EFFECTIVELY UTILIZING LEGUME COVER CROPS AS AN ORGANIC SOURCE OF NITROGEN IN CONCORD GRAPE

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of KYLE EDWARD BAIR find it satisfactory and recommend that it be accepted.

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EFFECTIVELY UTILIZING LEGUME COVER CROPS

AS AN ORGANIC SOURCE OF NITROGEN

IN CONCORD GRAPE

Abstract

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Leguminous cover crops are commonly used as green manures in organic cropping systems because they provide nitrogen (N) to plants. Concord grape (*Vitis labruscana* Bailey) is well suited for organic production because of low detrimental plant pathogen and insect pest pressure. The objectives of this research are to (i) evaluate the effectiveness of hairy vetch (*Vicia villosa* subsp. v*illosa* L.) and yellow sweet clover (*Melilotus officinalis* (L.) Lam.) in providing N to organically grown Concord grape, (ii) synchronize N release from mineralization following incorporation of cover crops with plant N demand and (iii) compare the ability of soluble, more readily available sources of N (blood meal and conventional fertilizer) to legume cover crops in providing N to grape.

Field analysis of research and commercial sites was initiated in 2003. Treatments consisted of spring and fall planted cover crops, 112 kg N ha^{-1} conventional fertilizer and 112 kg N ha^{-1} blood meal. Cover crops were incorporated in the early spring. Cover crop biomass depended on time of planting and material planted. Large seed size and careful water management were advantageous for cover crop establishment and biomass

production. Fall planted covers tended to establish better than those planted in the spring with hairy vetch being more consistent than yellow sweet clover. The yellow sweet clover did, however, show high biomass production potential.

Plant Root Simulator (PRS) and soil test NO_3-N peaked for legume and fertilizer treatments during the critical plant N demand period from bloom to veraison. Cumulative degree-days to peak NO_3-N availability were similar for measured treatments, although peak magnitude varied.

Grape yield and quality were different by site and year but not by treatments in the same site and year. Hence, yield was not influenced by treatment. Yield and quality data coupled with leaf tissue N data suggest that cover crops have the potential to provide sufficient plant available N for crop production.

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LITERATURE REVIEW

Demand for organically grown products has increased rapidly in response to a shift in consumer preferences (Zehnder et al., 2003). Ecological concern among consumers and producers contributes to the quantity of certified organic food products available. Pecuniary benefits from price premiums have enticed a growing number of growers and processors into this niche of the food system.

Nationally, the total acreage classified as certified organic has increased 63% from 1997 to 2003. USDA certified organic grape production in Washington state has far exceeded this growth, jumping from 176 hectares in 1997 to 921 hectares in 2003, an increase of 423% (USDA-ERS, 2005). Washington state is the national leader in total Concord grape (*Vitis labruscana* Bailey) production, growing nearly 40% of the 2004 U.S. crop (USDA-NASS, 2005), with a growing proportion of the total being produced organically. The south central counties of Yakima, Benton and Franklin account for the bulk of the state's juice grape production. Concords are well suited for organic management because detrimental plant pathogen and insect pest pressure is low compared to other crops such as wine grape (*Vitis vinifera* L.) (D. Walsh, personal communication, 2005).

Soil fertility management practices to ensure that the grape plant will receive a sufficient amount of nutrients in conjunction with plant demand must be carefully considered. Leguminous cover crops are frequently used in organically certified production systems as a means of providing nitrogen (N) to the crop of interest when synthetic fertilizers are not permitted (Kramer et al., 2002).

Some physical, chemical, and biological properties of the soil are positively affected by the presence of the cover crop and addition of organic matter from its biomass production. These benefits include decreased soil bulk density, increased water infiltration, aggregate stability, cation exchange capacity (MacRae and Mehuys, 1985; Bugg et al., 1996; Snapp et al., 2005), microbial biomass and enzyme activity (Mendes et al., 1999; Bandick and Dick, 1999). Vine growing conditions can be improved by these individual or collective changes. Conveniently, the space between grape vine rows is amenable to intercropping with a cover crop.

Organic producers are commonly faced with weed control issues. When herbicides cannot be used, controlling weed populations becomes complicated and input intensive. Weed populations are reduced when an adequate stand of the cover crop emerges in time to out compete the weeds for resources or possibly from the effects of allelopathy. Evaluating several potential cover crops for use in wine grape (*Vitis vinifera* L.) vineyards, Neumann (2000) observed that suppression of some weed species was likely due to inter-specific competition rather than an allelopathic interaction. Management practices that encourage cover crop growth must be carefully used to ensure a good stand and growth.

Cover crops also protect the soil from wind and water erosion. Wind erosion is of particular concern in the major Concord growing regions of Washington as low annual precipitation ($<260\ \text{mm} \cdot \text{yr}^{-1}$) and frequent high winds ($>7\ \text{m} \cdot \text{s}^{-1}$) coalesce to increase potential topsoil losses as a result of wind (PAWS, http://index.prosser.wsu.edu). The canopy of the cover crop reduces wind velocity nearly exponentially approaching the soil surface (Campbell and Norman, 1998), mitigating large losses of wind transported soil particles.

Some drawbacks of using cover crops must be weighed against benefits. Cover crops can create a desirable habitat for some insect and rodent species. Also, when intercropped, cover crops can compete for water and nutrients with the principal crop. Frost damage can occur because cover crops keep the soil temperature lower than a bare soil. If insufficient heat is released from soil storage during cold mornings the incidence of freezing is increased. Another disadvantage is that the number of passes made with equipment is increased to prepare a seed bed, mow the cover, incorporate the plant matter, and control for weeds. In these processes the equipment can cause localized compaction.

Historically, legume green manure has been viewed as a favorable nutrient additive to the soil. The Romans and Greeks were known to use green manures in vineyards and earlier references date back to 12th Century B.C. China (Pieters, 1927; Cook and Baker, 1983). Green manure use in the United States peaked during the years prior to the end of World War II but quickly receded with the onset of affordable synthetic N fertilizer sources following the war. The soaring cost of fertilizer in recent years has encouraged the use of alternative means to supply nutrients to the soil.

How much nitrogen is required for optimum Concord grape production? Ahmedullah and Roberts (1991) concluded that Concord grapes in the Yakima Valley showed yield response with N addition up to 180 $kg \cdot ha^{-1}$ while applications in excess of this resulted in no response. Research performed with *V. vinifera* L. cultivars grown in many climatologically different areas, proposed applications between 0 and 70 kg $N^{\cdot}ha^{-1}$ depending on the soil nutritional conditions (Löehnertz, 1991; Peacock et al., 1991; Williams, 1991; Spayd, et al., 1993). 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 (Löehnertz, 1991). 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 $N^{\cdot}ha^{-1}$ per year (Havlin et al., 1999), a portion of which can become plant available.

Legume cover crop roots grow in symbiosis with endophytic N fixing microorganisms that convert atmospheric N gas into a form that is available for plant use. Legume plants provide energy for the microorganism to fix N, a process that is energetically expensive. However, the burden of hosting the N fixing bacteria is marginalized because the N demand of the legume is satisfied by this symbiosis (Sylvia et al., 2005).

Decomposition and ensuing N mineralization of cover crop residues by microbial action consequently supplies inorganic forms of N to the crop. Aeration and tissue destruction resultant from mechanical incorporation enhances microbial activity expediting mineralization. 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 (Schomberg and Endale, 2004; Dharmakeerthi et al., 2005). Soil temperature and moisture are commonly related to decomposition rates because the metabolic processes of microorganisms depend largely on these factors. Generally, microbial activity is restricted during periods of cold temperature and/or dry soil conditions. When determining an incorporation date for cover crops, weather and irrigation patterns should be considered in order to achieve optimum breakdown (Adams and Jan, 1999).

At what growth period do Concords have a critical N demand? Grapevines have a critical N demand from the end of rapid shoot growth up to veraison (Conradie, 1986; Löhnertz 1991; Hanson and Howell, 1995). If N release does not correspond to this growth period, excess N that is not taken up can be lost via 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 such 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).

Empirical studies conducted in the field to determine N mineralization rates by following soluble N content illustrate useful trends subsequent to incorporation. In one study Rosecrance et al. (2000) estimated that vetch mineralization rate was 0.98 mg (NH_4^+ and NO_3^-)-N$\cdot$d^{-1} under a growth chamber environment corresponding to normal field conditions. Further, vetch mineralization rate was notably faster than rye (*Secale cereale* L.) and potential for loss was significantly higher with half occurring within 30 d of crop kill. Implications of the resultant data include matching periods of N mineralization to peak plant N demand, improving the N use efficiency of the crop and marginalizing N losses consequential to asynchrony.

Vetches (*Vicia* spp.) have been identified as excellent N fixers among legumes (Powers and Zachariassen, 1993; Ranells and Wagger, 1996; Mueller and Thorup-Kristensen, 2001; Rochester and Peoples, 2005). Hairy vetch (*Vicia villosa* subsp. v*illosa* L.) is one variety that fixes large quantities of N and is hardy enough to serve as a winter ground cover. Guldan et al. (1996) evaluated hairy vetch, barrel medic (*Medicago truncatula* L.), alfalfa (*Medicago sativa* L.), lentil (*Lens culinaris* L.) and red clover (*Trifolium pratense* L.) and concluded that whole plant N yield was greatest in hairy vetch treatments and that N uptake in sorghum (*Sorghum bicolor* L.) following hairy vetch was highest. Whether addition of organic residue will result in a net immobilization or a net mineralization is often distinguished by the amount of carbon (C) and N in the plant biomass. Hairy vetch has a C:N ratio between 10:1 and 16:1 (Ranells and Wagger, 1996; Vaughan and Evanylo, 1998; Sarrantonio, 2003) depending on the age of the plant sampled. Because the nitrogen content of hairy vetch is relatively high, microorganisms involved in residue breakdown will not scavenge for soluble N sources in the soil and immobilize N into their biomass. Instead, organic N forms of residue are converted to NH_4^+ and NO_3^- through the processes of ammonification and nitrification. These mineralized forms of N are considered plant available.

