Alleyway Cover Crops Have Little Influence on Pinot noir Grapevines (*Vitis vinifera* L.) in Two Western Oregon Vineyards

Rebecca M. Sweet[1] and R. Paul Schreiner[2]*

Abstract: Seven cover-crop treatments were compared in two north Willamette Valley Pinot noir vineyards over two years to test if alleyway cover crops that are mowed in spring and summer compete with grapevines for water or nutrients. Five different cover-crop mixtures were compared to a clean-cultivated control and resident vegetation treatments in 2004 and 2005. Treatments were evaluated for biomass production, quantity of nitrogen (N) contributed to the vineyard floor, weed suppression, and effect on soil water content. Vine responses to the different floor-management strategies included measures of shoot growth, water and nutrient status, yield, and juice quality. Three treatments were evaluated for their effect on fine roots and colonization by arbuscular mycorrhizal fungi (AMF). Cover crops influenced soil moisture in a different manner at each site, although the lowest soil moisture was consistently found in the perennial grass and clover mixture. Cover-crop treatments had an impact on grapevine N status at one vineyard, altering leaf blade N concentrations at bloom and juice N concentrations at harvest, although different treatments did not alter N status consistently over time. Cover crops did not alter shoot growth, pruning mass, leaf water potential, fine root density, or colonization of roots by AMF and did not affect yield, cluster weights, juice soluble solids, pH, or titratable acidity. Results showed that alleyway cover crops managed by spring and summer mowing do not have consistent effects on grapevines in western Oregon vineyards and suggest that little competition occurs between cover crops and vines in the mixtures evaluated. Further examination of cover crops composed primarily of clovers or of perennial grasses is warranted.

Key words: competition, leaf water potential, shoot growth, soil moisture, yield, fruit quality

Information on appropriate alleyway (between-row) cover crops and their management is scarce for western Oregon vineyards. The cool climate, low soil pH, low soil phosphorus availability, and infrequent use or availability of irrigation in this region distinguishes it from other wine grape growing regions where most cover-crop research has been conducted. In addition, there is a growing trend toward cultivation of vineyard alleys. Currently, many Oregon vineyard managers till at least every other alley in order to reduce water competition, increase nutrient availability, and increase heat accumulation in the vineyard. Because frequent tillage is associated with increased soil erosion, decreased soil quality, and pollution of watersheds (Baker and Laflen 1983, Shipitalo and Edwards 1998), research to understand if alleyway cover crops compete with grapevines is warranted.

Cover crops can provide important benefits to agroecosystems and can be used to reduce soil erosion (Louw and Bennie 1991), manage soil water (Smith et al. 2008), maintain good soil structure and water infiltration (Celette et al. 2005), alleviate soil compaction, and improve traffic surfaces in wet conditions (Gaffney and Van Der Grinten 1991). Cover crops may also suppress weeds (Baumgartner et al. 2008), contribute nitrogen (N) and carbon (C) to the soil (Ranells and Wagger 1996), enhance soil microfauna populations (Mendes et al. 1999, Ingels et al. 2005), increase functional biodiversity (Altieri 1994), and reduce dust associated with spider mite outbreaks (Costello and Daane 1998). Growing cover crops in vineyards can also have potential drawbacks, which can vary by site, grapevine genotype, and cover-crop species. Deleterious effects can include decreased vine vigor and yield (Tan and Crabtree 1990, Wolpert et al. 1993, Tesic et al. 2007), reduced petiole and must N (Rodriguez-Lovelle et al. 2000, Ingels et al. 2005), a perceived greater frost hazard, and increased pest presence such as cane borers (Wolpert et al. 1993) or pocket gophers (*Thomomys* spp.) (Ingels et al. 2005).

Effects of cover crops that are considered drawbacks at one site may be considered benefits at other sites. For example, a competitive cover crop can serve to control excess growth on high vigor sites (Rodriguez-Lovelle et al. 2000, Tesic et al. 2007). Canopies that are too vigorous

[1]Department of Horticulture, Oregon State University, Corvallis, OR 97330, present address, Van Duzer Vineyards, 11975 Smithfield Rd., Dallas, OR 97338; [2]USDA-ARS Horticultural Crops Research Laboratory, 3420 NW Orchard Ave., Corvallis, OR 97330.

*Corresponding author (email: Paul.Schreiner@ars.usda.gov)

Acknowledgments: This project was funded in part by the Northwest Center for Small Fruits Research.

The authors thank Leigh Bartholomew and Stirling Fox for cooperating in this study and for mowing cover crops in the plots; Matthew Scott and Stepfanie Lair for technical assistance; and Robert Bugg for advice regarding cover-crop mixtures.

Manuscript submitted Apr 2009, revised Oct 2009, accepted Dec 2009

Copyright © 2010 by the American Society for Enology and Viticulture. All rights reserved.

can lead to delayed and irregular fruit ripening, including low sugars, high acidity, and poor berry color (Jackson and Lombard 1993). Shaded fruit clusters in overly robust canopies can also lead to increased *Botrytis* bunch rot, decreasing wine quality (Smart and Robinson 1991). Compared to chemically weeded alleys, vines moderately stressed by a perennial grass cover crop have exhibited earlier bloom, veraison, and ripening, and yielded higher quality fruit (higher sugars and lower titratable acidity) (Rodriguez-Lovelle et al. 2000). However, perennial cover crops established for four years had no effect on grape yield or quality compared with a clean cultivated control in a California vineyard on a deep alluvial soil (Ingels et al. 2005).

There is growing interest in using native grasses and forbs as cover crops in vineyards because of their adaptation to local climate and soil conditions. Native grasses used as covers in California vineyards were found to outcompete weeds and to reestablish reasonably well (Bugg et al. 1996, Baumgartner et al. 2008).

The objective of this study was to investigate the influence of seven different alleyway cover-crop treatments on soil moisture and vine response in western Oregon vineyards. The main goal was to determine whether various cover-crop mixtures grown in vineyard alleyways and mowed in the spring and summer would compete with grapevines for water and/or nutrients. The ability of each cover-crop mixture to suppress weeds and provide a source of N to the vineyard floor was also assessed. A secondary objective was to evaluate the potential use of Willamette Valley native grasses and forbs as cover crops in vineyards.

Materials and Methods

Site, soil analysis, and weather. Cover-crop treatments were established in fall 2003 at two commercial Willamette Valley vineyards, designated AS and JH. Both vineyards were planted with Pinot noir (*Vitis vinifera* L., Pommard clone, FPS 91 on 3309C rootstock), were cane-pruned, and not irrigated in 2004 or 2005. The AS vineyard (45°15'N; -123°2'W) was planted in 1994 on a 1.8 x 1.1 m spacing (5123 vines ha^{-1}), located on a Jory (fine, mixed, active, mesic Xeric Palehumult) soil. The JH vineyard (45°15'N; -123°2'W) was planted in 2001 on a 2.4 x 1.5 m spacing (2690 vines ha^{-1}), located on a Yamhill (fine, mixed, superactive, mesic Pachic Ultic Haploxeroll) soil. Chemical analysis of representative soil samples (0–45 cm depth from 72 soil cores, collected 4 June 2004) from each site was conducted by the Oregon State University Central Analytical Laboratory using standard procedures for western Oregon (as in Schreiner 2005). Soil at AS had a pH of 6.3, contained 0.13% N, 9.8% organic matter (LOI), and contained the following available nutrients (mg kg^{-1}): P 13, K 366, Ca 1242, Mg 425, SO_4-S 24, Fe 24, Mn 33, Zn 6, B 0.7, and Cu 1. Soil at JH had a pH of 5.9, contained 0.14% N, 8.2% organic matter (LOI), and contained the following available nutrients (mg kg^{-1}); P 9, K 223, Ca 1864, Mg 413, SO_4-S 8, Fe 34, Mn 52, Zn 1, B 0.4, and Cu 1.

Seven cover-crop treatments were applied to plots on 23 and 24 Sept 2003. Each treatment was replicated four times at each site in a randomized complete block design. Treatment plots consisted of four adjacent alleys and three vine rows, each with eight (JH) or 10 (AS) vines. One clean-cultivated border alley divided the blocks. Data were not collected from border rows or from the first or last vine in any row.

There were seven cover-crop treatment mixtures: (1) winter annuals (WA), (2) clover mix (CM), (3) native grass mix (NGM), (4) native meadow mix (NMM), (5) perennial grass + clover mix (PGCM), and two controls of (6) resident vegetation (RV) and (7) clean cultivated (CC). Cover-crop species (Table 1) were selected based on consultation with local Willamette Valley botanists, researchers, winegrape growers, and seed company representatives. Species mixtures were chosen based on their function within the agro-ecological landscape. The RV treatment was characterized by a diverse assortment of annual and perennial grasses and forbs (largely of European origin) and was considered weed biomass for the purposes of this study. The CC treatment was kept weed-free during the growing season with frequent, shallow cultivation.

