Weed Control in a Newly Established Organic Vineyard

Mercy Olmstead^{1,4}, Timothy W. Miller², Callie S. Bolton², and Carol A. Miles³

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SUMMARY. Consumer demand for organic and sustainably produced products has increased the interest in organic wine grape (*Vitis vinifera*) production. However, organic production can be challenging, and weed management is a critical issue during the establishment of an organic vineyard. In 2009, the effectiveness of five cover crop treatments and cultivation regimes was evaluated for two years for weed control in a newly established organic vineyard of 'Pinot noir précoce' and 'Madeleine angevine' grape cultivars in northwestern Washington State. Alleyway management treatments were cultivation in alleyways with hand weeding in the vine row (control), grass cover crop which included perennial ryegrass (*Lolium perenne* ssp. *perenne*) and red fescue (*Festuca rubra* ssp. *arenaria*) seeded in the alleyway and in-row tillage with a specialty offset-type cultivator, winter wheat (*Triticum aestivum*) cover crop with in-row string-trimming, austrian winter pea (*Pisum sativum* ssp. *sativum* var. *arvense*) cover crop with in-row string-trimming, and winter wheat–austrian winter pea cover crop mix with in-row string-trimming. In 2009, weed dry biomass was lowest in the alleyway of the control ($0.8 \text{ g}\cdot\text{m}^{-2}$) and offset cultivator treatments ($6.3 \text{ g}\cdot\text{m}^{-2}$) on 3 Aug. and tended to be lowest in the alleyway of the control ($4.8 \text{ g}\cdot\text{m}^{-2}$) and offset cultivator treatments ($16.0 \text{ g}\cdot\text{m}^{-2}$) on 27 Sept. In the second year of establishment (2010), winter wheat and austrian winter pea were eliminated from the plots by mid-July, and white clover (*Trifolium repens*) and perennial ryegrass were the dominant weed species and accounted for a majority of the total weeds. On average over the two-year period, the control treatment required the most time for alleyway management ($92 \text{ h}\cdot\text{ha}^{-1}$) followed by the offset cultivator treatment ($64 \text{ h}\cdot\text{ha}^{-1}$), while the winter wheat, austrian winter pea, and winter wheat–austrian winter pea mixture required 32 to $42 \text{ h}\cdot\text{ha}^{-1}$. 'Madeleine angevine' produced more shoot growth than 'Pinot noir précoce' in Sept. 2010 (42.3 and 25.9 cm respectively), and shoot growth of both cultivars in the control treatment was significantly longer (125.0 cm) than under any other treatment (55.4 to 93.0 cm), illustrating the importance of weed control during vineyard establishment. In this study, the most effective weed management regime, although also the most time consuming, included a vegetative-free zone around the vines (e.g., in-row) maintained by hand weeding and a cultivated alleyway.

Interest in sustainable and organic production systems has increased worldwide, particularly in viticulture as fresh and processed grapes are

one of the major organic fruit crops worldwide (Granatstein et al., 2010; Willer and Kilcher, 2009). Environmental concerns regarding increased soil erosion, decreased soil fertility, limited water supply, biodiversity loss, and herbicide resistance have led growers to consider minimal input production systems (Krauss et al., 2010; Lal et al., 2007; Montgomery,

2007; Triplett and Dick, 2008). In addition, organic vineyard production systems have been found to preserve biodiversity of yeast strains associated with wine production (Cordero-Bueso et al., 2011). However, weed management is the most expensive and technically challenging practice for organic grape production (Dufour, 2006; Guthman, 2000), and many organic farmers rely on mechanical and hand cultivation for weed control. Although these methods are highly effective, they are also labor-intensive, more expensive, and their sustainability is questionable from a labor and environmental perspective (Guthman, 2000; White, 1996). Alternative practices that promote sustainability include the use of cover crops, mulches, reduced or no-tillage, and organic herbicides (Altieri, 1995). These techniques have resulted in wines with quality comparable or superior to conventionally managed grapes (Stolz and Schmid, 2007), sometimes resulting in higher prices for wines produced with organic grapes (Delmas and Grant, 2010).

Although there are many benefits to using cover crops, their primary use has been as an alternative weed suppression technique in organic and conventional vineyards worldwide (Dastgheib and Frampton, 2000; Liebman and Davis, 2000; McGourty, 2004; Pardini et al., 2002). Cover cropping can also improve soil organic matter, increase nutrient levels, improve soil structure, and increase earthworm populations, resulting in improved soil quality (Davies et al., 2001; Gulick et al., 1994; Nevens and Reheul, 2002; Paoletti et al., 1998; Pimentel et al., 2005; Tan and Crabtree, 1990). Incorporation of mowed grass cover crop residue increases organic matter, releases nitrogen and potassium into the soil, and increases soil pH (Ripoche et al., 2011; Snapp and Borden, 2005). Remaining stubble of

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¹Department of Horticultural Sciences, University of Florida, P.O. Box 110690, Gainesville, FL 32611-0690

