Impact of Shoot Thinning and Harvest Date on Yield Components, Fruit Composition, and Wine Quality of Marechal Foch

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Abstract: Marechal Foch grapevines were subjected to shoot thinning (~15 shoots per meter of row and no shoot thinning) in combination with two harvest dates (early harvest and late harvest) in a factorialized treatment arrangement for two years (2007 and 2008). With shoot thinning, yields were reduced by 3.1 to 7.2 kg per vine and clusters were reduced by up to 59 clusters per vine, while berry weight increased by 0.03 to 0.09 g. Shoot thinning reduced crop load by 4.3 to 7.8 kg yield per kg pruning weight, and increased soluble solids in 2008 by 0.7 to 1.2 Brix. Shoot thinning increased berry anthocyanins by 1.25 to 2.24 mg/g fresh skin weight malvidin-3-glucoside, but no corresponding increase was observed in wine anthocyanins. Delaying harvest resulted in increases of soluble solids (0.5 to 2.3 Brix) and berry anthocyanins (0.32 to 1.48 mg/g) and significantly higher anthocyanins in finished wines. Both late harvest and shoot-thinning treatments resulted in decreased six-carbon alcohols (3 to 33%) in finished wines. The total concentration of tannin in Foch fruit was comparable to that of some *vinifera* (0.75 to 1.05 mg/berry catechin equivalents). However, the extractability of tannins during winemaking was very low compared to most *vinifera* (2 to 4%), in part likely due to the low skin tannin concentration. Using a two-alternative forced choice test, panelists reported that later harvest 2008 wines were more "fruity" than their early harvest counterparts for both treatments and that shoot thinning did not affect fruitiness.

Key words: canopy treatment, anthocyanin, tannin, aroma compounds

Marechal Foch (Kuhlmann 188.2) is an interspecific hybrid red winegrape variety produced from a cross of Goldriesling (cross of Riesling and Courtiller Musque) and 101-14 Millardet et de Grasset (cross of *Vitis riparia* and *Vitis rupestris*) (Lehman and Gerrath 2004). Marechal Foch is widely planted in the eastern wine regions of the United States and Canada, partly because of its early ripening (early to mid-September in the Finger Lakes region) and its cold hardiness (winter hardy to -26°C to-29°C) (http://viticulture.hort.iastate.edu/info/pdf/cultivars08.pdf). Foch vines tend to be overcropped because of the fruitfulness of noncount shoots (Fisher 1979), resulting in negative impacts on fruit composition and wine qualities and reduced vigor in the following year. Balanced pruning does not provide adequate crop control for most French-American hybrids given the production of heavily fruited primary and secondary shoots and fruiting shoots can arise from latent buds on cordons and from basal nodes that are not counted during balanced pruning (Fisher 1979).

In the Finger Lakes region of New York, growers of Marechal Foch anecdotally report "beet" or "radish" aromas in the grapes in some years. As viticultural management of Foch in the region is generally not intensive given the low price value of the cultivar, we were interested in investigating low-cost viticultural practices that could improve the aroma of Foch wine. We hypothesized that increased exposure of clusters and reduced crop load as a result of shoot thinning, as well as increased ripening time, would reduce the negative aroma characteristics reported in locally produced Foch.

To our knowledge there are no reports on the impact of canopy management practices (including shoot thinning) on Marechal Foch. Shoot thinning is a common, and well researched, viticultural practice for *Vitis vinifera* (Reynolds et al. 2005), hybrids (*Vitis* sp.), and *Vitis labruscana*. It is generally reported to be an effective and inexpensive method for reducing yields and increasing canopy openness in hybrids prone to overcropping (Reynolds 1989), often leading to increased canopy photosynthesis, berry temperature, bud fruitfulness (Cahoon and Nonnecke 1982), and vine hardiness (Smart 1988). Fruit composition is often improved (Reynolds et al. 2005). Similarly, several studies have considered the impact of grape maturity on the volatile composition of *V. vinifera* grapes or resulting wines (Kalua and Boss 2009, Coelho et al. 2007), but the effects of harvest date on hybrid

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grapes, excepting *V. labruscana* (Shure and Acree 1994), are not reported. Several studies on *V. vinifera* have also considered the impact of canopy management practices or harvest maturity on polyphenols responsible for astringency (condensed tannins) and color (anthocyanins) (Koyama and Goto-Yamamoto 2008, Ristic et al. 2007), but by comparison, there are relatively few studies on the impact of canopy management on phenolic species in red hybrid winegrapes (Reynolds et al. 1995). In particular, to our knowledge, quantitative measurements of tannins or tannin extractability by tannin-precipitation assays such as the Adams-Harbertson assay have not been previously reported for French-American hybrids.

Quantitative gas chromatography-olfactometry (CHARM GC-O) was used recently to identify 56 aroma compounds with flavor dilution values >1 in Marechal Foch wine (Sun et al. 2009). The majority of odorants detected by GC-O in Marechal Foch wine was similar to those previously reported in *V. vinifera* wines (Lopez et al. 2002), although a few compounds with "vegetal" and "musty" aromas unique to Marechal Foch are not yet conclusively identified. While not all compounds detectable by GC-O are necessarily critical to the aroma of the resulting wine (Ferreira and Cacho 2008), the GC-O data set does provide a useful starting point for understanding how growing practices influence wine flavor chemistry.

The objective of this study was to assess the effects of two inexpensive viticultural practices, shoot thinning and harvest date, on the yield, wine and fruit composition, and wine sensory qualities of Marechal Foch in the Finger Lakes region of New York State.

Materials and Methods

Vineyard site and experimental design. This study was conducted in 2007 and 2008 with 32-year-old Marechal Foch vines at a commercial winery on the west side of Seneca Lake in Penn Yan, New York. The vines were grafted onto 3309C. Soil in the block was a well-drained Lima silt loam (USDA-NRCS soil maps). Vines were spaced at 2.1 m x 2.4 m (vine x row) in north-south oriented rows and trained to the Umbrella-Kniffen system. Drip irrigation was installed throughout the vineyard. Standard pest control practices for the region were used.

