Cover Crop and Floor Management Affect Weed Coverage and Density in an Establishing Oregon Vineyard

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SUMMARY. Five vineyard floor management treatments were evaluated for effects on weed control over two growing seasons in an establishing 'Chardonnay' (*Vitis vinifera*) vineyard in the Willamette Valley of Oregon. Four cover crop management treatments and an unplanted treatment were compared to assess the effects on vine row and alleyway weed coverage and densities of broadleaf and grass weeds. A winter annual cover crop was grown in alleyways of the cover-cropped treatments and was mowed in spring. The mowed residue was managed as follows: 1) residue transferred in-row as mulch representing the industry practice of "mow-and-throw," 2) residue transferred in-row as mulch at three times the rate of the earlier treatment, 3) mowed residue incorporated into alleyways, and 4) removal of mowed cover crop residue from the vineyard. Weed coverage was assessed visually within a 1.0-m² quadrat placed randomly in alleyways and vine rows, and densities of broadleaf and grass weeds were determined by counting and grouping individual weeds within each quadrat. Vine row weed coverage and densities were lower in treatments with residue mulch at each sampling date in 2009 and 2010, with nearly 100% in-row weed suppression by the heavier mulch treatment. Alleyway weed coverage was lowest when residue was incorporated and highest in the unplanted treatment at some sampling dates. Grass weed densities in alleyways were similar between treatments at all sampling dates. Results of this study indicate that in-row mulch of cover crop residues at fresh weight densities of 2.5–15.0 kg·m⁻² provided effective weed control in a non-irrigated vineyard in western Oregon. Also, alleyway weed coverage may be reduced through incorporation of mowed cover crop residues.

Weeds can compete with young wine grape vines for soil moisture and nutrients and can impact yield and fruit quality (Byrne and Howell, 1978). Root systems of young vines are small and subject to greater suppression of vine growth owing to weed competition compared with established or mature vines (Balerdi, 1972). Three weed management methods are generally used by grape growers: herbicide sprays, tillage, and/or cover crops. The majority of weed management in vineyards is focused within the vine row where weeds may compete

directly for water and nutrients. However, management of weeds in the alleyway is important in reducing the weed seed bank and can reduce the need for in-row management over time (Fourie et al., 2006; Moonen and Bárberi, 2004).

Although herbicide sprays are widely used to manage weeds in young and mature vineyards, some common herbicides have been observed to damage shoot and root tissue of grapevines (*Vitis* spp.) at standard concentrations (Balerdi, 1972; Lee and Cahoon, 1981). Tillage as a means of weed management

has been shown to lead to increased erosion, to create a more favorable environment for germination of some weed species, and to be ineffective in controlling rhizomatous weed species (Gago et al., 2007). Alternatives to herbicides are fundamental to low-input, integrated, and organic farming systems, which seek to reduce contamination of groundwater and the development of herbicide-resistant weeds, among other objectives (Bond and Grundy, 2001; Clements et al., 1994). Alternatives to tillage are important in reducing erosion and dust, maintaining populations of beneficial soil microbes (Ingels et al., 2005; Larson et al., 2001), and reducing fuel and tractor inputs. Certain cover crop management systems have been used as an alternative to herbicides and tillage to control weeds, thereby reducing the amount of adventitious weeds in vineyard alleyways (Baumgartner et al., 2008; Gago et al., 2007).

Cover crops can be used to manage weeds through several mechanisms. Competition between weeds and cover crops will occur to varying degrees based on the vineyard environment and management. Allelopathic suppression of weeds has been observed upon decomposition of legume residues, such as clovers [*Trifolium* spp. (Dyck and Liebman, 1994; Liebman and Davis, 2000)], and non-leguminous residues, such as cereal rye [*Secale cereale* (Weston, 1996)], and certain Brassicaceae species (Haramoto and Gallandt, 2005; Petersen et al., 2001). Physical suppression of weeds may be obtained when alleyway vegetation is mowed at strategic times during vine development and the residue transferred into vine rows as mulch. This method of mulching, known as "mow-and-throw," has been shown to reduce germination of weed seeds in the vine row (Elmore et al., 1998) and reduce overall weed biomass

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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
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha ⁻¹	0.8922
4.8824	lb/ft ²	kg·m ⁻²	0.2048
1.6093	mile(s)	km	0.6214
305.1517	oz/ft ²	g·m ⁻²	0.0033
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

more than herbicides or cultivation (Steinmaus et al., 2008). Many studies on vineyard weed management have been conducted using mature vines of 5 years of age or more, and more research is needed to study the effect of these methods in young vineyards.