²Department of Crop and Soil Sciences, Washington State University, Northwestern Washington Research and Extension Center, 16650 State Route 536, Mount Vernon, WA 98273-4768

³Department of Horticulture, Washington State University, Northwestern Washington Research and Extension Center, 16650 State Route 536, Mount Vernon, WA 98273-4768

⁴Corresponding author. E-mail: mercy1@ufl.edu.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
305.1517	oz/ft ²	g·m ⁻²	0.0033
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

a grass cover crop also allows for greater solar radiation absorption by the soil, and provides traction for equipment (Bugg et al., 1996; Gaffney and Van Der Grinten, 1991), both important benefits in a cool, maritime climate. Weed suppression by cover cropping can be achieved in production systems with grass, legume, or grass/legume mixes (Akemo et al., 2000).

Winter wheat and perennial ryegrass are common vineyard cover crops in Washington State (Olmstead et al., 2001). In western Oregon, with similar climate and soil properties as western Washington, five different mixtures of cover crops demonstrated low competition with mature 'Pinot noir' grapevines (Sweet and Schreiner, 2010), although effects on weed growth were not reported. Cover crop selections and stand establishment are particularly important in newly established vineyards as young vine growth can be more susceptible to cover crop competition (Bordelon and Weller, 1997). Since young vines have limited nutrient and carbohydrate reserves, cover crops for young vineyards must be less competitive than those for established vineyards (Balerdi, 1972; Byrne and Howell, 1978; Eastham et al., 1996).

Mulching can be an effective weed suppression tool, as found when mulched winter cereal rye (*Secale cereale*) and crimson clover (*Trifolium incarnatum*) residues reduced in-row weed cover to 5% or less in a young 'Chardonnay' vineyard in western Oregon (Fredrikson et al., 2011). Mulches composed of legumes can break down more quickly, while those comprised of grasses break down more slowly, providing sustained weed suppression (Teasdale and Mohler, 1993). Ideal stand establishment of the cover crop and proper timing of mulching into vine rows can suppress weed populations as well as or better than conventional tillage systems in vineyards (Steinmaus et al., 2008), predominantly through the exclusion of light required for seed germination (Buhler, 1997).

Cultivation is the traditional method for weed removal in organic systems, and specialty cultivators can be used to reduce in-row weed populations with minimal vine damage. Several in-row cultivators specifically designed for orchard and vineyard use are the Wonder Weeder (Harris

Manufacturing, Burbank, WA), Weed Badger® (Weed Badger Division, Marion, ND), and the French plow. Although these implements are able to cultivate more closely to the vine row than standard cultivators, the area immediately around the vines still requires manual weeding (Zabadal, 1999). The objective of this study was to compare the efficacy of traditional organic vineyard weed management techniques with four cover crop and tillage regimes for weed suppression in a newly planted vineyard in transition to organic production.

Materials and methods

A 3.0-acre vineyard was established in 2009 at the Washington State University (WSU) Northwest Washington Research and Extension Center (NWREC) in Mount Vernon, WA. Mount Vernon is in the Puget Sound American Viticultural Area and has low growing degree-days (1300–1600 at $\geq 50^{\circ}\text{F}$), cool, dry summers (50 to 68 $^{\circ}\text{F}$ and 3 to 6 inches precipitation) and mild, wet winters (21 to 40 $^{\circ}\text{F}$ and 20 to 26 inches precipitation) (AgWeather Net; Washington State University, 2011). The soil type is a Skagit Series soil (fine-silty, mixed, superactive, non-acid, and mesic Fluvaquentic Endoaquepts). The vineyard was established to achieve organic certification using trellis and irrigation materials listed with the Organic Materials Review Institute, and was managed accordingly (Washington State Department of Agriculture, 2012).

The experiment was a balanced split-plot design with main plots arranged in a randomized complete block design comprised of three replications. Main plots were weed suppression treatments and were nine rows wide and 84 ft long, with 14 plants per row. Rows were 8 ft apart and vines were spaced 6 ft apart in the row. Alleyway management treatments were instituted at the time of vineyard establishment and consisted of a standard treatment with clean cultivation provided by tillage in the alleyway and hand weeding in the row, a companion cover crop mix comprised of 75% 'Gator III' dwarf perennial ryegrass and 25% 'Osbeck' creeping red fescue with mowing in the alleyway and in-row tillage with a Lilliston spider-type offset cultivator (Wonder Weeder, Harris Manufacturing,