All plots were cultivated in mid-September 2003 to prepare a seedbed. At AS, beds were cultivated with a spader, followed by shallow rototilling, whereas a disk was used at JH. At both sites, seeds were hand-broadcast and incorporated with the roller of an empty drop-seeder. Seeds in the WA treatment were additionally hand-raked to achieve a greater planting depth (~2 cm). The WA treatment was cultivated and reseeded on 7 Oct 2004 as per 2003. Native annual forbs (*Clarkia amoena, C. purpurea, Collomia grandiflora, Madia elegans, Trifolium willdenovii, Gilia capitata,* and *Lotus unifoliolatus*) were also reseeded in the NMM treatment at AS in 2004 because flowers had been mowed during the growing season, preventing natural reseeding. The floor directly beneath the vines (designated as vine rows) was kept weed-free during the growing season at AS by shallow cultivation with a grape hoe (LUV side-mounted cultivator; Braun Maschinenbau Gmbh, Burrweiler, Germany) and at JH by a single glyphosate application in late March (2004) or cultivation with a similar grape hoe (2005). The width of the vegetation-free vine row was ~0.8 m at AS vineyard and ~1.0 m at JH vineyard.

Alleyway cover crops were mowed at a height of 10 cm several times during the growing season. AS was mowed more frequently than JH because of aesthetic requirements at AS and the desire to let native annuals reseed themselves at JH. In 2004, AS was mowed on 18 Apr, 5 June, and 26 June, and in 2005 on 1 Apr and 27 May. At JH, mowing occurred in 2004 on 20 May and 5 Aug and in 2005 on 1 May.

Cover-crop establishment and percent cover. Digital photographs of alleyway vegetation were taken one day before each mowing date, at 1.5 m above plots. The percentage of the soil surface area covered by vegetation within two 0.25 m^2 quadrats per plot was estimated from the photos using a calibrated template representing 4% of the quadrat area.

Cover-crop biomass and nitrogen content. Aboveground cover-crop biomass was estimated just before each mowing date by cutting the vegetation at a height of 10 cm within two randomly placed 0.25 m^2 quadrats in adjacent alleys of each experimental plot. Weeds and cover crops were separated, dried at 70°C for 48 hr, and weighed. Dried weed and cover-crop residues were combined into a single sample and ground in a Wiley Mill to pass through a 40-mesh (425 μm) screen to measure N inputs of mowed residues, as determined by combustion analysis (CNS 2000 MacroAnalyzer; Leco Inc., St. Louis, MO). Total N content of mowed residue was determined by multiplying N concentration by dry mass. Weeds and cover crops were combined to reflect the total N delivered as residue in each plot.

Soil water content. Volumetric soil water content in both the vine row and alley was determined every two weeks from late June to early September each year using time domain reflectometry (TDR, Trase System; Soil

Table 1 Cover-crop treatments and seeding rates applied at two north Willamette Valley vineyards, fall 2003.

Treatment/Plant species	Common name	Seeding rate (kg ha^{-1})
Winter annuals (WA)		
Secale cereale	Cereal Rye	28.0
Avena sativa Monida	Oat Monida	28.0
Vicia sativa	Common Vetch	28.0
Clover mix (CM)		
Trifolium hirtum Hykon	Hykon Rose Clover	4.2
T. subterraneum ssp. *subterraneum* Mt. Barker	Mt. Barker Subclover	4.2
T. subterraneum ssp. *yanninicum* Riverina	Riverina Subclover	4.2
T. subterraneum ssp. *subterraneum* Campeda	Campeda Subclover	4.2
T. resupinatum Nitro	Nitro Persian Clover	4.2
Medicago polymorpha Santiago	Santiago Burclover	4.2
Native grass mix (NGM)		
Koeleria macrantha	Prairie Junegrass	15.7
Danthonia californica	California Oatgrass	2.4
Festuca roemeri	Roemer's Fescue	13.5
Elymus glaucus	Blue Wildrye	2.4
Native meadow mix (NMM)		
Achillea millefolium	Common Yarrow	0.5
Lomatium utriculatum	Spring Gold	1.0
Sidalcea malviflora ssp. *virgata*	Rose Checker-mallow	1.4
Eriophyllum lanatum	Oregon Sunshine	1.0
Prunella vulgaris ssp. *lanceolata*	Lance Selfheal	1.0
Lupinus bicolor	Miniature Lupine	1.4
Trifolium willdenovii	Tomcat Clover	1.4
Madia elegans ssp. *densifolia*	Showy Tarweed	1.4
Clarkia purpurea	Purple Godetia	0.5
Clarkia amoena	Farewell to Spring	0.5
Agoseris grandiflora	Bigflower Agoseris	1.4
Gilia capitata	Bluehead Gilia	1.0
Lotus unifoliolatus var. *unifoliolatus*	Spanish Clover	1.0
Collomia grandiflora	Grand Collomia	1.4
Koeleria macrantha	Prairie Junegrass	3.5
Danthonia californica	California Oatgrass	0.5
Festuca roemeri	Roemer's Fescue	13.5
Elymus glaucus	Blue Wildrye	0.5
Perennial grass + clover mix (PGCM)		
Lolium perenne Essence	Dwarf Elf Ryegrass	5.2
Festuca brevipila Ridu	Hard Fescue Ridu	5.2
Festuca ovina Quatro	Sheep Fescue Quatro	5.2
Trifolium hirtum Hykon	Hykon Rose Clover	1.1
T. subterraneum ssp. *subterraneum* Mt. Barker	Mt. Barker Subclover	1.1
T. subterraneum ssp. *yanninicum* Riverina	Riverina Subclover	1.1
T. subterraneum ssp. *subterraneum* Campeda	Campeda Subclover	1.1
T. resupinatum Nitro	Nitro Persian Clover	1.1
Medicago polymorpha Santiago	Santiago Burclover	1.1

Moisture Equipment Corp., Santa Barbara, CA). In the spring, two sets of 45 cm waveguides were installed in all treatment plots at both sites except the RV treatment and left in place throughout the growing season. One set of waveguides was located in vine row (25 cm from a vine trunk at AS, 30 cm from a vine trunk at JH), and the other set was located in the middle of the alley (directly across from the vine row set).

Vine water status. Midday leaf water potential (Ψ_{leaf}) was measured approximately biweekly during the growing season, weather permitting, using a pressure chamber (model 610; PMS Instrument Company, Corvallis, OR). A fully sun-exposed, undamaged leaf was selected from the midcanopy within each plot and placed in a plastic bag before cutting the petiole with a razor blade. Each site was measured on consecutive cloud-free days, within 1.5 hr of solar noon.

Vine vigor. Shoot lengths were measured two times before hedging in each year on three vines per plot, except for JH in 2005 when vines were hedged before the second measurement (AS: 14 May and 17 June 2004, 1 June and 27 June 2005; JH: 13 May and 17 June 2004, 2 June 2005). Two shoots per vine were measured at the second and sixth nodal position from the trunk head and successive measurements were conducted on the same shoots. Dormant season pruning weights from 9 vines per plot were determined in winter 2004 at both sites and at AS only in 2005 (JH vineyard was pruned in 2005 prior to our data collection).

Vine nutrient status. Vine leaves were collected from 15 vines per plot (5 vines per treated row) from opposite-cluster nodes at bloom and at veraison. We examined opposite cluster leaves at veraison instead of recently expanded leaves (which is more typical for this time point) because older leaves should show the first symptoms of nutrient (particularly N) deficiencies due to translocation to the berries (Gärtel 1996). Leaf blades were separated from petioles, rinsed in distilled water, dried at 70°C for 48 hr, and ground in a Wiley mill to pass through a 40-mesh (425 μm) screen. N in leaf blades was determined via combustion analysis. Because of expense, P, K, S, Ca, Mg, Mn, Cu, B, Zn, and Fe concentrations were measured by inductively coupled plasma-optical emission spectrometry (Optima 3000DV; PerkinElmer, Wellesley, MA) in leaf blades from AS vineyard in 2005 only.

Vine root length and AMF colonization. Vine root samples were collected at bloom and again approximately 3 weeks after fruit harvest from three treatments (CC, WA, PGCM) and two locations (vine row and alley) at both sites. Samples from each plot were comprised of three large soil cores (5.7 cm diam, 0–45 cm depth) removed from the vine row or alley, representing ~2 kg (fresh mass) soil. Samples were stored at 4°C for up to 4 weeks before processing.