The experimental design consisted of two canopy treatments (no shoot thinning and shoot thinning) combined with two harvest dates (early and late) in a randomized complete block design with four replications. Treatments were designated as no shoot thinning, early harvest (CE); no shoot thinning, late harvest (CL); shoot thinning, early harvest (SE); and shoot thinning, late harvest (SL). Each experimental unit consisted of five panels of vines, with two panels randomly selected at the beginning of the experiment for data collection. For the shoot-thinning treatment, approximately 15 primary shoots were retained per meter and all secondary, tertiary, and noncount shoots were removed. Shoot-thinning treatments were applied when shoots reached ~51 to 127 mm in length in May. The harvest dates were based roughly on the beginning and end of the Foch harvest in the Finger Lakes region for each season. "Early" harvests occurred on 11 Sept 2007 and 10 Sept 2008 and "late" harvests occurred on 18 Sept 2007 and 23 Sept 2008.

Yield components. Vines were individually harvested by hand on 11 Sept (early harvest) and 18 Sept (late harvest) in 2007, and 10 Sept (early harvest) and 23 Sept (late harvest) in 2008. Yield per vine was quantified using a hanging scale (Salter Weigh-Tronix, Fairmont, MN) and cluster number per vine was counted. Cluster weights were calculated by dividing yield by cluster number on a per vine basis. A random sample of 15 to 20 clusters per panel was collected at harvest and stored at -20°C until analysis. Subsamples of 100 berries were weighed to determine mean berry weight. Berry number per cluster was calculated by dividing cluster weight by berry weight. Total shoots, base shoots, primary shoots, and secondary shoots were counted prior to pruning. Pruning weights were collected in early January in 2008 and 2009. Crop load was calculated by dividing yield by pruning weight on a per vine basis.

Canopy characterization. Enhanced point quadrat analysis (EPQA) (Meyers and Vanden Heuvel 2008) was used to characterize canopy light environment at approximately veraison in both years. A sharpened thin metal rod was inserted into the canopy at regular 10-cm intervals, and sequential contacts of leaves, clusters, and canopy gaps from one side to the other were recorded. Photon flux measurement was performed according to a previously described method (Meyers and Vanden Heuvel 2008). Canopy parameters were analyzed by EPQA and CEM Tools, version 1.6 (Cornell University, Ithaca, NY). Parameters included occlusion layer number (OLN), the number of shade-producing contacts (leaves and clusters per insertion); cluster exposure flux availability (CEFA), the percentage, expressed as a decimal of above-canopy photon flux that reaches clusters; and leaf exposure flux availability (LEFA), the percentage, expressed as a decimal of above-canopy photon flux that reaches leaves.

Berry and wine composition. A-100 berry sample was collected randomly in duplicate from each sample that was kept frozen at -40°C until analysis. The frozen berries were thawed at room temperature before collection. The berries were juiced by a blender and the slurry was pressed through cheesecloth. Brix was measured using an Abbé temperature-compensated refractometer (ATAGO, Bellevue, WA). Berry and wine pH were measured using an Orion 3-Star pH meter (Thermo-Fisher Scientific, Waltham, MA), and titratable acidity (TA) was determined on a 10 mL sample by Digital Buret autotitration (BrandTech Scientific, Essex, CT) using 0.1 M NaOH to an endpoint of pH 8.2. Wine alcohol concentration was measured by ebulliometer (DuJardin-Salleron, Arcueil Cedex, France). Wine-free SO_2 was measured by FIAstar 5000 analyzer (FOSS, Eden Prairie, MN). Berry and wine anthocyanins and tannins were determined by the Adams-Harbertson protein precipitation assay, using 20 berries (Harbertson et al. 2003).

Winemaking. Wines were made in duplicate after replicates for each treatment had been combined in the field. Fruit was destemmed, crushed, and treated with 50 mg/L sulfur dioxide. Diammonium phosphate (DAP) (Presque Isle Wine

Cellars, North East, PA) was added to a concentration of 1 g/kg, Fermaid K (Lallemand, Rexdale, ON, Canada) to 0.1 g/L, and Goferm (Lallemand) to 0.15 g/L. Skin fermentation was done in jacketed 114-L fermentors. Cap management was performed twice per day by manual punchdowns. The must was brought to 20°C and inoculated with EC1118 (Lallemand) to 0.26 g/L. The temperature profile of the fermentations was controlled by a connected computer. During the first three days of fermentation, the must was warmed slowly from 20°C to a maximum between 30 and 35°C. Temperature limits were set at 20°C and 30°C for the remainder of the alcoholic fermentation. Fermentation was complete when residual sugar was measured as less than 0.5% using Clinitest tablets (Bayer, Etobicoke, ON, Canada). Wines were pressed, topped, and inoculated with Alpha (Lallemand) to start malolactic fermentation (MLF). Upon completion of MLF, sulfur dioxide was added to maintain 40 mg/L free sulfur dioxide. Wines were cold stabilized at 2°C. Titratable acidity was adjusted to 6.5 g/L by addition of tartaric acid or potassium carbonate after cold stabilization. The wines were screened for faults by an expert panel prior to bottling. Bottling and screwcapping were performed manually.

Quantification of wine aroma compounds. Analysis of aroma compounds was adopted from previously reported methods (Lopez et al. 2002). Solid phase extraction (SPE) of a 50 mL wine sample containing 0.25 mg/L 2-octanol (Sigma-Aldrich, St. Louis, MO) (quantification internal standard) was performed on a LiChrolut EN column (Merck, Darmstadt, Germany) preconditioned with 4 mL dichloromethane (DCM), 4 mL methanol, and 4 mL 12% ethanol (all Fisher Scientific, Pittsburgh, PA). Following sample loading, the SPE column was dried under nitrogen (2 mL/min) for 15 min, and analytes were eluted by 1.3 mL DCM containing 1 mg/L 2-ethyl hexanoate (Sigma-Aldrich) as a quality-control internal standard. After extraction, compounds were quantified either by GC-FID (for higher concentration analytes) or by GC-MS. For GC-FID quantification, standard curves were generated for analytes in model wine with respect to the 2-octanol internal standard over the range observed in wine. Calibration curves were not prepared for the GC-MS semiquantification, but previous work (Lopez et al. 2002) demonstrated >90% recovery and good linearity for most the analytes in wine under study in our current work. The commercial source for each analyte, their method of quantification, and the calibration ranges used are shown (Table 1). Identification of compounds in samples was performed by comparison of linear retention indices and mass spectra to those of authentic standards.