Burbank, WA) in addition to separate plantings of winter wheat, austrian winter pea, and a combination of winter wheat and austrian winter pea (2:1). Winter wheat, austrian winter pea, and the winter wheat–austrian winter pea mixture were mowed in the alleyway and in-row weeds were controlled with a handheld string-trimmer. Non-treated winter wheat and austrian winter pea cover crop seed purchased from Peaceful Valley Farm & Garden Supply (Grass Valley, CA) in 2009 and Pacific Northwest Farmers' Cooperative (Genesee, ID) in 2010 were seeded in winter wheat (300 lb/acre), austrian winter pea (300 lb/acre), and winter wheat–austrian winter pea mixture plots (200:100 lb/acre), respectively, using a backpack cyclone spreader (Wilbur-Ellis Co., San Francisco, CA) on 30 June 2009 and on 23 Mar. 2010. Soil had been freshly tilled and was vegetation-free at the time of the 2009 seeding. Soil had been disked once and rototilled twice before the 2010 seeding, although moist soil allowed many of the weeds to survive tillage operations. Seeds were incorporated 1 to 2 inches into the soil, using a chain drag and roller attachment (fabricated on-farm) to an all-terrain vehicle. Companion grass mix (Peaceful Valley Farm & Garden Supply) was seeded using an Ortho® Whirly-bird Spreader (Scotts, Marysville, OH) at 10 lb/acre in July 2009, but due to insufficient establishment, it was reseeded at 13 lb/acre in Mar. 2010. Alleyway management differed by weed suppression treatment, with the control alleyway tilled, while all other treatments containing a cover crop or mixture were mowed at regular intervals.

Subplots included two wine grape cultivars, Madeleine angevine (four rows) and Pinot noir précoce (five rows), both well suited to the region (Moulton and King, 2005), and grafted on Couderc 3309 rootstock. 'Madeleine angevine' is an early ripening French white wine grape from a presumed cross between 'Madeleine royale' and 'Malingre precoce' or 'Circé' (Vargas et al., 2009). 'Pinot noir précoce' ('Pinot madeleine') is an early ripening wine grape resulting from a mutation of 'Pinot noir' (Konrad et al., 2003). The vineyard was amended for nitrogen, phosphorus, and potassium based on preplant soil

tests (Bolton, 2011), and dormant grafted vines were hand transplanted in June 2009. All vines were trained to a spur pruned, bilateral cordon system. Five vines were randomly selected and flagged for data collection within each subplot. Shoot length was measured from the base of the shoot to the shoot tip in both years. Pruning weights were collected as vines were pruned to two nodes on 16 to 18 Feb. 2010 and on 21 Jan. 2011.

Vines were drip-irrigated (18 mm emitters, 0.55 gal/h; Point Source Irrigation, Fresno, CA) for 3-h intervals twice per week from 1 June through 1 Sept. 2009, and from 6 July until 1 Sept. 2010. Total irrigation application in 2009 was 46 gal and 33 gal in 2010. In 2009, the vineyard was fertigated with 4.7 gal/h of 6N-0P-0K (Vegan Nitrogen, Westbridge Agricultural Products, Vista, CA) on 30 June, 7 July, and 21 July. In 2010, the vineyard was fertigated with 5.4 gal/h of 4N-0.9P-3.3K fish fertilizer (Phytamin; California Organic Fertilizers, Fresno, CA) on 27 July and 3 Aug. Vegetation management treatments were initiated when cover crop or weeds were 30 cm tall. Hand weeding was done in-row in the control and offset cultivator treatments on 21 July and 13 Aug. of 2009 and on 1 June, 29 June, and 11 Aug. of 2010. String-trimming vegetation to the soil level was used under the vines in winter wheat, austrian winter pea, and winter wheat-austrian winter pea mixture on 11 Aug. 2009, and on 14 May, 14 June, 6 July, and 3 Aug. 2010. Alleyways were cultivated in the control treatment on 8 Sept. and 7 Oct. 2009, and on 21 June, 3 Aug., and 14 Oct. 2010. Vegetation was mowed to a height of 2 inches in winter wheat, austrian winter pea, and winter wheat-austrian winter pea mixture on 8 Sept. and 7 Oct. in 2009, and on 11 May, 27 May, 18 June, and 6 July in 2010. Alleyways in the offset cultivator treatment were cultivated with the control treatment on 26 Mar. 2009 and 16 Mar. 2010 and mowed on the same date as other cover crops thereafter. A small percentage of vines (<5%) were lost because of graft union breakage or damage caused by string-trimming. Data were collected from the adjacent vine within the same treatment, and dead vines were replaced during the winter dormant season.

Weed and cover crop biomass collections were made in representative areas of the alleyway and in-row areas of each subplot on 3 Aug. and 27 Sept. 2009 and on 22 July and 27 Sept. 2010. Two 0.13 m² quadrats were placed in each subplot and all aboveground vegetation was clipped. The clipped vegetation was sorted by species and dried at 35 °C for ≈3 d, after which dry weight was recorded. The time needed for weed and cover crop maintenance was recorded in both years for all treatments, to compare the labor requirements for hand weeding and use of string-trimmer or specialty cultivator. Weed suppression, grapevine shoot length, and maintenance time were ranked in order for each alleyway management treatment, and the overall average rank was calculated.

All data were subjected to PROC GLM and PROC MIXED where appropriate, using JMP (version 9.0; SAS Institute, Cary, NC). Data were transformed as necessary to ensure that normality was satisfied. The whole plot factor was weed suppression treatment and the subplot factor was grape cultivar. Main effects and interactions were tested for significance; data with significant interactions were subjected to means separation using Tukey's honestly significant difference test at $P \leq 0.05$.

