Release of Available Nitrogen after Incorporation of a Legume Cover Crop in Concord Grape

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Abstract. Legume cover crops can be used to provide nitrogen (N) to organically produced Concord (*Vitis labruscana* Bailey) grape. The cover crop must be incorporated at a time such that subsequent N mineralization is synchronous with plant demand to maximize the amount of N available to the grape plant. The objectives of this research were to 1) evaluate the effectiveness of hairy vetch (*Vicia villosa* subsp. *villosa* L.) and yellow sweet clover [*Melilotus officinalis* (L.) Lam.] in providing N to organically grown Concord grape, 2) examine the synchronization of N release from mineralization after incorporation of cover crops with plant N demand, and 3) compare soluble, more readily available sources of N to legume cover crops in providing N to grape. This work was conducted on two Concord vineyards, one commercial (COM) and one research (RES) vineyard. Both vineyards were overhead sprinkler-irrigated and plots were established in a Latin square design with four or six replicates of each treatment. Treatments consisted of hairy vetch and yellow sweet clover planted in either the spring or fall, 112 kg·ha⁻¹ N added as either urea or blood meal, and a 0 kg·ha⁻¹ N control. Soils were sampled weekly (0 to 30 cm) from budbreak to cover crop plot treatment establishment and were analyzed for soluble (NO₃-N and NH₄-N) N. Soluble N release in the plots was monitored with ion exchange membranes (plant root simulators). Grapes were harvested and evaluated for yield and °Brix. Legume and fertilizer treatments resulted in increased N availability from grape bloom until veraison. As a result of rapid nitrification, NH₄-N was less useful than NO₃-N in determining N mineralization patterns. Available N peaks as high as 40 mg·kg⁻¹ NO₃-N were well timed with the critical N demand period for Concord grape. Soluble N sources (urea and blood meal) peaked higher than plant sources. No differences were detected between legume treatments. Legume covers did, however, supply more available N per unit of biomass to the soil than a small grain cover. Yield and °Brix varied by year but not by treatment, suggesting that the cover crop or plant and soil N reserves provided sufficient available N to the grape through the study period.

Demand for organically grown products has increased rapidly in response to a shift in consumer preferences (Zehnder et al., 2003). Nationally, the total acreage classified as certified organic has increased 63% from 1997 to 2003. U.S. Department of Agriculture-certified organic grape production (wine and juice) in Washington State has far exceeded this growth, jumping from 176 ha in 1997 to 921 ha in 2003 (USDA–Economic Research Service, 2005). Concord grape is well suited for organic management because detrimental plant pathogen and insect pest pressure are low compared with other crops such as wine grape (*Vitis vinifera* L.) (D. Walsh, pers. comm.).

Soil fertility management practices to ensure that the grape plant will receive a sufficient amount of nitrogen (N) in conjunction with plant demand must be carefully considered.

Ahmedullah and Roberts (1991) concluded that Concord grapes in the Yakima Valley showed yield response with N addition up to 180 kg·ha⁻¹. Because crop removal of N necessitates addition of nutrients to recharge depleted pools, fertilizers or green manures are plausible nutrient sources. Recent information suggests that legumes are capable of fixing between 11 and 336 kg·ha⁻¹ N per year (Havlin et al., 1999), a portion of which can become available to the plant. The amount of N supplied depends on the chemical composition, biomass, N content, and rate of mineralization of the cover crop as well as soil moisture, temperature, pH, and texture (Dharmakeerthi et al., 2005; Schomberg and Endale, 2004).

Grapevines have a critical N demand from the end of rapid shoot growth up to veraison (Conradie, 1986; Hanson and Howell, 1995; Löhnertz, 1991). Although plant organs store

a large percentage of N as reserve (Bates et al., 2002; Williams, 1991), uptake from the soil solution is essential to preserve fruit development (Löhnertz, 1991). If N release does not correspond to this growth period, excess N that is not taken up can be lost through denitrification, leaching, or by uptake in competing weed species. If N release is synchronous with plant needs, supplemental fertilizer applications may not be necessary (Griffin et al., 2000). The time at which the cover crop is incorporated into the soil is vital so that N release from organic pools corresponds to plant N demand (Weinert et al., 2002). Timing mineralization from leguminous cover crop residues to correspond with peak plant demand of N has been found effective in *V. vinifera* species (Patrick et al., 2004).

