (early March), with pruning weights determined. Pruning severity was regulated by retaining 20 nodes for each 1 lb of cane prunings, with an upper limit of 70 nodes per vine. Vines were pruned to six-node bearing units and two-node renewal spurs per convention, with both canes and spurs being preferentially retained in the lower 180° plane. Shoot thinning was conducted before bloom each bearing season, keeping a single shoot per retained node while removing all others not needed to

improve vine structure. After fruit set during the third and fourth seasons (2011 and 2012), fruit clusters were thinned to maintain one cluster on shoots that were 30 to 60 cm long, and two clusters on shoots longer than 60 cm, retaining, when possible, the more basal clusters. All fruit was hand-harvested with yields determined at maturity as defined by standard metrics such as percent soluble solids, pH, and titratable acidity.

EXPERIMENTAL TREATMENTS AND DATA COLLECTION. Two ‘Chambourcin’ vine types (own-rooted, grafted to 3309C rootstock) were subjected to four vine-training and protection techniques (open, tube, carton, and fan) with 12 blocked replications of each vine-type-by-training combination, resulting in 96 plots. Each treatment plot contained two vines, requiring a total of 192 vines for the study. The eight treatment combinations were completely randomized within each block, with two complete blocks per vineyard row. Guard rows and vines were employed appropriately.

The vine-training and protection treatments were as follows: open, tube, and carton treatments were all trained to two vertical shoots; fan vines were trained to six shoots—two vertical, and four additional shoots (two east and two west) secured to taut nylon twines radiating from both sides of the vine base to the cordon wire at a 45° angle to form a fan-shaped training pattern (Fig. 1). After the establishment year in fan-trained vines, the two most vigorous canes were retained and trained vertically to establish a vine form similar to the other treatments. Bamboo stakes (2 m) were installed at each vine upon which shoots were trained and protection devices secured. Open and fan-trained vines did not have trunk protection. Tube-treated vines were protected with cylindrical, translucent, peach-colored, polyethylene grow tubes that were 36 inches tall and 3.5 inches diameter (Jump Start Grow Tubes; Plantra, Eagan, MN). Carton-treated vines were protected with a 0.5-gal cuboid waxed paper-board carton used commercially as a retail orange juice container that, when opened and installed, measured 3.7 × 3.7 inches square and 12 inches tall (Parmalat, Toronto, ON). The cartons and tubes were installed within

2 d of planting, removed in early September during the first growing season, and not used thereafter.

On 8 Sept. 2009, an herbicide injury rating was conducted to assess damage from the mid-Aug. 2009 glyphosate application. Vines were rated as damaged or not damaged based on visual observation and without consideration of the degree of damage.

Upon the conclusion of the initial growing season, detailed morphological data were collected on all vines to quantify the physiological effects of the various establishment methods and rootstock use. Internode lengths on all existing shoots were measured at 60 and 160 cm from the vine-soil level junction. The 60-cm measurements were within the tube-protected area on vertical shoots that received the tube treatment, but well above the protected area on carton-treated vines. The 160-cm measurements were just below the cordon wire on vertical shoots. Diameter of each main shoot was also measured at 60 and 160 cm from the vine-soil level junction.

All vines in four of the treatment blocks were excavated and destructively harvested near the end of the initial growing season, but well before leaf senescence. All above-ground tissues were harvested 21–24 Sept. 2009, after which the entire root systems of the same vines were excavated 26–27 Sept. Aboveground materials were separated into leaf, shoot (nonglified current season’s growth), stem (lignified current season’s growth beyond the vertical or 45° trunk), and trunk (lignified vertical or 45° growth from soil level to the cordon wire). All leaves from each vine were collected and total leaf area determined with an area meter (LI-3100; LI-COR Biosciences, Lincoln, NE). The shoot, stem, and trunk tissues were cut into pieces, then all materials dried in a custom-made propane-fired dryer (about 50 °C for 4 d) and weighed to determine dry matter. Root systems were thoroughly washed to remove all soil particles, then separated into root shank (the vertically oriented parent tissue from which all subsequent root growth emerged) and roots. These tissues were similarly dissected, dried, and weighed.