Yellow sweet clover (*Melilotus officinalis* (L.) Lam.) is a member of the pea family that produces potentially large quantities of dry matter as well as fixing significant amounts of atmospheric N_2. Common applications of yellow sweet clover include use as a forage crop, and cultivation for honey production. Because the plant is drought tolerant, utilization in vineyards is attractive in instances where competition for limited water resources may be a concern. Like hairy vetch, yellow sweet clover is able to provide cover and remain hardy during cold winters (Brandæster et al., 2002). The C:N ratio of yellow sweet clover is generally <20:1; suggesting that a net mineralization of residue following incorporation will occur.

The objectives of this research are to (i) evaluate the effectiveness of hairy vetch and yellow sweet clover in providing N to organically grown Concord grape, (ii) synchronize N release from mineralization following incorporation of cover crops with plant N demand and (iii) compare soluble, more readily available sources of N (blood meal and conventional fertilizer) to legume cover crops in providing N to grape.

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CHAPTER TWO

COVER CROP BIOMASS PRODUCTION AND C:N

INTRODUCTION

Washington state is the national leader in Concord grape (*Vitis labruscana* Bailey) production. The number of acres classified as USDA certified organic grapes has outpaced national growth of all organic crops by more than 350% (USDA-ERS, 2005; USDA-NASS, 2005). Ecological concern among consumers and producers contributes to the quantity of certified organic food products available. Price premiums have enticed a growing number of growers and processors into this niche of the food system. The south central counties of Yakima, Benton and Franklin account for the bulk of the state's juice grape production. Compared to wine grape (*Vitis vinifera* L.), Concords are well suited for organic management because detrimental plant pathogen and insect pest pressure is low (D. Walsh, personal communication, 2005).

Leguminous cover crops are frequently used in organically certified production systems as a means of providing nitrogen (N) to the crop of interest when synthetic fertilizers are not permitted (Kramer et al., 2002). The ability of a cover crop to fix substantial amounts of N in its biomass that can later be utilized by the cash crop determines the effectiveness of the cover crop.

The addition of organic matter from the cover crop biomass can enhance some physical, chemical, and biological properties of the soil. Some benefits include decreased soil bulk density; increased water infiltration, aggregate stability, cation exchange capacity (MacRae and Mehuys, 1985; Bugg et al., 1996; Snapp et al., 2005), microbial biomass and enzyme activity (Mendes et al., 1999; Bandick and Dick, 1999). The presence of a cover crop between vine rows can also suppress weed populations. Evaluating several potential cover crops for use in wine grape vineyards, Neumann (2000) observed that suppression of some weed species was likely due to inter-specific competition. Cover crops also protect the soil from wind and water erosion. Soil particle loss from wind erosion is of concern in the major Concord growing regions of Washington due to low annual precipitation (<260 $mm \cdot yr^{-1}$) and high winds (>7 $m \cdot s^{-1}$) (PAWS, http://index.prosser.wsu.edu).

Drawbacks of using cover crops include the creation of a desirable habitat for some insect and rodent species, competition for water and nutrients with the major crop, increased frost damage potential, and soil compaction from increased equipment use.

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 $N \cdot ha^{-1}$ per year (Havlin et al., 1999), a portion of which can become plant available. 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 (Schomberg and Endale, 2004; Dharmakeerthi et al., 2005).

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

Whether addition of organic residue will result in a net immobilization or a net mineralization is often distinguished by the amount of carbon (C) and N in the plant biomass. Hairy vetch has a C:N ratio between 10:1 and 16:1 (Ranells and Wagger, 1996; Vaughan and Evanylo, 1998; Sarrantonio, 2003) depending on the age of the plant sampled. Because the nitrogen content of hairy vetch is relatively high, microorganisms involved in residue breakdown will not scavenge for soluble N sources in the soil and immobilize N into their biomass. Instead, organic N forms of residue are converted to NH_4^+ and NO_3^- through the processes of ammonification and nitrification.

Yellow sweet clover (*Melilotus officinalis* (L.) Lam.) is a member of the pea family that produces potentially large quantities of dry matter as well as fixing significant amounts of atmospheric N_2. Because the plant is drought tolerant, utilization in vineyards is attractive in instances where competition for limited water resources may be a concern. Like hairy vetch, yellow sweet clover is able to provide cover and remain hardy during cold winters (Brandæster et al., 2002). The C:N ratio of yellow sweet clover is generally in the high teens; suggesting that a net mineralization of residue following incorporation will occur.

The objectives of this research are to evaluate the effectiveness of hairy vetch and yellow sweet clover in producing a sufficient amount of narrow C:N biomass to provide N to organically grown Concord grape.

MATERIALS AND METHODS

To determine the potential of yellow sweet clover and hairy vetch to provide N in organic grape production, two Concord vineyards near Prosser, WA, 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. Vines in the commercial (OB) vineyard were planted in 2000 while the vines in the research (R) vineyard had been established in the early 1960’s. Both sites were irrigated with an overhead sprinkler system. The soil in the research and commercial vineyards is classified as Warden silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids) and Starbuck silt loam (loamy, mixed superactive, mesic Xeric Haplocambids) respectively. Since the commercial farm was certified organic, synthetic fertilizer comparisons were made on the research farm.

Plots established on both vineyards were 3 rows by 12.12 m in a Latin square design with 4 or 6 replicates of each treatment. Treatments in the OB vineyard consist of yellow sweet clover and hairy vetch in either a fall (18-30 August) or spring plant (30 June—18 July), hairy vetch with half planted in the fall and half in the spring, and a wheat (*Triticum aestivum* L.) or rye (*Secale cereale* L.) cover with 112 kg $N \cdot ha^{-1}$ applied as blood meal at incorporation. Treatments in the R vineyard include both legume cover crops planted in the fall, 112 kg $N \cdot ha^{-1}$ as urea applied in early April, and 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, a common practice in the Yakima Valley region of Washington to prevent topsoil losses from wind erosion, capture residual soil N and to reduce excessive soil moisture in the root zone during the spring (R. Stevens, personal communication). Treatments planted with wheat or rye will be referred to collectively as 'small grains' throughout this work. Table 2.1 summarizes which treatments apply to each vineyard.

A known area (11.0 m^2) of cover crop was cut from each plot and weighed to determine biomass and tissue sub-samples were taken. Sub-samples were dried at 65^o C for 2 days, weighed, and ground to 40 mesh to be analyzed for C and N using dry combustion (Yeomans and Bremner, 1991) with a LECO CNS 2000 (LECO Corporation, St. Joseph, MN). Biomass, C and N data were used as indices of potential N release following incorporation.

Statistical analysis of the data was performed using the PROC GLM of PC SAS (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

Cover crop biomass was significantly different by year and the interactive factors of year by site and year by cover crop (Table 2.2). Due to the large differences between years and the year by site interaction, data was analyzed separately for each year and site.

Overall, biomass production was higher in 2005 than 2004 (Table 2.2). Most likely the higher overall biomass in 2005 reflects progress in management practices to improve stand establishment. Water management of the cover crops proved important in establishing a good stand. The time when cover crops are planted may or may not coincide with when a grower will irrigate a Concord crop. If managed solely upon the needs of the grape, cover crops may not be irrigated until later in the growing season and unacceptable stands result. When management practices can be adjusted to accommodate both the cover crop and grape, better cover crop biomass production ensues.

There were no differences in biomass between treatments at the R vineyard in 2004. However, in 2005, clover biomass was significantly higher than small grain biomass, and vetch was intermediate (Fig. 2.1). Conversely, in both years, at the OB vineyard, fall planted vetch had higher biomass than fall planted clover (Fig. 2.2). In 2005, all other cover crops, regardless of time of planting, had higher biomass than fall planted clover.

Seed size has been shown to be influential in seed germination and establishment of many plant species (Moles and Westoby, 2004; Willenborg et al., 2005). Because yellow sweet clover seed is smaller than the other cover crops used, it is predisposed to poorer stands leading to lower biomass production. Although few significant differences occurred in biomass production, seed germination and emergence of vetch and the small grains were better.

Cover crop planting time was also important in stand establishment. Cover crops planted in the spring were commonly out competed by weeds. Because the covers were establishing at a time when weed growth was very aggressive, poor stands were common, especially with yellow sweet clover. Legumes planted in the fall established more successfully as weed competition was less vigorous. To show the large proportion of biomass that weeds produced, 2004 plot subsamples at the OB were separated into weed biomass and cover crop biomass and ranged from 44-66% weeds (Table 2.3). Because most of the biomass growth occurs in the early spring, delaying planting until fall will not decrease production (Shelton et al., 2000).