GC-FID analyses were performed in duplicate on a CP-3800 gas chromatograph (Varian Inc., Walnut Creek, CA)

Table 1 Compounds, retention index (RI), chemical standards, and quantification methods.

Compound	RI (CP-Wax)	Odorant description	Commercial source	Purity (%)	Quantification method	Quantification ion (*m/z*)	Calibration range (mg/L)
Isobutanol	1105	solvent	SAFC Supply Solution	99	FID		2–240
Isoamyl acetate	1135	banana	Aldrich	98	FID		0.05–5
1-Butanol	1161	fruit	Acros Organics	99	FID		2–220
Isoamyl alcohol	1234	chocolate	SAFC Supply Solution	98.5	FID		5–250
Ethyl hexanoate	1251	apple	Acros Organics	99	FID		0.05–3
Hexyl acetate	1273	fruit	Aldrich	99	FID		0.020–1
Ethyl lactate	1352	fruit	Acros Organics	95	FID		2.5–250
cis-3-Hexenol	1356	grass	SAFC Supply Solution	98	GC-MS	67	
1-Hexanol	1368	green	Fluka (Sigma–Aldrich)	99	FID		0.250–25
trans-2-Hexenol	1406	grass	SAFC Supply Solution	95	GC-MS	57	
Butyric acid	1593	sweat	Aldrich	99+	FID		0.2–6
α-Terpineol	1680	flower	Acros Organics	97+	GC-MS	59	
Isovaleric acid	1694	cheese	Aldrich	99	FID		0.1–10
Diethyl succinate	1704	fruit	Aldrich	99+	FID		0.23–23
Methionol	1743	potato	Aldrich	98	FID		0.1–3
Citronellol	1769	flower	Aldrich	95	GC-MS	71	
β-Phenethyl acetate	1835	rose	Acros Organics	98+	FID		0.023–1.2
β-Damascenone	1844	cooked apple	SAFC Supply Solution	1.1–1.3 wt	GC-MS	69	
Ethyl dihydrocinnamate	1857	flower	Aldrich	98	GC-MS	91	
Hexanoic acid	1871	sweat	Aldrich	99.5	FID		0.09–9
Guaiacol	1883	smoke	Aldrich	98	GC-MS	109	
Benzyl alcohol	1905	sweet	Acros Organics	99+	FID		0.02–1
β-Phenyl ethanol	1938	honey	Aldrich	99+	FID		3.5–70
γ-Nonalactone	2035	coconut	K & K Laboratories	98	GC-MS	85	
Octanoic acid	2084	sweat	Aldrich	98	FID		0.09–9
Ethyl cinnamate	2131	flower	Aldrich	99	GC-MS	131	
Eugenol	2191	bandaid	Aldrich	99	GC-MS	164	
4-Vinylguaiacol	2225	clove	SAFC Supply Solution	98	GC-MS	135	

equipped with a split/splitless injector and a CP-Wax 58 FFAP fused capillary column (30 m x 0.32 mm i.d. x 1.2 µm). Wine samples (3 µL) were injected into the column in splitless mode, with a purge time of 0.75 min. High-purity helium was used as carrier gas with flow rate of 3 mL/min. The injector temperature was 250°C and the FID detector temperature was 300°C. The oven temperature was held at 55°C for 5 min, then increased to 163°C at 3°C/min, then increased to 250°C at 10°C/min, then held at 250°C for 15min. Galaxie Workstation ver. 1.9.3.2 (Varian) was used for data acquisition and analysis.

GC-MS analyses were performed using a CP-3800 gas chromatograph coupled to a Saturn 2000 ion trap mass spectrometer (Varian). Chromatographic separation was achieved on a CP-Wax column (50 m x 0.25 mm x 0.2 µm) (Varian). High-purity helium was used as a carrier gas with flow rate of 1 mL/min. The injector was operated at 250°C and the detector at 300°C. The temperature program for the column oven was 40°C for 6 min, then 140°C to 170°C at a rate of 10°C/min, then 170°C to 250°C at a rate of 5°C/min, and finally 250°C, held for 20 min. Saturn GC-MS version 6.3 software (Varian) was used for data acquisition and analysis.

Sensory tests. The 2007 wines were evaluated and compared in February 2009 for all four treatments by triangle test. Wines were aged in bottle for approximately one year prior to evaluation. Clear, tulip-shaped 220-mL wineglasses coded with 3-digit numbers were used to serve wines in a sensory room illuminated with fluorescent lighting. Wine samples (25 mL) were poured into glasses and evaluated at room temperature. Panelists were separated from each other. All panelists expectorated wine samples and rinsed their mouths with water between tests. Water and plain bread were provided as cleansers (Lawless and Heymann 1999). Each test was carried out by 12 panelists with wine evaluation experience. Two sessions were conducted in the morning and afternoon comparing wines from the four different treatments. In session one, comparisons were made between SE versus CE and SL versus CL. In session two, comparisons were made between SE versus SL and CE versus CL. Each comparison was duplicated.

The 2008 wines were evaluated and compared in October 2009 for all four treatments by two-alternative forced choice (2-AFC) test (Bi et al. 1997, Ennis 1993). Wines were aged in bottle for approximately 6 months. The use of the 2-AFC test was based on the sensory test result of 2007 wines. Fourteen panelists with wine evaluation experience were selected for the test. A pair of coded samples for comparison was presented to panelists, who were asked to select the sample with the stronger fruitiness (Bi et al. 1997, Ennis 1993). Wines from each treatment were compared to one another. Each comparison was duplicated. One wine sample was randomly selected for sensory evaluation from duplicate wines.