FRUIT YIELDS AND ANALYSIS. Fruit produced from the remaining eight blocks was harvested 10–12 Sept. 2011 and 3–5 Sept. 2012. Upon harvest, the number of clusters per vine, average cluster weight, and total yield per vine were determined, and 100 random berries from each two-plant plot were collected to evaluate fruit composition. Fruit samples were promptly refrigerated, then analyzed within 2 d of harvest. Berries were macerated by hand, homogenized at room temperature using a paddle blender (Stomacher model 400 Circulator; Seward, Worthington, UK), pressed through two layers of grade 40 cheesecloth, and then centrifuged at 10,414 g_n for 3 min. Soluble solids in fresh juice were measured with a temperature-compensating refractometer (ABBE MARK II Plus; Reichert, Depew, NY). Juice pH was measured with a temperature-compensating pH probe and meter (Orion 3 Star; Thermo Fisher Scientific, Waltham, MA) calibrated with 4.01, 7.00, and 10.05 pH buffers. Titratable acidity, expressed as grams per liter tartaric acid, was determined using a 5-mL juice sample diluted to 100 mL with degassed and deionized water titrated to an endpoint of pH 8.2 with 0.1 N sodium hydroxide (NaOH) (Iland et al., 2004).

STATISTICAL DESIGN AND ANALYSIS. All data were subjected to analyses of variance in the form of a randomized complete block design using a general linear statistical model (SAS version 9.4; SAS Institute, Cary, NC) to evaluate the vines’ morphological responses to establishment treatment, vine type (own-rooted or grafted), and interactions thereof. Means were separated by the least significant difference test ($P \leq 0.05$). The experimental unit was the two-vine plot; however, all appropriate data are reported on a single vine basis.

Results and discussion

The grapevines grew and fruited vigorously throughout the 4-year study, regardless of experimental treatments, and virtually no winter damage was observed. The weather during the study (2009–12) encompassed a series of extreme events, recorded by a weather station less than 100 m from the vineyard. This

included record-breaking heat during 2011 and 2012 (43 and 42 °C, respectively), record-breaking cold during early 2011 (−26 °C), and the 2012 growing season being defined by extreme drought (836-mm precipitation with only 101 mm during the critical growing months of June, July, and August) (NOAA, 2015).

Statistically significant differences were detected among many of the experimental variables as a result of establishment treatment (open, tube, carton, and fan) and vine type (own-rooted and grafted). Table 1 summarizes the morphological differences in trunk development resulting from the experimental treatments in 2009. The data show that the portion of the growing and developing trunk contained within the tube (60 cm above soil level) became more elongated (9.1 cm) compared with trunks in all other cases (6.1 to 6.6 cm). In addition, trunk diameter at 60 cm in tube-treated vines was smaller compared with both unprotected vines and carton-protected vines where the protection device did not reach that high. We characterize this longer-but-thinner growth within the tubes as etiolation, likely due to reduced sunlight and changes in light spectral qualities therein. The trunk internode lengths at 160 cm (well beyond the tube and near the cordon wire) were less divergent, but here, were shorter on tube- and fan-treated vines. Hall and Mahaffee (2001) reported similar findings for shoot elongation with single-trunk ‘Chardonnay’ and ‘Cabernet Sauvignon’ grown within five different vine shelters, but in

contrast to the current study, trunk diameters within shelters were generally greater in protected vines. In South Africa, van Schalkwyk (2000) had varying results with 10 shelter types used with ‘Sauvignon blanc’ and ‘Chardonnay’ wine grape at different sites: in one case (‘Sauvignon blanc’), trunk girths above graft unions were decreased in sheltered vines, whereas in another case (‘Chardonnay’ at a second site) trunk girths within and outside shelters were generally not different. These varying results point to likely genetic and environmental effects in the morphological responses of grapevines to the use of various vine shelters. Vertical trunks on the fan-trained vines were thinner compared with most other vines, especially at 160 cm above soil level; this is likely because the finite supply of photosynthetic assimilate available to those trunks was shared with the additional four angled trunks in that training system. This is congruent with Miller et al. (1996a) who documented decreasing individual shoot weights with increasing shoot numbers per vine. When comparing own-rooted to grafted ‘Chambourcin’ across all vine-training techniques, grafted vines had shorter trunk internodes but increased diameter at 60 cm above soil level, suggesting a more focused increase in stem girth rather than shoot length resulting in stronger, stouter stems. Differences in trunk morphology were not evident between own-rooted and grafted vines near the cordon wire at 160 cm. No interactions were detected between

establishment treatment and vine type for any of these morphological characteristics. The short-term impact from these morphologically changed (etiolated) trunks within the grow tubes is uncertain, but some physiological vine characteristics such as first-year winter-hardiness in such trunks might be of concern. These data support the common assumption that grow tubes increase shoot elongation, but under the conditions of this experiment such primary growth (elongation) appears to have competed with secondary growth (diameter) resulting in thinner trunks.