Two methods were used to obtain roots from soil. In 2004, grapevine roots were carefully hand-picked with tweezers from small aliquots (~200 g fresh wt) of soil and stored in cold tap water until all soil was processed (see Schreiner 2005). In 2005, roots were retrieved by a wet-sieving method (Böhm 1979) to improve recovery of fine roots. Soil samples were placed in a large bucket and covered with cold tap water. The soil-water suspension was stirred vigorously and one-third at a time was poured over a 1-mm sieve. Roots and other organic debris caught on the sieve were rinsed and transferred to a white tray where grapevine roots were removed with tweezers. Roots obtained directly from soil (2004) or from washed soil samples (2005) were sonicated for 30 sec in a Ultrasonic LC 60 water bath (Lab-Line Instruments Inc., Melrose Park, IL) and rinsed over a 500-μm sieve to remove adhering soil particles. Roots were then separated into woody and fine root fractions under a stereomicroscope. Fine roots were defined as primary roots with an intact cortex varying in color from white to dark brown. Fine roots were blotted dry on paper towels and fresh weights were recorded. Fine roots were stored in FAA (formaldehyde/acetic acid/ethanol, 5%:10%:50%) for up to two months before clearing and staining to evaluate AMF colonization. Roots were cleared using KOH and H_2O_2 and stained with trypan blue (Schreiner 2003).

Fine root length was determined by the gridline intercept method (Newman 1966). Colonization of fine roots by AMF was determined on randomly selected root fragments mounted on slides using a previous method (McGonigle et al. 1990) as modified (Schreiner 2003). The proportion of fine root length containing any AMF structures (aseptate hyphae, vesicles, or arbuscules) and a separate count of only arbuscules was determined.

Fruit yield and quality. Fruit samples were collected 1 to 3 days before commercial harvest. All fruit clusters were removed from 6 vines per plot, counted, and weighed. Average cluster weight was calculated by dividing the total yield per vine by the number of clusters. Subsamples consisting of one representative cluster from each vine (selected after placing all clusters per vine on a large tray) were transported to the laboratory in coolers, stored at 4°C, and processed within 2 days. Berries were removed by hand and pressed in a small hand-crank press to obtain a juice yield of 625 mL kg^{-1} fresh weight of clusters. Juice soluble solids (Brix) were measured with a hand-held refractometer (Leica Microsystems, Buffalo, NY) and pH was determined with a pH meter. Titratable acidity (TA) was determined by titration to a pH meter endpoint of 8.2. Subsamples of juice were stored at -20°C for analysis of yeast assimilable nitrogen (YAN). In 2004, YAN was determined only at AS, while YAN was determined in juice from both sites in 2005. Ammonia-N in the must was determined by the enzymatic ammonia method (Bergmeyer and Beutler 1985). Amino-N in the must was determined by the NOPA method as described elsewhere (Dukes and Butzke 1998). YAN was the sum of ammonia-N and amino-N.

Statistical analysis. Data were analyzed by ANOVA or by Kruskal–Wallis (K–W) nonparametric ANOVA by ranks for those variables that could not be transformed to satisfy assumptions of ANOVA (see below). Data from each vineyard were analyzed separately using cover-crop treatment

and year (or sample date) as factors. Sample date was used in the analysis in place of year for those variables (soil moisture, Ψ_{leaf}, shoot length, root length, and AMF colonization) where multiple observations were recorded per year. Means were compared using Tukey's post-hoc test at 95% confidence whenever ANOVA was used, or by K–W multiple comparison test whenever K–W nonparametric ANOVA by ranks was used. Statistica software (v. 8.0; Statsoft Inc., Tulsa, OK) was used for all analyses and effects were considered significant at 95% confidence ($p < 0.05$).

Cover-crop establishment variables (biomass, % weeds, and nitrogen content) were analyzed by K–W, excluding the CC treatment from all analyses and excluding the RV treatment from the % weed mass analysis. Soil moisture data were analyzed by ANOVA using cover-crop treatment and sample date as factors for the vine row and alleyway sampling locations independently. However, overall seasonal changes in soil moisture content that occurred at each vineyard were computed from pooled data in the vine row and alleyway locations. Root length and AMF variables were evaluated by ANOVA in three treatments (CC, WA, and PGCM) using location and sample date as factors, after showing that cover-crop treatment itself and any interactions with location or sample date were not significant. Midday Ψ_{leaf} and shoot length data at both sites and yield data from AS vineyard were analyzed by K–W. Variables collected only one time (leaf nutrients other than N from AS vineyard in 2005, juice N concentrations from JH vineyard in 2005, and pruning weights from JH vineyard in 2004) were analyzed by ANOVA using cover-crop treatment as the sole factor. All other variables were analyzed by ANOVA using cover-crop treatment and year as factors.

Results

Weather and vine phenology. The 2004 grapevine growing season was warmer than the previous 10-year average, particularly during April, June, July, and August. In addition, 2004 was drier than the previous 10-year average early in the season (May to July), but this period was followed by an unusual amount of rainfall in August (53 mm) (Table 2). The 2005 growing season was slightly cooler and wetter than average, resulting mainly from high rainfall in May and cool temperatures in June. The warmer weather in 2004 resulted in an early bloom period with 50% flower capfall occurring the first week of June at both sites (7 June for AS, 4 June for JM), while in 2005 bloom occurred during the third week of June (21 June for AS, 20 June for JN). Veraison was earlier in 2004 (10 Aug for AS, 8 Aug for JH) than in 2005 (25 Aug for AS, 20 Aug for JH). Harvest was also earlier in 2004 than in 2005; fruit was harvested one week earlier at JH (23 Sept 2004 vs. 30 Sept 2005), and four weeks earlier at AS (17 Sept 2004 vs. 12 Oct 2005). Harvest dates were set by winemakers receiving fruit from each site.

Cover-crop establishment and N content of clippings. The different cover-crop treatments applied at both vineyards had a large impact on the biomass of alleyway vegetation, as expected (Table 3). Cover-crop treatment also affected the amount of weed biomass present and the quantity of N contributed to the vineyard floor in the form of plant litter (clippings). Differences due to year were only significant for weed biomass at JH vineyard, such that less biomass was attributed to weeds in 2005. Total plant biomass at AS was greater in the WA and CM treatments than in NGM and NMM, while PGCM and RV were intermediate. At JH, the WA treatment produced more biomass than NMM and RV, and CM also outproduced RV. The WA treatment suppressed weeds better than NGM and NMM at both sites, and CM suppressed weeds better than NGM at AS. The NGM treatment was slow to establish at both sites, producing no biomass (other than weeds) above the 10 cm mowing height in 2004, even though a good, albeit short, stand was established by then (data not shown). The CM treatment contributed the greatest quantity of N in the mowed clippings to plots at both sites, outproducing NGM, NMM, and RV at AS and RV alone at JH.

Similar quantities of alleyway vegetation were produced at both vineyards, although the first mowing at JH was ~1 month later in both years. At the first mowing date in the spring of each year, all cover-crop treatments covered at least 80% of the soil surface in all plots, except for the CC control that was excluded from this analysis (data not shown). Percent cover was not affected by cover-crop treatment at either vineyard. Greater details regarding the establishment of cover crops and the relative performance of

Table 2 Precipitation and heat accumulation at Forest Grove, Oregon, 2004 and 2005, with averages from preceding 10 years. Values from public weather station (www.usbr.gov/pn/agrimet/).

Parameter/Year(s)	Apr	May	June	July	Aug	Sept	Oct	Total Apr–Oct
Rainfall (mm)								
1994–2003 avg	68	50	30	6	12	30	94	290
2004	65	28	21	0	53	38	97	301
2005	66	104	40	5	3	33	110	360
GDD (>10°C)[a]								
1994–2003 avg	86	150	201	294	289	236	113	1369
2004	125	150	226	320	321	190	123	1454
2005	78	164	176	303	303	199	100	1323

[a]Growing degree days = Σ [(max. daily air temp + min. daily air temp) / 2] – 10°C, where the maximum cannot exceed 30°C and the minimum cannot be less than 10°C.

individual plant species in the treatments used in this study are available (Sweet 2006).

Soil and vine water status and vine growth. Differences in rainfall between 2004 and 2005 were clearly reflected in the seasonal soil moisture content changes at both sites (Figure 1A). Average soil moisture content was more rapidly depleted in 2004 than in 2005, and a partial recovery in soil moisture content after the unusual rainfall in August 2004 occurred at both sites. In both years, as the season progressed, lower soil moisture was recorded at the JH site. These findings are consistent with greater water stress (lower Ψ_{leaf}) at JH compared with AS in both years, and with the earlier seasonal decline in vine water status at both sites in 2004 (Figure 1B). The younger vines at JH experienced greater water stress than vines at AS, partly explained by the lower amount of soil water available at JH later in the growing season. The vines at AS did not experience significant water stress in either year, since Ψ_{leaf} was never below -1.0 MPa in 2005 and only reached ~-1.1 MPa before the August rains in 2004.