Vetches (*Vicia* spp.) have been identified as excellent N fixers among legumes (Mueller and Thorup-Kristensen, 2001; Powers and Zachariassen, 1993; Ranells and Waggoner, 1996; Rochester and Peoples, 2005). Hairy vetch (*Vicia villosa* subsp. *villosa* L.) is one crop that fixes large quantities of N and is hardy enough to serve as a winter groundcover.

Yellow sweet clover [*Melilotus officinalis* (L.) Lam.] can produce potentially large quantities of dry matter as well as fixing significant amounts of atmospheric N₂. Because the plant is drought-tolerant, utilization in vineyards is attractive in instances in which competition for limited water resources may be a concern. Like hairy vetch, yellow sweet clover has a low C:N ratio and is able to provide cover and remain hardy during cold winters (Brandæster et al., 2002).

The objectives of this research were to 1) evaluate the effectiveness of hairy vetch and yellow sweet clover in providing N to organically grown Concord grape, 2) examine the synchronization of N release from mineralization after incorporation of cover crops with plant N demand, and 3) compare soluble, more readily available sources of N (blood meal and conventional fertilizer) to legume cover crops in providing N to grape.

Materials and Methods

Two Concord vineyards, one commercial (lat. 46°16'35"N, long. 119°37'14"W) and another research (lat. 46°17'30"N, long. 119°44'45"W) were studied from 2003 to 2005 to determine the potential of yellow sweet clover and hairy vetch to provide N in organic grape production. All vines were own-rooted. Vines in the commercial vineyard (COM vineyard) were planted in 1999 (2.44 m vine spacing, 2.44 m row spacing) and the vines in the research vineyard (RES vineyard) in 1970 (2.44 m vine spacing, 2.74 m row spacing). The soil in the RES vineyard is classified as Warden silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids) and the COM vineyard as Starbuck silt loam (loamy, mixed superactive, mesic Xeric Haplocambids). Both vineyards were sprinkler-irrigated, own-rooted, single-curtain (2 m high) vines hand-pruned to

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90 buds per vine with no touchup or crop thinning. Because the COM farm was certified organic, synthetic fertilizer comparisons were made on the research farm.

Plots established on both vineyards were three vine rows by 12.12 m in a Latin square design with four or six replicates of each treatment on the RES and COM vineyards, respectively. Treatments in the COM vineyard from Spring 2004 through 2005 included: 1) spring-planted yellow sweet clover, 2) spring-planted hairy vetch, 3) fall-planted yellow sweet clover, 4) fall-planted hairy vetch, 5) hairy vetch with one alley adjacent to the vine row planted in the fall and the other in the spring, and 6) wheat (*Triticum aestivum* L.) or rye (*Secale cereale* L.) cover with 112 kg-ha⁻¹ N applied as blood meal (powder). Control plots were excluded from the privately owned COM vineyard to minimize any lasting soil infertility resulting from our research. Treatments in the RES vineyard from Spring 2004 through 2005 included: 1) fall-planted yellow sweet clover, 2) fall-planted hairy vetch, 3) 112 kg-ha⁻¹ N as granular urea, and 4) a 0 N control. Control and N-fertilized treatments in both vineyards were under a wheat or rye cover from late fall until early spring. Treatments planted with wheat or rye are referred to collectively as "small grains." Small grain covers planted in the fall are a common practice in the Yakima Valley to reduce wind and water erosion, improve soil structure, and to use excess soil water in the spring (M. Concienne, personal communication). Cover crop incorporation took place at bloom (late spring) for all treatments. Table 1 summarizes important dates related to cover crop planting, incorporation, and fertilization throughout the experiment.

Before incorporation, 9.75 m² of the aboveground portion of the cover crop was harvested from the central area on both sides of the middle vine row, weighed for yield, subsampled, and returned to the plot area. Approximately 500 g of the cover crop biomass subsamples were dried at 65 °C for 2 d, weighed, and ground to 40 mesh to be analyzed for total carbon and nitrogen using dry combustion (Yeomans and Bremner, 1991) with a LECO CNS 2000 (LECO Corp., St. Joseph, MN). Biomass, C, and N data were used as indices of potential N release after incorporation.