A 2-year study was developed to determine the effect of alleyway cover crop and management on weed coverage/density in an establishing vineyard. The study was ancillary to a systemic study, evaluating the effects of these treatments on vine growth, nutrition, and soil moisture and structure (Fredrikson, 2011). It was hypothesized that mowed alleyway residues transferred into the row would suppress weed emergence compared with unmulched treatments.

Materials and methods

EXPERIMENTAL DESIGN AND VINEYARD FLOOR MANAGEMENT TREATMENTS. This trial was conducted over 2 years at a commercial ‘Chardonnay’ vineyard 7 miles south of Independence, OR (lat. 44°77’N, long. –123°18’W, elevation 90 m). The 10-acre vineyard was planted in July 2008 with ‘Chardonnay’ (Dijon clone 96 on rootstock 3309-C) grapevines. Vines were spaced 7 ft (across alleyways) by 5 ft (in-row) and planted in north–south oriented rows. The soil is an Amity series (Fine-silty, mixed, superactive, mesic Argiaquic Xeric Argialboll) silty clay loam with a 0% to 3% slope across the experimental site. The total size of the experimental plot used within

the site was 140 ft (east to west) × 330 ft (north to south). The site was non-irrigated throughout the experiment.

Five vineyard floor management treatments (Table 1) were spatially distributed among five replicates across the site for a total of 25 experimental plots arranged in a completely randomized design. Each replicate plot included 20 vines and was 100 ft long. Replicate plots were 11 ft wide and included 3-ft-wide vine rows (i.e., in-row) and the adjacent 4-ft-wide alleyways on either side of the vine row. A buffer vine row separated each replicate plot from other plots.

A winter annual cover crop mix of cereal rye and crimson clover (*Trifolium incarnatum*) was planted in Sept. 2008 and 2009 in each plot with the exception of the unplanted treatment. The cover crop was seeded at a rate of 30 lb/acre cereal rye and 20 lb/acre crimson clover. The crimson clover seed had been preinoculated with rhizobium to ensure proper nodulation of roots for nitrogen (N) fixation. A double-roller drop-seeder (Sure-StandTM SSP-5; Brillion Farm Equipment, Brillion, WI) was used to plant the cover crop seed into a 4-ft-wide seedbed that had been prepared by harrowing once and rolling twice before planting. No fertilizer or irrigation was applied to the vineyard throughout the duration of the experiment.

There were five treatments included in the study, including four that used cover crop residues and one that

was left unplanted (Table 1). Cover crop plots were mown when crimson clover reached 90% flowering in May each year, when it was at the highest potential N contribution based on total biomass and percent N (Ranells and Waggoner, 1991). The unplanted treatment plots were not seeded to cover crop and were kept at minimal vegetative coverage using glyphosate (Bronco®; Monsanto, St. Louis, MO) applied at a rate of 1.0 lb/acre (acid equivalent) in January each year.

In 2009, mowed alleyway residue was applied to the in-row area as mulch in the mulch1 treatment in the quantity of 5 kg·m⁻² fresh weight to an approximate thickness of 10 cm and width of 1 m. The mulch3 treatment received residue density at 3-fold that of mulch1 with 15 kg·m⁻² fresh weight at an approximate thickness of 30 cm and width of 1 m. Residue was applied by hand to ensure even distribution across each treatment replicate. Mowed residue was managed in the same manner in 2010. However, residue applied in-row and incorporated between-row in 2010 was lower owing to reduced growth of the cover crop. The mulch1 and mulch3 treatments received 2.5 and 7.5 kg·m⁻² fresh weight residue in-row, respectively, in 2010.