Statistical analysis. Mixed-model ANOVA was performed using JMP software (ver. 8.0; SAS Institute, Cary, NC). Probabilities for the triangle test were calculated by Excel (version 2007; Microsoft, Redmond, WA) using the formula: p = 1- BINOMDIST (r-1, n, 1/3, TRUE), where r is successes out of n trials and n is the number of trials. The 2-AFC test statistical analysis was performed by an established method (Bi et al. 1997).

Results

Yield components. In 2007, shoot thinning reduced yield per vine, cluster number per vine, and berry number, but increased berry weight (Table 2). Yield reductions ranged from 3.1 to 4.7 kg/vine, primarily as a function of cluster

Table 2 Impact of shoot thinning and harvest date on yield compositions of Marechal Foch, 2007 and 2008.

Treatment[a]	Yield/vine (kg)	Clusters/ vine	Cluster wt (kg)	Berries/ cluster	Berry wt (g)	Crop load (kg yield/ kg pruning wt)
2007						
Control, early (CE)	14.7	91	0.17	162	1.03	21.9
ST, early (SE)	10.0	65	0.17	150	1.12	19.7
Control, late (CL)	14.5	89	0.16	160	0.99	24.9
ST, late (SL)	11.4	69	0.16	156	1.02	24.2
***p* value**						
Shoot thinning	0.001	0.002	0.642	0.002	0.0009	0.347
Harvest date	0.523	0.814	0.477	0.112	0.0003	0.356
Shoot thinning x harvest date	0.556	0.858	0.765	0.019	0.0080	0.491
2008						
Control, early (CE)	23.2	154	0.15	146	0.99	23.2
ST, early (SE)	15.9	95	0.17	154	1.08	18.9
Control, late (CL)	21.5	145	0.14	146	1.00	24.4
ST, late (SL)	15.1	91	0.17	153	1.09	16.6
***p* value**						
Shoot thinning	<0.001	<0.001	0.043	0.016	0.003	0.011
Harvest date	0.347	0.369	0.560	0.723	0.619	0.821
Shoot thinning x harvest date	0.752	0.693	0.602	0.689	0.866	0.382

[a]Control: no shoot thinning; ST: shoot thinning (15 primary shoots/m); early; early harvest (11 Sept 2007, 10 Sept 2008); late, late harvest (18 Sept 2007, 23 Sept 2008).

number, which was reduced by up to 26 clusters per vine. Cluster weight and crop load were not affected by shoot-thinning treatment. In 2008, yield per vine was reduced to a greater degree than in 2007 (with reductions ranging from 6.4 to 7.2 kg/vine) due to large decreases in cluster number per vine with shoot thinning (up to 59 clusters per vine). Shoot thinning reduced crop load, but increased cluster weight and berry weight (Table 2).

Harvest date only reduced berry weight in 2007 and had no impact on yield components in 2008. In 2007, there were significant interactions between shoot thinning and harvest date for berries per cluster and berry weight (Table 2). The SE treatment showed a significant decrease in berries per cluster compared to the CE treatment. The SE treatment increased berry weight to a greater extent than the CE treatment, but there was no significant difference between CL and SL.

Vine canopy. Shoot-thinning treatments increased CEFA from 0.16 to 0.21 in 2007 and 0.12 to 0.19 in 2008. LEFA increased by 0.35 to 0.40 in 2008 by shoot-thinning treatments. Shoot thinning did not affect OLN in both years. Harvest date had no effect on CEFA, LEFA, and OLN.

Berry composition. In 2007, shoot thinning had no effect on berry pH and Brix, but increased TA (Table 3). Berry anthocyanin concentration, as malvidin-3-glucoside equivalents, increased as a result of shoot thinning as did berry skin tannin (catechin equivalents) (Table 4). In 2008, shoot thinning increased Brix but had no effect on pH and TA (Table 3). Berry anthocyanin and skin tannin were also increased by shoot-thinning treatment (Table 4). In 2007, berry pH, Brix, and TA were increased by the CL and SL treaments (Table 3). Berry anthocyanin was increased by CL and SL (Table 4). In 2008, CL and SL treatments increased pH and Brix. Harvest date had no effect on berry TA (Table 3). Berry anthocyanin increased, while berry seed tannin was decreased by CL and SL treatments (Table 4).

Wine composition. In 2007, shoot thinning increased wine pH (Table 3) and wine tannin (Table 4). In 2008, thinning slightly increased wine pH, alcohol, and TA (Table 3). The impact of late harvest was more pronounced in both years. In 2007, wine pH and alcohol were increased by CL and SL treatments while wine TA decreased (Table 3). Wine anthocyanin was increased by CL and SL treatments (Table 4). In 2008, wine pH and alcohol were increased by CL and SL treatments (Table 3). Wine anthocyanin increased (Table 4). The SE treatment decreased wine TA compared to CE, but the SL treatment did not decrease wine TA compared to the CL treatment (Table 3).

Wine aroma chemistry. Based on previous GC-O work (Sun et al. 2009), 28 aroma compounds (six esters, five fusel alcohols, four fatty acids, three terpenoids, six shikimic acid derivatives, three C_6 alcohols, and one other compound) were selected for study (Table 5). Of these compounds, 17 were quantified against calibration curves based on authentic standards and 11 were semiquantified based on relative response with respect to the 2-octanol internal standard. As mentioned previously, not all odorants detected by GC-O in our earlier work have been confidently identified, including some compounds that are unique to Marechal Foch. Therefore, they are not included in the GC-MS analysis.

Because of the observed similarities in treatment effects to related compounds within a compound class and the high number of volatiles under investigation, we converted absolute changes to relative percent changes and pooled together related compounds. In 2007, the SE treatment increased esters and shikimic acid derivatives by 9% and 11, respectively, and decreased fatty acids, fusel alcohols, terpenoids, and C_6

Table 3 Impact of shoot thinning and harvest date on berry and wine composition of Marechal Foch, 2007 and 2008.