Results and discussion

COVER CROP AND WEED BIOMASS. Cover crop and weed dry biomass differed significantly by treatment and row location on almost all dates in both years ($P \leq 0.05$) but was not influenced by grape cultivar (data not shown), thus all data were combined for analysis. In 2009, the companion grass cover crop mix did not establish because of droughty conditions and no cover crop was detected in the offset cultivator treatment on either sample date. Austrian winter pea biomass in the alleyway on 3 Aug. was four times greater in the austrian winter pea treatment than in winter wheat-austrian winter pea mixture (Table 1) and in-row biomass of the austrian winter pea treatment was three times greater than in the winter wheat-austrian winter pea mixture (Table 1). In addition, biomass in the austrian winter pea treatment was 40% greater in the alleyway than in-row, reflecting the higher seeding

rate in the alleyway as compared with in-row. In the winter wheat-austrian winter pea mixture, austrian winter pea biomass was similar in the alleyway and in-row suggesting that austrian winter pea did not become well established in the alleyway, perhaps due to competition with winter wheat (Akemo et al., 2000).

By 27 Sept., austrian winter peas were eliminated in both the sole austrian winter pea treatment and the winter wheat-austrian winter pea mixture treatments. In contrast, winter wheat dry biomass was about equal in the alleyways of the winter wheat and winter wheat-austrian winter pea mixture treatments on 3 Aug. (Table 1), despite the 33% higher seeding rate in the winter wheat treatment suggesting that a 200 lb/acre seeding rate was adequate for the establishment of the winter wheat cover crop. In the winter wheat and winter wheat-austrian winter pea mixture treatments, winter wheat biomass was about twice as great in the alleyway as in-row during both sampling periods reflecting the higher seeding rate in the alleyway as compared with in-row (Table 1).

Primary weed species collected in all treatment plots in 2009 were common lambsquarters (*Chenopodium album*), shepherd's-purse (*Capsella bursa-pastoris*), lady's-thumb (*Polygonum persicaria*), pale smartweed (*Persicaria lapathifolium*), and henbit (*Lamium amplexicaule*); dry biomass of these species is presented collectively as "other weeds" in Table 1. Weed biomass in the alleyway on 3 Aug. tended to be lowest in the control and offset cultivator treatments (Table 1), but was not significantly different on 27 Sept. from other treatments as a result of the large variation in recovery of weed biomass. In alleyways and in-row, weeds accounted for almost 100% of the biomass in the control and offset cultivator treatments, 42% to 60% in the austrian winter pea treatment, 33% to 55% in the winter wheat treatment, and 21% to 48% in winter wheat-austrian winter pea mixture treatment. In general, two times greater weed biomass was found in-row than in the alleyway of all treatments.

These shifts in winter wheat and austrian winter pea populations between the first and second sampling reflect both the biological life cycle of

Table 1. Mean dry aboveground biomass of cover crop and weeds in alleyways and within grapevine rows under alleyway and in-row management regimes in 2009.^z

Treatment	Austrian winter pea biomass (g·m ⁻²) ^y		Winter wheat biomass (g·m ⁻²)		Other weeds biomass (g·m ⁻²)		Total biomass (g·m ⁻²)	
	3 Aug.	27 Sept.	3 Aug.	27 Sept.	3 Aug.	27 Sept.	3 Aug.	27 Sept.
Alleyway								
Control	0.0 c ^x	0.0 b	0.0 c	0	0.8 c	4.8	0.8 b	4.8
Offset cultivator	0.0 c	0.0 b	0.5 c	0	5.8 c	16	6.3 b	16
Winter wheat	0.0 c	0.0 b	158.2 a	80.2	78.4 bc	4.4	236.6 a	84.6
Austrian winter pea	155.5 a	0.0 b	7.3 c	0	116.9 abc	56.5	279.7 a	56.5
Winter wheat–austrian winter pea mix	38.0 c	0.0 b	157.0 a	57.4	51.2 bc	6.3	246.2 a	63.7
In-row								
Control	0.0 c	0.0 b	2.2 c	0	186.2 ab	34	188.4 a	34
Offset cultivator	0.0 c	0.0 b	1.7 c	0	274.2 a	56.3	275.9 a	56.3
Winter wheat	0.0 c	0.0 b	85.5 b	26.2	103.4 abc	27.9	188.9 a	54.1
Austrian winter pea	93.1 b	1.3 a	3.4 c	0	141.6 abc	102.7	238.1 a	104
Winter wheat–austrian winter pea mix	31.7 c	0.0 b	85.6 b	44.1	107.1 abc	37.8	224.4 a	81.9
T × L Significance ^w	P = 0.03	P = 0.007	P = 0.004	NS	P = 0.005	NS	P < 0.001	NS

^zAlleyway management and in-row treatments were: standard cultivation alleyway and hand weeding in-row (control), companion cover crop mix-seeded alleyway with in-row tillage using an offset spider-type cultivator, winter wheat cover crop seeded 300 lb/acre and in-row string-trimming, austrian winter pea cover crop seeded at 300 lb/acre and in-row string-trimming, and winter wheat–austrian winter pea cover crop mixture seeded at 200 and 100 lb/acre, respectively, with in-row string-trimming; 1 lb/acre = 1.1209 kg·ha⁻¹.