Cover-crop treatment significantly altered soil water content in the vine row and in the alleyway at both sites when data from all sampling times were analyzed together, but effects on vine water status or vine growth were not significant (Table 4). At AS, the CM, NGM, and NMM treatments had higher soil water contents in the vine row than PGCM and CC. At JH, the WA treatment was higher than CC, NMM, and PGCM in the vine row. In the alleyway, the CM treatment had greater soil moisture than all other treatments except CC at AS, while NGM and NMM were higher than WA, CM and PGCM at JH. The lowest values for soil moisture consistently occurred in the PGCM treatment, at both sites and both sampling locations. Cover-crop treatment did not significantly affect soil moisture content at either vineyard or sampling location when analyzed at any single measurement date. There was also no interaction between sample date and cover-crop treatment for soil moisture data. Cover-crop treatment had no effect on midday Ψ_{leaf}, shoot length measured early in the summer, or pruning weight measured during the dormant period at either vineyard when all sample dates were combined in one analysis (Table 4), or at any single sampling date (data not shown). Sample date affected Ψ_{leaf} and shoot length in a predictable manner (water stress and shoot length increased over the season) and altered prune weights at AS, such that

Table 3 Total plant biomass, proportion of biomass attributed to weeds, and total N content of alleyway vegetation (above 10-cm mowing height) in six cover-crop treatments at the first seasonal mowing date in two north Willamette Valley vineyards, 2004 and 2005. Values represent means (with standard errors).

Treatment[a]/ Year	Dry biomass (kg ha^{-1})	% Biomass as weeds	Total N (kg ha^{-1})
AS vineyard			
WA	2133 (436) a[b]	3 (2) c	51 (11) ab
CM	2153 (272) a	8 (3) bc	86 (15) a
NGM	325 (115) b	76 (10) a	10 (4) bc
NMM	339 (79) b	61 (15) ab	12 (3) bc
PGCM	1167 (424) ab	51 (16) abc	44 (17) abc
RV	694 (237) ab	100	4 (1) c
Trtm signf	<0.001	<0.001	<0.001
2004	1163 (235)	57 (9)	26 (6)
2005	1125 (226)	40 (9)	45 (10)
Year signf	0.837	0.063	0.167
JH vineyard			
WA	2754 (720) x	9 (2) z	22 (5) yz
CM	1949 (412) xy	28 (4) yz	45 (12) y
NGM	1149 (331) xyz	62 (14) y	20 (7) yz
NMM	658 (234) yz	55 (8) y	32 (12) yz
PGCM	1378 (177) xyz	42 (10) yz	37 (6) y
RV	525 (226) z	100	5 (2) z
Trtm signf	0.002	0.002	0.003
2004	1682 (332)	60 (7) w	27 (6)
2005	1123 (170)	39 (7) x	27 (5)
Year signf	0.410	0.028	0.789

[a]Treatments: WA, winter annuals; CM, clover mix; NGM, native grass mix; NMM, native meadow mix; PGCM, perennial grass and clover mix; RV, resident vegetation.
[b]Means within a column at each site followed by the same letter are not significantly different at 95% confidence.

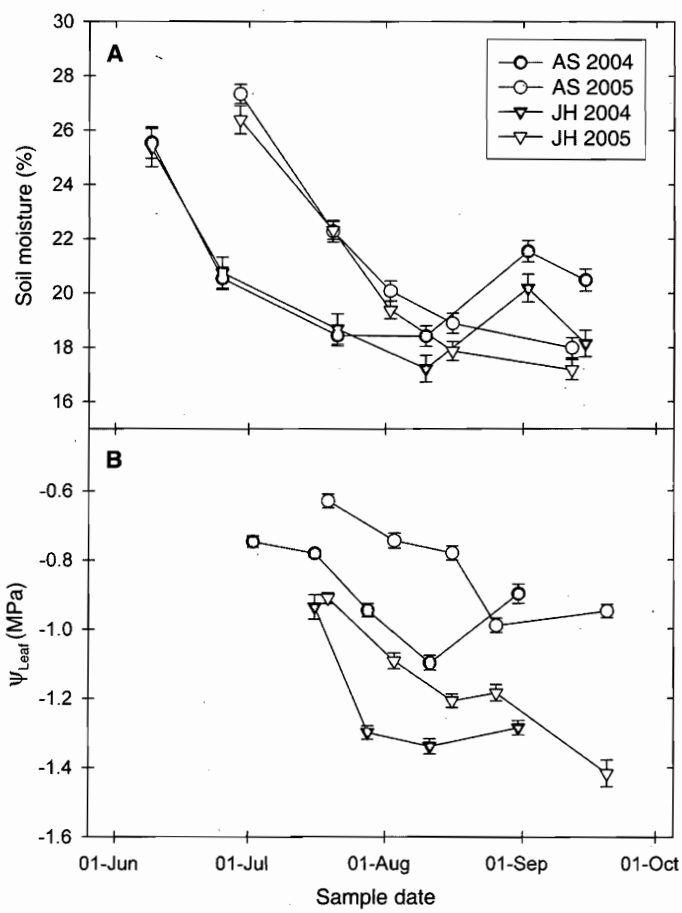

Figure 1 Seasonal changes in volumetric soil moisture content (**A**) and vine water status (**B**) at two north Willamette Valley vineyards, 2004 and 2005. Data for (A) is the average across both vine row and alley sampling locations from 0-45 cm soil depth. Data for both plots was pooled across all cover-crop treatments and represents mean values at each site ± standard errors (n = 24 for soil moisture, n = 28 for Ψ_{leaf}).

pruning weights were greater in 2005 than in 2004 (data not shown).

Leaf blade N concentrations at bloom and at veraison were most strongly affected by year at both sites (Table 5). Leaf N was lower in 2005 than 2004. Cover-crop treatment affected leaf N at AS at bloom, and an interaction between cover crop and year was significant at AS at bloom. Based on the interaction between year and cover-crop treatment at AS at bloom, there were no differences among cover-crop treatments in 2004, but CM had higher leaf N than CC, WA, and NGM in 2005. Cover crops did not alter leaf N concentrations at JH. Petiole N concentration data supported our results with leaf blades, showing the same factors were significant at bloom or veraison at each vineyard as per the leaf blade data (data not shown).

Cover crops significantly affected leaf blade P, K, and Zn concentrations at bloom and S, B, Zn, and Fe concentrations in leaf blades at veraison at AS in 2005 (Table 6). Changes in leaf nutrient concentrations were not consistently expressed at both bloom and veraison, except for Zn, which was higher in the CC treatment than in PGCM on both dates. Leaf P concentrations at bloom were higher in the PGCM treatment than in CC and WA. Leaf K concentrations at bloom were highest in the CC treatment, significantly greater than in WA, NMM, PGCM, and RV. Leaf S concentrations at bloom were higher in the NMM treatment than in RV. At veraison, leaf B was higher in the CC treatment than in NMM and RV, and leaf Fe was higher in the PGCM leaves than in CM, NGM, NMM, and RV.

Vine roots and AMF colonization. Fine root length density of grapevines and the extent of root colonization by AMF did not differ among the three cover-crop treatments evaluated (CC, WA, and PGCM) at either vineyard. There was also no interaction between cover-crop treatment and sampling date or sampling location that affected root parameters. However, sampling time and sampling location influenced both root density and colonization by AMF (Figure 2). Fine root density at AS was affected by location, date, and their interaction. More fine roots grew in the vine row than the alleyway, and the increase in fine root density that occurred from bloom to postharvest was much greater in the vine row (Figure 2A). Overall, the proportion of fine roots in the vine row accounted for 72% of fine root length at AS. Fine root density was similar in the vine row versus alleyway at JH (55% of fine roots were retrieved from the vine row) and was only affected by sampling date, such that root density increased from 2004 to 2005 (Figure 2D). Roots in the vine row were more heavily colonized by AMF than alleyway roots at both sites, while changes over time or an interaction between time and location were not significant at either site (Figure 2B, E). The proportion of roots with arbuscules was also higher in vine row roots than in alleyway roots at both vineyards, changing with sample date (Figure 2C, F). Generally, arbuscule colonization increased from bloom to postharvest, but the opposite trend occurred in vine row roots in 2004 at both sites (a significant interaction between time and location was found only at AS).

Table 4 Effect of cover-crop treatments on soil and vine water status and vine shoot growth at two north Willamette Valley vineyards, in 2004 and 2005. Values represent means of all sampling dates for each variable with (standard errors).

