Cover Crops and Tillage in a Mature Merlot Vineyard Show Few Effects on Grapevines

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Abstract: Permanent cover crops are commonly used in vineyard floor management because of their beneficial effects to soil and vine health, but studies evaluating their competitive effects on vines have been conducted primarily in nonirrigated vineyards. Future air quality regulations could mandate the use of no-till floor management practices in California's Central Valley. We evaluated the combined effects of cover crop type (oats alone or oats grown with legumes) and tillage on soil nutrient availability, vine nutrition, growth, and yield characteristics of *Vitis vinifera* cv. Merlot grown under regulated deficit irrigation in a commercial vineyard from 2008 to 2010. Five treatments were used: Resident Vegetation (RV) + Till, Oats + Till, Oats/Legumes +Till, Oats + NoTill, and Oats/Legumes + NoTill. No differences in soil nutrient availability were found among the treatments. Of the numerous nutritional constituents analyzed on leaf petioles and blades, only NO_3-$N_{petiole}$ was affected by floor management. At nearly all growth stages among all years, NO_3-$N_{petiole}$ of tilled treatments was twice the no-till treatments. At harvest, yield, mean cluster weight, cluster number per vine, and aboveground cover crop biomass differed among treatments in 2009 and/or 2010 but not in the first year (2008); however, responses were not consistent among treatments within each respective year. Importantly, yields were similar from all four cover crop treatments compared to the typical management (RV + Till), suggesting that use of cover crops and/or no-till practices may be implemented in an irrigated vineyard with little immediate effect on grape productivity in mature vineyards.

Key words: tillage, nutrient management, competition, legume, no-till

When cover crops are grown with winegrapes they can regulate vine growth and nutrient status, influence rooting distributions, affect juice composition and wine flavor, and enhance soil biological and chemical properties (van Huyssteen 1988, Merwin et al. 1994, Petgen et al. 1998, Hartwig and Ammon 2002, Morlat and Jacquet 2003, Colugnati et al. 2004, Baumgartner et al. 2005, Ingels et al. 2005, McGourty and Reganold 2005, Monteiro et al. 2008, Smith et al. 2008, Steenwerth and Belina 2008a, 2008b, Celette et al. 2009, Guerra and Steenwerth 2012). In general, permanent cover crops have a devigorating effect on the vines (Guerra and Steenwerth 2012), but not all devigoration is undesirable. In a 17-year trial conducted in the Loire Valley (France) (550 mm annual rainfall), increasing levels of soil coverage by tall fescue (*Festuca arundinacea*) controlled vine growth, including lower pruning weights, fewer lateral shoots, and lower yield; increased canopy exposure and temperature; and decreased *Botrytis* infection (Morlat and Jacquet 2003). In New South Wales (Australia), canopy openness increased (that is, fewer interior leaves) and shoot length decreased with increasing percentage of soil coverage by permanent cover crops (Tesic et al. 2007). Berry weight, cluster number, and yield were reduced after the third year with a cover crop, effects that were more pronounced in a dry, warm site than in a cool, humid site. Findings from a study of vineyard nitrogen (N) and water dynamics conducted over three years in an unfertilized, dry-farmed vineyard in Montpellier (France) underscore the importance of N uptake and water use by both the cover crop and grapevines (Celette et al. 2009). The temporal changes in N content in both the tissue of grapevines and cover crops in relation to soil N pools indicated that the permanent grass cover crop competed for N more strongly than the nonpermanent cover crop and elicited N reductions in grapevine storage organs.

Together these studies suggest that cover crops most strongly influence grapevine nutritional status when water is a limiting factor, but studies heralding such findings have been conducted primarily in nonirrigated, rain-fed vineyards (Morlat and Jacquet 2003, Celette et al. 2005, 2008, 2009). The western United States produces more than 90% of U.S. winegrapes, and more vineyards are irrigated than dry-farmed. Moreover, adoption of permanent cover crops and other vineyard floor management practices such as no tillage in the California Central Valley are considered integral to achieving state air quality standards regulating airborne particulates smaller than 10 µm (California Air Resources Board 2002) and could be mandated in the future. The objectives of this study were to test the effect of cover crop type and tillage on growth and nutrition of grapevines grown under

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sustained, regulated deficit irrigation. Grapevines grown with permanent cover crops and without tillage were expected to show nutritional stress, and those grown with cover crops that included leguminous N-fixers were expected to display little effect on N status of grapevines.