Weather data were collected (Table 2) from an on-site weather station (Vantage Pro2TM; Davis Instruments, Hayward, CA) and regional weather station for Corvallis, OR [AgriMet (U.S. Department of the

Table 1. Floor management treatments imposed in May 2009 and 2010 in a ‘Chardonnay’ vineyard near Independence, OR.

Treatment	Alleyway management (each yr) ^a	In-row management (each yr) ^a
Unplanted	Not seeded to cover crop in fall. Sprayed with herbicide once in winter to control weeds. Rototilled twice in summer to control weeds.	Sprayed once with glyphosate in winter concurrent with alleyway spray. Glyphosate used to control weeds in summer.
Remove	Planted to cover crop in fall. Mowed in spring and residue removed from the alleyway. Rototilled twice in summer to control weeds.	Glyphosate used to control weeds in summer.
Incorporate	Planted to cover crop in fall. Mowed in spring and residue left in alleyway to be incorporated. Rototilled twice in summer to control weeds.	Glyphosate used to control weeds in summer.
Mulch1	Planted to cover crop in fall. Mowed in spring and residue transferred into vine row as a mulch. Rototilled twice in summer to control weeds.	Mowed alleyway residue transferred in-row as a mulch at 5 kg·m ⁻² fresh weight in 2009 and 2.5 kg·m ⁻² fresh weight in 2010. Glyphosate used to control weeds in summer.
Mulch3	Planted to cover crop in fall. Mowed in spring and residue transferred into vine row as a mulch. Rototilled twice in summer to control weeds.	Mowed alleyway residue transferred in-row as a mulch at 15 kg·m ⁻² fresh weight in 2009 and 7.5 kg·m ⁻² fresh weight in 2010. Glyphosate used to control weeds in summer.

^aDates of treatment imposition were determined by phenology of crimson clover (90% flowering) and ‘Chardonnay’ grapevines (EL 11–15, one to five leaves unfolded).

^b1 kg·m⁻² = 0.2048 lb/ft².

Table 2. Weather parameters of the vineyard site near Independence, OR, and the phenology of young 'Chardonnay' grapevines for each growing season.

	Mean monthly temp (°C) ^z		GDD > 10 °C ^y		ET ₀ (mm) ^x		Accumulated precipitation (mm)		Phenology dates of 'Chardonnay' grapevines	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
April	9.2	9.0	28	68	84	87	31	102	Budbreak: 20 Apr.	Budbreak: 2 Apr.
May	13.1	11.4	158	103	152	114	89	78		
June	16.4	14.6	200	157	162	140	15	66	Bloom: 15 June	
July	20.3	18.5	317	270	227	226	19	2		Bloom: 7 July
August	18.6	18.2	268	259	173	183	6	13	Véraison: 24 Aug.	
September	16.7	16.2	221	215	128	94	28	64		Véraison: 10 Sept.
October	10.9	11.5	99	113	52	53	73	119		
November	7.8	7.3	22	35	20	19	142	144	Leaf fall: 20 Nov.	Leaf fall: 16 Nov.
Cumulative ^w			1301	1221	943	920	388	499		

^z(1.8 × °C) + 32 = °F.^yGrowing degree days (base 10 °C) accumulated each month.^xEvapotranspiration (Kimberly-Penman) accumulated each month, collected from a Corvallis, OR, Agrimet weather station (U.S. Department of the Interior, Bureau of Reclamation, 2010); 1 mm = 0.0394 inch.^wCumulative GDD, ET₀, and precipitation from budbreak to leaf fall for each year.

Interior, Bureau of Reclamation, 2010)]. Soil temperature data were recorded in the vine row using dataloggers (HOBOTM micro station; Onset, Pocasset, MA) for mulched and unmulched treatments at depths of 15 and 30 cm, respectively.

WEED MANAGEMENT. One week before treatment application, weeds in the vine rows were desiccated using 0.67% glyphosate. Alleyway biomass samples were collected before treatments and were applied and used to estimate total weed biomass in each treatment. During the season, weeds in the alleyway were controlled by disking based on commercial vineyard management practices in 2009 (14 July and 1 Sept.) and 2010 (7 Aug.). In-row weeds were controlled as needed in summer with applications of glyphosate on 27 May, 14 July, and 31 Aug. 2009 and on 16 June 2010. The overall reduced growth of weeds in 2010 resulted in less need for control and only one sampling date was possible. Weeds were assessed 1 d before each disking or spray application.