Plant root simulator (PRS) probes (Western Ag Innovations, Saskatoon, Canada) were used in conjunction with weekly soil samples to measure soluble N release from yellow sweet clover and hairy vetch decomposition after incorporation. The two techniques provide different information. Whereas the soil sample provides point in time measurements, the ion exchange membrane of the PRS probe integrates plant-available N from the soil solution over the time they are in the soil (Quian et al., 1992). Anion (for NO₃-N) and cation (for NH₄-N)-specific probes were placed below the soil surface (10 cm from the soil surface to the middle of the exchange membrane) in the middle of the alley to the

Table 1. Planting, incorporation and fertilization dates for the cover crops at the commercial (COM) and research (RES) sites during the study period 2003 to 2005.

Year	Spring/Fall	Site	Date planted	Date incorporated ^z	Date fertilized
2003	Spring	RES			6 May
	Fall	COM	27 Aug.		
2004	Spring	RES	27 Aug.		
		COM	27 May	24 May	28 May
	Fall	RES		6 May	1 Apr.
		COM	16 Aug.	24 May	
2005	Spring	RES	15 Aug.	6 May	
		COM	14 June	13 June	15 June
	Fall	RES		8 June	16 Apr.
		COM	22 Aug.	13 June	
		RES	22 Aug.	8 June	

^zBoth spring- and fall-planted cover crops were incorporated during the year after planting.

Table 2. Mean PRS NO₃-N concentrations in 2004 and 2005 at research (RES) and commercial (COM) sites during time designations of prebloom (PB), bloom to veraison (BT), and postveraison (PV).^z

Year	Site	Treatment	PB ^y	BT ^y	PV
			µg·mL ⁻¹ NO ₃ -N/17.5 cm ² /week ⁻¹		
2004	RES	Fertilizer	10.17 a ^x	10.05 a	3.50 a
		Control	1.29 b	4.39 b	1.98 a
		Fall vetch	1.82 b	6.84 ab	4.08 a
		Fall clover	2.05 b	8.08 a	3.87 a
		Blood meal	5.78 a	2.95 a	-
	COM ^w	Fall vVetch	9.25 a	8.61 a	1.69 a
		Fall clover	9.69 a	3.86 a	2.76 a
		<i>P</i> value	<0.001	0.069	0.157
	RES	Fertilizer	—	9.34 ab	6.45 a
		Control	—	6.00 b	5.61 a
2005	COM	Fall vetch	—	12.25 a	5.32 a
		Fall clover	—	12.65 a	4.65 a
		Blood meal	—	24.81 a	8.17 a
		Spring vetch	—	13.57 b	8.27 a
		Fall vetch	—	12.69 b	5.34 ab
	RES	Vetch-half/half	—	19.23 ab	5.95 ab
		Spring clover	—	13.84 b	5.96 ab
		Fall clover	—	15.62 b	4.50 b
		<i>P</i> value		<0.001	0.137

^z*P* values are given for each year and time designation combination.

^yNo soil samples were taken before grape bloom in 2005.

^xMeans with different letters in the same column and site are significantly different at *P* = 0.05 using Duncan multiple range test.

^wPRS measurements were not made on spring planted cover treatments in this site and year.

PRS = plant root simulators.

Fig. 1. Average plant root simulators NO₃-N collected during 2004 at the research vineyard. Fall refers to the time of cover crop planting. Bold vertical lines correspond to the dates of full bloom and veraison.

west of the vine row to track soluble N (Quian and Schoenau, 2000). PRS probes were exchanged weekly for the first 4 weeks after incorporation of cover crops and then twice monthly for the duration of the sampling period. Probes were extracted with 20 mL of 0.5 M hydrochloric acid (Quian et al., 1992) and analyzed for $\text{NH}_4\text{-N}$ (U.S. Environmental Protection Agency, 1984a) and $\text{NO}_3\text{-N}$ (U.S. Environmental Protection Agency, 1984b). PRS soluble N values were calculated by dividing extracted solution concentrations by the PRS membrane area (17.5 cm^2) and the length of exposure to the soil (weeks). The resulting units were $\mu\text{g}\cdot\text{mL}^{-1}$ ($\text{NO}_3\text{-N}$ or $\text{NH}_4\text{-N}$)/ $17.5 \text{ cm}^2\cdot\text{week}^{-1}$ (Johnson et al., 2005).