^y1 g·m⁻² = 0.0033 oz./ft².

^xMeans followed by the same letter within columns are not significantly different via Tukey's honestly significant difference at $P \leq 0.05$; NS = not significant.

^wT = weed suppression treatment, L = location sampled (alleyway or in-row).

each crop and the management techniques used. Austrian winter pea is a relatively short-lived annual, while winter wheat is a relatively long-lived annual crop. The mowing and string-trimming of the cover crop treatments most likely eliminated the shoot meristem of austrian winter peas, which is located at the apical portion of the plant, while the growing point of winter wheat is at the distal portion (base) of the plant.

In 2010, although both winter wheat and austrian winter pea were seeded in plots on 23 Mar., significant biomass of these crops was not found in the respective treatments on 22 July (data not shown). Maintenance programs coupled with poor cover crop stand establishment and competition from two weed species, white clover and perennial ryegrass, appeared to have eliminated the annual cover crops by mid-July. Because of their abundance, biomass of white clover and perennial ryegrass are reported separately, while biomass of common lambsquarters, shepherd's-purse, pale smartweed, and panicked willowherb (*Epilobium brachycarpum*) are presented collectively as "other weeds" (Table 2). Perennial ryegrass was part of the companion cover crop mix seeded in the offset cultivator treatment, whereas annual ryegrass (*Lolium*

multiflorum) was a common weed species present at the site. Separation and identification of these two grasses with certainty was not possible due to lack of reproductive features at the time of biomass sampling. In this study, the perennial ryegrass biomass in the alleyway of the offset cultivator treatment is considered to be the intentionally seeded perennial ryegrass cover crop, while the annual ryegrass in all other locations is considered to be a weed.

Cover crop perennial ryegrass biomass in the alleyway of the offset cultivator treatment was unchanged over the sample period (Table 2). Total biomass in the alleyway on both dates tended to be lowest in the control and was four times lower than in all other treatments (Table 2). Total in-row biomass on both dates also tended to be lowest in control and offset cultivator treatments and was at least eight times lower than in all other treatments. Of the total biomass in the control on both dates, an average of 85% was other weeds in the alleyway and 79% were other weeds in-row. In the offset cultivator treatment, white clover biomass was 19% greater than other weeds in the alleyway on both dates, and 41% greater in-row. In the alleyway of the winter wheat, austrian winter pea, and winter wheat–austrian winter pea mixture

treatments on both dates, the total biomass averaged 39% white clover, 25% perennial ryegrass, and 36% other weeds. In-row of the winter wheat, austrian winter pea, and winter wheat–austrian winter pea mixture treatments, the total biomass averaged 57% white clover, 27% perennial ryegrass, and 16% other weeds. Biomass of other weeds in the alleyway of all treatments except the control declined 50% on average on 27 Sept. as compared with 22 July to 27 Sept., potentially because of the increased competition from white clover, which increased 2- to 6-fold between the two sampling dates.

These results reflect the loss of seeded annual cover crops throughout the growing season and the ability of white clover to become established in a mowed system. Annual ryegrass biomass was greatest in the austrian winter pea alleyway and in-row on both dates, reflecting the invasiveness of annual ryegrass when minimal competition exists from a cover crop. This is of particular concern as glyphosate and glufosinate-resistant annual ryegrass species are found in the Pacific northwestern United States (Avila-Garcia and Mallory-Smith, 2011). Although the research vineyard located at WSU-NWREC was in transition to organic certification, fields

surrounding the vineyard are not certified organic and incorporate non-organic herbicides. It is essential that a good cover crop stand is established to be effective in preventing weed seed germination (Brennan and Smith, 2005; Teasdale, 1993; Teasdale and Daughtry, 1993). Narrow row spacing precluded the use of a grain drill to seed cover crops in this trial, but availability of narrow width seeding

equipment might result in more effective cover crops establishment in a young vineyard, particularly in the second year and beyond.

GRAPEVINE SHOOT LENGTH AND PRUNING WEIGHT. Shoot length differed because of alleyway management treatment and cultivar on almost all sample dates in both years [$P \leq 0.05$ (Figs. 1 and 2)] and there were no interactions between alleyway management

treatments and cultivars (data not shown). ‘Madeleine angevine’ shoot growth was $\approx 66\%$ greater than that for ‘Pinot noir précoce’ throughout the season in 2009 and $\approx 20\%$ greater in 2010 ($P \leq 0.05$). In this study, ‘Madeleine angevine’ exhibited good shoot growth and canopy development while ‘Pinot noir précoce’ was less vigorous, as previously reported by Kliewer and Dokoozlian, (2005).