Cover crops were harvested, subsampled and analyzed for total C and N to determine what N process would likely transpire. Because significant differences only occurred by treatment and not between years and sites (α=0.05), C:N data are presented as treatment averages for both sites and years. Small grains had the highest C:N ratio while vetch and clover treatments were not significantly different (Table 2.4). Given the C:N ratios of the different cover crops, legumes were more likely to mineralize faster than small grain covers. Because weeds accounted for a large portion of biomass collected, weed subsamples were analyzed for total C and N in 2004. Weed C:N averaged 23:1, slightly higher than both vetch and clover C:N averages.

The product of cover crop total N concentration and biomass production give the amount of total N contributed from the aboveground biomass, a portion of which becomes plant available. Hence, treatments with low biomass production and/or low N content contributed less N. Examples of this were seen with the fall clover treatments at the OB site in 2005 that had low biomass, and the small grains treatments at both sites in 2005 where there was high or low biomass and low total N concentration resulting in a small N contribution (Fig. 2.3). Furthermore, if high C:N weeds contributed substantially to the total biomass, the N contribution was small and more likely to immobilize than legume biomass N.

CONCLUSIONS

Cover crop type and planting date were important in establishing acceptable stands and biomass. Large seed-size cover crops generally resulted in better seedling emergence. Covers planted in the fall tended to have less weed competition than spring planted covers and were able to be more productive. However, more research is needed to determine alternative planting times while still attaining good cover yields since fall is an extremely busy time of year for growers. Although vetch and small grain treatments were generally better biomass accumulators, the clover plots at the R site in 2005 showed amazing potential when growing conditions were favorable. Careful water management to accommodate the cover crops proved to be vital in the production system.

The C:N values for the legumes studied is in a desirable range to expedite mineralization of N through microbial processes. Compared to a small grain cover, legumes provide comparable biomass with a lower C to N ratio. The result of this is a higher total N contribution and potentially more N available to the grape plant. However, small grains have soluble and slowly available N constituents that increased soil N following incorporation. In this study, both yellow sweet clover and vetch aboveground biomass generally contained >120 kg $N \cdot ha^{-1}$ that was incorporated into the soil. If weed control is not practiced, the C:N ratio will most likely increase, changing the dynamics of N breakdown, release, and availability. Cost analysis should be conducted to determine if legume cover are suitable in a given production system.

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TABLES

Table 2.1. Table of treatments for the commercial and research Concord grape vineyards in 2005.

Treatment*	Commercial Vineyard	Research Vineyard
Control (0 N fertilizer)		√
112 kg N ha^{-1} (Blood meal)	√	
112 kg N ha^{-1} (Conventional)		√
Yellow Sweet Clover[1]	√	√
Yellow Sweet Clover[2]	√	
Hairy Vetch[1]	√	√
Hairy Vetch[2]	√	
Hairy Vetch[3]	√	

[1] Fall plant
[2] Spring plant
[3] Half fall plant, half spring plant
* All treatments incorporated at bloom (late spring)

Table 2.2. Average cover crop biomass and level of significance for each year, site and treatment in Concord grape. The two sites, OB and R represent a commercial and research vineyard, respectively. The significance of interactive factors is also shown.

		Average Biomass ($g \cdot m^{-2}$)	Level of Significance (*P*)
Year (Y)	2004	452	<0.0001
	2005	746	
Site (S)	OB	584	0.7021
	R	593	
Treatment (T)	Small Grains	632	0.0806
	Fall Vetch	667	
	Spring Vetch	737	
	Vetch Half/Half	780	
	Fall Clover	581	
	Spring Clover	941	
		Y*S	<0.0001
		Y*T	<0.0001
		T*S	0.7064

Table 2.3. Range and mean percent biomass of clover and vetch after weed removal from four OB site subsamples collected in 2004.

	Range	Mean
	%	
Clover	34-35	35
Vetch	52-56	54

Table 2.4. Average C:N ratio of cover crops used as N sources in two Concord grape vineyards in 2004 and 2005. Because no statistical differences occurred by year or site, the C:N data represent the average for both years and sites of the treatment. Means followed by the same letter are not significantly different (α=0.05).

Treatment	C:N
Small Grains	27a
Clover	18b
Vetch	13b

FIGURES

Figure 2.1. Average cover crop biomass production at the R vineyard in 2004 and 2005. Covers were sown 18-30 August. The small grains designation corresponds to the average of plots that received either 0 kg N·ha^{-1} or 112 kg N·ha^{-1}. Error bars represent the standard error of the mean. Biomass means in the same year followed by the same letter are not significant (α = 0.05).

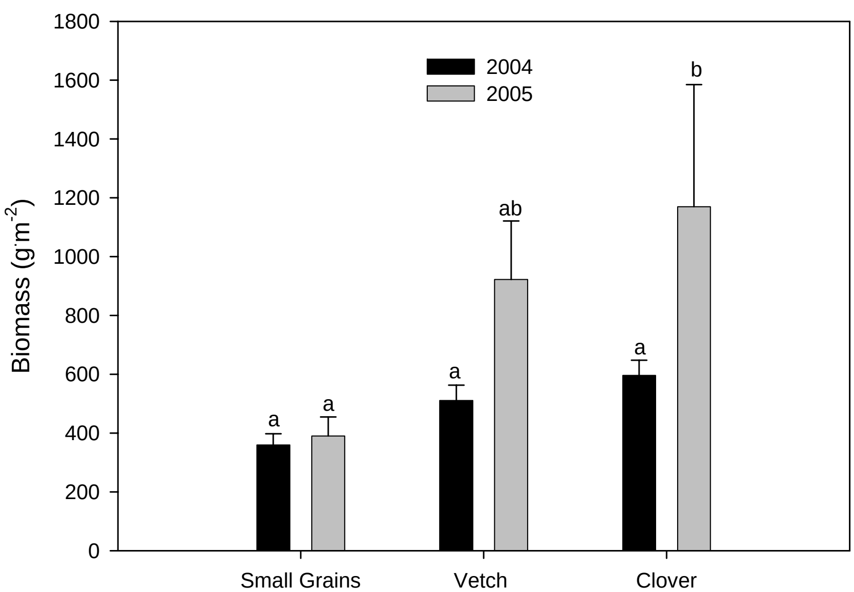


Figure 2.2. Average cover crop biomass production at the OB vineyard in 2004 and 2005. Spring and fall refer to the time of cover crop planting. The half/half treatment had one row adjacent to the vine row planted in the spring and the other planted in the fall. The small grains treatment was amended with blood meal. Error bars represent the standard error of the mean. Biomass means in the same year followed by the same letter are not significant ($\alpha = 0.05$).

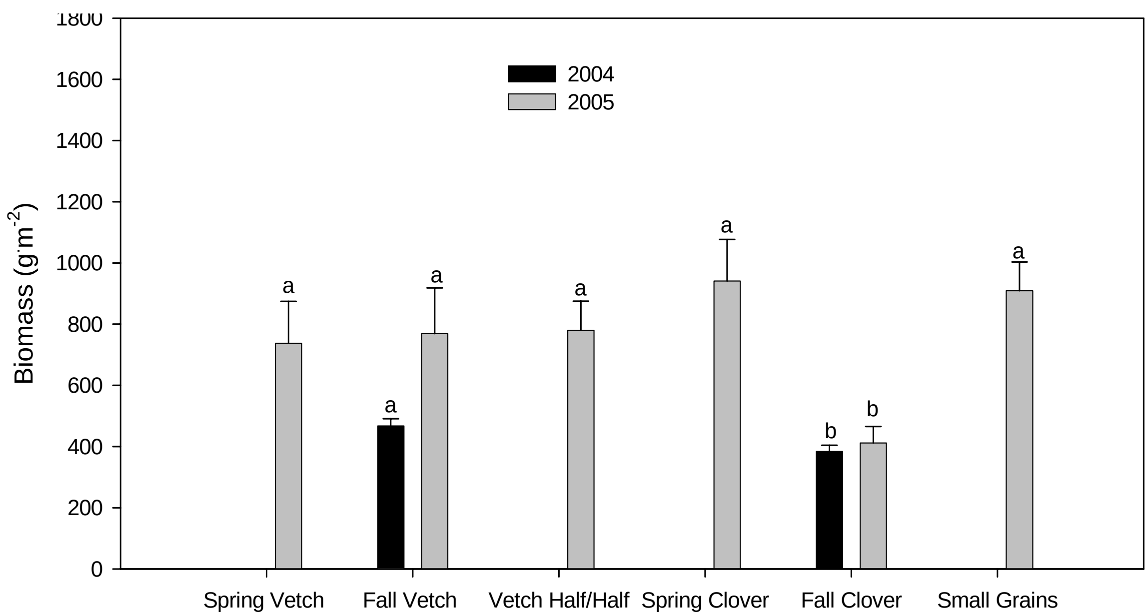
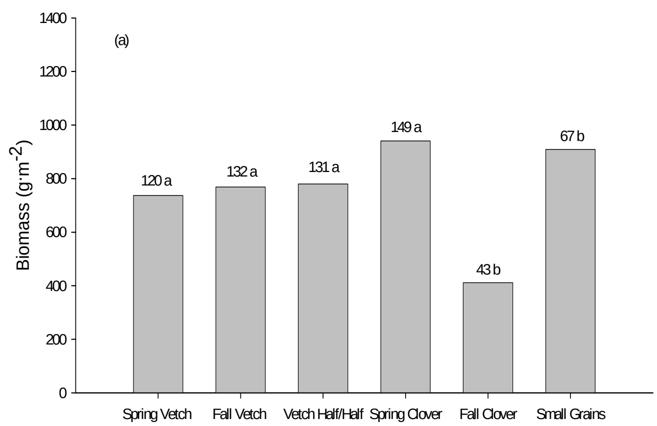
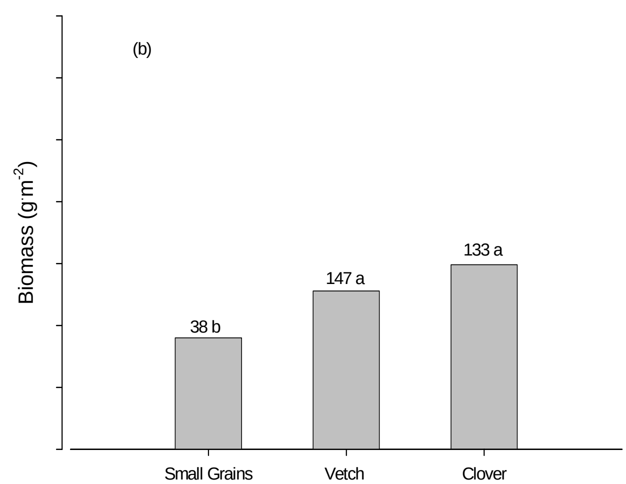