Materials and Methods

Site description. The study site was a mature Merlot (FPS 3; 110 Richter rootstock, *Vitis berlandieri* x *V. rupestris*) vineyard (15.5 ha, 3.1 m x 2.1 m spacing) planted in 1995 within the Lodi American Viticulture Area, San Joaquin County, California (long. 121°08′59”W; lat. 38°11′43”N). Ten-year average air temperature ranged from 8°C in winter (December to February, 1998–2008) to 24°C in summer (June to August, 1999–2009) (Table 1). Ten-year average air temperature in spring (March to May, 1999–2009) and autumn (September to November, 1999–2008) was 15°C. Ten-year average annual precipitation was 443 mm (1999–2008). The vineyard was composed of two soil types: San Joaquin loam, thick surface, 0 to 2% slopes (fine, mixed, thermic Abruptic Durixeralf) and Exeter sandy loam, 0 to 2% slopes (fine-loamy, mixed, thermic Typic Durixeralfs), although the cemented duripan had been disrupted through deep ripping (1.5 m) prior to vineyard establishment. Soil characteristics (n = 40) were as follows: total N by combustion, 0.10%; total carbon by combustion, 1.03%; Olsen phosphorus (P), 18.72 µg/g; exchangeable (X-) potassium (K), 0.58 $cmol_c$/kg; X-sodium (Na), 0.02 $cmol_c$/kg; X-calcium (Ca), 7.23 $cmol_c$/kg; X-magnesium (Mg), 0.81 $cmol_c$/kg; and cation exchange capacity, 10.59 $cmol_c$/kg. Texture was 53.3% sand, 32.0% silt, and 14.7% clay.

The vine rows ran east to west. Vines were trained to bilateral cordons on a vertical shoot-positioned trellis using two pair of positioning wires. Vines were machine pruned to four nodes in early January and were later hand pruned (late February) to leave a two-bud spur. The vines were mechanically hedged in summer to control excessive canopy growth. The vineyard was drip-irrigated using sustained, regulated deficit irrigation (Williams et al. 2010). Drip emitters (3.8 L/hr) were spaced at one emitter between each two adjacent vines throughout the entire vineyard. The same amount was applied throughout the entire vineyard based on weekly, theoretical crop evapotranspiration (ET_c) estimates of vineyard water demand calculated from the California Irrigation Management Information System (CIMIS station Lodi West #166, San Joaquin County; long. 121°19’W; lat. 38°12’N) and shaded area as described below. The station provided reference evapotranspiration (ET_o) estimates (based on water use of a model grass crop under similar microclimatic conditions), which were then multiplied by a crop coefficient (K_c) derived using the methods of William and Ayars (2005). Briefly, shaded area under the vine was determined at solar noon by placing a light-colored surface on the vineyard floor between two vines; the area was large enough to ensure that the full width of the shadow cast onto the vineyard floor was contained on the surface. An image of the shaded surface was captured with a digital camera, and the percentage of the surface area occupied by shade was quantified from the digital images using Adobe Photoshop software. Shaded area was quantified at five different locations in the vineyard on each date throughout the growing season. In July, the K_c developed from shaded area estimates plateaued when canopy expansion ceased. The mean of three subsequent K_c values (after the plateau) were used for the remainder of the season. Sustained deficit irrigation was regulated by measuring weekly midday leaf and stem water potential using a Scholander-type pressure chamber and standard methods described by Williams and Aruajo (2002). The target ET_c value for deficit irrigation was 60 to 70% ET_c. Once critically low water potential values (stem water potential = -14 to -15 bars) were achieved, irrigation was temporarily supplemented above the target to ET_c values between 80 and 95% in consultation with the vineyard manager. Additional supplemental irrigation was needed only a few times in each growing season. All other standard management practices were conducted by the vineyard manager (Table 2).

Table 1 Annual weather conditions at field site (CIMIS station Lodi West #166, San Joaquin County).