Soil samples were collected with a 3-cm diameter soil probe from 0 to 15 and 15 to 30 cm using six random points within 50 cm of the PRS probes at the same time the probes were exchanged. Soil samples were allowed

to air-dry and were ground to pass a 2-mm sieve. Soluble $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ were extracted with 2.0 N potassium chloride (Mulvaney, 1996) and analyzed colorimetrically with an EasyChem flow analyzer (Syntex Scientific LLC, Oak Brook, IL).

As a result of the low annual precipitation in this growing area (Washington State University, 2007) soil moisture was monitored weekly at each growing area using a neutron probe (Troxler Electronics, Research Triangle Park, NC). There was little difference between sites and no relationship with measured soil N parameters; thus, these data are not presented.

Fruit was harvested from the four center plants in each plot. Yield was calculated and fruit subsamples were taken, crushed with a blender, and filtered. The resulting juice was measured for °Brix with a digital refractometer (Kernco, El Paso, TX).

Data were analyzed using analysis of variance with PROC GLM of PC SAS (SAS Institute, Cary, NC). Because year was highly significant for all parameters, data were analyzed separately by year. Mean separation used least significant difference at the 0.05 level.

Results and Discussion

Plant root simulator-measured soluble $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$. Statistical analysis of treatments was conducted across the sampling dates of prebloom (PB), bloom to veraison (BTV), and postveraison (PV) to reduce the large number of data points. For $\text{NO}_3\text{-N}$, significant differences occurred by year, treatment, and time of season. Data collected for $\text{NH}_4\text{-N}$ did not appear to be useful in measuring mineralization of organic

matter because $\text{NH}_4\text{-N}$ accumulation was consistently below $1.0 \mu\text{g}\cdot\text{mL}^{-1}$ $\text{NH}_4\text{-N}$ /PRS area/week. These PRS $\text{NH}_4\text{-N}$ results are consistent with the findings of other researchers (Quian and Schoenau, 1995; Smith, 1965) who suggested that $\text{NO}_3\text{-N}$ is a better index of soil N availability. Low PRS $\text{NH}_4\text{-N}$ values do, however, suggest a rapid nitrification is taking place.

PRS $\text{NO}_3\text{-N}$ data (Table 2) for RES and COM vineyards show that during the PB period (only measured in 2004), PRS $\text{NO}_3\text{-N}$ was higher with commercial fertilizer than with the control or legume covers. By the BTV period, only the control had significantly lower PRS $\text{NO}_3\text{-N}$ concentrations and by PV; PRS $\text{NO}_3\text{-N}$ concentration was equally low under all treatments. The 2004 RES vineyard PRS $\text{NO}_3\text{-N}$ concentrations at each sampling interval illustrate the variation in plant-available N by treatment throughout the growing season (Fig. 1). Statistical analysis of data corresponding to Figure 1 (Table 2) shows that at PB, the fertilizer treatment was statistically the highest, which is expected because the fertilizer was applied in early April. PRS $\text{NO}_3\text{-N}$ in the fertilizer and clover treatments were significantly higher than the control from BTV. Elevated levels of PRS $\text{NO}_3\text{-N}$ occurred for all treatments at the RES vineyard during the critical N demand period of BTV compared with PB and PV. PV concentrations were not statistically different by treatment at the RES vineyard in 2004.

As a whole, 2005 treatments at both sites had significantly higher accumulations of PRS $\text{NO}_3\text{-N}$ than in 2004 from BTV and PV (Table 2). The RES fertilizer plots were the only exception. COM vineyard PRS $\text{NO}_3\text{-N}$ concentrations in 2005 were significantly

Table 3. Nitrogen contribution from cover crops incorporated for research (RES) and commercial (COM) vineyards in 2004 and 2005.