Figure 2.3. Average 2005 biomass at OB (a) and R (b) sites. Spring and fall refer to the time of cover crop planting. The half/half treatment had one row adjacent to the vine row planted in the spring and the other planted in the fall. The small grains treatment was amended with blood meal at the OB site while at the R site small grains were averaged for plots that received either 0 kg N·ha^{-1} or 112 kg N·ha^{-1}. Numbers above bars represent the N contribution of the aboveground biomass (kg N·ha^{-1}) calculated as the product of the N concentration and biomass production. N contribution means followed by the same letter are not significantly different (α = 0.05).





CHAPTER THREE

RELEASE OF PLANT AVAILABLE N FOLLOWING INCORPORATION OF COVER CROPS

INTRODUCTION

Concord grape (*Vitis labruscana* Bailey) is a major production crop in Washington state. Nearly 40% of the 2004 U.S. crop (USDA-NASS, 2005) was grown in Washington; the bulk of which was grown in the south central counties of Yakima, Benton and Franklin. A growing proportion of the crop is being produced organically to meet the shift in consumer demands. Concords are well suited for organic management because detrimental plant pathogen and insect pest pressure is low compared to other crops such as wine grape (*Vitis vinifera* L.) (D. Walsh, personal communication, 2005).

Because inorganic synthetic fertilizers are not permitted in organic production systems, a source of available nitrogen (N) must be added to avoid decreases in crop yield due to N infertility and to limit depletion of phytoavailable N pools. Legume cover crop are an attractive option because their roots grow in symbiosis with endophytic N fixing microorganisms that are able to convert atmospheric N gas into a form that is known to be available for plant use. Recent information suggests that legumes are capable of fixing between 11 and 336 kg $N \cdot ha^{-1}$ per year (Havlin et al., 1999), a portion of which can become plant available.

There are other advantages in addition to N fixation when intercropping with a cover crop. Some physical (MacRae and Mehuys, 1985), chemical (Bugg et al., 1996; Snapp et al., 2005), and biological (Mendes et al., 1999; Bandick and Dick, 1999) properties of the soil are positively affected by the presence of the cover crop and addition of organic matter from its biomass production.

Historically, legume green manure has been viewed as a favorable nutrient additive to the soil. The Romans and Greeks were known to use green manures in vineyards and earlier references date back to 12th Century B.C. China (Pieters, 1927; Cook and Baker, 1983). Green manure use in the United States peaked during the years prior to the end of World War II but quickly receded with the onset of affordable synthetic N fertilizer sources following the war. The soaring cost of fertilizer in recent years has encouraged the use of alternative means to supply nutrients to the soil.

Research with Concord grape and other *V. vinifera* cultivars proposed applications between 0 and 180 kg $N \cdot ha^{-1}$, depending on the soil nutritional conditions (Ahmedullah and Roberts, 1991; Löehnertz, 1991; Peacock et al., 1991; Williams, 1991; Spayd, et al., 1993). Plant organs store a large percentage of N as reserve (Bates et al., 2002; Williams, 1991), however, uptake from the soil solution is essential to preserve fruit development (Löehnertz, 1991).

The period of critical N demand for grapevines is from the end of rapid shoot growth up to veraison (Conradie, 1986; Löhnertz 1991; Hanson and Howell, 1995). Synchrony of N release with this demand period may render supplemental fertilizer applications unnecessary (Griffin et al., 2000). If asynchrony occurs then losses via several N cycle pathways can result. Thus, the time at which the cover crop is incorporated into the soil is vital such that N release from organic pools corresponds to plant N demand (Weinert et al., 2002). When determining an incorporation date for cover crops, weather and irrigation patterns should be considered in order to achieve optimum breakdown (Adams and Jan, 1999).

Vetches (*Vicia* spp.) have been identified as excellent N fixers among legumes (Powers and Zachariassen, 1993; Ranells and Wagger, 1996; Mueller and Thorup-Kristensen, 2001; Rochester and Peoples, 2005). Hairy vetch (*Vicia villosa* subsp. v*illosa* L.) is one variety that fixes large quantities of N and is hardy enough to serve as a winter ground cover. Hairy vetch also has a low C:N ratio that facilitates microbial breakdown and release of mineralized N forms.

Yellow sweet clover (*Melilotus officinalis* (L.) Lam.) is a member of the pea family that produces potentially large quantities of dry matter as well as fixing significant amounts of atmospheric N_2. Because the plant is drought tolerant, utilization in vineyards is attractive for instances where competition for limited water resources may be a concern. Like hairy vetch, yellow sweet clover is able to provide cover and remain hardy during cold winters (Brandæster et al., 2002). The C:N ratio of yellow sweet clover is generally in the high teens; suggesting that a net mineralization of residue following incorporation will occur.

The objectives of this research are to (i) evaluate the effectiveness of hairy vetch and yellow sweet clover in providing N to organically grown Concord grape, (ii) synchronize N release from mineralization following incorporation of cover crops with plant N demand and (iii) compare soluble, more readily available sources of N (blood meal and conventional fertilizer) to legume cover crops in providing N to Concord grape.

MATERIALS AND METHODS

Two Concord vineyards near Prosser, WA, 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. Vines in the commercial (OB) vineyard were planted in 2000 while the vines in the research (R) vineyard had been established in the early 1960's. The soil in the R and OB vineyards is classified as Warden silt loam (coarse-silty, mixed, superactive, mesic Xeric Haplocambids) and Starbuck silt loam (loamy, mixed superactive, mesic Xeric Haplocambids) respectively. Since the commercial farm was certified organic, synthetic fertilizer comparisons were made on the research farm.

Both vineyards were sprinkler irrigated and monitored for soil moisture weekly at 0.15 m increments during the growing season using a neutron attenuation probe (Campbell Pacific Nuclear, Martinez, CA). Soil temperature for each treatment was monitored using HOBO® data loggers (Onset Computer, Bourne, MA) at 0.10 and 0.30 m depths on both sites. Soil temperature was used to determine thermal time (degree-days) to release of N from breakdown of organic residues. In addition, weather data from 2002 through December 2005 was collected (PAWS, http://index.prosser.wsu.edu). Weather data consisted of average daily air temperature, precipitation, and evapotranspiration (ET_r, mm).

Plots established on both vineyards were 3 vine rows (2.44 m between vine rows) by 12.12 m (8 vines) in a Latin square design with 4 or 6 replicates of each treatment. Treatments in the OB vineyard consisted of yellow sweet clover and hairy vetch in either a fall (18-30 August) or spring (30 June—18 July) plant, hairy vetch with half planted in the fall and half in the spring, and a wheat (*Triticum aestivum* L.) or rye (*Secale cereale* L.) cover with 112 kg $N \cdot ha^{-1}$ applied as blood meal at incorporation. Treatments in the R vineyard included both legume cover crops planted in the fall, 112 kg $N \cdot ha^{-1}$ applied in early April as urea, and 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, a common practice in the Yakima Valley region of Washington to prevent topsoil losses from wind erosion, capture residual soil N and to reduce excessive soil moisture in the root zone during the spring (R. Stevens, personal communication). Treatments planted with wheat or rye will be referred to collectively as 'small grains' throughout this work. Table 2.1 summarizes which treatments apply to the research and commercial vineyards. Cover crop incorporation took place at bloom for all treatments using a tractor propelled rotovator that mixed the top 8 cm of soil. Bloom occurred on May 30, 2004 and 3 June, 2005.

Representative grape plant tissue samples were collected and analyzed as whole leaf (leaf blade and petiole) total N to assess the relative impacts of each treatment on plant N status at bloom and 650 degree-days (based 10^{o} C). These two phenological times are consistent with suggested Concord sampling dates for N nutrition in research (Davenport et al., 2003; Keller et al., 2004). Leaf samples were dried at 65^{o} C for 2 days and ground to 40 mesh to be analyzed for nitrogen using dry combustion (Yeomans and Bremner, 1991) with a LECO CNS 2000 (LECO Corporation, St. Joseph, MN).