Treatment[a]	Soil moisture 0–45 cm (% vol)		Midday Ψ_{leaf} (MPa)	Shoot length (cm)	Pruning mass[b] (g)
	Vine row	Alley			
AS vineyard					
CC	19.3 (0.6) b[c]	21.2 (0.5) ab	-0.79 (0.03)	117 (7)	913 (59)
WA	20.2 (0.6) ab	20.6 (0.5) bc	-0.84 (0.03)	108 (6)	770 (77)
CM	21.7 (0.6) a	22.4 (0.5) a	-0.85 (0.03)	115 (7)	961 (111)
NGM	21.4 (0.7) a	20.5 (0.6) bc	-0.81 (0.03)	115 (6)	752 (61)
NMM	21.4 (0.6) a	19.9 (0.6) bc	-0.84 (0.03)	111 (7)	856 (88)
PGCM	19.2 (0.6) b	19.4 (0.5) c	-0.86 (0.03)	104 (6)	750 (74)
RV	-	-	-0.83 (0.03)	114 (6)	845 (64)
Signf level	<0.001	<0.001	0.636	0.807	0.065
JH vineyard					
CC	19.0 (0.5) z	20.1 (0.6) yz	-1.16 (0.04)	92 (7)	400 (31)
WA	21.3 (0.5) y	19.6 (0.6) z	-1.22 (0.04)	83 (5)	292 (26)
CM	20.1 (0.5) yz	19.3 (0.7) z	-1.22 (0.04)	82 (6)	284 (13)
NGM	19.5 (0.6) yz	21.7 (0.7) y	-1.11 (0.04)	92 (5)	420 (36)
NMM	19.0 (0.6) z	21.4 (0.6) y	-1.21 (0.05)	92 (6)	358 (57)
PGCM	18.1 (0.7) z	19.5 (0.7) z	-1.19 (0.04)	86 (6)	325 (19)
RV	-	-	-1.22 (0.04)	87 (7)	356 (57)
Signf level	<0.001	<0.001	0.238	0.715	0.135

[a]Treatments: CC, clean cultivated; WA, winter annuals; CM, clover mix; NGM, native grass mix; NMM, native meadow mix; PGCM, perennial grass and clover mix; RV, resident vegetation.
[b]Pruning mass not available from JH vineyard in 2005; only data from 2004 is shown.
[c]Means within a column at each site followed by the same letter are not significantly different at 95% confidence.

Fruit yield and composition. Cover-crop treatments had no effect on fruit yield, cluster weights, soluble solids, pH, or TA of Pinot noir grapes, and cover-crop treatment did not interact with year to alter these variables. Yield was also not influenced by year at either vineyard. Clusters were significantly larger in 2004 than in 2005 at both sites. Average cluster mass with (standard errors) at AS was 75.6 g (1.3 g) in 2004 and 50.1 g (1.6 g) in 2005 and at JH was 66.7 g (1.9 g) in 2004 and 39.9 g (1.5 g) in 2005. Soluble solids were higher at both sites in 2005, pH was lower at both sites in 2005, and TA was lower at AS only in 2005 (data not shown).

Cover-crop treatment and year influenced juice N concentrations at AS (Table 7). Amino-N concentrations were higher in 2004, but ammonia-N concentrations were higher in 2005, resulting in no difference in YAN between years. Cover-crop treatment influenced amino-N and YAN directly (main effect), but also interacted with year to influence ammonia-N and YAN. Ammonia-N was higher in the CM treatment in 2005 than in NMM in 2005 or in WA and PGCM in 2004. Higher levels of YAN were found in the CM treatment in 2005 than in NMM in 2005 and PGCM in 2004. YAN levels were not consistent within each cover-crop treatment over the two years. For example, the CC treatment had the highest YAN concentration in 2004, while CM had the highest YAN in 2005. In both 2004 and 2005, no treatment was significantly different from the CC control. Juice N data from JH in 2005 had an average YAN concentration of 294 mg N L^{-1}, but neither YAN, amino-N, nor ammonia-N was altered by treatment at JH in 2005 (data not shown).

Table 5 Effect of cover-crop treatments on leaf blade N concentrations (g N kg^{-1} dry mass) at two north Willamette Valley vineyards, 2004 and 2005. Values represent means (with standard errors).

	AS vineyard		JH vineyard	
Treatment[a]	Bloom	Veraison	Bloom	Veraison
2004				
CC	36.4 (1.1) a[b]	23.7 (1.3)	37.1 (0.7)	24.6 (1.0)
WA	32.2 (0.2) ab	22.5 (0.7)	34.9 (1.0)	22.4 (0.6)
CM	35.5 (0.9) a	24.3 (1.0)	35.8 (0.7)	23.5 (1.1)
NGM	34.4 (1.5) ab	23.3 (0.7)	36.3 (0.4)	22.1 (0.9)
NMM	32.4 (1.0) ab	22.6 (0.6)	38.0 (1.1)	23.5 (1.2)
PGCM	33.4 (0.3) ab	21.8 (0.4)	36.4 (0.5)	22.8 (0.2)
RV	36.2 (1.1) a	23.8 (0.6)	35.2 (1.1)	23.1 (0.6)
All trtms	34.4 (0.4) A	23.1 (0.3) A	36.2 (0.3) A	23.2 (0.3) A
2005				
CC	25.7 (0.4) d	19.2 (0.6)	29.5 (0.7)	20.9 (0.2)
WA	26.3 (0.9) d	17.8 (0.9)	30.4 (0.9)	19.6 (0.3)
CM	31.7 (1.7) abc	20.5 (0.8)	29.5 (1.5)	22.0 (0.5)
NGM	26.5 (0.7) d	18.4 (0.9)	28.7 (0.7)	19.2 (0.8)
NMM	27.0 (1.1) cd	18.6 (0.4)	30.5 (0.5)	20.3 (0.7)
PGCM	29.7 (0.8) bcd	19.9 (1.0)	30.0 (0.5)	19.4((0.7)
RV	27.0 (0.5) cd	18.8 (0.5)	29.8 (0.6)	19.3 (0.5)
All trtms	27.7 (0.5) B	19.0 (0.3) B	29.8 (0.3) B	20.1 (0.3) B
ANOVA signf level				
Year	<0.001	<0.001	<0.001	<0.001
Trtm	0.001	0.140	0.334	0.054
Y x T	0.004	0.496	0.427	0.776

[a]Treatments: CC, clean cultivated; WA, winter annuals; CM, clover mix; NGM, native grass mix; NMM, native meadow mix; PGCM, perennial grass and clover mix; RV, resident vegetation.
[b]Means within a column followed by the same letter are not significantly different at 95% confidence (uppercase letters indicate differences by year and lowercase letters indicate differences between all year x treatment combinations).

Discussion

The primary goal of this study was to test the hypothesis that mowed alleyway cover crops compete with grapevines for nutrients or water in western Oregon vineyards. Results show that competition between alleyway cover crops and grapevines is fairly weak and inconsistent when vegetation is mowed in spring and summer and the floor directly under the vines is kept vegetation-free with cultivation or herbicides. Cover-crop treatment altered soil water content at both vineyards and altered leaf nutrients (including N) and juice N concentrations at one vineyard. The most consistent effect of different cover-crop treatments was low soil moisture, which occurred in the PGCM treatment in the alleyway and the vine row at both sites (Table 4). This effect on soil water content did not translate to an impact on vine water status or vine growth, since these variables were not affected by cover-crop treatment at either vineyard. The low soil moisture in the PGCM treatment could not be tied to the effects on vine N status that were observed at AS vineyard, as the PGCM treatment did not differ from any other cover-crop treatment for leaf N at bloom (Table 5) or for different juice N fractions (Table 7). The PGCM treatment did have the lowest juice N concentrations in 2004, but not in 2005. Indeed, neither leaf N nor juice N differences observed at AS vineyard were consistent among the different cover-crop treatments in 2004 and 2005. The lack of difference in vine N status between the PGCM and the other treatments is probably related to the inclusion of clovers in this perennial grass mix, which resulted in high N inputs in this treatment (Table 3). Had we only used perennial grasses in this treatment, the resulting low soil moisture without the added benefit of high N input could have resulted in a significant impact of perennial grasses on the vines.

Previous research conducted in western Oregon during the 1980s at numerous sites also found no evidence for competition between cover crops and vines for soil water in established vineyards, as long as the vine row itself (~1 m-wide strip) was not vegetated (Soil Conservation Service 1986, Lombard et al. 1988). However, vine growth and leaf N concentrations were reduced by grass sod grown in the alleys of a newly planted Chardonnay vineyard in Oregon that received a high rate of irrigation (25 mm/week) (Tan and Crabtree 1990). An ongoing trial in western Oregon has similarly found no effect of an alleyway grass sod crop on vine water status (Ψ_{leaf}), although decreased vine prune weights and juice YAN concentrations

have been found in the second year of this study at one of two vineyards examined (P. Skinkis, unpublished data, 2009). These findings together indicate that competition between grass cover crops and vines may be related more to N than to water. Indeed, root growth responses to grass swards in vineyards suggests that vines can compensate for competition by directing root growth to deeper soil layers to obtain water, but these areas of the soil profile have less available N (Morlat and Jacquet 2003, Celette et al. 2009). It is also possible that vine N status is a more sensitive indicator of competition between grass cover crops and grapevines than changes in vine water status, or vine growth. Clearly, longer term studies are needed to evaluate alleyway cover crops that are dominated by perennial grasses in western Oregon, given the known competitive effects between grasses and vines observed in many studies (Tan and Crabtree 1990, Morlat and Jacquet 2003, Tesic et al. 2007, Celette et al. 2009).