	Berry			Wine		
Treatment[a]	pH	Brix	TA (g/L)	pH	Alcohol (% v/v)	TA (g/L)
2007						
Control, early (CE)	3.62	22.7	8.67	3.57	11.28	6.70
ST, early (SE)	3.66	22.9	9.36	3.60	11.50	6.55
Control, late (CL)	3.69	23.2	9.32	3.64	12.35	6.40
ST, late (SL)	3.70	24.3	9.50	3.72	12.80	6.20
***p* value**						
Shoot thinning	0.276	0.107	0.0002	0.021	0.061	0.080
Harvest date	0.008	0.022	0.001	0.006	0.0008	0.012
Shoot thinning x harvest date	0.428	0.295	0.357	0.407	0.437	0.756
2008						
Control, early (CE)	3.50	22.1	11.06	3.66	10.70	6.90
ST, early (SE)	3.55	23.3	11.04	3.72	11.00	6.60
Control, late (CL)	3.62	24.3	10.28	3.73	12.00	6.50
ST, late (SL)	3.68	25.1	11.01	3.77	12.10	6.45
***p* value**						
Shoot thinning	0.020	0.005	0.094	0.0007	0.027	0.002
Harvest date	<0.0001	<0.001	0.057	0.0004	<0.0001	0.0004
Shoot thinning x harvest date	0.709	0.435	0.071	0.089	0.234	0.008

[a]Control, no shoot thinning; ST, shoot thinning (15 primary shoots/m); early, early harvest (11 Sept 2007, 10 Sept 2008); late, late harvest (18 Sept 2007, 23 Sept 2008).

alcohols by 6%, 5%, 12%, and 10%, respectively. The CL treatment increased esters by 7% and decreased fatty acids, fusel alcohols, terpenoids, shikimic acid derivatives, and C_6 alcohols by 20%, 10%, 22%, 18%, and 18%, respectively. The SL treatment increased esters by 7% and decreased fatty acids, fusel alcohols, terpenoids, shikimic acid derivatives, and C_6 alcohols by 27%, 16%, 42%, 1%, and 33%, respectively (Figure 1).

In 2008, the SE treatment increased terpenoids by 31% and decreased esters, fusel alcohols, fatty acids, shikimic acid derivatives, and C_6 alcohols decreased by 1%, 2%, 6%, 8%, and 14%, respectively. The CL treatment increased esters, fusel alcohols, and terpenoids by 3%, 1%, and 17%, respectively, and decreased fatty acids, shikimic acid derivatives, and C_6 alcohols by 23%, 4%, and 3%, respectively. The SL treatment increased esters and terpenoids by 4% and 31%, respectively, and decreased fusel alcohols, fatty acids, shikimic acid derivatives, and C_6 alcohols decreased by 5%, 30%, 11%, and 32%, respectively (Figure 1).

Sensory test. Panelists were able to distinguish between SL/CL and SE/SL at $p < 0.01$ for 2007 Foch wine (Table 6). Panelists were able detect differences in fruitiness between SE and SL, CE and CL ($p < 0.01$), and CE and SL ($p < 0.05$) for 2008 Foch wine (Table 7).

Discussion

Effects of shoot thinning. The shoot densities in this study were 15 shoots per meter of row and no shoot thinning. Although vines were not very vigorous (2.5 to 3.2 OLN in 2007, 2.9 to 3.2 OLN in 2008) and were highly cropped in both years, shoot thinning improved CEFA in both years of the study. Higher LEFA of shoot-thinned vines in 2008 suggests a possible increase in canopy photosynthesis (Vasconcelos and Castagnoli 2000), which may be attributed to the improved Brix. Reducing the number of shoots per vine also resulted in less clusters per vine; hence, lower yield and generally higher Brix (Bravdo et al. 1984).

Shoot thinning increased berry TA in 2007, but no effect was observed in 2008. The effect of shoot thinning on TA in previous reports is similarly inconsistent. The increase in anthocyanin in grapes but not in wines of shoot-thinned treatments may have been mediated by increased light exposure (Dokoozlian and Kliewer 1996), although other reports have not observed an increase (Ristic et al. 2007). It is not clear why the differences in berry anthocyanin concentration did not persist into the finished wines. Other differences in color composition or appearance may have occurred, such as changes in polymeric pigment or tristimulus values, but these were not measured in our study.

The shoot-thinning treatment resulted in higher berry skin tannin (10 to 30%) in both years, which is consistent with a previous report (Ristic et al. 2007), although the increase was not apparent in wine tannin. Seed tannin was not affected by the shoot-thinning treatment, in contrast to other work (Ristic et al. 2007). The Foch wines in our study had very low tannin (29 to 60 mg/L catechin equivalents), in concordance with anecdotal reports that wines produced from Marechal Foch and other French-American hybrids possess low astringency. By comparison, the mean tannin concentration in California, Oregon, and Washington State *V. vinifera* red wines is reportedly 544 mg/L, with less than 2% of wines reported to have <100 mg/L tannin (Harbertson et al. 2008). The standard Adams-Harbertson has a loss of accuracy for tannin concentrations <100 mg/L (Jensen et al. 2008). However, even with

Table 4 Impact of shoot thinning and harvest date on berry and wine anthocyanin and tannin of Marechal Foch, 2007 and 2008.