	Soil temp (°C) (n = 365 days)			Air temp (°C) (n = 365 days)			Precipitation
Year[a]	Daily max	Daily min	Daily average	Daily max	Daily min	Daily average	Annual total[b] (mm)
2008							
Mean	16.7	15.1	15.9	23.0	7.2	14.9	325
Annual max	29.3	26.4	26.9	40.2	19.8	29.2	na
Annual min	7.4	5.8	6.8	5.9	-3.3	3.4	na
2009							
Mean	16.8	15.5	16.2	23.5	8.3	15.5	354
Annual max	26.9	23.2	24.1	39.7	17.3	28.4	na
Annual min	8.1	0.0	7.6	5.4	-2.1	2.4	na
2010							
Mean	16.7	15.5	16.1	23.0	8.3	15.3	474
Annual max	25.2	22.6	23.4	38.8	18.7	28.9	na
Annual min	7.3	6.4	6.8	6.6	-4.8	1.1	na

[a]Annual maximum (max) and annual minimum (min) indicate the greatest or lowest value observed during the respective year.
[b]Total precipitation occurred during the annual winter rainy season, calculated from August of the preceding year through July of the following year (e.g., 2008 values were calculated from Aug 2007–July 2008). na: not applicable.

Experimental design. The experimental design was a randomized complete block with four blocks, each consisting of two treatment replicates per block. Each block was ~400 m east to west, with 190 vines per row and 12 vine rows per block. Treatment replicates were composed of two adjacent alleys on either side of a vine row. Ten adjacent data vines per replicate were sampled each time (n = 8 total replicates per treatment). When the project was initiated, all treatment rows were disked and rolled and the respective cover crops were planted into these prepared seedbeds. The strip (50 cm width) under the vine was maintained free of vegetation by herbicide (see Table 2). The treatment representing typical management (RV + Till) consisted of alleys that were disked to 15 to 20 cm in the fall (October) and spring before budbreak (April); resident vegetation emerged in early November, was allowed to grow during the rainy season, and then mown and disked into the soil. The resident vegetation was dominated by *Amsinckia intermedia*, *Medicago hispida*, *Stellaria media*, *Cerastium* spp., *Erodium* spp., *Poa annua*, and *Vulpia myuros*. In the cover crop treatments, Dusky oats (*Avena sativa*) (Oats) or a mixture of Dusky oats and legumes—Oats/Legumes; 37% oats, 28% Fava bean (*Vicia faba*), 10% common vetch (*Vicia sativa*), 25% Magnus peas (*Pisum sativum*)—was drill-seeded annually in early November (112 kg/ha; 6 Nov 2008, 6 Nov 2009, 5 Nov 2010). All cover crop treatments were mown at the same time as RV + Till, and then cover crops were either tilled into the soil (Oats + Till, Oats/Legumes + Till) or not tilled and remained on the alley surface (Oats + NoTill, Oats/Legumes + NoTill) in spring before budbreak (April). Only soils of the three tilled treatments were disked and rolled before budbreak, three times in summer, and once each October before planting the cover crops. Cover crops in the no-tillage treatments were drill-seeded without seedbed preparation.

Grapevine and cover crop biomass. Aboveground plant biomass (three 0.25 m^2 quadrats) was collected adjacent to the data vines before mowing and tillage occurred in the spring. Samples were sorted into legumes, oats, and mixed weeds, and dried at 60°C for 72 hr. All samples were massed after drying, and total nitrogen (N) and carbon (C) were determined by combustion (Pella 1990). Grape yields and total number of clusters were measured just prior to commercial harvest. Clusters were harvested from facing cordons from two sets of adjacent data vines. Internode length between the third and fourth internodes was measured. The mass of pruned grapevine canes was collected annually in February despite annual hedging each June.

Gravimetric water content (GWC) and potential net mineralized N was measured annually in April when plant biomass was collected. Soil cores from five locations along permanent 40 m transects were combined, mixed, and placed on ice in the field. For GWC, soil (100 g) was dried at 105°C for 48 hr. Potential net N mineralization, an assay of soil N availability, was measured by anaerobic incubation (Waring and Bremner 1964, Soon et al. 2007). Briefly, soil (~7 g) was submerged in 10 mL DDI water at 40°C for 7 days, extracted with 4 M KCl (10 mL added to slurry), and analyzed for NH_4-N and NO_3-N content by colorimetric analysis (Forster 1995, Kempers and Kok 1989).

Table 2 Schedule of vineyard management events, 2008–2010.