The other grass treatment used in our trial was comprised of native grasses (NGM), which were slow to establish and less effective in suppressing weeds than other cover-crop mixtures used (particularly WA and CM treatments) (Table 3). The NGM did produce a good stand by 2005 at JH with no apparent competitive effect on the vines. The

Table 6 Effect of cover-crop treatments on leaf blade nutrients at AS vineyard, 2005. Values represent means (with standard errors).

	Macronutrient (g kg^{-1})				
Treatment[a]	**P**	**K**	**S**	**Ca**	**Mg**
Bloom					
CC	2.3 (0.2) b[b]	13.4 (0.0) a	3.3 (0.3)	17.7 (1.0)	2.6 (0.1)
WA	2.4 (0.1) b	11.2 (0.3) b	2.9 (0.1)	17.1 (0.5)	2.6 (0.1)
CM	2.9 (0.3) ab	11.8 (0.0) ab	3.0 (0.1)	17.4 (0.6)	2.6 (0.2)
NGM	3.6 (0.5) ab	11.9 (0.8) ab	3.3 (0.2)	19.5 (0.8)	2.6 (0.0)
NMM	3.1 (0.3) ab	11.3 (0.4) b	3.4 (0.1)	19.0 (0.8)	2.6 (0.1)
PGCM	4.1 (0.3) a	11.6 (0.3) b	3.5 (0.4)	19.3 (0.4)	2.7 (0.1)
RV	2.7 (0.2) b	11.0 (0.3) b	3.3 (0.3)	18.5 (0.4)	2.4 (0.0)
Signf level	0.002	0.003	0.709	0.131	0.522
Veraison					
CC	1.9 (0.1)	15.5 (0.8)	3.5 (0.1) yz	24.2 (1.0)	2.9 (0.1)
WA	1.7 (0.1)	14.9 (0.7)	3.2 (0.1) yz	24.0 (0.7)	2.9 (0.2)
CM	2.4 (0.2)	15.0 (0.8)	3.3 (0.2) yz	25.0 (1.0)	3.0 (0.2)
NGM	2.3 (0.2)	15.2 (0.6)	3.5 (0.2) yz	24.5 (0.8)	2.8 (0.2)
NMM	2.4 (0.1)	13.9 (0.4)	3.6 (0.1) y	26.9 (0.9)	2.9 (0.1)
PGCM	2.5 (0.6)	15.2 (0.6)	3.3 (0.2) yz	25.1 (0.6)	2.8 (0.1)
RV	2.1 (0.2)	14.0 (0.6)	3.0 (0.1) z	26.9 (0.4)	3.0 (0.1)
Signf level	0.177	0.441	0.024	0.081	0.901
	Micronutrient (mg kg^{-1})				
Treatment[a]	**Mn**	**Cu**	**B**	**Zn**	**Fe**
Bloom					
CC	167 (8)	11 (0)	60 (7)	29 (1) a	112 (10)
WA	157 (5)	10 (0.3)	58 (8)	25 (2) ab	120 (7)
CM	160 (21)	11 (0.4)	61 (2)	21 (1) b	106 (6)
NGM	162 (6)	12 (1.1)	62 (3)	28 (2) a	99 (6)
NMM	158 (3)	12 (0.5)	57 (3)	24 (1) ab	100 (6)
PGCM	174 (5)	12 (0.8)	67 (6)	20 (2) b	151 (30)
RV	170 (15)	12 (1.1)	54 (4)	23 (2) ab	108 (13)
Signf level	0.901	0.203	0.561	0.004	0.208
Veraison					
CC	180 (8)	308 (24)	27 (2) y	27 (1) y	298 (14) yz
WA	177 (16)	299 (15)	22 (1) yz	22 (1) yz	323 (32) yz
CM	173 (10)	292 (12)	23 (1) yz	22 (2) yz	256 (9) z
NGM	169 (9)	333 (15)	23 (1) yz	24 (1) yz	274 (11) z
NMM	177 (6)	335 (28)	20 (1) z	25 (2) yz	272 (13) z
PGCM	200 (15)	327 (26)	22 (1) yz	20 (2) z	405 (61) y
RV	192 (11)	298 (14)	21 (2) z	19 (1) z	237 (12) z
Signf level	0.371	0.347	0.018	0.010	0.008

[a]Treatments: CC, clean cultivated; WA, winter annuals; CM, clover mix; NGM, native grass mix; NMM, native meadow mix; PGCM, perennial grass and clover mix; RV, resident vegetation.
[b]Means within a column at each sampling date followed by the same letter are not significantly different at 95% confidence.

stand at AS was less vigorous, but vines in this treatment tended to have low leaf N in 2005. Results indicate that native grasses can be established in Oregon hillside vineyards if one year is allowed for a good stand to develop. However, the long-term performance of these grasses warrants further study on their ability to suppress weeds, tolerate vineyard traffic, and compete with vines for nitrogen.

The lack of consistent effects of cover crops between years and the two sites examined in our trial is not new. Competition between cover crops and grapevines has resulted in reduced vine growth, vine water status, yield, and fruit quality (Tan and Crabtree 1990, Wolpert et al. 1993, Celette et al. 2005, Tesic et al. 2007). However, numerous studies have also found minimal or no competitive effects of alleyway cover crops on grapevines (Olmstead et al. 2001, Ingels et al 2005, Baumgartner et al. 2008, Smith et al. 2008). There are numerous and site-specific reasons for divergent effects of cover crops on vines across studies (Tesic et al. 2007), but one important factor is the ability of cover crops to produce significant biomass.

The biomass produced by cover crops in our study was significantly less than in other trials in Oregon and California. For example, the clover mix (CM) produced about one-third of the biomass that can typically be produced in the Willamette Valley (Sattell et al. 1999). The winter annual mix (WA) produced about one-fourth of the total biomass that each of the individual species in it had produced in a California vineyard (Bugg et al. 1996), although plots were irrigated in the California study to ensure early emergence in the fall. In recent California studies (Ingels et al. 2005, McGourty et al. 2008), cover-crop mixtures produced about 2 to 4 times more biomass than similar treatments in our trial. Despite the lower biomass produced by cover crops in our trial, continuous use of clovers in the alleyway may eventually provide too much N for winegrapes grown in the Willamette Valley. The amount of N contributed to plots in our CM mix at AS vineyard (86 kg N ha^{-1}) exceeds the annual N requirement of vines grown in the region (Schreiner et al. 2006). Apparently, some of this N was taken up by the grapevines at AS, since the