For the fan-trained vines, we compared trunk internode length and diameter (both at 60 and 160 cm) between the two west-trained 45° trunks and the two east-trained 45° trunks, finding no differences (data not shown); therefore the data from all four 45°-trained trunks were combined and compared with the two vertical trunks on those vines (Table 2). When comparing trunk internode lengths and diameters within the fan-trained vines, the internodes were longer on the angled trunks at 60 cm from soil level, but not different at 160 cm. Further, diameter was thicker in vertical trunks compared with the angled trunks. This might have been caused by reduced availability of sunlight lower in the vineyard canopy on angled trunks, thereby inducing etiolation of the shoots present in that sector of the canopy. When comparing vine type (own-rooted, grafted) in fan-trained vines, trunk internodes at both positions were longer in own-rooted vines,

Table 1. ‘Chambourcin’ grapevine internode lengths and diameters on vertical trunks as affected by establishment treatment and rootstock vine type at Mount Vernon, MO, in 2009.

Variable ^z	Subvariable	n	Trunk internode length at 60 cm (cm) ^y	Trunk internode length at 160 cm (cm)	Trunk diam at 60 cm (mm) ^y	Trunk diam at 160 cm (mm)
Treatment ^x	Fan ^w	80–93	6.2 b ^v	8.2 b	6.8 b	7.0 c
	Open	92–95	6.6 b	8.9 a	7.6 a	8.1 a
	Tube	68–69	9.1 a	8.2 b	7.0 b	7.5 b
	Carton	82–83	6.1 b	9.3 a	7.6 a	8.3 a
	P value		<0.0001	0.0002	<0.0001	<0.0001
Vine type	Grafted	166–173	6.8 b	8.6	7.4 a	7.7
	Own rooted	156–167	7.1 a	8.9	7.1 b	7.8
	P value		0.0419	NS	0.0086	NS

^zStatistical interactions between treatment and vine type were not significant ($P \leq 0.05$) for all factors.

^y1 cm = 0.3937 inch, 1 mm = 0.0394 inch.

^wFan = six shoots (two vertical, two east at 45°, two west at 45°), unprotected; open = two vertical shoots, unprotected; tube = two vertical shoots, protected with 36-inch-tall plastic tube; carton = two vertical shoots, protected with 12-inch-tall paperboard carton (1 inch = 2.54 cm).

^xFor fan-trained vines, data from only the two vertical trunks were used.

^vMeans within subcolumns with the same letters are not different according to the least significant difference test ($P \leq 0.05$); NS = nonsignificant.

Table 2. Morphology of ‘Chambourcin’ grapevines in fan training system as affected by trunk angle and rootstock vine type at Mount Vernon, MO, in 2009.

Variable ^z	Subvariable	n	Trunk internode length at 60 cm (cm) ^y	Trunk internode length at 160 cm (cm)	Trunk diam at 60 cm (mm) ^y	Trunk diam at 160 cm (mm)
Trunk angle	90°	80–93	6.4 b ^x	8.7	6.8 a	7.0 a
	45°	132–161	7.0 a	8.2	6.5 b	6.4 b
	<i>P</i> value		0.0119	NS	0.0295	0.0018
Vine type	Grafted	112–127	6.5 b	8.2 b	6.8 a	6.4 b
	Own-rooted	100–127	7.1 a	8.8 a	6.4 b	6.9 a
	<i>P</i> value		0.0150	0.0435	0.0094	0.0107

^zStatistical interactions between trunk angle and vine type were not significant ($P \leq 0.05$) for all factors.

^y1 cm = 0.3937 inch, 1 mm = 0.0394 inch.