Year/ irrigation stage[a]	Irrigation	Fertilization					Herbicide application			
	L H_2O/ vine	Date (m/d/y)	Type	N (kg/ha)	P (kg/ha)	K (kg/ha)	Date (m/d/y)	Type[b]	a.i.[c]	kg a.i./ ha
2008										
Pre-B	291	11/15/07	Ever Grow[d]	44.8	22.4	44.8	11/1/07	RoundUp	Glyphosate	3.08
B to V	796	11/16/07	$CaCO_3$[e]	–	–	–	3/19/08	Buccaneer Plus	Glyphosate	2.69
V to H	401	–	–	–	–	–	3/19/08	Goal 2XL	Oxyfluorfen	2.53
Post-H	390	–	–	–	–	–	3/19/08	Surflan A.S.	Oryzalin	5.04
Total	1878	–	–	–	–	–				
2009										
Pre-B	0	10/23/08	5-0-12	6.7	0.0	13.5	3/20/09	Chateau SW	Flumioxazin	0.22
B to V	1003	5/30/09	5-0-12	5.0	0.0	10.1	3/20/09	Prowl H2O	Pendimethalin	4.26
V to H	537	6/25/09	5-0-12	5.0	0.0	10.1	3/20/09	Buccaneer Plus	Glyphosate	1.12
Post-H	450	7/9/09	5-0-12	5.0	0.0	10.1	5/29/09	Rely 200	Glufosinate ammonium	1.17
Total	1990	–	–	–	–	–	5/29/09	Buccaneer Plus	Glyphosate	2.24
2010										
Pre-B	26	10/27/09	5-0-12	8.2	0.0	16.5	2/20/10	Chateau SW	Flumioxazin	0.36
B to V	696	–	–	–	–	–	2/20/10	Prowl H2O	Pendimethalin	5.32
V to H	620	–	–	–	–	–	2/20/10	Touchdown Total	Glyphosate	1.46
Post-H	431	–	–	–	–	–	6/5/10	Buccaneer Plus	Glyphosate	2.24
Total	1773	–	–	–	–	–	6/5/10	Rely 280	Glufosinate ammonium	1.31

[a]The year of study runs from the preceding year after grapevine dormancy through harvest of the subsequent year (e.g., Oct 2007–Sept 2008 corresponds to 2008). Pre-B, prebloom; B to V, bloom to veraison; V to H, veraison to harvest; Post-H, postharvest.
[b]Inclusion of these product names does not constitute endorsement, but instead reflects choices made by the grower cooperator.
[c]a.i. = active ingredient in the respective herbicide.
[d]Also contained 11.2 kg Mg/ha, 22.4 kg S/ha, 6.7 kg Fe/ha, and 11.2 kg Ca/ha.
[e]Contributed 896 kg Ca/ha.

Grape leaf and petiole analysis. Grapevine leaves and petioles were collected for nutrient analyses at bloom, veraison, and just before commercial harvest. Bloom (22 May 2008, 21 May 2009, 8 June 2010) and veraison (29 July 2008, 3 Aug 2009, 7 Aug 2010) were defined as when >50% of flowers opened and >50% of berries had gained full coloration, respectively. Harvest samples were collected 25 Aug 2008, 3 Sept 2009, 7 Sept 2010). Five leaves with petioles were collected on the north side of each data vines, for a total of 50 leaves and 50 petioles per set of 10 data vines. Petioles were detached from the leaves; both were dried at 60°C for 72 hr and analyzed for macro- and micronutrients. Total N content was determined by combustion (Pella 1990). Ammonium (NH_4-N) and nitrate (NO_3-N), phosphate (PO_4-P), and potassium (K) were extracted from samples in 2% acetic acid and then determined quantitatively by the diffusion conductivity analyzer method, flow injection analyzer (Lachat), and inductively coupled plasma atomic emission spectrometry, respectively (Carlson et al. 1990, Prokopy 1995, Jones 2001, Telliard 2001). Boron (B) and zinc (Zn) concentrations were determined through microwave acid digestion followed by spectrometry (Meyer and Keliher 1992, Sah and Miller 1992).

Juice measurements. Berries and vine yields were collected just prior to commercial harvest. From each of the 10 data vines per sampling location, 10 berries were collected from single clusters on the north and south sides of the vine (200 berries/10 data vines). Two hundred berries were weighed and then juice from 100 berries was strained through cheesecloth after berries were lightly pressed using a mortar and pestle. Juice pH (Accumet AP72 pH meter, Fisher Scientific, Waltham, MA) and total soluble solids (TSS) (PAL-1 Pocket Refractometer, Atago, Tokyo, Japan) were measured and titratable acidity (TA) was determined through an acid-base titration using 0.1 N NaOH as a buffer and 1% phenolphthalein solution in 70% ethanol as an indicator (Zoecklein et al. 1999).