Table 2. Mean dry aboveground biomass of white clover, perennial ryegrass, other weeds and the combined total of all weeds within grapevine rows or in alleyways under alleyway and in-row management regimes in 2010.^a

Treatment	White clover biomass ($\text{g}\cdot\text{m}^{-2}$) ^y		Perennial ryegrass ^x biomass ($\text{g}\cdot\text{m}^{-2}$)		Other weeds biomass ($\text{g}\cdot\text{m}^{-2}$)		Total biomass ($\text{g}\cdot\text{m}^{-2}$)	
	22 July	27 Sept.	22 July	27 Sept.	22 July	27 Sept.	22 July	27 Sept.
Alleyway								
Control	0.3	0	5.0 c ^w	4.8 b	23.4	35.3	28.7 c	40.1 b
Offset cultivator	11.6	69.0	152.2 a	154.0 a	1.2	0.7	165.0 bc	223.7 ab
Winter wheat	49.4	87.1	32.2 bc	16.5 b	107.6	37.3	189.2 bc	140.9 ab
Austrian winter pea	12.2	64.0	102.9 ab	56.8 ab	78.3	29.7	193.4 bc	150.5 ab
Winter wheat–austrian winter pea mix	54.2	139.0	43.6 bc	12.2 b	94.8	52.4	192.6 bc	206.3 ab
In-row								
Control	0.3	11.5	0.1 c	0.1 b	20.2	17.0	20.6 c	28.6 b
Offset cultivator	25.7	6.2	19.3 bc	5.3 b	8.2	7.1	53.2 c	18.6 b
Winter wheat	97	207.0	70.2 abc	73.0 ab	60.9	58.6	228.1 abc	338.6 a
Austrian winter pea	136.4	146.2	137.8 a	88.9 ab	27.1	65.3	301.3 ab	300.4 a
Winter wheat–austrian winter pea mix	312.3	217.6	73.8 abc	55.2 b	39.8	42.9	425.9 a	315.7 a
T × L Significance ^v	NS	NS	$P < 0.0001$	$P < 0.0001$	NS	NS	$P = 0.009$	$P = 0.002$

^aAlleyway management and in-row treatments were: standard cultivation alleyway and hand weeding in-row (control), companion cover crop mix-seeded alleyway with in-row tillage using an offset spider-type cultivator, winter wheat cover crop seeded 300 lb/acre and in-row string-trimming, austrian winter pea cover crop seeded at 300 lb/acre and in-row string-trimming, and winter wheat–austrian winter pea cover crop mixture seeded at 200 and 100 lb/acre, respectively, with in-row string-trimming; 1 lb/acre = 1.1209 kg·ha⁻¹.

^y1 $\text{g}\cdot\text{m}^{-2}$ = 0.0033 oz/ft².

^xMeans in alleyway of CG treatment is perennial ryegrass cover crop while in all other treatments and locations annual ryegrass as a weed is reported.

^wMeans followed by the same letter or no letter within columns are not significantly different via Tukey's honestly significant difference at $P \leq 0.05$; NS = not significant.

^vT = weed suppression treatment, L = location sampled (alleyway or in-row).

Fig. 1. Effect of alleyway and in-row management regimes on (A) ‘Madeleine angevine’ and (B) ‘Pinot noir précoce’ grapevine shoot length in 2009. Regimes included standard cultivation alleyway and hand weeding in-row (control), companion cover crop mix-seeded alleyway with in-row tillage using an offset spider-type cultivator (offset cultivator), winter wheat cover crop seeded 300 lb/acre and in-row string-trimming, austrian winter pea cover crop seeded at 300 lb/acre and in-row string-trimming (pea), and winter wheat–austrian winter pea cover crop mixture seeded at 200 and 100 lb/acre, respectively, with in-row string-trimming; 1 lb/acre = 1.1209 kg·ha⁻¹, 1 cm = 0.3937 inch.

Fig. 2. Effect of alleyway and in-row management regimes on (A) 'Madeleine angevine' and (B) 'Pinot noir précoce' grapevine shoot length in 2010. Regimes included standard cultivation alleyway and hand weeding in-row (control), companion cover crop mix-seeded alleyway with in-row tillage using an offset spider-type cultivator (offset cultivator), winter wheat cover crop seeded 300 lb/acre and in-row string-trimming, austrian winter pea cover crop seeded at 300 lb/acre and in-row string-trimming, and winter wheat–austrian winter pea cover crop mixture seeded at 200 and 100 lb/acre, respectively, with in-row string-trimming; 1 lb/acre = 1.1209 kg·ha⁻¹, 1 cm = 0.3937 inch.