SAMPLING WEED BIOMASS IN COVER-CROP STANDS. Cover crop and weed biomass was sampled in all treatments except the unplanted 1 d before implementing treatments. The sampling procedure did not include the unplanted treatment as minimal vegetative coverage was maintained (Table 1). Biomass was sampled by randomly throwing a 1.0-m² quadrat into the alleyway and harvesting all above-ground biomass 5 cm above the soil surface to simulate mowing. One sample was taken from the east and one from the west alleyway of each plot. Weed and cover crop biomass were separated by hand, and fresh weights were measured separately for each biomass sample. Cereal rye, crimson clover, and weed biomass were oven-dried separately to determine percent moisture content.

WEED DENSITIES AND ESTIMATION OF COVERAGE. Coverage of weeds in alleyways was estimated using a method similar to the procedure described by Gago et al. (2007), though a 1.0-m² quadrat was used instead of 0.25-m² and six replicates per plot instead of 12. The quadrat was placed randomly in the alleyway east of each treatment vine row three times and then three times in the west alleyway. Within the 1.0-m² quadrat, weed coverage was visually estimated as a percent of total

groundcoverage (Vitta and Quintanilla, 1996) by the same trained assessor each time. Weeds within the quadrat were then counted individually and grouped as either “broadleaf” or “grass” species. Though weeds were not quantified by species in this study, individual weeds that comprised weed biomass, percent coverage, and count data were photographed, visually identified, and classified according to genus and species when possible. Alleyway weeds were assessed on 30 June, 13 July (percent coverage only), and 31 Aug. 2009 and on 6 Aug. 2010.

In-row weeds were assessed by the same visual and counting methods with a 1.0-m² quadrat placed at six different predetermined positions across a replicate. Predetermined positions were used to prevent assessing areas that had been compromised by other measurements (e.g., soil cores). The mulch layer of mulch1 and mulch3 plots was removed for weed assessment and then put back into place. After the in-row weeds were assessed, glyphosate was applied at a rate of 1.0 lb/acre (acid equivalent) in-row with a tractor-mounted sprayer. In-row weeds were assessed on 26 May, 13 July, and 31 Aug. 2009 and on 16 June 2010. In-row and alleyway weeds were assessed at different sampling dates because of differences in weed control dates as determined by the vineyard management.

DATA ANALYSIS. Data were analyzed with SAS (version 9.2; SAS Institute, Cary, NC) using proc analysis of variance (ANOVA), GLM, and MIXED procedures where appropriate. Levene’s test was used to control for homogeneity of variance in the data and residuals were examined for skew or lack of normality. Data violating the assumptions of ANOVA were transformed before analysis using the log, square root, or arcsine transformations with the addition of a constant to meet the assumptions, and the data were rechecked to ensure that assumptions were met posttransformation. Back-transformed means are presented in the tables where transformed values were used. Percent coverage data were transformed before analysis using the square root or arcsine transformations with the addition of a constant to meet the assumptions of ANOVA. Dry weights of weeds in alleyway biomass samples were converted to a percent of total alleyway biomass and transformed using the square root transformation.

ANOVA-type III sums of squares were used to assess effects of treatment, sampling date, and interactions between treatment $\times$ date. Years were analyzed independently because cumulative effects of treatments from 2009 to 2010 could have violated the assumption of independence between years. Tukey’s honestly significant difference test was used to compare treatment means ($n = 5$) at 95% confidence. Effects were considered significant at 95% confidence ($P < 0.05$).

Results and discussion

CLIMATE. The climatic information from the research vineyard for the 2009 and 2010 growing seasons was monitored from budbreak to leaf abscission (20 Apr. through 20 Nov. 2009; 2 Apr. through 16 Nov. 2010). The 2009 season had 2341 °F growing degree days (GDD), 388 mm precipitation, and a relatively cool spring and moderate summer (Table 2). The 2010 growing season was the coolest year in 20 years (U.S. Department of the Interior, Bureau of Reclamation, 2010) with 2198 °F GDD and 499 mm precipitation (Table 2). Seasonal soil temperatures were moderated by mulching treatments (data not shown). Soil temperatures in-row were buffered in mulched treatments at 15 and 30 cm with daily fluctuations of 0.5–1.0 °C, whereas unmulched treatments fluctuated 3.0–5.0 °C per day. Mean soil temperatures in mulched treatments were generally 3.0–5.0 °C lower than unmulched treatments during the growing season.