Treatment[a]	Berry anthocyanin (mg/g M-3-G[b] fresh skin wt)	Wine anthocyanin (mg/L M-3-G[b])	Berry skin tannin (mg/berry catechin eq.)	Berry seed tannin (mg/berry catechin eq.)	Wine tannin (mg/L catechin eq.)	% Tannin extraction
2007						
Control, early (CE)	5.78	478.5	0.21	0.64	48.55	3.53
ST, early (SE)	8.02	505.5	0.27	0.81	59.81	3.72
Control, late (CL)	6.73	644.0	0.19	0.66	45.06	3.15
ST, late (SL)	8.34	661.5	0.21	0.61	54.18	4.04
***p* value**						
Shoot thinning	0.0002	0.413	0.030	0.472	0.024	
P Harvest date	0.011	0.003	0.056	0.329	0.186	
Shoot thinning x harvest date	0.089	0.855	0.663	0.245	0.728	
2008						
Control, early (CE)	4.64	753.0	0.18	0.81	39.55	2.38
ST, early (SE)	5.89	777.5	0.22	0.90	40.69	2.36
Control, late (CL)	5.45	861.5	0.19	0.70	29.28	1.98
ST, late (SL)	7.37	919.0	0.23	0.63	34.68	2.64
***p* value**						
Shoot thinning	0.011	0.166	0.035	0.903	0.393	
Harvest date	0.032	0.007	0.305	0.026	0.076	
Shoot thinning x harvest date	0.396	0.533	1.000	0.292	0.567	

[a]Control, no shoot thinning; ST, shoot thinning (15 primary shoots/m); early, early harvest (11 Sept 2007, 10 Sept 2008); late, late harvest (18 Sept 2007, 23 Sept 2008).
[b]Malvidin-3-glucoside equivalents.

a two-fold allowance for error, this work provides the first confirmation of low tannins in French-American hybrid wines by a protein-precipitation assay.

Skin tannin in our study ranged from 0.19 to 0.23 mg/berry and the total tannin concentration ranged from 0.82 to 1.12 mg/berry. Skin tannin concentration per berry in Foch is ~60% less than values reported in Cabernet Sauvignon and Syrah (Harbertson et al. 2002), although the concentrations are more similar on a by-weight basis because of the smaller berry size of Marechal Foch. The seed tannin concentration per berry is similar to values reported in *vinifera* (Harbertson et al. 2002), where tannin extractability is calculated by dividing the tannin quantity in wines by the tannin in grapes and correcting for yield during pressing. We calculated that only 2 to 4% of tannin in Marechal Foch fruit of this study was extracted into wine during winemaking. For wine made from *vinifera*, extractability is reported to range from 4.9 to 61% (Harbertson et al. 2002), with the lowest extractability reported for Pinot noir. Both Foch and Pinot noir possess low levels of skin tannin, which is reported to be extracted more rapidly during fermentation than seed tannin. A low extractability of total tannin (9%) from Pinot noir during winemaking has been reported, with higher extractability (29% versus 6%) of skin tannin versus seed tannin (Kennedy 2008). Using this reported extraction efficiency, we would expect a median concentration of 155 mg/L total wine tannin (91 mg/L from skin tannin and 64 mg/L from seed tannin) from Foch, or about a factor of 3 greater than what we observed. The very low tannin concentration of Foch wines compared to most *V. vinifera* wines appears to be due to both its lower skin tannin

Table 5 Impact of shoot thinning and harvest date on wine aroma compounds of Marechal Foch, 2007 and 2008.

	2007 treatments[a]				*p* value			2008 treatments[a]				*p* value		
Compound	**CE**	**SE**	**CL**	**SL**	**Shoot thin**	**Harvest date**	**Thin x harvest**	**CE**	**SE**	**CL**	**SL**	**Shoot thin**	**Harvest date**	**Thin x harvest**
Esters (mg/L)														
Ethyl lactate	146.0	144.1	140.6	131.6	0.556	0.176	0.374	86.24	81.91	73.30	70.25	0.026	<0.0001	0.664
Ethyl hexanoate	0.465	0.440	0.315	0.295	0.482	0.007	0.936	0.340	0.340	0.370	0.330	0.161	0.574	0.210
Hexyl acetate	0.130	0.130	0.130	0.130	1.000	1.000	1.000	0.140	0.120	0.120	0.120	0.020	0.006	0.020
Isoamyl acetate	1.405	1.295	1.500	1.195	0.214	0.987	0.526	1.830	1.660	1.720	1.610	0.051	0.247	0.611
Ethyl succinate	2.715	5.145	3.135	4.260	0.500	0.119	0.479	0.840	0.880	0.990	1.070	0.086	0.0004	0.507
β-Phenethyl acetate	0.825	0.860	1.300	1.215	0.663	0.002	0.323	2.140	2.560	3.060	3.180	0.0003	<0.0001	0.016
Fusel alcohols (mg/L)														
Isobutanol	33.21	32.65	28.90	31.47	0.278	0.093	0.466	29.25	28.20	25.90	24.90	0.066	<0.0001	0.953
1-Butanol	2.925	3.045	3.450	3.275	0.812	0.025	0.246	3.380	3.300	3.360	3.320	0.248	0.950	0.714
Methionol	2.240	1.755	1.630	1.375	0.283	0.173	0.720	1.210	1.090	1.210	0.960	0.031	0.417	0.399
Isoamyl alcohol	157.1	152.2	129.4	112.3	0.239	0.013	0.485	136.7	132.8	132.9	123.6	0.069	0.073	0.431
β-Phenyl ethanol	12.88	12.55	11.55	10.31	0.492	0.161	0.685	10.64	11.53	12.86	12.76	0.048	<0.0001	0.017
Terpenoids														
Citronellol	0.009	0.008	0.006	0.005	0.275	0.034	1.000	0.028	0.035	0.040	0.047	0.014	0.0004	0.868
α-Terpineol	0.016	0.016	0.014	0.012	0.047	0.0006	0.047	0	0	0	0			
β-Damascenone	0.019	0.014	0.015	0.008	0.057	0.092	0.836	0.070	0.090	0.070	0.090	<0.0001	0.800	0.613
Fatty acids (mg/L)														
Caproic acid	2.435	2.320	1.490	1.240	0.386	0.006	0.737	2.020	1.820	1.770	1.610	0.155	0.077	0.864
Octanoic acid	1.530	1.385	0.955	0.825	0.306	0.008	0.952	1.030	0.910	0.790	0.690	0.002	<0.0001	0.705
Isovaleric acid	1.345	1.280	1.460	1.325	0.094	0.155	0.486	1.630	1.710	1.420	1.320	0.877	<0.0001	0.014
Butyric acid	3.610	3.425	3.210	3.110	0.264	0.031	0.718	3.220	2.960	1.760	1.660	0.241	<0.0001	0.604
Shikimic acid derivatives														
Ethyl dihydrocinnamate	0.010	0.012	0.008	0.008	0.552	0.086	0.552	0	0	0	0			
Benzyl alcohol	0.380	0.335	0.335	0.345	0.441	0.441	0.250	0.430	0.440	0.350	0.230	0.0001	<0.0001	<0.0001
Ethyl cinnamate	0.046	0.035	0.032	0.027	0.066	0.025	0.424	0	0	0	0			
4-Vinylguaiacol	3.232	2.701	2.187	1.691	0.193	0.035	0.961	0.220	0.170	0.180	0.180	0.449	0.698	0.510
Guaiacol	0.108	0.106	0.091	0.118	0.413	0.895	0.367	0.030	0.030	0.040	0.040	0.177	0.177	0.640
Eugenol	0.001	0.002	0.001	0.002	0.040	0.374	0.374	0.080	0.070	0.070	0.070	0.633	0.075	0.633
C_6 alcohols														
cis-3-Hexenol	0.355	0.310	0.265	0.205	0.001	0.0001	0.320	1.020	0.870	1.010	0.790	<0.0001	0.028	0.085
trans-2-Hexenol	0.370	0.330	0.310	0.240	0.005	0.002	0.208	0.300	0.260	0.290	0.150	<0.0001	<0.0001	0.0003
1-Hexanol	5.000	4.645	4.330	3.935	<0.0001	<0.0001	0.3528	6.330	5.410	6.070	4.920	<0.0001	0.001	0.205
Other														
γ-Nonalactone	0.046	0.049	0.050	0.058	0.035	0.027	0.238	0	0	0	0			