^xMeans within subcolumns with the same letters are not different according to the least significant difference test ($P \leq 0.05$); NS = nonsignificant.

whereas diameter was smaller in own-rooted vines at 60 cm, but greater at 160 cm. This is consistent with the shorter-but-thicker growth results for grafted vines described earlier.

Some minor but notable glyphosate injury occurred with the mid-August application during the establishment year (2009), despite ideal conditions and extra effort to keep spray materials directed to weeds on the soil berms. In all cases where injury was noted, it was manifested as scattered curled, distorted, or discolored leaves in the lower parts of the canopy, but in no cases were entire plants stunted or killed. Data in Table 3 clearly show the value of the tubes and cartons in protecting newly established, fully foliated trunks and shoots from herbicide injury (protection levels between these two treatments were not different). Nearly half the fan-trained vines, which usually had more leaf area near soil level, incurred some notable herbicide damage. Rogers et al. (1978) found very little damage from commercial glyphosate applications to grapevines when a 24-inch leaf-free zone was maintained above soil level. The tubes (36 inches tall) and cartons (12 inches tall) in the present study provided herbicide protection without necessitating leaf removal and concomitantly reducing the photosynthetic capacity of the vines. No differences in herbicide injury were noted between own-rooted and grafted vines, and no treatment-by-rootstock interactions were detected for herbicide injury. As the deleterious effects of weed competition on young vine growth are well known and documented (Bordelon and Weller, 1997; Zabadal and Dittmer, 2001a, 2001b), any methods or materials that help mitigate this threat to

Table 3. Glyphosate damage to ‘Chambourcin’ grapevines affected by establishment treatment and rootstock vine type at Mount Vernon, MO, in 2009.

Variable ^z	Subvariable	Damaged vines (%)
Treatment ^y	Fan	47.9 a ^x
	Open	12.5 b
	Tube	3.1 b
	Carton	3.2 b
	<i>P</i> value	<0.0001
Vine type	Grafted	11.7
	Own-rooted	18.9
	<i>P</i> value	NS

^zStatistical interactions between treatment and vine type were not significant ($P \leq 0.05$) for all factors.

^yFan = six shoots (two vertical, two east at 45°, two west at 45°) unprotected; open = two vertical shoots, unprotected; tube = two vertical shoots, protected with 36-inch-tall plastic tube; carton = two vertical shoots, protected with 12-inch-tall paperboard carton (1 inch = 2.54 cm).

^xMeans within subcolumns with the same letters are not different according to the least significant difference test ($P \leq 0.05$); NS = nonsignificant.

vine establishment should be embraced by producers. Commercial-scale herbicide application conditions and methods commonly practiced in the region might further increase the benefits of protection devices and outweigh the potential benefits of the fan training system, which is not generally compatible with standard trunk protection devices.

Results from the destructive harvests and dry matter quantifications during the establishment year are detailed in Table 4. The open, carton, tube, and fan training systems, respectively, required progressively more labor to install and maintain in this setting (data not shown). The extra effort invested in the fan training method resulted in an increase of 32% to 42% in the amount of leaf area produced, compared with all other treatments. In addition, fan-trained vines had more leaf-stem-shoot, trunk, root, and total dry matter compared with all other treatments. Vines within the remaining

treatments (open, tube, and carton) did not differ in combined leaf-stem-shoot and root dry matter, but tube-treated vines had reduced trunk dry matter, which clearly reflects the etiolated trunks on those vines described earlier. These results concur with those reported for tube-protected vines by Hall and Mahaffee (2001). When comparing own-rooted and grafted vines across all four establishment treatments, there were no differences in total leaf area and total vine dry weight; however, trunk and root shank weights were greater in grafted vines, apparently at the expense of root weight. The increased root shank weights in grafted vines may have been an artifact of the grafting process and the original nursery vine structure. No interactions between establishment treatment and vine type were observed for leaf area or vine dry matter.

Data related to vine size and pruning are presented in Table 5. Although fan-trained vines produced numerically greater pruning weights

Table 4. Morphology of ‘Chambourcin’ grapevines in response to establishment treatment and rootstock vine type, determined by destructive harvest at Mount Vernon, MO, in 2009.