OBSERVED WEED SPECIES. A general shift in the composition and density of weed species (abundance) over the entire site was visually observed between 2009 and 2010. Weed species recorded in 2009 were lambsquarters (*Chenopodium album*), pigweed (*Amaranthus retroflexus*), sow thistle (*Sonchus arvensis*), fescues (*Festuca* spp.), perennial ryegrass (*Lolium perenne*), black nightshade (*Solanum nigrum*), willowherb (*Epilobium* spp.), wild carrot (*Daucus carota*), buckhorn plantain (*Plantago lanceolata*), common knotweed (*Polygonum erectum*), and common groundsel (*Senecio vulgaris*). Weed species observed in 2010 included the species listed for 2009, with the exception of buckhorn plantain, and included prickly lettuce (*Lactuca serriola*) and two species of willowherb.

WEED BIOMASS IN ALLEYWAY COVER CROP. Total dry weights of alleyway weeds in 0.25-m² quadrat samples, taken just before imposing treatments in 2009 and 2010, did not differ between treatments. Percent weed biomass of the total sampled alleyway biomass also did not differ between treatments (data not shown). This was expected in 2009, as all cover-cropped alleyways had been treated similarly before planting. It was hypothesized that reduced weed biomass would occur due to decreased seed-to-soil contact in treatments where residue was incorporated into alleyways (Liebman and Mohler, 2001). The lowest mean weed dry matter was found in the incorporate treatment (4.6 g·m⁻²) where biomass was tilled into the alleyway. Other treatments in the study had 6.2–7.6 g·m⁻² dry matter. Total cover crop biomass grown in alleyways did not differ across treatments in either year of the study (Fredrikson, 2011). Cumulative effects of mulched residues from 2009 on in-row weeds in 2010 may have occurred. Based on visual observation, the mulch layer completely degraded in the mulch1 treatment and degraded by $\approx 90\%$ in the mulch3 treatment over the Winter 2009–2010.

IN-ROW WEED COVERAGE AND DENSITIES. Mulched treatments had lower weed coverage and densities in in-row than unmulched treatments (Figs. 1–3) when analyzed across the 2009 season. The mulch1 and mulch3 treatments had mulch-dry matter rates of 1.0 and 3.0 kg·m⁻², respectively, which is in excess of the 0.6 kg·m⁻² proposed by Teasdale and Mohler (1993) to be the minimum biomass required to suppress weed seed germination through light interception. The same effect was observed at the 2010 sampling date (Figs. 1–3) despite the mulch biomass applications being 50% lower in 2010 due to reduced total cover crop biomass accumulation by Spring 2010. The cooler seasonal temperatures in 2010 may have reduced weed emergence compared with 2009 (Forcella et al., 2000). Weed emergence may have also been reduced by the more buffered soil temperatures in mulched vine rows compared with unmulched vine rows (Forcella et al., 2000). Allelopathic chemicals from the cereal rye and crimson clover residues also may have inhibited weed development (Liebman and Mohler, 2001;

Fig. 1. Mean ($\pm$ SE) weed percent coverage at three sampling dates in 2009 and one sampling date in 2010 with different vineyard floor management treatments in the vine rows and alleyways of a young 'Chardonnay' vineyard. Unplanted, Remove, Incorporate, Mulch1, and Mulch3 represent vineyard floor management treatments (Table 1). Means followed by the same letter within a given sampling date do not differ by Fisher's protected least significant difference test at $\alpha = 0.05$.

Weston, 1996), though allelopathy was not measured directly in this study.

