AN ABSTRACT OF THE THESIS OF

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Abstract approved

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It is estimated that 50-75% of Oregon vineyards cultivate at least every other alley in order to 1) reduce water stress 2) increase vineyard canopy temperatures and 3) increase nutrient availability. Because many vineyards are situated on steep hillsides, frequent tillage could result in increased soil erosion, decreased soil quality and potential pollution of watersheds. Seven cover crop treatments were established at two commercial vineyards in the northern Willamette Valley in the fall of 2003 and monitored for establishment and their impact on grapevines in 2004 and 2005. Treatments were as follows: 1) winter annuals (oats, rye and vetch), 2) clover mix (subclovers, clovers and medic), 3) native grass mix (Willamette Valley upland prairie species), 4) native meadow mix (forbs plus grasses), 5) perennial grass mix (sheep fescue, dwarf perennial rye and hard fescue), 6) resident vegetation, and 7) a clean cultivated control. Each treatment was replicated four times at each of the vineyards in a randomized complete block design. Treatments were applied to four adjacent alleys flanking 8 or 10 vines in three vine rows with one clean cultivated boarder dividing blocks. Cover crop establishment was measured by destructively removing biomass during the growing season. Weeds were sorted from cover crops, and both were dried, weighed and measured for nitrogen (N) content. Over the course of the growing season,

soil water was measured in the vine row and alleys with time domain reflectometry, and midday vine leaf water potential was measured with a pressure bomb. Shoot lengths were measured twice during the season. Vine leaf blades were collected at bloom and veraison for nutrient analysis (N,P,K, S, Ca, Mg, Mn, Cu, B, Zn and Fe). Root samples were taken at bloom and post harvest in the vine row and alley in three treatments (winter annuals, perennial grass mix and clean cultivated) and analyzed for colonization by arbuscular mycorrhizal fungi (AMF). At harvest, fruit yield was measured and fruit quality assessed by measuring soluble solids (BRIX), titratable acidity, pH and N content. Shoot prunings were collected and measured after vine dormancy. We expected to see 1) a higher amount of water in the soil, less vine water stress and more vigorous vine growth in the clean cultivated treatment compared to the others and 2) either an increase in vigor or concentration of N in vine tissues in response to the clover mix treatment.

Biomass production and coverage of the soil by cover crops, as well as responses to treatments in the soil and vine often varied between sites. In general, cover crop treatments, including the clean cultivated control, had little effect on soil water content, vine water status, or vine vegetative growth. There was, however, a clear N affect from the clover mix treatment on vines, even without mechanical incorporation of cover crop residues. Vine leaf N and juice YANC both increased, and yield per vine and cluster weights both decreased in the clover mix treatment. However, the yield reductions were more pronounced in year two and only at one site. The increase in juice N was possibly an indirect effect of the lower yield, concentrating N in the remaining fruit. Results from this two year study indicate no apparent advantage to keeping the alleyways of established vineyards weed free with cultivation.

Influence of Cover Crops on Vine Performance at Two Willamette Valley Vineyards

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Rebecca Marie Sweet, Author

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CHAPTER 1. INTRODUCTION AND LITERATURE REVIEW

Introduction

Information on appropriate cover crops for Western Oregon vineyards is scarce. The cool climate, low soil pH, limiting phosphorus, and infrequent use or availability of irrigation in this region distinguishes it from other wine grape growing regions where most cover crop research has been done. While there is little cover crop information specific for Oregon vineyards, there has been a growing trend towards clean-cultivating vineyard alleys. In the last 3-5 years, it is estimated that 50-75% of Oregon vineyards till at least every other vineyard alleyway (between rows of vines) in order to 1) reduce water competition, 2) increase heat accumulation in the vineyard canopy, and 3) increase nutrient availability (Connelly, pers. comm.). Because many vineyards are situated on steep hillsides, frequent tillage is likely to result in increased soil erosion, decreased soil quality, and pollution of watersheds (Baker and Laflen, 1983; Shipitalo and Edwards, 1998). The Yamhill River Sub-basin Agricultural Water Quality Management Area Plan sets forth state-mandated water quality goals that encourage growers to actively address such soil conservation issues (Yamhill, 2000). The objective of this study was to investigate the influence of seven different vineyard alleyway treatments on Western Oregon vineyards. Specifically, I wanted to know if cover crops competed with grapevines for water and/or nutrients, or if cover crops (particularly legumes) contribute significant N to vines. The ability of each cover crop mixture to out compete weeds was

also assessed. A secondary objective was to explore the feasibility of using Willamette Valley native grasses and forbs as cover crops in vineyards.