Statistical analysis. Using a mixed model for repeated measures analysis, effects of treatment, year, and treatment-year interaction on fixed response variables were analyzed (proc mixed; SAS ver. 9.3, SAS Institute, Cary, NC; Littell et al. 1996). Block was treated as a random variable. A mixed model for repeated measures analysis was also used to determine effects of fixed variables treatment, year, and growth stage (bloom, veraison, and just prior to commercial harvest, or harvest). The effect of growth was nested within year [growth(year)] and tested for its interaction with treatment [treatment x growth(year)]. Block was again treated as a random variable. To model variable correlation across dates, the covariance structure was compound symmetry, chosen based on Akaike information criterion (AIC). Where interactions existed, Tukey's adjustment for multiple comparisons was performed to identify treatment differences within sampling year.

Table 3 Means and standard errors (x ± se) across all treatments of leaf and petiole nutrients by year and vine growth stage (n = 40).

	Leaf[b]							Petiole[b]						
Year/ stage[a]	B (µg/g)	K (% g/g)	NH_4-N (µg/g)	NO_3-N[c] (µg/g)	N (% g/g)	PO_4-P (µg/g)	Zn[d] (µg/g)	B (µg/g)	K (% g/g)	NH_4-N (µg/g)	NO_3-N (µg/g)	N (% g/g)	PO_4-P (µg/g)	Zn (µg/g)
2008														
Bloom x	48.50	1.26	95.25	14.63	3.27	848.25	16.98	39.00	3.75	73.75	251.50	1.03	2839.25	32.28
Bloom se	0.93	0.01	3.91	0.83	0.02	19.20	0.18	0.38	0.03	5.93	23.71	0.01	98.88	0.63
Veraison x	50.10	1.12	187.50	22.50	2.82	755.25	16.25	47.13*	3.90	40.25	61.63*	0.51	3077.25	71.20
Veraison se	0.73	0.02	3.84	0.69	0.01	10.16	0.19	0.48	0.08	1.36	6.48	0.01	168.79	2.59
Harvest x	43.50*	0.83	153.50	33.25	1.99	396.00	16.85	37.48	2.44*	36.75	206.25	0.48	1601.75*	66.65
Harvest se	0.49	0.01	4.97	0.97	0.02	10.83	0.70	0.29	0.08	1.26	20.18	0.01	109.28	1.93
2009														
Bloom x	54.42*	1.29	1020.00	13.50	3.62	1642.00	18.09*	45.64	2.93	1243.50	291.50	1.17	5185.75	40.99
Bloom se	0.72	0.02	183.12	1.08	0.04	62.07	0.27	0.80	0.05	70.58	30.43	0.02	75.58	0.73
Veraison x	38.26	0.84	185.00	10.38	2.76	615.00	12.77	39.39	3.27	37.50	15.13	0.55	2562.75	71.01
Veraison se	0.55	0.01	5.56	0.38	0.01	8.47	0.10	0.18	0.06	0.78	1.92	0.00	137.52	1.63
Harvest x	36.32	0.65	69.50	17.25	2.13	421.75	12.74	30.59	1.44	64.25	138.50	0.46	1664.00	66.55
Harvest se	0.40	0.01	2.51	0.71	0.01	6.29	0.12	0.15	0.08	9.04	15.64	0.01	106.70	1.28
2010														
Bloom x	51.15*	1.21	970.59	12.62	3.40	1547.08	17.02*	42.86	2.75	1165.11	273.39	1.10	4872.58	38.44*
Bloom se	1.16	0.04	176.88	1.02	0.07	66.99	0.43	1.06	0.07	68.39	29.27	0.02	112.15	0.91
Veraison x	33.46	0.74	161.80	9.09	2.41	537.68	11.18	34.46	2.87	32.78	13.28	0.48	2246.23	69.59
Veraison se	0.59	0.01	4.10	0.19	0.02	9.87	0.12	0.30	0.06	1.04	1.89	0.00	124.75	1.56
Harvest x	31.09	0.51	60.73	15.13	1.86	368.58	11.46	26.78	1.26*	56.55	121.01	0.41	1457.30	60.78
Harvest se	0.44	0.01	2.99	0.60	0.01	5.51	0.52	0.29	0.07	8.18	13.88	0.01	101.58	1.28