To measure soluble N release from yellow sweet clover and hairy vetch decomposition after incorporation, plant root simulator (PRS™) probes (Western Ag

Innovations, Saskatoon, Canada) were used in conjunction with weekly soil samples. Anion (for NO_3-N) and cation (for NH_4-N) specific probes were placed 6.0 cm below the soil surface to track soluble N (Quian and Schoenau, 2000). PRS probes were exchanged weekly for the first four weeks after incorporation of cover crops and then bi-weekly for the duration of the sampling period. Concentrations extracted from the probes represent the availability of soluble N to an area of root over a week *in situ*. Probes were extracted with 20 mL of 0.5 M hydrochloric acid (HCl) (Quian et al., 1992) and analyzed colormetrically for NH_4-N (Environmental Protection Agency, 1984a) and NO_3-N (Environmental Protection Agency, 1984b) using an EasyChem Flow Analyzer (Systea Scientific LLC, Oak Brook, IL).

Representative soil samples were collected at 0-15 and 15-30 cm depths from each plot in conjunction with PRS exchanges. Soil samples were allowed to air-dry and were ground to pass a 2 mm sieve. Soluble NH_4-N and NO_3-N were extracted with 2.0 N potassium chloride (KCl) (Mulvaney, 1996) and analyzed colormetrically with an EasyChem Flow Analyzer. Extract samples were frozen for storage and thawed prior to analysis.

Harvest consisted of collecting the fruit from four plants in the center of each plot. Yield was calculated and fruit sub-samples were taken, crushed with a blender, and filtered. The resulting juice was measured for ^{o}Brix (soluble sugar) with a digital refractometer (Kernco, El Paso, TX).

Statistical analysis of the data was performed using the PROC GLM of PC SAS (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

SOIL TEMPERATURE, MOISTURE AND MINERALIZATION RELATIONSHIP

Soil temperature and moisture affect mineralization of organic matter. The soil environment influences microbes that decompose residue. Extremes (hot, cold, dry, wet) will limit the processes of mineralization. Measurement of soil temperature and moisture has been used to quantify hydrothermal-time for the actualization of biological processes. Modeling of dormancy-loss for *Bromus tectorum* L. (Bair et al., 2006) is a specific example.

Average soil temperature data collected in 2005 correlates well with soil test NO_3-N at similar dates (R^2=0.91) (Fig. 3.1a). The relationship observed agrees with other findings that suggest that when soil temperature is increased from 5 to 25^{o}C, microbial processes approximately doubled for each 10^{o}C change in temperature which leads to more N mineralization resulting in higher soluble N released in the soil solution from organic matter (Kladivko and Keeney, 1987; Zaman and Chang, 2004). Sufficient moisture for microbial activity has also been shown to be important in N transformations (Schroth et al., 2001). However, in this application there was little change in soil moisture (on a per week basis) throughout the growing season and a poor relationship between soil moisture and NO_3-N levels was observed (R^2=0.0353) (Fig. 3.1b). These findings suggest that in this system, where irrigation was scheduled to maintain adequate moisture for grape production, thermal-time is a better predictor for N mineralization patterns than hydrothermal-time.

Degree-days to mineralization were calculated from soil temperatures after incorporation and PRS NO_3-N data corresponding to peak N accumulation dates for several treatments with a base temperature of 0^oC (Honeycutt and Potero, 1990). Levels of PRS NO_3-N varied for all treatments due to differences of chemical composition of the cover. However, blood meal and spring clover NO_3-N data peaked between 520-550 degree-days at the OB site in 2005 (Table 3.1). Similar results have been found in incubation and field mineralization studies of organic amendments (Griffin and Honeycutt, 2000; Schomberg and Endale, 2004). Data obtained from the R site in 2005 were less definitive indicators of degree-days to peak N mineralization because PRS NO_3-N levels peaked sporadically during the sampling period.

GRAPE TISSUE N

Grape tissue N was measured at bloom and 650-degree days (DD) (base 10^oC) to determine if grape leaf N content differed by treatment. In 2005, statistical differences in mean leaf N concentration occurred by site and the interactive factors of site and sampling date (bloom or 650-DD).

Only the conventional fertilizer treatment sampled at bloom was significantly different than other treatments (Table 3.2). The soluble N source likely resulted in higher N uptake than the legume treatments at bloom because fertilizer was applied in April while incorporation of cover crops did not take place until bloom. At 650-DD, no statistical differences by treatment resulted; however, tissue N levels were significantly higher as a result of more N being partitioned to vegetative growth.

The OB site in 2005 had no statistical differences in grape tissue N by treatment at bloom or 650-DD. The site by sampling date interaction however, showed that tissue collected at 650-DD was lower in N than samples taken at bloom. This is the opposite of what occurred at the R vineyard. Patterns of N uptake and distribution were likely different between these two sites because of the age of the vines. At bloom the older R vines had a lower tissue N concentration than the younger OB vines. Comparison of sites at 650-DD shows little difference in tissue N concentration. It appears that from bloom to 650-DD the R vines allocated more N to vegetative growth while the OB vines moved N away from vegetative growth. The approximate two-fold difference in yield between the R and OB sites substantiates that the OB vines allocated more N to fruit production in 2005. Similar results have been found in cranberry (*Vaccinium macrocarpon* Ait.). Vanden Heuvel and Davenport (2006) found that when cranberry yield was low, tissue N tended to be high and *vice versa*.

Comparison of tissue N concentration with plant available N (PRS and soil test NO_3-N) can be seen in Table 3.2. Patterns of plant available N from bloom to 650-DD are similar within the same vineyards. The R site available N decreased while available N at the OB site generally increased from bloom to 650-DD. A relatively higher concentration of available N at the OB site at 650-DD was not reflected as tissue N at this sampling date compared to bloom. The opposite was true at the R site where higher available N at bloom was not reflected in higher tissue N concentration at bloom than at 650-DD, with the fertilizer treatment being an exception. This suggests that tissue N levels may differ due to the partitioning patterns of a given vine.

Compared to critical tissue N levels from several sources (Robinson, 1992; Mills and Jones, 1996; Robinson et al., 1997), tissue sampled at bloom and 650-DD tested above the “adequate” range for all treatments. This suggests that all treatments provided adequate N for production in these vineyards.

PRS MEASURED SOLUBLE NO_3-N AND NH_4-N

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 $\mu g \cdot ml^{-1}$ (NO_3-N or NH_4-N)$\cdot$17.5 $cm^{-2} \cdot week^{-1}$. Statistical analysis of treatments was conducted across sampling dates to reduce the large number of data points. Treatments were analyzed to show differences during three key phenological time periods, pre-bloom (PB), bloom to veraison (BTV), and post-veraison (PV). For NO_3-N, significant differences occurred by year, treatment and time of season. Data collected for NH_4-N did not appear to be useful in measuring mineralization of organic matter because solution nutrient accumulations were consistently below 1.0 $\mu g \cdot ml^{-1}$ NH_4-N$\cdot$PRS $area^{-1} \cdot week^{-1}$ (Fig. 3.2). These small accumulations of PRS NH_4-N are consistent with the findings of researchers (Smith, 1965; Quian and Schoenau, 1995), who suggested that NO_3-N is a better index of soil N availability. Low PRS NH_4-N values do, however, suggest a rapid nitrification is taking place.

Because nitrification occurred, PRS NO_3-N data were more definitive than PRS NH_4-N when assessing mineralization patterns. In 2004, R PRS NO_3-N patterns can be delineated by treatment (Fig. 3.3). Statistical analysis of data corresponding to Fig. 3.3 (Table 3.3) shows that at PB the fertilizer treatment was statistically the highest, which is expected because the fertilizer was applied in early April. From BTV fertilizer and clover treatments were significantly higher than the control, while the vetch was intermediate. Elevated levels of PRS NO_3-N occurred for all R treatments during the critical N demand period of BTV. PV concentrations were not statistically different by treatment at the R vineyard in 2004. Since the PRS levels for all treatments remained high PB and then BTV decreased dramatically, movement of NO_3-N from vine or weed uptake, leaching, immobilization, or gaseous losses is likely occurring. Because the decreases in PRS NO_3-N approximately coincided with the time of peak plant N demand plant uptake is a likely pathway, however, other pathways cannot be entirely excluded. Table 3.3 also gives average PRS data from the OB site in 2004. No significant differences were noted by treatment or time of season designations.

As a whole, 2005 treatments at both sites had significantly higher accumulations ($P<0.001$) of PRS NO_3-N than in 2004 from BTV and PV. The R fertilizer plots were the only exception. Increases were directly related to the higher production of cover biomass from 2004 to 2005. OB vineyard PRS NO_3-N concentrations in 2005 were significantly higher in the blood meal treatment from BTV than legume treatments except for the vetch-half/half, which was intermediate (Fig. 3.4). 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 NO_3-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. Results of the corresponding data from the R vineyard in 2005 show that both legume treatments were significantly higher than the control from BTV, however, the legumes were not different from each other (Table 3.4).

SOIL TEST NH_4-N AND NO_3-N

Soil samples taken at 0-15 and 15-30 cm depths were analyzed for NH_4-N and NO_3-N at each sampling date to track soluble N level changes after cover crop incorporation as a result of mineralization. Like PRS NH_4-N, soil test NH_4-N was less useful than NO_3-N in showing mineralization patterns following incorporation. Statistical analysis of soil N treatments was conducted across sampling dates to reduce the large number of data points. Treatments were analyzed to show differences during three key phenological time periods, pre-bloom (PB), bloom to veraison (BTV), and post-veraison (PV). Statistical differences existed by year (P<0.001), time of season (P<0.001), treatment (P<0.001), and depth (P=0.001).