Literature Review

Drawbacks and Benefits of Cover Crops

Cover crops are valuable management tools in agroecosystems. They can be used to reduce soil erosion (Hall, 1984; Louw & Bennie, 1991), manage soil water (Blake, 1991; Wyland et al. 1996), help maintain good soil structure and water infiltration (Celette et al. 2005; Morlat and Jacquet, 2003), alleviate soil compaction (Wolfe, 1997), suppress weeds (Elmore et al. 1998), contribute to soil N pools (Jackson, 2000; Ranells & Wagger, 1996), or even immobilize excess soil N (Wyland et al. 1996), enhance soil microfauna populations (Ingels et al. 2005; Mendes et al. 1999), increase functional biodiversity, improve traffic surfaces in wet conditions (Gaffney & Van Der Grinten, 1991) and enhance aesthetics. "Cover crop" is a broad term that can be applied to annuals (green manures) or perennials (permanent swards, living mulches).

Growing cover crops in vineyards can have potential drawbacks, which can vary by site, grapevine genotype, and cover crop species. Deleterious effects can include; decreased vine vigor and yield (Tan and Crabtree, 1990; Wolpert et al. 1993), a perceived greater frost hazard, increased pest presence such as cane borers (Wolport et al. 1993), pocket gophers (*Thomomys* spp.) (Ingels et al. 2005), and increased production costs (Ingels et al. 2001).

Reduced vine growth and fruit yield are often reported with cover crops in vineyards (Celette et al. 2005; Ingels et al. 2005; Rodgiguez-Lovelle et al. 2000a, Sicher

et al. 1995). Such reductions have been attributed largely to nutrient competition. Grass sod in every alley resulted in low juice and petiole N concentrations in grapevines compared to tilled or chemically-weeded treatments (Rodriguez-Lovelle et al. 2000b). Low must N is undesirable as it can result in slow or "stuck" fermentations (Bisson, 1999). Concentrations of N, K, Ca and Mg in vine leaf blades and petioles were reduced by resident vegetation and perennial grass treatments as compared to chemically weeded or clean-cultivated alleys in Italy (Sicher et al. 1995). While neither of the above studies measured water status of the vine, it can be presumed that vine nutrients were affected at least in part by lower water availability to the vines in the cover cropped treatments.

Effects of cover crops that are considered drawbacks at one site may be considered benefits at other sites. For example, cover crops can serve to control excess growth on high vigor sites. Excess vigor leading to fruit shading and high yields over three tons per acre are generally not desirable in the high-quality wine grape industry in Oregon. Canopies that are too vigorous can lead to delayed and irregular fruit ripening, including low BRIX, high acidity and poor color (Jackson and Lombard, 1993). Shaded fruit clusters in overly robust canopies can also lead to increased *Botryis* bunch rot, decreasing wine quality (Smart and Robinson, 1991; Sicher et al. 1995). Compared to chemically-weeded alleys, vines moderately stressed by perennial grass competition exhibited advanced bloom, veraison, and ripening, and yielded higher quality fruit (higher BRIX and lower titratable acidity) (Rodriguez-Lovelle et al. 2000b). However, cluster weights and pruning weights were reduced by the sod treatment. Research in a California vineyard on deep alluvial soils has shown that perennial cover crops

established for four years had no effect on grape yield or quality compared to a tilled control (Ingels et al. 2001).

The perennial nature of grapevines has allowed for exploration of novel cover crop species for use on vineyard floors. Native grasses have been explored for use as covers in California vineyards and were found to out-compete weeds and to re-establish themselves well (Bugg et al. 1996). In an Ohio vineyard, several shallow-rooted, low-growing, perennial ornamentals were studied for their effects on vines, including tall fescue (*Festuca arundinacea*), white mazus (*Mazus japonicus*), English pennyroyal (*Mentha pulegium*), dwarf creeping thyme (*Thymus serpyllum minus*), strawberry clover (*Trifolium fragiferum*), 'Heavenly Blue' veronica (*Veronica prostrata* 'Heavenly Blue'), and a grass mixture of 75% perennial ryegrass (*Lolium perenne*) and 25% red fescue (*Festuca rubra*) (Krohn and Ferree, 2005). Of these, *Mazus* expressed the best combination of high weed-suppression and low competition with vines, as measured by shoot length, cluster size, and single-leaf photosynthesis.