[a]Bloom, veraison, and harvest differ from each other within a given year, growth(year), $p < 0.05$. When only one growth stage differs within a year, an asterisk (*) is used to indicate the respective growth stage.
[b]B, boron; K, potassium; NH_4-N, ammonium nitrogen; NO_3-N, nitrate nitrogen; N, total nitrogen by combustion; PO_4-P, phosphate; Zn, zinc.
[c]Included for information purposes only. Treatment x growth(year) is significant for NO_3-N_{leaf} ($p < 0.05$).
[d]Zn_{leaf} is not significantly different by growth stage in 2008.

Results

Very few measured variables responded to vineyard floor treatment. Mean internode length did not vary by treatment or year (data not shown). Berry size (222 to 333 g fresh wt/200 berries), total soluble solids (23.0 to 24.6 Brix), and titratable acidity (5.7 to 6.3 g/L as per tartaric acid equivalents) varied annually (n = 40; $p < 0.0001$) (data not shown). $NH_4\text{-}N_{leaf}$, $NH_4\text{-}N_{petiole}$, $NO_3\text{-}N_{leaf}$, $PO_4\text{-}P_{leaf}$, $PO_4\text{-}P_{petiole}$, K_{leaf}, $K_{petiole}$, B_{leaf}, $B_{petiole}$, Zn_{leaf}, and $Zn_{petiole}$ varied only by growth stage within year ($p < 0.0001$; Table 3) but not by treatment. Only $NO_3\text{-}N_{petiole}$ differed by growth stage among treatments within year ($p < 0.05$, treatment x growth[year]). At nearly all growth stages among all years, $NO_3\text{-}N_{petiole}$ of tilled treatments was twice the no-till treatments (Figure 1; $p < 0.05$). Cover crop type had little effect on petiole nitrate even though the mass of N contained in total aboveground cover crop biomass per square meter was 40 to 60% greater in treatments that included legumes rather than oats alone (Treatment, $p < 0.0001$; Figure 2). Oats + NoTill was intermediate in value and did not differ significantly from any treatment. Soil N availability as

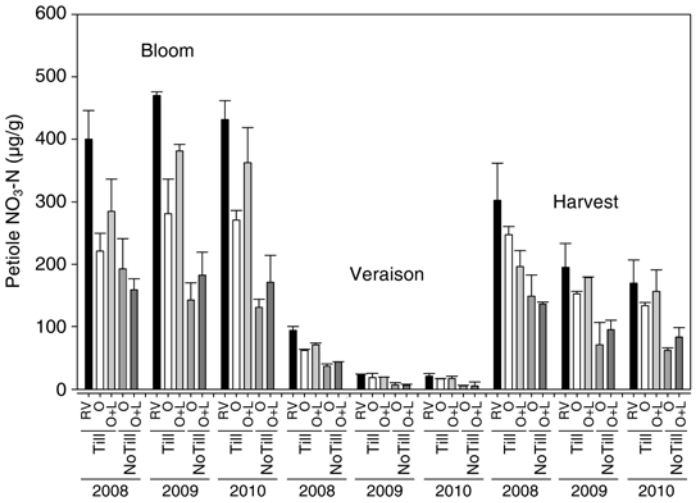

Figure 1 Means and standard errors of petiole NO_3-N (n = 8). Significant differences were determined by ANOVA [treatment x growth (year), $p < 0.05$]. Abbreviations: RV, resident vegetation; O, oats; L, legumes; Till, tilled treatments; NoTill, no tillage treatments. 2008, 2009, and 2010 are years of the study.