[a]CE: control, early harvest (11 Sept 2007, 10 Sept 2008); SE: shoot thinning, early harvest (11 Sept 2007, 10 Sept 2008); CL: control, late harvest (18 Sept 2007, 23 Sept 2008); SL: shoot thinning, late harvest (18 Sept 2007, 23 Sept 2008).

concentration and to lower tannin extractability (comparable to or less than Pinot noir). Factors that decrease tannin extractability from winegrapes during winemaking are poorly understood. Previous studies reported it is because of tannin binding to grape cell walls (Adams and Scholz 2008, Hanlin et al. 2010). It is also hypothesized to be due to increased polysaccharide-tannin interactions during grape maturation. Further study will be necessary to determine if this is a general phenomenon for other hybrid winegrapes.

The aroma analysis did not identify any "beet" or "radish" aromas as reported by the local grape and wine industry in Foch. Shoot thinning impacted only a few aroma compounds in wines, and the impact of the treatment was often inconsistent across years or harvest dates. For example, concentrations of some esters (ethyl lactate, hexyl acetate), a fusel alcohol (methionol), and fatty acids (hexanoic acid, octanoic acid) all decreased as a result of the shoot-thinning treatment in 2008, but this effect was not apparent in 2007. All compounds mentioned above are derived from fermentation. Although winemaking conditions were the same for all treatments, the initial soluble solids, pH, and composition of grape juice varied among treatments and between years, which may have affected formation of the compounds. For example, both total yeast assimilable nitrogen (YAN) concentration and the relative proportions of amino acids composition in juice are reported to modify concentration of esters, fusel alcohols, and fatty acids during fermentation (Saerens et al. 2008). However, even in cases where the differences were significant, the magnitude of the effect caused by shoot thinning was generally small (<20%).

The shoot-thinning treatment resulted in a consistent decrease in C_6 alcohols (1-hexanol, *cis*-3-hexenol, and *trans*-2-hexenol) in finished wines across both harvest dates and years of study. These C_6 alcohols possess herbaceous aromas and can be formed immediately following crushing of grape berries from lipid-precursors or by reduction of analogously formed C_6 aldehydes during fermentation (Joslin and Ough 1978). Several groups have reported that the total C_6 concentration of *V. vinifera* grapes (aldehydes + alcohols) decreases during grape ripening (Joslin and Ough 1978, Kalua and Boss 2009), but to our knowledge the impact of canopy-management practices on resultant levels of C_6 compounds in wines has not been reported. Although the importance of the C_6 alcohols to Marechal Foch wines still needs to be demonstrated, the current work demonstrates that shoot thinning can be used to reduce these potentially negative compounds.

Effects of harvest date. Harvest date impacted basic fruit and wine chemistry as expected. Later harvest dates resulted in grapes with higher pH, higher Brix, and lower TA. The resulting wines had higher ethanol concentration. Harvest date did not affect OLN, CEFA, or LEFA in either year.

Harvest date increased both berry and wine anthocyanins. The increase in berry anthocyanins was calculated as mg/g fresh skin weight and likely indicates continued accumulation of anthocyanins during maturation. In 2007, the higher anthocyanin concentration of late harvest wines may also be