Variable ^z	Subvariable	Total leaf area (cm ²) ^y	Leaf, stem, shoot dry wt (g) ^y	Trunk dry wt (g)	Root dry wt (g)	Root shank dry wt (g) ^x	Total dry wt (g) ^w
Treatment ^v	Fan	28,118 a ^u	705 a	26 a	142 a	25	890 a
	Open	18,981 b	468 b	20 b	112 b	23	617 b
	Tube	17,223 b	397 b	17 c	89 b	22	518 b
	Carton	16,328 b	420 b	19 bc	93 b	23	547 b
	<i>P</i> value	<0.0001	<0.0001	<0.0001	0.0013	NS	<0.0001
Vine type	Grafted	20,524	527	28 a	96 b	27 a	669
	Own-rooted	19,919	470	13 b	122 a	20 b	620
	<i>P</i> value	NS	NS	<0.0001	0.0112	0.0001	NS

^zStatistical interactions between treatment and vine type were not significant ($P \leq 0.05$) for all factors.

^y1 cm² = 0.1550 inch², 1 g = 0.0353 oz.

^xRoot shank was the original belowground portion of vine from which all new growth emerged that year.

^wDue to rounding, figures in this column may not add up exactly to the sum of the previous four columns.

^vFan = six shoots (two vertical, two east at 45°, two west at 45°), unprotected; open = two vertical shoots, unprotected; tube = two vertical shoots, protected with 36-inch-tall plastic tube; carton = two vertical shoots, protected with 12-inch-tall paperboard carton (1 inch = 2.54 cm).

^uMeans within subcolumns with the same letters are not different according to the least significant difference test ($P \leq 0.05$); NS = nonsignificant.

in 2010 (1 year after the establishment year when greater overall dry matter was produced), this amount was not statistically different from the other treatments ($P < 0.119$). In subsequent years, relatively small but sometimes significant differences in vine size were observed among establishment methods, but these differences and patterns were relatively inconsistent and difficult to attribute to treatments executed 2 and 3 years earlier. Grafted vines produced greater pruning weights in both 2010 and 2011 compared with own-rooted vines suggesting an initial benefit of rootstock use, but by the conclusion of the 2012 season, grafted and own-rooted vines produced equal pruning weight.

Fruit yield and composition determined 3 and 4 years after establishment (2011 and 2012) are displayed in Table 6. Yields in these young vines increased from 2011 to 2012 as the vines matured, along with the number of clusters per vine and mean cluster weight; however, we did not compare years statistically. As grapevines are expected to be long-lived perennial crops, differences that manifest consistently over multiple seasons are of the greatest interest. Few differences were detected for most yield and fruit characteristics in both 2011 and 2012 that could be clearly attributed to 2009 establishment treatments. Despite greater leaf area and overall dry matter production in the fan-trained vines during establishment, neither yield nor berry size was larger during the next 2 years.

Table 5. ‘Chambourcin’ grapevine pruning weights in response to establishment treatment and rootstock vine type at Mount Vernon, MO, for the 2010–12 growing seasons.

Variable ^z	Subvariable	Pruning wt 2010 (kg) ^y	Pruning wt 2011 (kg)	Pruning wt 2012 (kg)
Treatment ^x	Fan	1.73 ^w	1.16 a	0.89 ab
	Open	1.64	1.14 a	0.94 a
	Tube	1.53	0.96 b	0.81 b
	Carton	1.67	1.03 ab	0.82 b
	<i>P</i> value	NS	0.0165	0.0094
Vine type	Grafted	1.77 a	1.16 a	0.88
	Own-rooted	1.52 b	0.99 b	0.84
	<i>P</i> value	<0.0001	0.0004	NS

^zStatistical interactions between treatment and vine type were not significant ($P \leq 0.05$) for all factors.

^yAll data for a stated growing year were determined in March of the following year; 1 kg = 2.2046 lb.

^xFan = six shoots (two vertical, two east at 45°, two west at 45°), unprotected; open = two vertical shoots, unprotected; tube = two vertical shoots, protected with 36-inch-tall plastic tube; carton = two vertical shoots, protected with 12-inch-tall paperboard carton (1 inch = 2.54 cm).

^wMeans within subcolumns with the same letters are not different according to the least significant difference test ($P \leq 0.05$); NS = nonsignificant.