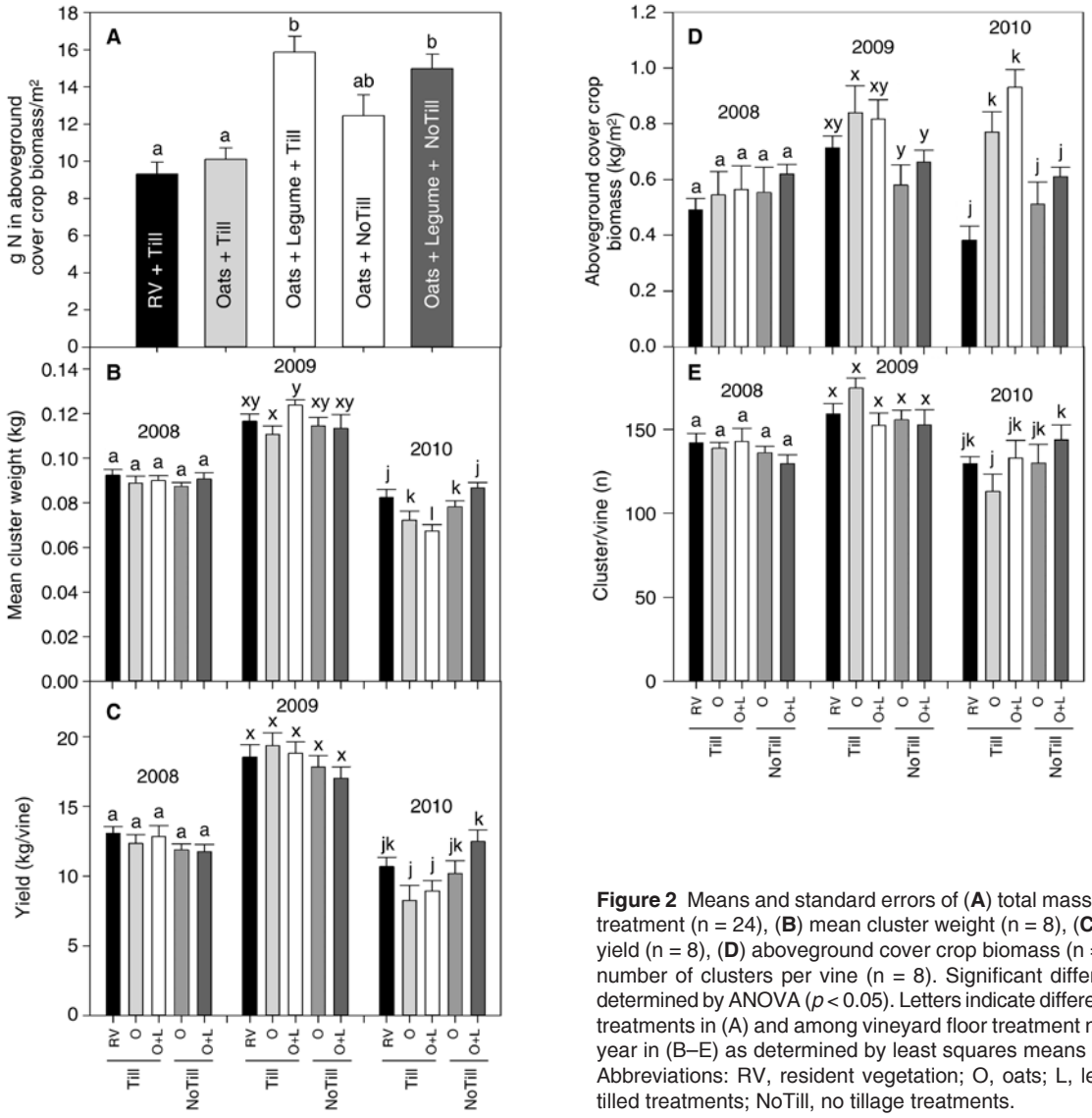

Figure 2 Means and standard errors of (**A**) total mass of N in each treatment (n = 24), (**B**) mean cluster weight (n = 8), (**C**) total grape yield (n = 8), (**D**) aboveground cover crop biomass (n = 8), and (**E**) number of clusters per vine (n = 8). Significant differences were determined by ANOVA ($p < 0.05$). Letters indicate differences among treatments in (A) and among vineyard floor treatment means within year in (B–E) as determined by least squares means comparison. Abbreviations: RV, resident vegetation; O, oats; L, legumes; Till, tilled treatments; NoTill, no tillage treatments.

determined by potential net NH_4-N mineralization differed only by year ($p < 0.05$; data not shown).

Pruning weights from RV + Till were consistently 15% greater than all cover crop treatments, but no differences among cover crop treatments occurred (treatment, $p = 0.02$; ~0.90 kg/vine RV + Till versus 0.78 kg/vine for all other treatments; data not shown). At harvest, grape yield, mean cluster weight, cluster number per vine, and aboveground cover crop biomass were all significant for the interaction treatment x year (Figure 2, $p < 0.05$). Differences among treatments were observed in the second (2009) and/or third (2010) years of the trial but not in the first year (2008). Nonetheless, no consistent trend among treatments within each respective year was observed.