In 2009, shoot length for 'Madeleine angevine' was unaffected by alleyway management treatment on 30 July, but on 13 Aug. and 26 Sept., shoot length was greatest in the control and offset cultivator treatments followed by the austrian winter pea, winter wheat–austrian winter pea mixture, and winter wheat treatments (Fig. 1A). Shoot growth of 'Pinot noir précoce' also did not differ on 30 July, but by 26 Sept. was greatest in offset cultivator and control treatments (Fig. 1B). In 2010, on all sample dates except 27 May, 'Madeleine angevine' shoot length was greatest in the control, followed by the offset cultivator, austrian winter pea, winter wheat, and winter wheat–austrian winter pea mixture treatments (Fig. 2A), while for 'Pinot noir précoce', shoot length was greatest in the control followed by the offset cultivator, winter wheat, austrian winter pea, and winter wheat–austrian winter pea mixture treatments (Fig. 2B).

In both years, shoot length and pruning weight was greater in the control and offset cultivator treatments for both 'Madeleine angevine' and 'Pinot noir précoce' (Figs. 1 and 2, Table 3), underscoring the importance of reducing competition within the row of young vineyards (Bordelon and Weller, 1997). In 2010, while total in-row groundcover biomass was similar between the control and offset

Table 3. Effect of alleyway and in-row management regimes on 'Madeleine angevine' and 'Pinot noir précoce' total pruning weight in 2009 and 2010.^z

	Pruning wt (kg) ^y	
	2009	2010
'Madeleine Angevine'		
Control	17.9 a ^x	5.3 ab
Offset cultivator	16.6 ab	2.8 bc
Winter wheat	3.0 cdef	0.5 c
Austrian winter pea	5.4 cd	0.9 c
Winter wheat–austrian winter pea mix	4.5 cde	1.0 c
'Pinot noir précoce'		
Control	5.3 bcd	6.4 a
Offset cultivator	6.1 abc	3.3 abc
Winter wheat	1.1 f	1.2 c
Austrian winter pea	1.9 def	1.3 c
Winter wheat–austrian winter pea mix	1.4 ef	1.0 c

^zAlleyway management and in-row treatments were standard cultivation alleyway and hand weeding in-row (control), companion cover crop mix-seeded alleyway with in-row tillage using an offset spider-type cultivator, winter wheat cover crop seeded 300 lb/acre and in-row string-trimming, austrian winter pea cover crop seeded at 300 lb/acre and in-row string-trimming, and winter wheat–austrian winter pea cover crop mixture seeded at 200 and 100 lb/acre, respectively, with in-row string-trimming; 1 lb/acre = 1.1209 kg·ha⁻¹.

^y1 kg = 2.2046 lb.

^zMeans followed by the same letter or no letter within columns are not significantly different via Tukey's honestly significant difference at $P \leq 0.05$.

cultivator treatments, biomass in the alleyway was almost six times greater in the offset cultivator treatment than in the control (Table 2). This suggests that presence of perennial ryegrass cover crop in the offset cultivator treatment was responsible for the difference in shoot growth during the second season of vineyard establishment. Even in mature vineyards, competition from planted alleyways can reduce vine root growth into the alleyways thereby limiting vine root

access to nutrient and soil structure benefits of the alleyway (Morlat and Jacquet, 2003). In certain high-vigor situations in mature vineyards, increased competition because of cover crops is desired and can mitigate imbalances in shoot growth and crop load (Hatch et al., 2011; Tesic et al., 2007). However, during vineyard establishment competition from weeds and cover crops should be kept at a minimum to encourage formation of the grapevine permanent structure.

ALLEYWAY MANAGEMENT MAINTENANCE REQUIREMENTS. The least amount of maintenance time occurred in the winter wheat, austrian winter pea, and winter wheat–austrian winter pea mixture treatments as compared with control and offset cultivator treatments (Table 4). In 2009, more time was spent hand weeding than on any other task in control and offset cultivator treatments. In 2010, the greatest percentage of time (41%) spent in winter wheat, austrian winter pea, and winter wheat–austrian winter pea mixture treatments was for string-trimming (Table 4); however, the most time spent on a single task was in-row hand weeding in the control treatment (73.6 h·ha⁻¹). The specialty cultivator

effectively reduced in-row weeding time as hand weeding in the control treatment took over twice as long as in the offset cultivator treatment during 2009, and about five times as long in 2010. In 2010, 58 h·ha⁻¹ were spent operating the specialty cultivator in the offset cultivator treatment. When averaged across treatments, in-row maintenance took 19 times longer than in the alleyway in 2009 and four times longer in 2010. It is also important to note that operating the specialty cultivator for in-row weed management is far less physically taxing than hand weeding. Additionally, string-trimming in-row areas of winter wheat, austrian winter pea, and winter wheat–austrian winter pea mixture resulted in 2% accidental grapevine

death (28 vines) during 2009 when vines were tender and more easily damaged, but no accidental vine kill occurred in 2010 as the vines increased in trunk diameter. There was no difference in maintenance requirements between grape cultivars (data not shown).