Site	Cover crop	2004 ^z	2005
		(kg·ha ⁻¹ N) ^y	
RES	Small grains	41.4	30.1
RES	Fall vetch	77.3	145.6
RES	Fall clover	42.6	132.2
COM	Small grains	—	67.2
COM	Fall vetch	50.4	132.1
COM	Fall clover	67.2	42.5
COM	Spring vetch	—	119.8
COM	Spring clover	—	149.0
COM	Vetch-half/half	—	131.0

^zNo covers were planted at COM site in Spring 2003.

^yValues reported are on a per hectare of planted grape rather than per hectare of planted cover crop.

Table 4. Mean soil test $\text{NO}_3\text{-N}$ concentrations in 2004 and 2005 at research (RES) and commercial (COM) sites during time designations of prebloom (PB), bloom to veraison (BTV), and postveraison (PV).^z

Year	Site	Treatment	PB		BTV		PV	
-----mg·kg ⁻¹ NO ₃ -N -----								
2004	RES	Depth	0–15	15–30	0–15	15–30	0–15	15–30
		Fertilizer	16.26 a ^y	4.69 a	7.04 a	10.02 a	3.30 b	4.76 ab
		Control	0.97 b	0.67 b	4.37 b	3.12 c	3.10 b	2.84 b
		Fall vetch	3.03 b	1.45 b	7.39 a	7.36 b	4.87 a	7.76 a
	COM	Fall clover	1.08 b	0.88 b	5.95 ab	5.15 c	3.42 b	6.62 ab
		Blood meal	—	—	17.35 a	22.33 a	6.61 a	15.53 a
		Spring vetch	—	—	6.75 b	7.11 b	—	—
		Fall fetch	0.83 a	0.61 a	10.09 b	12.99 b	5.28 a	8.23 b
		Vetch-half/half	—	—	7.82 b	7.48 b	—	—
		Spring clover	—	—	8.21 b	7.41 b	—	—
		Fall clover	0.97 a	0.48 a	10.21 b	12.59 b	6.95 a	13.23 ab
		<i>P</i> value	<0.001	<0.001	<0.001	<0.001	0.214	<0.001
2005	RES	Fertilizer	18.73 a	24.61 a	13.77 a	18.43 a	5.97 a	10.37 ab
		Control	4.01 b	1.35 b	6.66 b	3.56 c	4.39 a	5.46 b
		Fall vetch	7.18 b	6.80 b	11.64 a	11.44 b	5.86 a	13.43 a
	COM	Fall clover	5.79 b	1.69 b	10.77 a	8.55 b	5.64 a	12.02 ab
		Blood meal	0.37 c	0.92 c	29.60 a	24.12 a	4.92 a	17.71 a
		Spring vetch	5.05 b	3.32 ab	8.83 b	10.78 bc	4.56 a	3.75 b
		Fall vetch	7.45 a	3.60 a	11.58 b	11.46 bc	2.63 c	6.53 b
		Vetch-half/half	7.66 a	3.05 ab	9.86 b	13.52 b	4.04 ab	7.00 b
		Spring clover	4.05 b	2.22 abc	8.22 b	10.20 bc	3.25 bc	7.87 b
		Fall clover	2.96 b	1.56 bc	7.71 b	6.79 c	2.79 c	5.31 b
		<i>P</i> value	<0.001	<0.001	<0.001	<0.001	0.018	<0.001

^zP values are given for each year and time designation combination.

^yMeans with different letters in the same column and site are significantly different at $P = 0.05$ using Duncan multiple range test.

higher in the blood meal treatment from BTV than legume treatments except for the vetch-half/half, which was intermediate. Legume treatments were not statistically different from one another. PV concentrations returned to low levels with few differences by treatment. Blood meal resulted in the highest sustained levels of PRS $\text{NO}_3\text{-N}$ in 2005; this was not true in 2004, implying that year-to-year variability in plant-available N from blood meal application can be significant (Table 2). Results of the corresponding data from the RES vineyard in 2005 show that both legume treatments were significantly higher than the control during BTV; however, the legumes were not different from each other (Table 2). Because cover crop N concentration remained constant among legumes, increases in soluble N were directly related to the higher production of cover biomass from 2004 to 2005. Table 3 shows how significantly biomass contributes to the total amount of N supplied.