Tables 3.5 and 3.6 summarize the mean soil test NO_3-N at two depths for all treatments for both sites and years of the study. As a whole, soil NO_3-N levels were significantly lower in 2004 than 2005. This is explained by the increased cover crop biomass production in 2005 for most treatments. Statistical differences by depth were most evident in the treatments that received soluble N sources that can be susceptible to rapid leaching. Because depths were collected separately, movement of NO_3-N can be seen. For example, peaks in soil test NO_3-N for the fertilizer treatment in 2004 occurred earlier at the shallow depth and the lower sampling depth peak followed by approximately 2 weeks (Fig. 3.5).

All treatments in both sites and years had higher NO_3-N levels during the critical N demand period of BTV than PB and PV except the conventional fertilizer treatment. In 2004 at the R site, BTV NO_3-N was lowest in the control plots at both depths. No statistical difference occurred between the other treatments at 0-15 cm. In the 15-30 sampling depth, the fertilizer treatment was the highest, making manifest more downward movement during BTV compared to other treatments. PB fertilizer plots were high in soil NO_3-N because plots were fertilized in early April while 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 R and OB sites during PV. During this period, the deeper sampling depth tested higher in NO_3-N than the shallow depth. This could be the result of breakdown and movement of more recalcitrant organic materials.

Patterns that prevailed in 2004 can also be seen in 2005 (Fig. 3.6 and 3.7). Soluble N sources tended to have the highest peaks during BTV and no single green manure treatment was consistently highest in NO_3-N. However, significantly lower biomass production led the fall clover treatment at the OB site to low nitrate levels during all sampling periods. As sampling depth increased, separation between treatments becomes more defined (Fig. 3.5, 3.6, 3.7). This is important because vine roots are more abundant below 30 cm (Wample et al., 2000; Smart et al., 2006) and may have been exposed to more extremes of high and low levels of NO_3-N than what is tested above 30 cm.

GRAPE YIELD AND QUALITY

To evaluate if treatment influenced the yield of Concord grape, fruit was harvested in 2004 and 2005 and weighed to determine yield. Yield was significantly different by year and site (α=0.05) and by the interactive factors of year by site (Table 3.7). Because of the large differences between years and the year by site interaction, data was analyzed separately for each year and site.

Overall, yield was higher in 2005 than in 2004 and the OB vineyard had higher yield than the R vineyard (Table 3.7). Statewide, Concord grape yields averaged 12 $Mg \cdot ha^{-1}$ in 2004 and 23 $Mg \cdot ha^{-1}$ in 2005 (USDA-NASS, 2006). Although yields at the

OB site were lower than regional averages in both years, the yield trend between 2004 and 2005 was similar. Average air temperatures from January 3-8, 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, R 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 R vineyard is related to the old age of the vines in the R vineyard. Additionally, the absence of yield difference in the R vineyard between the control and fertilized plots suggest that the massive trunk and root system can serve as a reservoir for N. This indicates that more than the two years of this study would be needed for withholding N to induce yield reduction in Concord grape.

High yields in 2005 at the OB site were accompanied by large variation within treatments (Table 3.8). Variation is typical of high yields and is augmented by natural areas of low and high productivity in the OB vineyard. Despite the approximately three-fold increase in yield from 2004 to 2005 at the OB site, no differences in yield resulted because of treatment, suggesting that the amount of N the plant needs is not limiting at this point.

Harvested grapes were subsampled and crushed to measure ^{o}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 (Table 3.7). The strong statistical difference between 2004 and 2005 is consistent with regional ^{o}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 ^{o}Brix.

CONCLUSIONS

Changes in soil temperature were directly related to changes in available N because of better conditions for microbial breakdown of organic matter. A similar trend was not observed for soil moisture, likely because moisture was maintained to provide adequate water for grape production with little variability. This does not suggest that soil moisture is not important for microbial activities.

Leaf tissue N concentrations were not influenced by legume treatment. Only the grape plants sampled at bloom receiving 112 kg $N \cdot ha^{-1}$ had higher tissue N concentrations and, based on published nutrient guidelines, all treatments at both sampling periods had adequate N for crop production. When comparing tissue N with yield data at the two sites, it appears that there is an antagonistic relationship between tissue N and yield. The OB site had lower tissue N and high yield while the R site had higher tissue N and lower yield.

PRS NO_3-N data imply that the timing of peak N availability following incorporation and breakdown of cover crops coincides well with the critical N demand stage of Concord grape. Soil test NO_3-N data further substantiates that release of NO_3-N is synchronous with grape plant demand. Soluble sources resulted in more plant available N and differences between legumes was closely associated with biomass production. Hence, no single legume treatment resulted in more available N than any other when biomass production was similar.

Grape yield and quality tended to follow yearly regional trends and were not related to treatment. Because Concord grape wood and root tissue is capable of storing large amounts of N for later use, two years of experiment were insufficient to determine differences in yield by treatment. This also suggests that if N was taken up from soil pools, there was an adequate amount available for crop production. 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.

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TABLES

Table 3.1. Dates corresponding to peak PRS NO_3-N accumulations for two treatments at the OB Concord grape vineyard in 2005. Cumulative degree-days (CDD) (base 0^oC) after incorporation to peak NO_3-N levels are also given.

Treatment	Peak PRS NO_3-N*	Date	CDD
Blood meal	38.55	7/20/2005	545
Spring Clover	19.47	7/20/2005	521

*$\mu g \cdot ml^{-1}$ NO_3-N$\cdot$17.5 $cm^{-2} \cdot week^{-1}$

Table 3.2. Average grape tissue N levels for treatments at bloom and 650 degree-days (DD) in 2005. PRS and soil NO_3-N data corresponding to the sampling dates closest to bloom and 650-DD are also given. Means with different letters in the same column and site are statistically different (α=0.05).

Site	Treatment	N Content (%)		PRS NO_3-N*		Soil NO_3-N†	
		Bloom	650-DD	Bloom	650-DD	Bloom	650-DD
R	Fertilizer (112 kg N·ha^{-1})	3.37 a	3.29 a	10.47 b	8.85 b	18.73 a	8.98 a
	Control (0 kg N·ha^{-1})	3.01 b	3.23 a	6.64 b	3.8 c	4.01 c	2.92 c
	Fall Vetch	3.19 b	3.40 a	25.86 a	16.59 a	11.77 b	6.42 b
	Fall Clover	3.06 b	3.30 a	21.81 a	11.93 ab	15.67 a	7.92 ab
OB	Blood meal	3.50 a	3.40 a	13.27 a	38.55 a	-	28.81 a
	Spring Vetch	3.50 a	3.41 a	-	18.41 c	5.06 b	6.54 b
	Fall Vetch	3.60 a	3.43 a	10.05 a	21.00 bc	7.46 a	8.70 b
	Vetch Half/Half	3.45 a	3.34 a	-	25.41 b	7.66 a	7.12 b
	Spring Clover	3.61 a	3.44 a	-	19.47 bc	4.05b	5.60 b
	Fall Clover	3.56 a	3.37 a	10.64 a	29.85 b	2.96 c	8.17 b

* μg·ml^{-1} NO_3-N·17.5 cm^{-2}·week^{-1}
† mg·kg^{-1} NO_3-N at 0-15 cm sampling depth

Table 3.3. Mean PRS NO_3-N concentrations in 2004 at R and OB sites during time designations of pre-bloom (PB), bloom to veraison (BTV), and post-veraison (PV). Means with different letters in the same column and site are significantly different (α=0.05). *P*-values are given for each year and time designation combination.

Site	Treatment	PB	BTV	PV
		$\mu g \cdot ml^{-1}$ NO_3-N $\cdot$ 17.5 $cm^{-2} \cdot week^{-1}$		
R	Fertilizer	10.17 a	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
OB	Blood meal	5.78 a	2.95 a	na
	Fall Vetch	9.25 a	8.61 a	1.69 a
	Fall Clover	9.69 a	3.86 a	2.76 a
P-value		<0.001	0.069	0.157

Table 3.4. Mean PRS NO_3-N concentrations in 2005 at R and OB sites during time designations of bloom to veraison (BTV) and post-veraison (PV). Means with different letters in the same column and site are significantly different (α=0.05). *P*-values are given for each year and time designation combination.

Site	Treatment	BTV	PV
		$\mu g \cdot ml^{-1}$ NO_3-N $\cdot$ 17.5 $cm^{-2} \cdot week^{-1}$	
R	Fertilizer	9.34 ab	6.45 a
	Control	6.00 b	5.61 a
	Fall Vetch	12.25 a	5.32 a
	Fall Clover	12.65 a	4.65 a
OB	Blood meal	24.81 a	8.17 a
	Spring Vetch	13.57 b	8.27 a
	Fall Vetch	12.69 b	5.34 ab
	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
P-value		<0.001	0.137

Table 3.5. Mean soil test NO_3-N concentrations in 2004 at R and OB sites during time designations of pre-bloom (PB), bloom to veraison (BTV), and post-veraison (PV). Means with different letters in the same column and site are significantly different (α=0.05). *P*-values are given for each year and time designation combination.

Site	Treatment	PB		BTV		PV	
		$mg \cdot kg^{-1}$ NO_3-N					
Depth		0-15	15-30	0-15	15-30	0-15	15-30
R	Fertilizer	16.26 a	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
	Fall Clover	1.08 b	0.88 b	5.95 ab	5.15 c	3.42 b	6.62 ab
OB	Blood meal	-	-	17.35 a	22.33 a	6.61 a	15.53 a
	Spring Vetch	-	-	6.75 b	7.11 b	-	-
	Fall Vetch	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
	P-value	<0.001	<0.001	<0.001	<0.001	0.214	<0.001

Table 3.6. Mean soil test NO_3-N concentrations in 2005 at R and OB site during time designations of pre-bloom (PB), bloom to veraison (BTV), and post-veraison (PV). Means with different letters in the same column and site are significantly different (α=0.05). *P*-values are given for each year and time designation combination.