RANKING OF TREATMENT EFFECTIVENESS. Weed suppression was most effective in the control, followed by the offset cultivator, winter wheat–austrian winter pea mixture, winter wheat, and austrian winter pea treatments (Table 5). Shoot growth was greatest in the control, followed by the offset cultivator, austrian winter pea, winter wheat, and winter wheat–austrian winter pea mixture treatments. Maintenance time was least in the winter wheat treatment, followed by the winter wheat–austrian winter pea mixture, austrian winter pea, offset cultivator, and control. Based on the combined ranking of all three factors, the overall rank of alleyway management treatments were the control, offset cultivator, winter wheat, winter wheat–austrian winter pea mixture, and austrian winter pea. These results indicate an inverse relationship between weed biomass and time, and between shoot length and weed biomass. That is, more maintenance time is required to reduce weed biomass, and lower weed biomass resulted in greater shoot growth.

In this study, winter wheat persisted better in alleyways than in-row, indicating that string-trimming to the soil level caused more injury to winter wheat than mowing at 2 inches. Austrian winter pea was eliminated in both the alleyway and in-row due to mowing and string-trimming,

Table 4. Mean annual maintenance labor including mowing, disking, in-row cultivating, hand weeding, and string-trimming for vineyard alleyway and in-row management regimes in ‘Madeleine angevine’ and ‘Pinot noir précoce’ grapevine in 2009 and 2010.^z

	Mean annual labor required (h·ha ⁻¹) ^y	
	2009	2010
Treatment		
Control	79.7 a ^x	104.2 a
Offset cultivator	47.2 b	81.2 ab
Winter wheat	12.8 c	52.0 b
Austrian winter pea	18.4 c	66.3 b
Winter wheat–austrian winter pea mix	18.4 c	62.3 b
Location		
Alleyway	3.5 b	27.54 b
In-row	67.1 a	118.9 a

^zAlleyway management and in-row treatments were standard cultivation alleyway and hand weeding in-row (control), companion cover crop mix-seeded alleyway with in-row tillage using an offset spider-type cultivator, winter wheat cover crop seeded 300 lb/acre and in-row string-trimming, austrian winter pea cover crop seeded at 300 lb/acre and in-row string-trimming, and winter wheat–austrian winter pea cover crop mixture seeded at 200 and 100 lb/acre, respectively, with in-row string-trimming; 1 lb/acre = 1.1209 kg·ha⁻¹.

^y1 h·ha⁻¹ = 0.4047 h/acre.

^xMeans followed by the same letter within columns are not significantly different via Tukey’s honestly significant difference at $P \leq 0.05$.

Table 5. Ranked order of combined alleyway and in-row management regimes based on total weed biomass, grapevine shoot length, and mean maintenance labor required combined for 2009 and 2010.^z

Treatment	Weed suppression		Grapevine shoot length		Maintenance time			Overall rank
	Total weed biomass (g·m ⁻²) ^y	Rank ^x	Final shoot length (cm) ^y	Rank	Total maintenance time (h·ha ⁻¹) ^y	Rank	Avg rank	
Control	344	1	160.4	1	183.94	5	2.3	1
Offset cultivator	507	2	124.8	2	128.41	4	2.7	2
Winter wheat	1,111	4	84.8	4	64.81	1	3	3
Austrian winter pea	1,363	5	91.2	3	84.64	3	3.7	5
Winter wheat–austrian winter pea mix	1,343	3	82.3	5	80.64	2	3.3	4

^zAlleyway management and in-row treatments were standard cultivation alleyway and hand weeding in-row (control), companion cover crop mix-seeded alleyway with in-row tillage using an offset spider-type cultivator, winter wheat cover crop seeded 300 lb/acre and in-row string-trimming, austrian winter pea cover crop seeded at 300 lb/acre and in-row string-trimming, and winter wheat–austrian winter pea cover crop mixture seeded at 200 and 100 lb/acre, respectively, with in-row string-trimming; 1 lb/acre = 1.1209 kg·ha⁻¹.

^y1 g·m⁻² = 0.0033 oz/ft², 1 cm = 0.3937 inch, 1 h·ha⁻¹ = 0.4047 h/acre.

^x1 = best performance within a category, 5 = poorest performance within a category.

respectively. Under the maintenance regimes used in this study, the life-spans of austrian winter pea and winter wheat were about three months, suggesting that these cover crops are not well suited to vineyard systems where weed control is needed for a longer period of time. This is especially true in western Washington where weed growth occurs year-round. An alternative strategy to single plantings of short-lived cover crops is to stagger plantings of similar-lived cover crop cultivars throughout the growing season to provide continual weed suppression.

In a newly established organic vineyard, the most effective weed suppression technique allowing for maximum vine shoot growth would be clean cultivation based on results in this study. However, labor efficiency must be taken into consideration when establishing a high-value enterprise such as a vineyard. Including a vegetation-free zone using a specialty cultivator can minimize the time needed for in-row hand weeding, while still allowing for good vine shoot growth. Another option would be to use conventional production techniques that use synthetic herbicides during the establishment phase, and once established, transition the vineyard to achieve organic certification. Further research is needed to identify cover crops that suppress annual and perennial weed species in the alleyway and that do not reduce shoot growth during the establishment years. A perennial cover crop that is maintained by mowing may be more labor efficient and environmentally sustainable than the cultivation and reseeded that is required for annual cover crops.

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