Soil test $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$. Soil samples taken at 0- to 15- and 15- to 30-cm depths were analyzed for $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ at each sampling date to track soluble N level changes after cover crop incorporation as a result of mineralization. Like PRS $\text{NH}_4\text{-N}$, soil test $\text{NH}_4\text{-N}$ values were low (data not shown). Statistical analysis of soil N treatments was conducted in the same manner as PRS N data. Statistical differences existed by year, time of season, treatment, and depth.

As a whole, soil $\text{NO}_3\text{-N}$ levels were significantly lower in 2004 than 2005 (Table 4). This may be explained by increased cover crop biomass production in 2005 for most treatments. Statistical differences between depths (0 to 15, 15 to 30 cm) were most evident in the treatments that received soluble N sources that can be susceptible to rapid leaching.

All treatments in both sites and years had higher $\text{NO}_3\text{-N}$ levels during the critical N demand period of BTV than PB and PV except the conventional fertilizer treatment. In 2004 at the RES site, BTV $\text{NO}_3\text{-N}$ was lowest in the control plots at both depths. No statistical difference occurred between the other treatments at 0 to 15 cm. The conventional fertilizer treatment had the highest $\text{NO}_3\text{-N}$ concentration in the 15- to 30-cm sampling depth, showing more downward movement during BTV compared with other treatments. PB fertilizer plots were high in soil $\text{NO}_3\text{-N}$ because plots were fertilized in early April, whereas the legume and control treatments were lower. There was a large difference between the two sampling depths for most treatments in 2004 and 2005 at the RES and COM sites during PV. During this period, the deeper sampling depth tested higher in $\text{NO}_3\text{-N}$ than the shallow depth. This could be the result of breakdown and movement of $\text{NO}_3\text{-N}$ released from more recalcitrant organic materials.

Patterns that prevailed in 2004 can also be seen in 2005 (Figs. 2 and 3). Soluble N sources tended to have the highest peaks during BTV and no single green manure treat-

Fig. 2. Average soil test $\text{NO}_3\text{-N}$ in 2005 at the commercial vineyard at (A) 0 to 15 and (B) 15 to 30 cm. Bold vertical lines correspond to the dates of full bloom and veraison.

ment was consistently highest in $\text{NO}_3\text{-N}$. However, significantly lower biomass production led the fall clover treatment at the COM site to low nitrate levels during all sampling periods. At the 15- to 30-cm sampling depth, variability between treatments was greater (Figs. 2 and 3). This is important because vine roots are more abundant below 30 cm (Smart et al., 2006; Wample et al., 2000) and may have been exposed to more extremes of high and low levels of $\text{NO}_3\text{-N}$ than what was found above 30 cm.

Grape yield and quality. Concord grape yield was significantly different by year and site ($\alpha = 0.05$) and by the interactive factors of year by site. Because of the large differences between years and the year by site interaction, data were analyzed separately for each year and site.

Overall, yield was higher in 2005 (30 $\text{mg}\cdot\text{ha}^{-1}$) than in 2004 (14 $\text{mg}\cdot\text{ha}^{-1}$) and the COM vineyard had higher yield than the RES vineyard. Statewide, Concord grape yields averaged 12 $\text{mg}\cdot\text{ha}^{-1}$ in 2004 and 23 $\text{mg}\cdot\text{ha}^{-1}$ in 2005 (USDA–National Agricultural Statistics Service, 2006). Although yields at the COM site were lower than regional averages in both years, the yield trend between 2004 and 2005 was similar. Average air temperatures from 3 to 8 Jan. 2004 were several degrees below freezing (PAWS, <http://index.prosser.wsu.edu>). Chilling injury can cause physiological damage that may not be reversible depending on the duration and severity of cold temperatures (Jackson, 2000). However, RES site yields did not vary significantly by year. Most likely the yield difference observed between the two sites

and the lack of difference between years in the RES vineyard is related to the old age of the vines in the RES vineyard. Additionally, the absence of yield difference in the RES vineyard between the control and fertilized plots suggests that the massive trunk and root system can serve as a reservoir for N required in low-yielding conditions. This indicates that more than the 2 years of this study would be needed for withholding N to induce yield reduction in Concord grape.