Larger individual berries were produced on tube-treated vines in 2011, but this pattern did not continue in 2012. Although some treatment differences were detected in fruit pH (with tube-treated vines generally producing fruit with lower pH), it is difficult to discern any patterns that might logically be attributed to establishment treatments 2 and 3 years prior, and the observed differences are likely of limited commercial significance. But when comparing grafted vs. own-rooted vines across all establishment treatments, more differences in fruit yield and composition were observed. By 2012, grafted vines out-yielded own-rooted plants. Grafted vines produced smaller berries, greater cluster numbers, and smaller individual clusters consistently

over both seasons. Although pH values were not consistent across the two seasons, titratable acidity was lower for grafted vines in both seasons. No experimental interactions between establishment treatment and vine type for fruit yields, berry size, clusters, or fruit composition were detected.

Conclusion

Under the conditions of this experiment, the four different establishment methods evaluated were equally effective in developing mature, productive ‘Chambourcin’ grapevines. The regional industry-standard method of training one to two shoots inside vine shelters appears adequate and equivalent to more intensive training methods, even though the

Table 6. Yield and fruit composition of ‘Chambourcin’ grape in response to establishment treatment and rootstock vine type at Mount Vernon, MO, in 2011–12.

Year	Variable ^z	Subvariable	Fruit yield (kg/vine) ^y	Berry wt (g) ^y	Clusters (no./vine)	Mean cluster wt (g)	Soluble solids (%)	pH	Titrateable acidity (g·L ⁻¹) ^y
2011	Treatment ^x	Fan	10.9 ^w	1.91 b	53	204	22.4	3.83 ab	6.03
		Open	11.5	1.88 b	62	191	22.5	3.84 a	6.03
		Tube	11.7	2.04 a	56	213	22.3	3.81 b	5.86
		Carton	12.1	1.90 b	62	195	22.3	3.83 ab	5.75
		<i>P</i> value	NS	0.0001	NS	NS	NS	0.0482	NS
	Vine type	Grafted	11.9	1.83 b	62 a	195 b	22.5 a	3.79 b	5.74 b
		Own-rooted	11.2	2.03 a	54 b	209 a	22.2 b	3.86 a	6.09 a
		<i>P</i> value	NS	<0.0001	0.0163	0.0198	0.0076	<0.0001	0.0034
	2012 Treatment	Fan	17.5	1.79	82	218	19.9	3.61 a	5.21
		Open	17.6	1.73	83	218	19.9	3.59 ab	5.36
		Tube	16.8	1.73	78	218	19.4	3.55 b	5.43
		Carton	17.7	1.70	79	227	19.7	3.63 a	5.19
		<i>P</i> value	NS	NS	NS	NS	NS	0.0423	NS
	Vine type	Grafted	18.3 a	1.69 b	88 a	211 b	19.7	3.62 a	5.22 b
		Own-rooted	16.6 b	1.79 a	73 b	229 a	19.8	3.57 b	5.38 a
		<i>P</i> value	0.0037	0.0027	<0.0001	0.0079	NS	0.0075	0.0363

^zStatistical interactions between treatment and vine type were not significant ($P \leq 0.05$) for all factors.

^y1 kg = 2.2046 lb, 1 g = 0.0353 oz, 1 g·L⁻¹ = 0.1%.

^xFan = six shoots (two vertical, two east at 45°, two west at 45°), unprotected; open = two vertical shoots, unprotected; tube = two vertical shoots, protected with 36-inch-tall plastic tube; carton = two vertical shoots, protected with 12-inch-tall paperboard carton (1 inch = 2.54 cm).

^wMeans within subcolumns with the same letters are not different according to the least significant difference test ($P \leq 0.05$); NS = nonsignificant.

latter are capable of developing higher leaf area and vine dry weights in the initial establishment year. The use of two different vine shelters equally reduced herbicide injury to young grapevines therein. Producers’ decisions to employ vine shelters should be made with consideration for site, climate, and genotype-specific factors in addition to management needs and objectives. The limited soluble solids accumulation and unchanged pruning weight under high yield conditions in the last season of this study demonstrate the limited increase in capacity sometimes observed with 3309C rootstock relative to own-rooted vines (Morris et al., 2007). Grafting ‘Chambourcin’ to 3309C rootstock appears to offer only limited early benefits to producers in the lower midwestern United States, and warrants further and longer-term investigation.

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