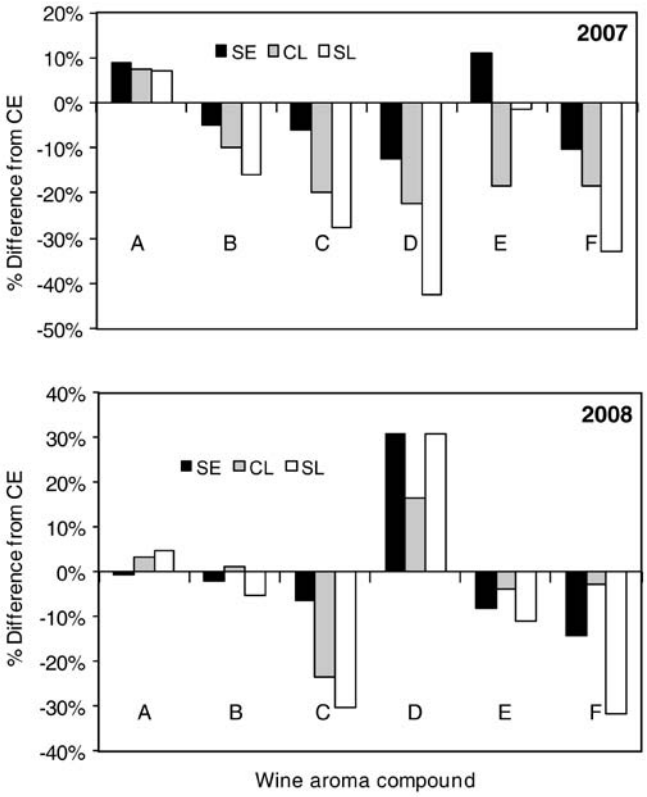

Figure 1 Impact of shoot thinning and harvest date on wine aroma compounds of Marechal Foch, 2007 and 2008. Y-axis: Average % change compared to the CE treatment (normalized to 0%). A: esters; B: fusel alcohols; C: fatty acids; D: terpenoids; E: shikimic acid derivatives; F: C_6 alcohols.

Table 6 Sensory results from triangle test of Marechal Foch, 2007.

Treatment comparison[a]	Correct responses (out of 24)	Probability of result by chance (%)
ST, early/control, early (SE/CE)	5	0.941
ST, late/Control, late (SL/CL)	14	0.010
ST, early/ST, late (SE/SL)	14	0.010
Control, early/control, late (CE/CL)	9	0.406

[a]Control, no shoot thinning; ST, shoot thinning (15 primary shoots/m); early, early harvest (11 Sept 2007, 10 Sept 2008); late, late harvest (18 Sept 2007, 23 Sept 2008).

Table 7 Sensory results from 2-AFC test of 2008 Marechal Foch.

Treatment[a]	Proportion[b]	d'	Variance d'	SD d'	*p* value
(1-SE/2-CE)	0.57	0.25	0.23	0.524	0.300
(1-CL/2-CE)	0.79	1.15	0.29	2.135	0.016
(1-SL/2-SE)	0.79	1.15	0.29	2.135	0.016
(1-SL/2-CL)	0.57	0.25	0.23	0.524	0.300
(1-SL/2-CE)	0.86	1.53	0.35	2.593	0.005
(1-SE/2-CL)	0.5	0	0.22	0.474	0.500

[a]Early harvest control (CE) and shoot thinning (SE) (11 Sept 2007, 10 Sept 2008); late harvest control (CL) and shoot thinning (SL) (18 Sept 2007, 23 Sept 2008).
[b]Proportion of 1 "more fruity" than 2.

partially due to berry dehydration (decrease of 0.075 g in average berry weight between early and late harvest). In 2008, the CL and SL berries contained lower seed tannin, but that did not translate into increased wine tannin, likely because of the low extractability of seed tannin.

Among the aroma compounds, the herbaceous C_6 alcohols showed the most consistent and greatest percent reduction as a result of the CL and SL treatments. Late harvest wines possessed lower 1-hexanol, *cis*-3-hexenol, and *trans*-2-hexenol than their early harvest counterparts. As mentioned previously, lower levels of C_6 aldehydes and alcohols are reportedly formed from more mature grapes following crushing (Joslin and Ough 1978, Kalua and Boss 2009). Although the aldehydes are reduced to their corresponding alcohols during fermentation (Joslin and Ough 1978), a recent report did not observe a clear correlation between C_6 compounds in wine and berry maturity (Canuti et al. 2009). The shoot-thinning treatment also reduced C_6 alcohols, and no significant interaction term (harvest date x treatment) was observed with the exception of the 2008 *trans*-2-hexenol levels. Thus, in most cases, harvest date and shoot thinning appear to independently reduce C_6 alcohols. Potentially, growers could use a combination of later harvest and shoot thinning to reduce these herbaceous compounds in Foch, although future sensory studies are necessary to establish their sensory importance.

The other compounds measured in our study (esters, fusel alcohols, fatty acids, terpenoids, and shikimic acid derivatives) did not vary consistently among years between different harvest dates. One exception was the straight-chain fatty acids (octanoic and butanoic), which decreased in both years with both treatments. Production of straight-chain fatty acids by yeast during fermentation is linked to several factors, including the availability of unsaturated fatty acids, oxygen, and fermentation temperature (Ugliano and Henschke 2008). While the latter two factors are not expected to vary, the concentration of polyunsaturated fatty acids is reported to decrease with grape maturity (Iglesias et al. 1991), potentially resulting in greater mid-chain fatty acid production (Yunoki et al. 2007).

Sensory experiments. Results indicated that harvest date is generally more important than shoot-thinning treatment in affecting fruitiness. Thus, even though shoot thinning resulted in some changes to berry chemistry, that did not translate into differences in fruitiness. However, the panel also observed no difference in fruitiness between CL and SE treatments, indicating that shoot thinning may permit an earlier harvest to achieve similar levels of fruitiness.

Conclusion

Shoot-thinning treatments (15 shoots/m) on Marechal Foch grapevines resulted in improved canopy microclimate (CEFA, LEFA), decreased yield, and improvement in some chemical parameters (higher Brix and anthocyanins in berries and decreased concentrations of the herbaceous C_6 alcohols in resulting wines). However, the impact of shoot thinning was generally comparable to or less than the differences observed with late harvest. Similarly, sensory evaluations indicated that 2008 wines produced from CL and SL treatments were fruitier than their early harvest counterparts but that shoot-thinned treatments were not different than their nonthinned counterparts. Therefore, delayed harvest may have a larger impact on the flavor chemistry of Marechal Foch than shoot thinning. Finally, there was both low skin tannin and low tannin extractability in Marechal Foch grapes and, consequentially, very low levels of tannin in the resulting wines. Increasing tannin extraction from Foch or other hybrids during winemaking may be an interesting direction for improving the chemosensory attributes of the resulting wines. Growers and winemakers should delay harvest on Foch to improve fruitiness and decrease herbaceousness of wines.

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