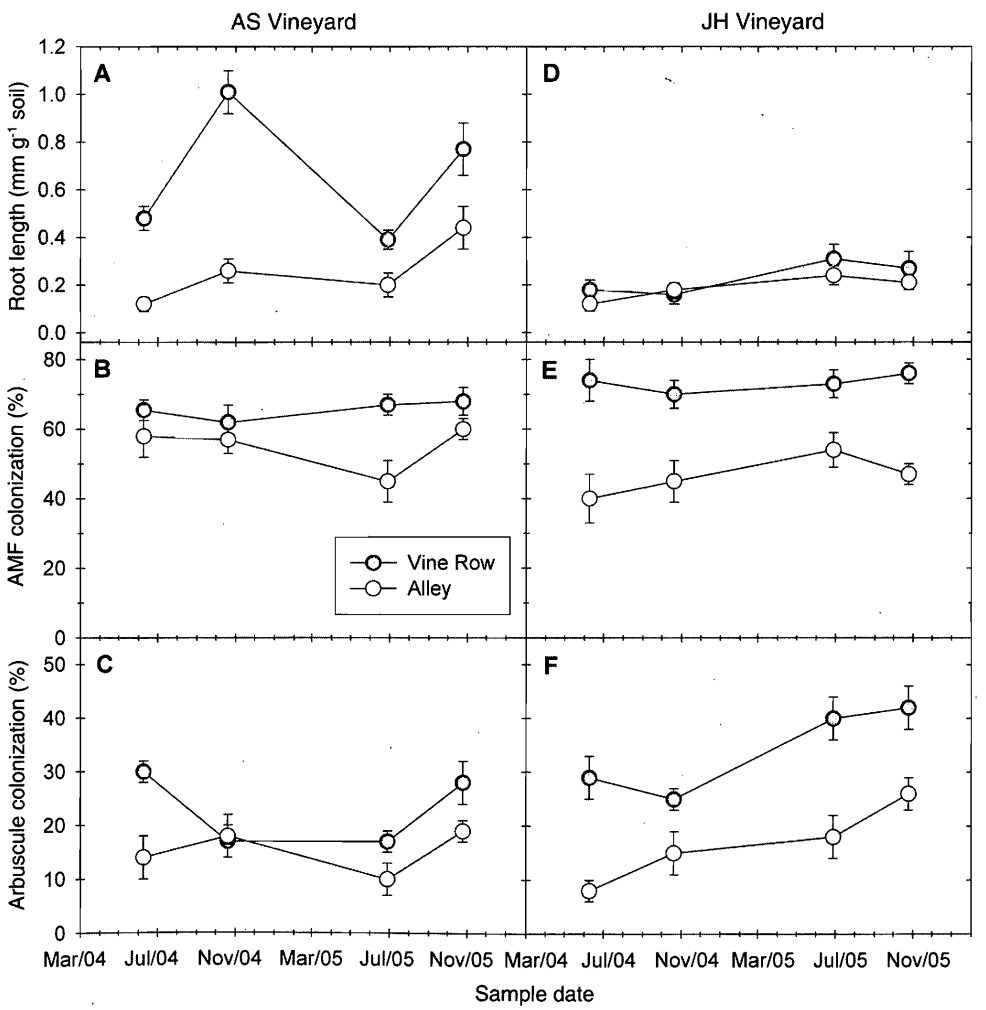

Figure 2 Fine root length (**A**, **D**), percent of root length colonized by AMF (**B**,**E**), and percent of root length colonized by arbuscules (**C**, **F**) in vine rows and alleyways from 0–45 cm soil depth at two north Willamette Valley vineyards, 2004 and 2005. Data for all plots was pooled across three cover-crop treatments (CC, WA, PGCM) and represents mean values for each sampling location at each site ± standard errors (n = 12).

Table 7 Effect of cover-crop treatments on juice N concentrations (mg N L^{-1}) at AS vineyard, 2004 and 2005. Values represent means (with standard errors).

Treatment[a]	Amino-N	Ammonia-N	YAN[b]
2004			
CC	163 (9)	60 (7) abc[c]	223 (9) ab
WA	138 (10)	51 (8) bc	189 (16) ab
CM	158 (17)	55 (6) abc	213 (22) ab
NGM	162 (19)	69 (14) abc	231 (30) ab
NMM	145 (13)	58 (13) abc	203 (23) ab
PGCM	111 (16)	34 (8) c	145 (15) b
RV	162 (21)	58 (6) abc	221 (23) ab
All trtms	148 (6) A	55 (4) B	204 (9)
2005			
CC	133 (11)	61 (12) abc	195 (22) ab
WA	131 (3)	84 (4) ab	215 (7) ab
CM	172 (19)	103 (14) a	276 (32) a
NGM	120 (3)	63 (11) abc	183 (14) ab
NMM	113 (11)	52 (7) bc	165 (15) b
PGCM	118 (4)	71 (9) abc	190 (12) ab
RV	119 (8)	71 (11) abc	190 (15) ab
All trtms	130 (5) B	72 (5) A	202 (9)
ANOVA signf level			
Year	0.012	0.002	0.866
Trtm	0.022	0.153	0.018
Y x T	0.175	0.032	0.033

[a]Treatments: CC, clean cultivated; WA, winter annuals; CM, clover mix; NGM, native grass mix; NMM, native meadow mix; PGCM, perennial grass and clover mix; RV, resident vegetation.
[b]Yeast assimilable nitrogen (amino-N + ammonia-N).
[c]Means within a column followed by the same letter are not significantly different at 95% confidence (uppercase letters indicate differences by year and lowercase letters indicate differences between all year x treatment combinations).

effect of cover-crop treatment on leaf N and juice N was predominantly driven by the high values in the CM treatment in 2005 (Table 5, Table 7).

Leaf nutrient concentrations at AS vineyard were the only vine variables that we measured that resulted in significant differences between any vegetated treatment and the CC control. For example, leaf N concentrations in the CM treatment were greater than the CC treatment at bloom in 2005, but not in 2004 (Table 5). Leaf P concentrations were lower in the CC control than the PGCM treatment at bloom, and leaf K concentrations were higher in the CC control than in four of the six vegetated treatments at bloom (Table 6). However, these effects were no longer significant by veraison. Only Zn showed a consistent effect at bloom and veraison, with higher concentrations in vines from the CC control than in the PGCM treatment. In general, the effects of cover crops on leaf nutrients were small, and all nutrients appeared to be above critical levels identified in grapevines (Robinson 1992, Gärtel 1996), which may explain why we did not observe effects of cover crops on vine growth. Others have also reported effects of cover crops on various leaf or petiole nutrient concentrations without observing effects on vine growth or yield (Baumgartner et al. 2008, Smith et al. 2008).

Other factors that may also account for the weak competitive effects of cover crops in this study include the weather, the low crop load carried on vines, and the fact that in the alleyway few vine roots grew in close proximity to cover crops. The generally mild climate in western Oregon coupled with the low crop loads typical for the region (4500–6500 kg ha^{-1}) certainly reduces the likelihood that cover crops will compete with vines as compared to warmer and drier regions. In addition, the years of this study were not particularly stressful in vineyards across the region. Although 2004 was a warm year, the unusual rainfall in August replenished soil water reserves and boosted vine water status (Table 2), particularly in vines at AS vineyard (Figure 1). In 2005, it was cool and wet in western Oregon. Had our trial been conducted over two consecutive warm and dry years, results may have been different. Competition between cover crops and vines also seems unlikely whenever vine roots are concentrated in the vine row. This was clearly evident at AS vineyard, where nearly three-fourths of fine roots were found in the vegetation-free zone directly under the vines (Figure 2).

The greater abundance of fine roots in the vine row at AS vineyard confirms earlier observations in a mature (21-year-old) Oregon Pinot noir vineyard using a more intensive sampling strategy (Schreiner 2005). Morlat and Jacquet (2003) found that 69% of all vine roots were located in the vine row when a long-term grass cover crop was present in the alleyway, but only 49% of all vines roots were located in the row when alleys were kept vegetation-free with herbicides. Had cover crops been planted over the entire vineyard floor in our trial, it is likely that root-root competition would have occurred between the cover and the vines, potentially leading to significant effects on vine productivity (Morlat and Jacquet 2003, Tesic et al. 2007). Limiting vegetation from the vineyard floor directly beneath the vines (a standard practice in western Oregon) obviously reduces the direct root competition that can be expected to occur. We also expected to find more vine roots growing in the alleyways of the clean-cultivated (CC) treatment than in the alleys with cover-crop treatments, but that was not the case in either vineyard.

It was interesting that grapevine roots at JH were not as confined in the vine row as they were at AS. The quantity of fine roots in the row versus the alleyway at JH was not significantly different (Figure 2). It is not clear why, but we suspect that cultivation of the alleyways at JH in the years before our trial led to favorable soil conditions (no vegetation and possibly lower soil bulk density), allowing for greater spread of roots into the alleys. Alleyway cover crops were used at AS vineyard for many years before our trial. The higher proportion of fine roots in the alley at JH vineyard suggests that the vines would have been more likely to compete with alleyway cover crops. We also expected that competition between cover crops and vines would have been more evident at JH than at AS because vines were younger with less developed root systems, vines experienced greater water stress, and cover crops were

mowed about one month later. Contrary to expectations, the impact of cover crops was more apparent at AS vineyard. These findings show that cover-crop effects on vines are site specific, but do not help clarify what may drive such differences between sites.

The higher rate of root colonization by AMF in vine row roots than in alleyway roots at both sites (Figure 2) confirms previous observations in an Oregon vineyard (Schreiner 2005). We attributed this lower colonization by AMF to cultivation of the alleyway soil in the previous study, which probably also explains why alleyway roots had lower AMF colonization in the present study. Vines at JH vineyard had a greater proportion of roots with arbuscules than vines at AS, which was consistent with lower soil moisture and greater water stress at JH. These results confirm findings from an irrigation trial, where vines receiving less water than the standard deficit practice had more arbuscules in roots (Schreiner et al. 2007). Vines at JH were clearly under greater water stress in both years of this study (Figure 1) and were presumably more reliant on AMF to supply nutrients from soil than were the less stressed vines at AS.