When no yield differences were observed among treatments in the first year (2008), no differences in aboveground cover crop biomass occurred (Figure 2). However, in the second year (2009), aboveground cover crop biomass in Oats + Till was 25% greater than in Oats + NoTill and Oats/Legumes + NoTill and the remaining two treatments were intermediate in value. In the third year (2010), aboveground cover crop biomass in Oats + Till and Oats/Legumes + Till was 40 to 50% greater than in Oats + NoTill, Oats/Legumes + NoTill, and RV + Till. Yield, mean cluster weight, and cluster number per vine did not show distinct differences among treatments until the third year (2010).

Discussion

In general, few differences among treatments were observed in cover crop and grape biomass and leaf and petiole nutrients. The majority of differences were observed among years, which corresponded to differences in annual rainfall and climate (Table 1). It was anticipated that the grapevines grown with no-till practices would show nutritional stress due to immobilization of nutrients in aboveground cover crop tissue, yet no differences in leaf or petiole measurements were detected among treatments. As grapevines are perennial species containing significant nutrient reserves in woody structures (Keller 2010), such effects from cover crop competition may not be immediately observed. Indeed, treatment effects on yield, cluster number, and mean cluster weight were not observed until the third year of the study.

Effects of floor management on vine reproductive development were small and inconsistent each year, suggesting that tillage in this case has little potential to change competitiveness of cover crops in the short term. The annual sensitivity of cover crop competitiveness to floor management is conveyed by comparisons of cover crop aboveground biomass and vine yield in 2009 and 2010. Cover crop biomass increased in tilled treatments in 2009 and 2010, but yield per vine was altered exclusively in 2010 when yield was reduced by half, the lowest value of the study in all treatments. Although the causes of low yields in 2010 are unknown, the high value of the yield per vine/pruning weight ratio in 2009 (~25) suggests that vines were overcropped. Decreases in mean cluster number among Oats + Till, Oats/Legumes + Till, and Oats + NoTill in the third year suggest that initiation of primordia in 2009 may have been impacted by overcropping.

Few treatment effects may also have occurred because this study was conducted in a mature vineyard with grapevines that had established rooting structures that could likely compete effectively with cover crops for nutrients and other resources such as water (van Huyssteen 1988, Van Zyl 1988, King and Berry 2006). As mechanical hedging to control vine growth decreases individual shoot vigor but increases vine capacity (Intrieri et al. 2011), this practice presents potential interference with detecting treatment effects. When the ratio of pruning weight per vine to cordon length was calculated, the range was 0.37 to 0.43 kg/vine/m, suggesting that the grapevines possessed low vigor that masked any incremental devigoration from the cover crop.

To provide some context for the current work, other studies have demonstrated that cover crops can impose increased canopy and cluster openness and decreased growth and production of the grapevines. Increasing percentage of soil coverage by permanent cover crops elicited increased canopy openness (fewer interior leaves) and decreased shoot length in New South Wales (Australia) (Tesic et al. 2007). Berry weight, cluster number, and yield were reduced after the third year with a cover crop. These effects were more marked in a dry, warm site (304 mm annual rainfall) than in a cool, humid site (492 mm annual rainfall) (Tesic et al. 2007), suggesting that irrigation and fertilization practices could compensate for establishment of a permanent cover crop in a warm climate. In a Swiss study, berry, cluster, and pruning weights were also reduced by cover crops, particularly tall fescue (*F. arundinacea*), which increased canopy aeration and caused vine growth to stop earlier than did low fescue (*F. rubra*), a fescue/ryegrass mix (*F. rubra* 70%, *Lolium perenne* 30%), or a control treatment of herbicide (David et al. 2001). In the current study, little effect of cover crop treatment was documented.

Conclusion

Reductions in yield among all four cover crop treatments compared to the resident vegetation (RV + Till) were not detected in this three-year study, suggesting that use of cover crops and/or no-till practices may be implemented in an irrigated vineyard with little immediate effect. This outcome facilitates the use of cover crops to reduce both soil erosion and generation of airborne particulates and improve soil organic matter content, structure, and fertility. The minimal and inconsistent treatment effects and confounding factors observed in this study underscore the necessity to conduct long-term studies in established vineyards with balanced growth.

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