Cover crops can aid in reducing pest damage in agroecosystems. In western Oregon, spider mites are the main above ground invertebrate pests of concern, with damage on the rise (Connelly, 2005). Dusty conditions have been associated with spider mite outbreaks (James, 2002). Growing a summer cover crop can reduce dust while having the added benefit of providing nectar and pollen resources for natural enemies of mites, in particular predatory mites (Prischman et al 2002). In a trial in a California vineyard, the presence of ‘Berber’ orchardgrass during the growing season reduced the presence of thrips, grape leafhoppers, and Willamette mites compare to clean cultivated alleys (Wolpert et al. 1993).

Although invertebrate pests of Oregon vineyards are currently of little consequence, this may change with continued growth of vineyard acreage. It is theorized that biologically diversified agro-ecosystems are less susceptible to pest outbreaks compared to monocultures (Altieri, 1994; Gurr et al., 2003). Several pests of concern are currently managed in other crops grown in western Oregon that are considered moderate to severe pests of grapevines in Washington and California, such as black vine weevil, variegated cutworm, and thrips (Fisher et al. 2003; Flaherty et al. 1992; James, 2002). Maintaining landscape diversity within vineyards with cover crops may be one way to prevent future pest outbreaks.

Effects of Cover Crops on Soil Water

Growing cover crops within vineyards has been limited due in part to concerns about water competition with vines. Although cover crops obviously use water, studies have shown that this may be offset by enhanced water infiltration into soils with vegetated soil surfaces. Celette et al. (2005) found that alleyway soils under perennial grasses had higher water contents during the winter compared to chemically weed-controlled surfaces, an effect presumed to be due to improved water infiltration. Water use by the perennial grass in the alleyway was heavier in the spring than in the summer, which was temporally compatible with the later demands of the grapevine. However, vines within perennial grass treatments showed decreased vegetative vigor despite no differences in vine water stress as indicated by predawn leaf water potential. Water infiltration was 10-50% higher in vegetated surfaces compared to herbicide-treated surfaces in an Ohio ‘Seyval blanc’ vineyard (Krohn and Ferree, 2005). In California’s central valley, infiltration of flood-irrigation waters have been greatly improved by

growing annual ‘Blando’ brome grass as a winter cover crop in ‘Thompson’ seedless vineyards (Gulick et al. 1994). In a sandy clay loam soil with legume cover crops, water infiltration was increased tenfold after five years compared to bare soil (Obi, 1999). In addition, water competition between vines and cover crops may be lessened by the potential differences in rooting depth.

Effects of Cover Crops on Grapevine Water

Grapevine water status can be assessed by measuring predawn leaf, midday leaf, or midday stem water potential, with a high level of correlation between these measurements (Williams and Araujo, 2002). Water potential can be simply defined as osmotic pressure subtracted from hydrostatic pressure (Hopkins, 1995). Leaf water potential measured during the day is the result of both soil water potential and transpiration (Smart, 1974), while leaf water potential measured at predawn is indicative of the soil water potential. As Ψ_{soil} decreases, the risk of breakage of the water column in xylem vessels, known as cavitation, increases, which can permanently disable the vessel. Xylem vessels formed by vines growing under moderate water stress are narrower than those grown with abundant water, decreasing the chances of subsequent cavitation when vines are exposed to water stress (Lovisolo and Schubert, 1998). Older vines may be less vulnerable to cavitation due to their capacity for water storage in the trunk and woody structures (Keller, 2005).

Studies of water stress in vines with and without cover crop treatments have produced variable results. Significantly higher levels of water stress have been measured in vines with associated alleyway plantings of annual cover crops compared to cultivated soil (Pelligrino, 2004). In another study by Ingels et al. (2005), vines with a clover mix

(established for one year) and native grasses (established for two years) in adjacent alleys exhibited a higher degree of water stress compared to vines grown with winter annuals and clean cultivated treatments. However, in the following year there were no differences in midday vine leaf water potential between these treatments. Celette et al. (2005) found no difference in predawn leaf water potential or stomatal conductance between treatments that included well-established perennial grass and herbicide-treated vineyard alleyways. Soil depth may be an important factor in vine water response to a cover crop treatment. Blake (1991) observed that vines growing in soils with higher subsoil clay contents exhibit greater water stress with a grass cover crop than with cultivated alleyways.