Site	Treatment	PB		BTV		PV	
		$mg \cdot kg^{-1}$ NO_3-N					
	Depth	0-15	15-30	0-15	15-30	0-15	15-30
R	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
	Fall Clover	5.79 b	1.69 b	10.77 a	8.55 b	5.64 a	12.02 ab
OB	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
	P-value	<0.001	<0.001	<0.001	<0.001	0.018	<0.001

Table 3.7. Average yield and °Brix and level of significance (LOS) for each year, site and treatment. The significance of interactive factors is also shown.

		Average Yield ($Mg \cdot ha^{-1}$)	LOS	Average °Brix	LOS
Year (Y)	2004	14	<0.0001	18.32	<0.0001
	2005	30		16.33	
Site (S)	OB	23	0.0104	16.58	0.0467
	R	19		17.66	
Treatment (T)	Fertilizer	22	0.9134	16.40	0.3959
	Control	19		16.65	
	Blood meal	24		17.70	
	Fall Vetch	20		16.88	
	Spring Vetch	19		18.05	
	Vetch Half/Half	24		17.80	
	Fall Clover	21.4		17.15	
	Spring Clover	23		17.65	
		Y*S	<0.0001	-	<0.0001
		Y*T	0.9972	-	0.9810
		T*S	0.3938	-	0.1779

Table 3.8. Average (± standard deviation) grape yield from plots where legume cover crops have been established in 2004 and 2005 at commercial (OB) and research (R) farms. *P*-values are given for each year and time designation combination.

Treatment	Average Yield ($Mg\cdot ha^{-1}$)	
	2004	2005
Fertilizer R	19.43 ± 1.65	18.69 ± 6.67
Control R	19.51 ± 3.13	20.29 ± 2.68
Fall Vetch R	22.70 ± 3.09	15.16 ± 4.37
Fall Clover R	19.72 ± 3.12	14.80 ± 0.86
Fall Vetch OB	8.97 ± 2.78	35.15 ± 13.19
Spring Vetch OB	8.06 ± 3.78	30.18 ± 10.66
Vetch Half/Half OB	9.83 ± 6.68	37.29 ± 24.15
Fall Clover OB	12.30 ± 6.65	39.11 ± 12.23
Spring Clover OB	12.12 ± 6.92	33.45 ± 13.04
Blood meal OB	11.14 ± 6.66	35.78 ± 18.24
P-value	0.0375	0.4721

FIGURES

Figure 3.1. Soil test NO_3-N as a function of average (a) soil temperature and (b) soil moisture that correspond to the soil N sampling date for blood meal, fall clover and fall vetch treatments in 2005 at the OB vineyard.

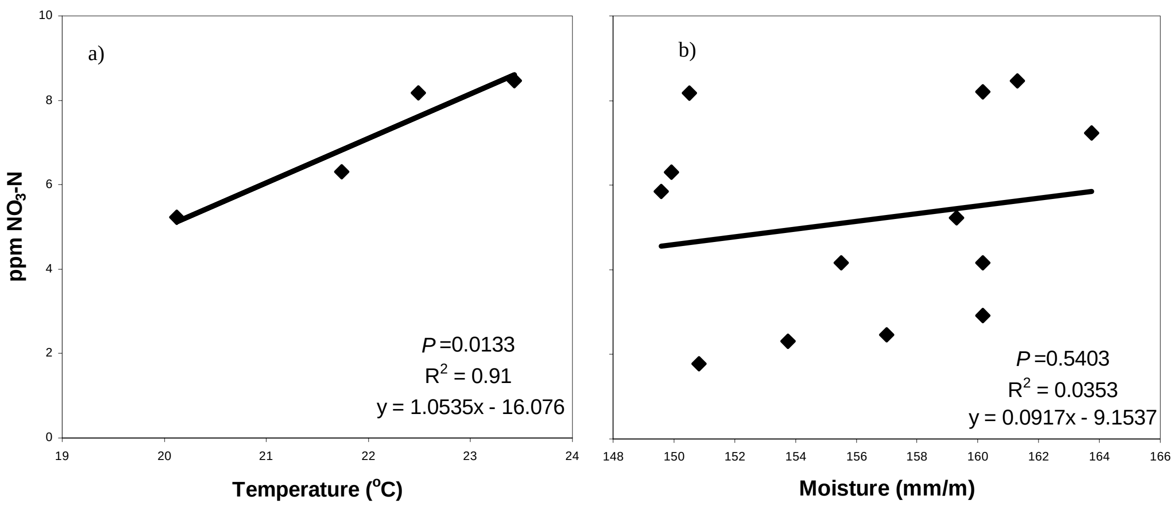


Figure 3.2. Average PRS NH_4-N collected during 2005 at the R vineyard. Bold vertical lines correspond to the dates of full bloom and veraison.

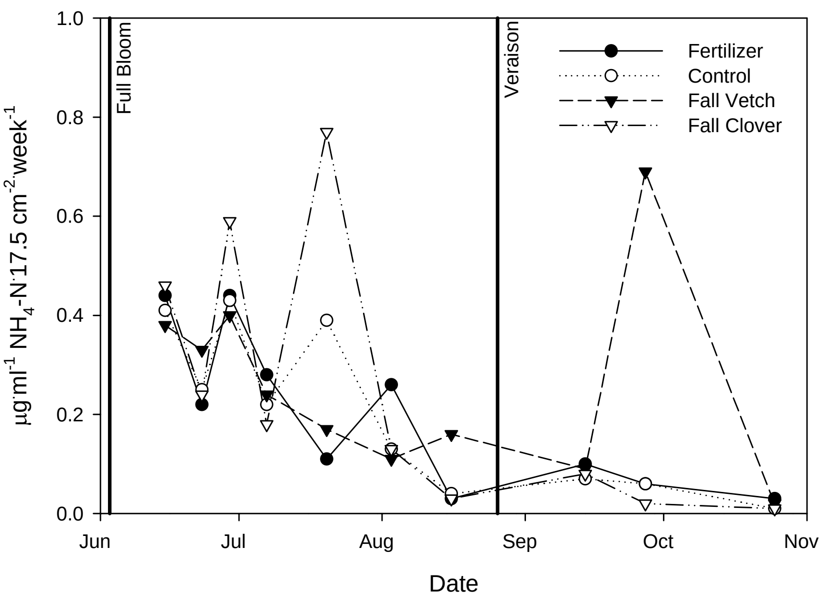


Figure 3.3. Average PRS NO_3-N collected during 2004 at the R vineyard. Spring and fall refer to the time of cover crop planting. The half/half treatment had one row adjacent to the vine row planted in the spring and the other planted in the fall. Bold vertical lines correspond to the dates of full bloom and veraison.

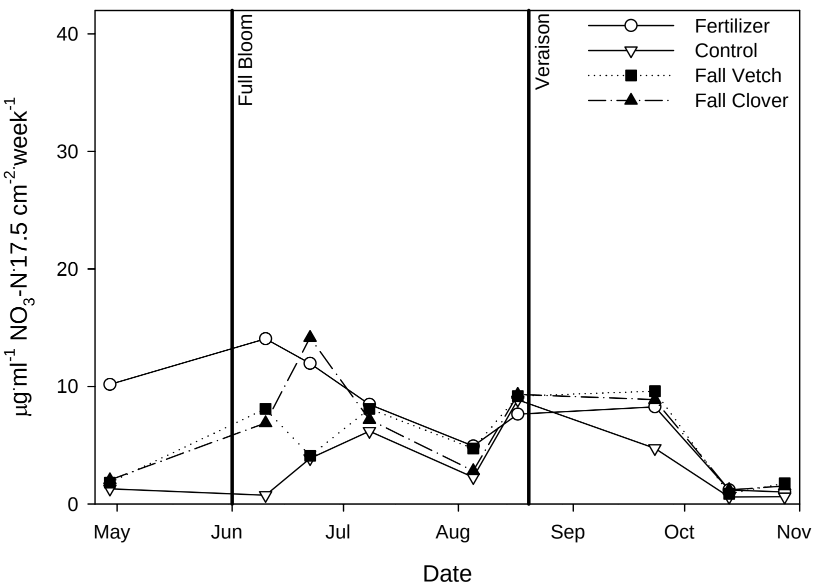


Figure 3.4. Average PRS NO_3-N collected during 2005 at the R (a) and OB (b) vineyards. Spring and fall refer to the time of cover crop planting. The half/half treatment had one row adjacent to the vine row planted in the spring and the other planted in the fall. Bold vertical lines correspond to the dates of full bloom and veraison.