Cumulative weed coverage in-row includes the summation of coverage from each sampling date across a season, and it was 19% to 23% in unmulched treatments and 1% to 3% in mulched treatments during 2009 (Fig. 1). At each evaluation date in 2009, mulched treatments had lower weed coverage than unmulched treatments (Fig. 1). A similar trend in weed coverage was observed in 2010 (Fig. 1). In both years, mulch3 plots were nearly weed-free compared with the other treatments (Figs. 1–3). Similarly, mulch3 had mean broadleaf and grass densities <1.0 weed/m² at each sampling date in 2009 and 2010 (Figs. 2–3). Based on this information, residue fresh weight applications in mulch3 vine rows of 15.0 kg·m⁻² in the first year and 7.5 kg·m⁻² in the second year of this study attained nearly complete weed control. Mulch densities of 5.0 kg·m⁻² in the first year and 2.5 kg·m⁻² in the second year for the mulch1 treatment still suppressed weeds as indicated by

the 5- to 10-fold reduction in coverage and densities compared with unmulched treatments (Figs. 1–3). These results are consistent with a similar study conducted in a 'Red Delicious' apple (*Malus × domestica*) orchard in which three different organic mulch treatments at 10-cm thickness suppressed broadleaf and grass weed species better than the unmulched treatments (Granatstein and Mullinix, 2008). Hostetler et al. (2007) applied composted bark mulch to vine rows at a similar thickness as mulch3 and observed reduced weed growth compared with an unmulched control, although various perennial broadleaf and grass species persisted in bark mulch treatments with coverage as high as 35%.

Two methods of in-row weed assessment may have influenced the results. During assessment of weeds in the mulched treatments, the mulch was temporarily removed by hand, and it is possible that existing weeds were severed at the soil surface and not accounted for in the assessment. However, severing of weeds was never

observed during mulch removal. Even though the mulch layer may have acted as a barrier to glyphosate contact to weeds, the data indicate that weed growth and densities were reduced in mulched treatments as compared with unmulched treatments (Fig. 1).

Grass weed species accounted for greater density than broadleaf species in 2009 and 2010 (Figs. 2–3); however, percent coverage data were correlated more closely with broadleaf density ($r^2 = 0.81$; $P < 0.0001$) than grass density ($r^2 = 0.60$; $P < 0.0001$). These correlations suggest that coverage data were more reflective of broadleaf weed coverage than grass coverage, which was consistent with the results obtained by Neeser et al. (2000). Mulched treatments had lower broadleaf densities in-row than unmulched treatments at each sampling date in 2009 and 2010 (Fig. 2). In 2010, mulch3 had lower densities of broadleaf species than mulch1 with 0.8 and 6.5 broadleaf weeds/m², respectively (Fig. 2). As expected, in-row broadleaf densities were not different between

Fig. 2. Mean ($\pm$ SE) broadleaf weed density at multiple sampling dates in 2009 and one sampling date in 2010 with different vineyard floor management treatments in the vine rows and alleyways of a young ‘Chardonnay’ vineyard. Unplanted, Remove, Incorporate, Mulch1, and Mulch3 represent vineyard floor management treatments (Table 1). Means followed by the same letter within a given sampling date do not differ by Fisher’s protected least significant difference test at $\alpha = 0.05$; 1 weed/ $\text{m}^2 = 0.0929$ weed/ ft^2 .

unmulched treatments (unplanted, remove, incorporate) at any sampling date in 2009 or 2010 (Fig. 2) because the in-row area was treated similarly between these treatments except for an additional application of glyphosate in the unplanted treatment in winter.

In-row grass densities averaged between 0 and 1 grass weed/ m^2 in mulched treatments and between 29 and 30 grass weeds/ m^2 in unmulched treatments on 26 May 2009 (Fig. 3). These results indicate that mulched treatments suppressed the emergence of early-season grass weeds almost completely compared with unmulched treatments. No differences were seen at the latter sampling dates in 2009 due to glyphosate that killed emerging weeds; mean grass densities were <1 grass weed/ m^2 in all treatments on those dates (Fig. 3). However, across-season analysis for 2009 indicated that mulched treatments had lower grass densities in-row than unmulched treatments (Fig. 3). A similar trend in grass density was observed in 2010 with mean densities of 0–1 grass weed/ m^2

in mulched treatments and 11–20 grass weeds/ m^2 in unmulched treatments (Fig. 3). These results corroborate the findings of Monks et al. (1997). However, residue mulch has been observed to decrease broadleaf density without a concurrent decrease in grass weed density (Hoy et al., 2002; Shilling et al., 1986). The treatment where residues were incorporated had a density of 11 grass weeds/ m^2 , which was less than the treatment where residues were removed, which had a density of 20 grass weeds/ m^2 in 2010 (Fig. 3), suggesting an effect of alleyway residue incorporation on grass weed density in-row. In-row soil moisture did not differ between unmulched treatments where the residue was incorporated or removed from the alleyway in either year (Fredrikson, 2011), although weed seed dispersal may have been different between the two treatments.