Different species of cover crops can use water at different times. Especially in soils with poor drainage, water use by cover crops in wet springs which are often experienced in the western Willamette Valley may be a benefit to vineyards. Conversely, timing of competition for water can be critical in terms of grapevine fruit set and yield. Even a mild water deficit at bloom can limit pollen productivity, pollination and fertilization (Smart and Coombe, 1983). Fruit set was reduced in pot-grown 'Syrah' vines that experienced a moderate soil water deficit in half of the root system, also known as partial rootzone drying or "PRD", at bloom, although no water stress symptoms were visible (Rogiers et al. 2004). However, fruit set may be affected by water stress more when N is also limiting. For example, potted Cabernet Sauvignon vines growing under a water deficit at bloom showed improved fruit set with N supplementation (Keller et al. 1998).

Effects of Cover Crops on Grapevine Roots

Grapevine root distribution can be influenced by the presence of cover crops. Smart et al. (2006) note that several studies have found that clean cultivation or the presence of a grassy inter-row greatly reduces the presence of vine roots in the upper 20-30 cm of soil in the vineyard alleyways, depending on depth of tillage and type of cover crop. At a half meter depth, vine roots were more abundant under the vine row in vegetated treatments than when the alleyway was herbicide treated (Celette et al. 2005), suggesting that alleyway vegetation excluded vine roots. A similar distribution of vine roots in response to an intercrop was also noted by Morlat and Jacquet (2003): Grapevine root density decreased in the alleyway in the upper soil layers in the presence of a perennial grass, but vines appeared to compensate for increased competition by increasing roots in the vine row. In addition, vine roots were found in greater densities on the herbicide-treated alley side of a vineyard with alternate-row cultivation where perennial grass occupied the opposite alley. Root distribution alone, however, may not indicate the resources available to the vine. Grapevine roots are commonly colonized by mycorrhizal fungi, allowing the vine to exploit a larger area of soil than allowed by roots alone.

Effects of Cover Crops on Arbuscular Mycorhizal Fungi (AMF)

Heavy colonization of grapevine roots by mutualistic, arbuscular mycorrhizal fungi (AMF) is common in field soils. AMF have been shown to increase vine drought tolerance (Nikolaou et al. 2003) and aid in uptake of P, Zn, and Cu (Biricolti et al. 1997; Karagiannidis et al. 1995) in grapevines. Grapevines appear to be highly dependant on the mycorrhizal symbiosis (Schreiner 2005a). Grapevines in California planted in

fumigated soil (which killed AMF) showed variable establishment (Menge et al. 1983). After three years of field growth, severely stunted vines, about 50% of the total, lacked AMF colonization, while the roots of vines with normal growth were well colonized by AMF. There is some evidence for N transfer from grass and, to a lesser extent, a legume cover crop to grapevines via AMF hyphae in a pot experiment (Cheng and Baumgartner, 2004).

The negative impact of tillage on AMF is well known (McGonigle and Miller 1993, Douds et al. 1995, Kabir et al. 1997). Frequent tillage of soil breaks apart the hyphal network and often reduces subsequent root colonization of crops. Inter-row tillage can result in reduced AMF colonization of grape roots that can persist for more than one year after the tillage event (Schreiner, 2005b). However, shallow cultivation, which is commonly used for weed control within the vine row, did not effect mycorrhizal colonization of vines in a California vineyard (Baumgartner et al. 2004).

Cover crops grown in annual rotations can increase the number of infective AMF propagules and ensure high rates of AMF colonization in subsequent crops (Boswell et al. 1998, Galvez et al. 1995). Annual cover crops have also enhanced the number of AMF spores found in vineyards compared to alleyways with no vegetation (Baumgartner et al. 2004, Petgen et al.1998). Some plants commonly used as cover crops, such as those in the family Brassicaceae and genus *Lupinus*, are not hosts for AMF and do not enhance AMF populations in the soil. Petgen et al. (1998) found reduced root colonization in Sylvaner grapevines and fewer AMF propagules in plots with mustard cover crops compared with grass or legume cover crops.