Conclusions

The overall results from this two-year study do not show a clear advantage to using particular cover-crop mixtures or clean cultivating the alleyways between vine rows in established vineyards in western Oregon. While the different cover-crop treatments had an impact on soil moisture, leaf nutrients, and juice N concentrations, effects were not consistent over time or between sites. Differences between vegetated treatments and the clean-cultivated control were evident only for leaf nutrient concentrations at one vineyard. The clean-cultivated treatment did not differ from any vegetated treatment in vine growth, water status, or yield of grapes at either site. In addition, the younger vineyard (where vines experienced greater water stress) was less affected by cover crops than the older vineyard. Therefore, advantages of using cover crops (like protecting soil from erosion, increasing soil organic matter and nutrient cycling, and suppressing weeds) may be more important considerations than competition with vines when growers evaluate the use of alleyway cover in western Oregon vineyards. However, consideration should be given to the long-term effect of certain cover crops, including a clover mix like we used, which could result in the supply of too much N to vines, and the use of perennial grass swards, which may eventually reduce vine access to N.

Literature Cited

Altieri, M.A. 1994. Biodiversity and pest management in agroecosystems. Haworth Press, New York.

Baker, J.L., and J.M. Laflen. 1983. Water quality consequences of conservation tillage. J. Soil Water Cons. 38(3):186-193.

Baumgartner, K., K.L. Steenwerth, and L. Veilleux. 2008. Cover-crop systems affect weed communities in a California vineyard. Weed Sci. 56:596-605.

Bergmeyer, H.U., and H.O. Beutler. 1985. Ammonia. *In* Methods of Enzymatic Analysis. 3d ed. H.U. Bergmeyer (ed.), pp. 454-461. Verlag Chemie, Weinheim.

Böhm, W. 1979. Methods of Studying Root Systems. Springer-Verlag, New York.

Bugg, R.L., G. McGourty, M. Sarrantonio, W.T. Lanini, and R. Bartolucci. 1996. Comparison of 32 cover crops in an organic vineyard on the north coast of California. Biol. Agric. Hortic. 13:63-81.

Celette, F., J. Wery, E. Chantelot, J. Celette, and C. Gary. 2005. Belowground interactions in a vine (*Vitis vinifera* L.)- tall fescue (*Festuca arundinacea* Shreb.) intercropping system: Water relations and growth. Plant Soil 276:205-217.

Celette, F., A. Findeling, and C. Gary. 2009. Competition for nitrogen in an unfertilized intercropping system: The case for an association of grapevine and grass cover in a Mediterranean climate. Eur. J. Agron. 30:41-51.

Costello, M.J., and K.M. Daane. 1998. Arthropods. *In* Cover Cropping in Vineyards, a Grower's Handbook. C.A. Ingels et al. (eds.), pp. 93-106. Publication 3338. University of California, Division of Agriculture and Natural Resources, Oakland.

Dukes, B.C., and C.E. Butzke. 1998. Rapid determination of primary amino acids in grape juice using an *o*-phthaldialdehyde/N-acetyl-L-cysteine spectrophotometric assay. Am J. Enol. Vitic. 49:125-134.

Gaffney, F.B., and M. Van Der Grinten. 1991. Permanent cover crops for vineyards. *In* Cover Crops for Clean Water. W.L. Hargrove (ed.), pp. 32-33. Soil and Water Conservation Society, Ankeny, IA.

Gärtel, W. 1996. Grapes. *In* Nutrient Deficiencies and Toxicities in Crop Plants. W.F. Bennett (ed.), pp. 177-183. APS Press, St. Paul, MN.

Ingels, C.A., K.M. Scow, D.A. Whisson, and R.E. Drenovsky. 2005. Effects of cover crops on grapevines, yield, juice composition, soil microbial ecology, and gopher activity. Am. J. Enol. Vitic. 56:19-29.

Jackson, D.I., and P.B. Lombard. 1993. Environmental and management practices affecting grape composition and wine quality: A review. Am. J. Enol. Vitic. 44:409-430.

Lombard, P., S. Price, W. Wilson, and B. Watson. 1988. Grass cover crops in vineyards. *In* Proceedings of the Second International Symposium for Cool Climate Viticulture and Enology. Smart et al. (eds.), pp. 152-155. New Zealand Society for Viticulture and Enology, Auckland.

Louw, P.J.E., and A.T.P Bennie. 1991. Soil surface condition effects on runoff and erosion on selected vineyard soils. *In* Cover Crops for Clean Water. W.L. Hargrove (ed.), pp. 25-26. Soil and Water Conservation Society, Ankeny, IA.

McGonigle, T.P., M.H. Miller, D.G. Evans, G.L. Fairchild, and J.A. Swan. 1990. A new method which gives an objective measure of colonization of roots by vesicular-arbuscular mycorrhizal fungi. New Phytol. 115:495-501.

McGourty, G., J. Nosera, S. Tylicki, and A. Toth. 2008. Self-reseeding annual legumes evaluated as cover crops for untilled vineyards. Calif. Agric. 62:191-194.

Mendes, I.C., A.K. Bandick, R.P. Dick, and P.J. Bottomley. 1999. Microbial biomass and activities in soil aggregates affected by winter cover crops. Soil Sci. Soc. Am. J. 63:873-881.

Morlat, R., and A. Jacquet. 2003. Grapevine root system and soil characteristics in a vineyard maintained long-term with or without interrow sward. Am. J. Enol. Vitic. 54:1-7.

Newman, E.I. 1966. A method of estimating the total length of root in a sample. J. Appl. Ecol. 3:139-145.

Olmstead, M.A., R.L. Wample, S.L. Greene, and J.M. Tarara. 2001. Evaluation of potential cover crops for inland Pacific Northwest vineyards. Am. J. Enol. Vitic. 52:292-303.

Ranells, N.N., and M.G. Wagger. 1996. Nitrogen release from grass and legume cover crop monocultures and bicultures. Agron. J. 88:777-782.

Robinson, J.B. 1992. Grapevine nutrition. *In* Viticulture. Vol. 2. Practices. B.G. Coombe and P.R. Dry (eds.), pp. 178-208. Winetitles, Adelaide.

Rodriguez-Lovelle, B., J.P. Soyer, and C. Molot. 2000. Nitrogen availability in vineyard soils according to soil management practices, effects on vine. Acta Hortic. 526:277-285.

Sattell, R., T. Buford, H. Murray, R. Dick, and D. McGrath. 1999. Cover crop dry matter and biomass accumulation in western Oregon. Extension publication 8739. Oregon State University, Corvallis.

Schreiner, R.P. 2003. Mycorrhizal colonization of grapevine rootstocks under field conditions. Am. J. Enol. Vitic. 54:143-149.

Schreiner, R.P. 2005. Spatial and temporal variation of roots, arbuscular mycorrhizal fungi, and plant and soil nutrients in a mature Pinot noir (*Vitis vinifera* L.) vineyard in Oregon, USA. Plant Soil 276:219-234.

Schreiner, R.P, C.F. Scagel, and J. Baham. 2006. Nutrient uptake and distribution in a mature 'Pinot noir' vineyard. HortScience 41:336-345.

Schreiner, R.P., J.M. Tarara, and R. Smithyman. 2007. Deficit irrigation promotes arbuscular colonization of fine roots by mycorrhizal fungi in grapevines (*Vitis vinifera* L.) Mycorrhiza 17:551-562.

Shipitalo, M.J., and W.M. Edwards. 1998. Runoff and erosion control with conservation tillage and reduced-input practices on cropped watersheds. Soil Till. Res. 46:1-12.

Smart, D.R., and M. Robinson. 1991. Sunlight into Wine. A Handbook for Winegrape Canopy Management. Winetitles, Adelaide.

Smith, R., L. Bettiga, M. Cahn, K. Baumgartner, L.E. Jackson, and T. Bensen. 2008. Vineyard floor management affects soil, plant nutrition, and grape yield and quality. Calif. Agric. 62:184-190.

Soil Conservation Service. 1986. Cover Crops for Vineyards. Agronomy Technical Note No. 55. Soil Conservation Service, USDA, Portland, OR.

Sweet, R.M. 2006. Influence of cover crops on vine performance at two Willamette Valley vineyards. MS thesis, Oregon State University, Corvallis.

Tan, S., and G.D. Crabtree. 1990. Competition between perennial ryegrass sod and 'Chardonnay' wine grapes for mineral nutrients. HortScience 25:533-535.

Tesic, D., M. Keller, and R.J. Hutton. 2007. Influence of vineyard floor management practices on grapevine vegetative growth, yield, and fruit composition. Am. J. Enol. Vitic. 58:1-11.

Wolpert, J.A., P.A. Phillips, R.K. Striegler, M.V. McKenry, and J.H. Foott. 1993. Berber orchardgrass tested as cover crop in commercial vineyard. Calif. Agric. 47(5):23-25.