ALLEYWAY WEED COVERAGE AND DENSITIES. Alleyway weed coverage compared across three sampling dates in 2009 indicates a treatment effect (Table 3). The treatment where residues

were incorporated had a lower mean coverage than all other treatments when analyzed across 2009; there was no interaction between treatment and sampling date. This followed the hypothesis that growing and incorporating cover crop biomass (mowed residue, stubble, and roots) would reduce weed growth, as is well documented in several studies (Brennan and Smith, 2005; Dyck and Liebman, 1994; Lehman and Blum, 1997; Liebman and Mohler, 2001). Sweet and Schreiner (2010) found that alleyway weeds were reduced in a winter annual cover crop treatment as compared with perennial grass cover and resident vegetation treatments. At the 13 July 2009 sampling date when alleyway weed coverage was greatest, the unplanted treatment had the greatest percent coverage, followed by treatments remove, mulch1, and mulch3, with the incorporate treatment having the lowest coverage (Fig. 1). It was also hypothesized that remove, mulch1, and mulch3 would have similar values for alleyway weed coverage and densities as

Fig. 3. Mean ($\pm$ SE) grass weed density at multiple sampling dates in 2009 and one sampling date in 2010 with different vineyard floor management treatments in the vine rows and alleyways of a young 'Chardonnay' vineyard. Unplanted, Remove, Incorporate, Mulch1, and Mulch3 represent vineyard floor management treatments (Table 1). Means followed by the same letter within a given sampling date do not differ by Fisher's protected least significant difference test at $\alpha = 0.05$; 1 weed/ $m^2 = 0.0929$ weed/ ft^2 .

they were managed similarly in the alleyway (Table 1). The differences between the treatments remove, mulch1, and mulch3, compared with incorporate and unplanted treatments, may be attributed to differences in alleyway management (Table 1). The unplanted treatment was treated with glyphosate in winter, and the soil surface was subject to compaction by winter rains. Also, the treatments remove, mulch1, and mulch3 had cover crop root biomass remaining during incorporation, and this may have suppressed weed emergence. The additional cover crop residue disked into the incorporate treatment may have further suppressed weeds compared with the other treatments. Hoffman et al. (1996) found that cereal rye root residues delayed weed emergence, whereas shoot residues had little effects on weed emergence.

The differences in alleyway weed coverage found on 13 July 2009 were not observed at other sampling dates

in 2009 or 2010 (Fig. 1). At the 30 June assessment in 2009, incorporate had the lowest coverage and differed from the other treatments except mulch1 (Fig. 1). This may be attributed to the relatively low growth of weeds at that first sampling date. Interestingly, the unplanted treatment had greater alleyway broadleaf density than other treatments on 30 June 2009, whereas the percent coverage in the unplanted treatment did not differ from other treatments except incorporate (Figs. 1–2). This suggests that weeds in the unplanted treatment were smaller in size than weeds in other treatments based on the correlation between broadleaf density and weed coverage. In 2010, the lowest coverage (5.3%) was in the treatment where residue was incorporated, whereas there was 20.0% and 23.3% coverage in treatments that were unplanted and where residues were removed, respectively (Fig. 1).

Results indicate that mulch1 coverage was 6.0%, which was less than unplanted and remove (Fig. 1), and mulch3 did not differ in weed coverage from any treatment in 2010 (Fig. 1). The variation between sampling dates may be ascribed to the relatively low coverage and high variation between field replicates.