Providing N with Cover Crops

Although N is not generally considered a limiting nutrient in most established Oregon vineyards, some sites may benefit from a low rate of N fertilization annually, especially during the first few years of a vineyard's establishment (Campbell and Fey, 2003). Oregon's Low Input Viticulture and Enology management guidelines recommend fertilizing in proportion to annual crop removal and vine growth, ranging from 3.5-20.6 kg N/ha/year (LIVE, 2006). Leguminous cover crops can fix atmospheric N, thereby potentially increasing the amount of nitrogen available in the vineyard without the use of organic or inorganic fertilizers. Subclovers grown in the Willamette Valley have been reported to accumulate an average of 129 kgN/ha. Half of this could be available for crop uptake within the same year if tilled under, providing N far in excess of the recommended input for most Oregon vineyards (Sattell et al. 1998). However, subclovers are usually not incorporated in perennial systems.

Total nitrogen contribution by cover crops depends on the cover crop biomass produced, which can vary widely from year to year in the Willamette Valley. Examples of biomass and N accumulation values from a fall to spring field trial in the mid-Willamette Valley are: hairy vetch, 2.2 tons/ac, 160 lb N/ac; crimson clover, 3.2 tons/ac, 125 lb N/ac; and cereal rye, 3.3 tons/ac, 70 lb N/ac (Sattell et al. 1999). To maximize N availability, cover crops should be killed by mowing, cultivation or herbicide application at the phenological stage when N content is highest in the vegetation, which for most species is early to mid bloom (Sarrantonio, 1998).

The release of plant-available nutrients from decomposing cover crop residues is dependant on soil biological processes, which require adequate soil moisture,

temperature, aeration, nutrients, and pH (Myrold, 1999). Soil water content in Oregon vineyards is largely dependant on seasonal rainfall, and in some cases is controlled by irrigation. Incorporating plant residue by tilling increases the surface area contact of organic residues with the microbe-rich region of the upper soil horizon, therefore accelerating the decomposition process (Wagner and Wolf, 1999). Mowing can also increase the contact area between plant residue and the soil surface by leaving cut residue on the soil surface. Additionally, earthworms can efficiently incorporate mowed plant residues into the soil (Bhadauria and Ramakrishnan, 1996; Lee, 1985), thereby avoiding the need for energy-intensive tillage.

The rate of release of N from cover crop residues is influenced by the C:N ratio of the residue itself. Nitrogen release from hairy vetch (*Vicia villosa*), crimson clover (*Trifolium incarnatum* L.) and cereal rye (*Secale cereale* L.) residues was found to be greatest from those with lower C:N ratios and lower concentrations of cellulose and hemicellulose (Wagger, 1989). The C:N ratio of individual cover crop plant species can be manipulated in the field (Ranells and Wagger, 1996). When grown in a rye/hairy vetch biculture, cereal rye had an average C:N ratio of 24, in contrast to a C:N ratio of 40 when grown in monoculture. Subsequent N release rates were parallel with respective C:N ratios of residues. Cover crop residues with very high C:N ratios can initially be sinks for N due to the immobilization of soil N, but would eventually release N over time as mineralization proceeds (Myrold, 1999).

Synchronizing periods of high vine N demand with cover crop release of N is difficult. This challenge can be addressed by tilling or mowing cover crops at different times during the growing season or by growing cover crop species or mixtures of species

to vary the C:N ratio of residues. Entering vineyards with heavy equipment in the spring, fall or winter is generally not recommended or even possible in western Oregon due to high soil moisture. Most vineyards in this region are located on soils high in clay content, where soil compaction and movement of equipment are concerns in wet conditions. Therefore, growing cover crops with different C:N ratios may be a more practical management technique for Western Oregon. For example, it is possible that growing a recalcitrant cover crop (high C:N ratio) over the winter, mowing it in the spring and allowing earthworms to incorporate the residues throughout the growing season could maximize the N available for post harvest uptake when fall rains increase soil moisture.