High yields in 2005 at the COM site were accompanied by large variation within treatments (Table 5). Variation is typical of high yields and is augmented by natural areas of low and high productivity in the COM vineyard. Despite the approximately threefold increase in yield from 2004 to 2005 at the COM site, there were no differences in yield among treatments. Harvested grapes were subsampled and crushed to measure °Brix. Like the yield data, significant differences were seen with the main effects of year and site and the interactive factors of year by site. The strong statistical difference between 2004 and 2005 is consistent with regional °Brix that averaged 17.7 and 16.6, respectively (C. Bardwell, personal communication). The increase in yield from 2004 to 2005 was negatively related to °Brix.

Conclusion

PRS NO₃-N data imply that the timing of peak N availability after incorporation and breakdown of cover crops coincided well with the critical N demand stage of Concord grape. Soil test NO₃-N data further substantiated that release of NO₃-N was synchronous with grape plant demand. Soluble sources resulted in more plant-available N. Differences between legumes were closely associated with biomass production. When biomass production was similar, no single legume treatment resulted in more available N than any other. Compared with the control treatment, cover crops provided more available N because of the low C:N ratio of the legume biomass. Thus, for N-supplying covers to be effective, they must produce a large amount of biomass that is also relatively high in total N. A small grain cover may satisfy the first condition but will not meet the second as well as a legume cover.

Grape yield and quality tended to follow yearly regional trends and were not related to treatment. Two years of experiment were insufficient to determine differences in yield by treatment because Concord grape wood and root tissue is capable of storing large amounts of N for later use. Despite the evidence for a large differences in soil-available N among treatments, yields did not differ. Caution must be taken by growers to assure that the soil is not mined of available N because recharging of this pool in organic systems can be a prolonged endeavor.

Cost is a major force for guiding management decisions. A simple cost analysis pertaining to this project showed that per unit N, legumes and urea fertilizer prices were very

Fig. 3. Average soil test NO₃-N in 2005 at the research vineyard at (A) 0 to 15 and (B) 15 to 30 cm. Bold vertical lines correspond to the dates of full bloom and veraison.

Table 5. Average (±sd) grape yield and °Brix from plots where legume cover crops have been established in 2004 and 2005 at commercial (COM) and research (RES) farms.²

Treatment	Avg yield (mg·ha ⁻¹)		Avg °Brix	
	2004	2005	2004	2005
Fertilizer RES	19.43 ± 1.65	18.69 ± 6.67	17.2	15.6
Control RES	19.51 ± 3.13	20.29 ± 2.68	17.9	15.4
Fall vetch RES	22.70 ± 3.09	15.16 ± 4.37	17.0	15.4
Fall clover RES	19.72 ± 3.12	14.80 ± 0.86	17.5	16.7
Fall vetch COM	8.97 ± 2.78	35.15 ± 13.19	18.2	16.9
Spring vetch COM	8.06 ± 3.78	30.18 ± 10.66	19.3	16.8
Vetch-half/half COM	9.83 ± 6.68	37.29 ± 24.15	18.7	16.9
Fall clover COM	12.30 ± 6.65	39.11 ± 12.23	18.7	15.7
Spring clover COM	12.12 ± 6.92	33.45 ± 13.04	18.8	16.5
Blood meal COM	11.14 ± 6.66	35.78 ± 18.24	18.7	16.7
P value (year)	<0.0001		<0.0001	
P value (site)	0.0021		0.0353	
P value (year*site)	<0.0001		0.0005	

²P values are given for each year, site, and the interactive factors of year by site.

close, \$1.11 and \$1.02 per kilogram of N, respectively (this assumes for legumes 135 kg-ha⁻¹ N added from biomass and \$4.40/kg of seed planted at 34 kg-ha⁻¹ and for urea fertilizer \$0.47/kg). Application of blood meal as a source of N was more than 10 times higher (\$14/kg N) than legume or urea application. Two caveats should be considered when comparing legume and urea prices. First, prices shown are per unit N, not per unit of available N. Second, cover crops require more labor and equipment inputs to plant, mow, and incorporate than a simple urea application. Additionally, U.S. Department of Agriculture-certified organic legume seed must be used for cover crops unless it is not available, as was the case with this project. If available, legume price per unit N will likely increase substantially. The same is true for increases in urea prices as the price of energy continues to inflate.

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