Alleyway broadleaf densities followed a similar trend as percent coverage in 2010, but not in 2009 (Figs. 1–2). Across-season analyses in 2009 indicate that the unplanted treatment had greater broadleaf weed density than all other treatments (Table 3), which further suggests that the differential treatment of the alleyway in winter and lack of cover crop biomass may have allowed for greater proliferation of broadleaf weeds relative to the other treatments. In 2010, broadleaf density in the unplanted treatment was greater than all treatments except where residues were removed (Fig. 2).

Table 3. Analysis of variance *F* values and associated probability values at $\alpha = 0.05$ for experimentwise variation between means of weed coverage and density, in the vine rows and alleyways, at each sampling date in a young 'Chardonnay' vineyard.

Sampling location	In-row					Alleyway				
	ANOVA <i>F</i> value (<i>P</i> value)									
Sampling date	26 May 2009	13 July 2009	31 Aug. 2009	Across 2009 ^a	16 June 2010	30 June 2009	13 July 2009	31 Aug. 2009	Across 2009	6 Aug. 2010
Coverage	3.9 (0.016)	3.7 (0.021)	5.1 (0.006)	19.6 (<0.001)	19.4 (<0.001)	4.8 (0.007)	5.1 (0.005)	2.1 (0.123)	9.8 (<0.001)	4.3 (0.011)
Broadleaf density	6.8 (0.001)	7.0 (0.001)	5.5 (0.004)	12.7 (<0.001)	11.1 (<0.001)	4.0 (0.015)	— ^b	3.4 (0.029)	4.7 (0.003)	5.1 (0.006)
Grass density	13.3 (<0.001)	1.1 (0.393)	1.0 (0.431)	13.5 (<0.001)	11.8 (<0.001)	2.5 (0.074)	—	0.9 (0.488)	4.1 (0.007)	2.1 (0.124)

^aValues represent analysis across three sampling dates in 2009 (two sampling dates for alleyway broadleaf density and grass density).

^bBroadleaf and grass densities were not assessed on 13 July 2009.

Similarly, Monteiro and Lopes (2007) found that annual broadleaf species in a vineyard were more abundant in unplanted alleyways than cover-cropped alleyways, whereas grass species were more abundant in cover-cropped alleyways.

When analyzed across the 2009 season, alleyway grass densities were lower in unplanted and incorporate treatments compared with remove, mulch1, and mulch3 treatments (Table 3). However, no differences were observed at individual sampling dates in either year (Fig. 3). Grass weed density may have been lower in the incorporate treatment as there was greater alleyway residue incorporated than in remove, mulch1, and mulch3 to potentially reduce weed seed-to-soil contact. Still, differences in grass weed density were marginal (Fig. 3) and only seen when analyzed across the 2009 season.

Studies using similar floor management treatments reached variable conclusions regarding cover crop effects on weed densities (Baumgartner et al., 2008; Mennan et al., 2006; Reddy, 2001; Vasilakoglou et al., 2006). Vineyard floor cultivation has been found to be a more important factor in weed recruitment than cover crop management (Ingels et al., 2005), though a less effective weed management strategy than herbicide (Baumgartner et al., 2007). Although we did not measure the effect of cultivation on alleyway weeds, we found that a sown winter annual cover crop reduced the weed coverage and broadleaf density compared with the unplanted alleyway at some sampling dates. Incorporation of mowed residue further reduced alleyway weed coverage and broadleaf density.

Conclusion

Using mowed cover crop residue as a mulch in vine rows provided nearly complete weed control when compared with unmulched vine rows in a growing season with minimal summer precipitation. Supplemental mulch in the mulch3 treatment provided similar in-row weed control as the mulch1 treatment, which reflects the "mow and throw" technique, indicating that mulching can provide effective weed control when cover crop residue levels are greater than 2.5 kg·m⁻² fresh weight in the vine row. Incorporating cover crop biomass into

vineyard alleyways suppressed weed growth as compared with an unplanted treatment or removing mowed residue, whether it was mulched into vine rows. Alleyway broadleaf weed growth was reduced in cover-cropped alleyways as compared with unplanted, herbicide-treated alleyways. Few differences in alleyway grass weed densities were found between these floor management treatments. The results of this study suggest that cover crops may be effectively managed to control in-row and alleyway weeds simultaneously in vineyards located in areas of limited summer rainfall.

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