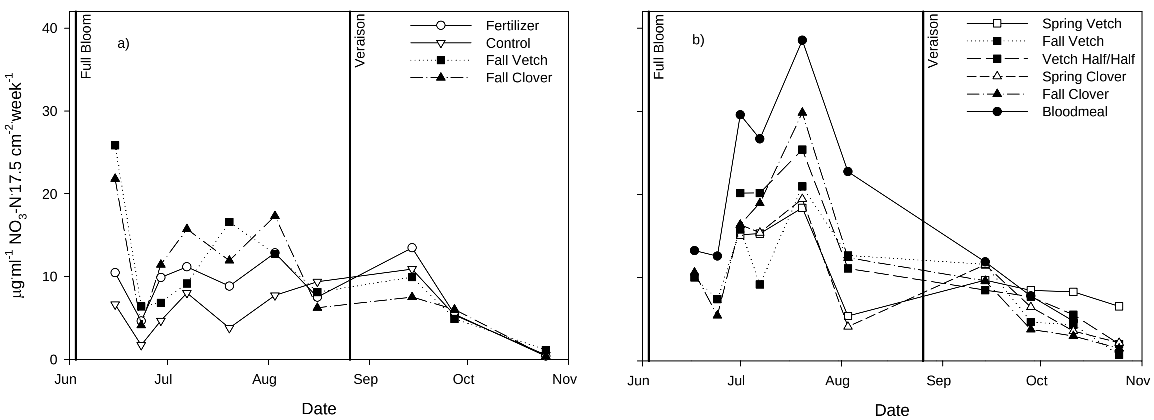


Figure 3.5. Average soil test NO_3-N in 2004 at R vineyard at (a) 0-15 and (b) 15-30 cm. Bold vertical lines correspond to the dates of full bloom and veraison.

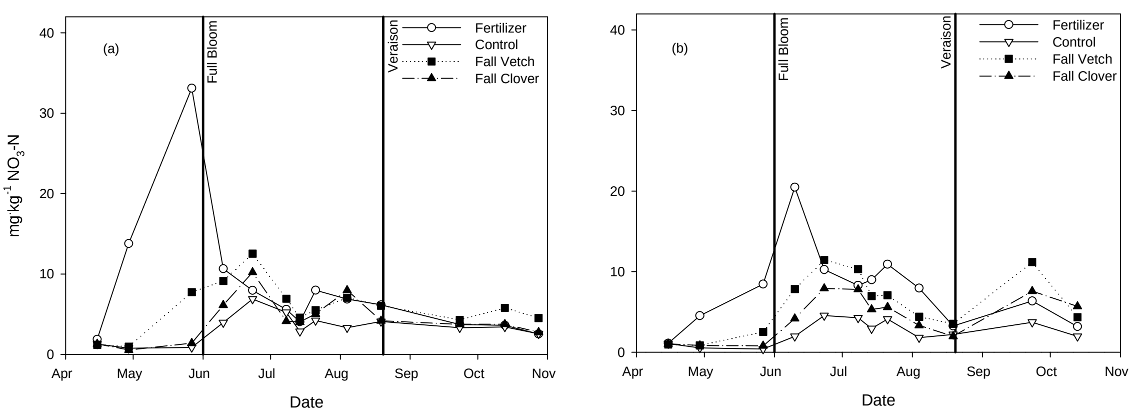


Figure 3.6. Average soil test NO_3-N in 2005 at OB vineyard at (a) 0-15 and (b) 15-30 cm. Bold vertical lines correspond to the dates of full bloom and veraison.

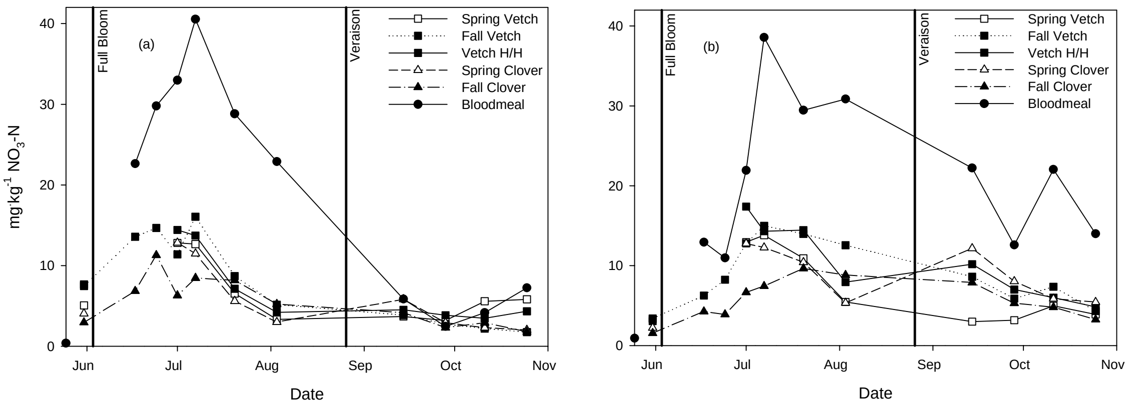
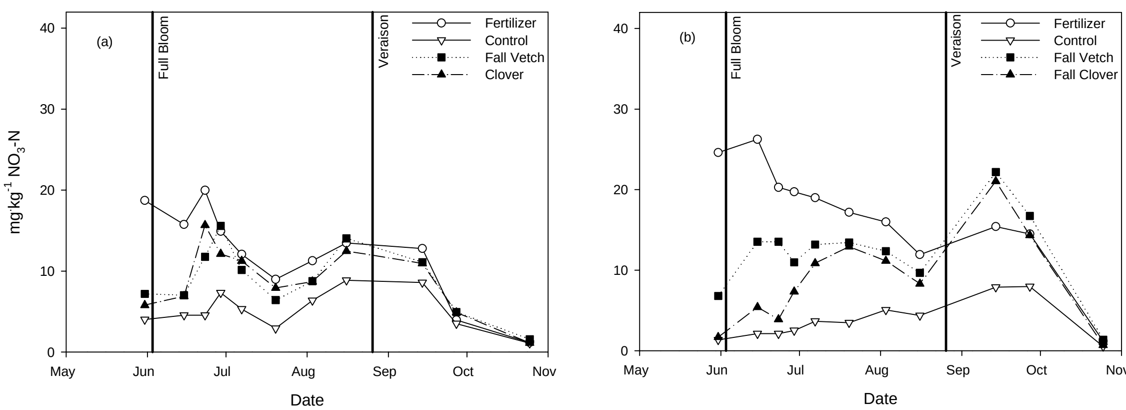


Figure 3.7. Average soil test NO_3-N in 2005 at R vineyard at (a) 0-15 and (b) 15-30 cm. Bold vertical lines correspond to the dates of full bloom and veraison.



CHAPTER FOUR. SUMMARY AND CONCLUSIONS

The objectives of this project were to determine if yellow sweet clover and hairy vetch could supply sufficient nitrogen (N) to Concord grapevines in synchrony with plant demand and compare the legume covers to more soluble N sources. The study was conducted on both a research vineyard, so that inorganic N amendments could be utilized, as well as a USDA certified organic commercial vineyard. The commercial vineyard was useful for making comparisons based on management techniques. Although soil and growing conditions were similar on the two vineyards, the age difference between the vines at the two sites broadened the interpretation of the study results. Cover crops were seeded in either the spring or fall to determine if planting time resulted in better cover crop growth.

Cover crop biomass and N concentration were measured as a means to determine how much total N was introduced into the system when the legumes were incorporated at grape bloom. Nitrogen additions, regularly >120 kg $N \cdot ha^{-1}$, from the legume cover crops were consistently higher than a small grain cover. This total amount was in the range of a typical N recommendation, given the existing N levels in the soil. Because the N contribution was a factor of tissue biomass and tissue N concentration, the latter being more consistent, good stand and growth of covers is necessary. Management practices, including adequate watering and weed control, must be adjusted to accommodate the development of the cover as well as the grapevines. Cover crops with a larger seed size, such as wheat and hairy vetch, were able to establish and grow better than the yellow sweet clover, which has a smaller seed size.

Weekly soil samples at surface and subsurface depths were analyzed for NO_3-N in conjunction with PRS measured NO_3-N and indicated that available N mineralized from incorporated cover crop biomass peaked during the critical N demand period of Concord grape. This period is defined as the end of rapid shoot growth up to veraison. Peaks varied in magnitude depending upon the treatment. Soluble N sources (urea and blood meal) had the highest peaks and legume treatments were lower. However, plant available N from legumes was significantly higher than the control from bloom to veraison. Minimal differences in available N between the two legume treatments imply that one legume did not perform better than the other.

Information collected from temperature gauges placed beneath the soil indicated that peaks in available N were congruent with the soil temperature, a phenomenon related to the metabolic activates of organisms involved in mineralization of organic matter. The same was not true for soil moisture where little variability in soil water was found during the growing season. Moisture, however, must be maintained for grapevine and cover crop growth and microbial needs.

Leaf tissue sampled at bloom and 650-DD for total N infers that there was sufficient N for productive crop growth according to other researchers. Differences between the two sites were apparent based on the age of the vines. The older vines directed N toward vegetative growth while the younger vines partitioned N away from vegetative growth. The result of this was a large difference in yield between the two sites.

Yield and quality indices were influenced by year and site but not by the treatments. The large difference in yield at the commercial site between 2004 and 2005 followed regional production trends. Cold temperatures in early 2004 fated Concords to reduced yields. Like yield, ^{o}Brix was not affected by treatment, but was negatively correlated with yield.

After two years of research, yield, quality, and leaf N concentrations have all been maintained at comparable levels across all treatments. This suggests that the N supplied by cover crops is adequate to meet the plants demands in this production system. Because the control treatment also showed no decrease in yield, quality, or leaf N concentration, we conclude that two years may be an insufficient amount of time to see differences in grape production due to treatment where Concord organs can store large amounts of N for future use. More time will be necessary to observe differences in production based on the treatments.