Grapevine N

Vine nutrient concentrations vary in any given tissue and can be influenced by several factors including soil type, cultivar, soil water (Keller, 2005), phenologic stage (Conradie 1980; Schreiner et al. 2006), and canopy management (Poni et al. 2003). Vine N demand and partitioning of N within the vine varies throughout the growing season. At budbreak, it has been shown that most of the N required comes from the reserves in the vine storage tissues (i.e. roots, trunk and cordons). As leaves expand and increase in number, and fruits grow and develop, vines shift more toward the soil as the primary N source. For example, about 40% of the N needed by growing shoots in young, pot-cultured vines was accounted for by remobilization from the roots (Conradie, 1980). Another study showed no remobilization of N at all from the roots, but rather 14-26% of the N required for new shoots came from the trunk and cordons (Araujo and Williams 1988). Post-harvest storage of N in woody tissues after leaf-fall can be important for

next year's spring growth of shoots before leaves become photosynthetically productive and can support additional growth (Bates et al, 2002; Conradie, 1980). However, the degree to which canopy demand for nutrients is met by remobilization of stored reserves may depend on soil moisture (Schreiner et al, 2006).

Of particular concern to winemakers is having a sufficiently high level of yeast-assimilable N in musts to meet yeast demands during fermentation. N can move into the grapes after veraison by reallocation from other vine tissues or from the soil. Williams (1987) did not observe any relocation of N from vegetative structures of 'Thompson Seedless' grapevines while cluster N increased, indicating that all the N in the fruit had been taken up from the soil in the current year. However, N remobilization from other vine tissues into the fruit has also been observed (Schreiner et al, 2006). Applications of up to 56 kg N/ha have been recommended for low-N soils of Washington's grape growing regions to increase nitrogenous compounds in juice, although these rates slowed accumulation of sugars in the fruit (Spayd et al. 1994).

In the only nutrient study of mature, field-grown, non-irrigated Oregon vines, N concentration was high (20g/kg dry mass) in fine roots at budbreak, and also from harvest to leaf fall and leaf fall to pruning (Schreiner et al. 2006). Fifty percent of the total canopy demand for N was met via remobilization from stored reserves, with more N moving after bloom than before bloom. Remobilization was more important in dry years for N, K and especially P. Results from this study stand in contrast to previous studies, leading to the conclusion that rain-fed vines may rely on nutrient reserves for longer into the summer than irrigated vines.

Other nutrients that are frequently low in Western Oregon vineyards are B and P (Campbell and Fey, 2003). B deficiencies in grapevines can produce stunted root and shoot growth and a hen-and-chick pattern in the fruit cluster. P deficiencies in vines can be expressed as decreases in leaf expansion and photosynthesis. High levels of N have been shown to decrease P uptake (Spayd et al. 1993), but not always (Keller et al. 1995).

Justification

While the body of literature dealing with cover crops in vineyards worldwide is growing, there are a number of reasons that my experiment was justified. The climate of the Pacific North West is unique among wine grape growing regions, characterized by abundant rainfall from fall to spring, and warm dry summers with cool nights. There is little information on how cover crops affect the nutrient status of vines aside from N. Of particular interest in Western Oregon may be how P is affected by cover crop competition due to low P soils in this region. Of the studies that have been conducted on the competitive effects of cover crops on grapevines, few have examined both vine tissue nutrient concentrations in combination with vine or soil water status. Seed for grassland species native to this bioregion are just now becoming commercially available, making them a new option for alleyway cover in vineyards. Finally, local mandates and third-party certifiers encourage cover cropping as an important part of soil conservation and sustainable viticulture. With this experiment, I began to explore some of the benefits and drawbacks of growing cover crops in Willamette Valley vineyards.

CHAPTER 2. ESTABLISHMENT AND N CONTENT OF COVER CROPS, AND DESCRIPTION OF FIELD SITES AND WEATHER

Materials and Methods

Site Descriptions, Soil Analysis and Weather

Cover crop treatments were established in fall 2003 at two commercial North Willamette Valley vineyards, designated here as AS and JH. Both vineyards are planted with 'Pinot noir' (*Vitis vinifera* L., Pommard clone on 3309-C rootstock) grapevines. The AS vineyard (45 °15'N, -123 °2'W) was planted in 1994 on a 1.8 x 1.1 m. spacing (5123 vines/ha), and is located on a Jory (fine, mixed, active, mesic Xeric Palehumult) silty clay loam soil. The JH vineyard (45 °15'N, -123 °2'W) was planted in 2001 on a 2.4 x 1.5 m. spacing (2690 vines/ha), and is located on a Yamhill (fine, mixed, superactive, mesic Pachic Ultic Haploxeroll) silty clay loam soil.

Chemical analysis of representative soil samples (0-45 cm depth from 72 soil cores, collected June 4, 2004) from each site was conducted by the Oregon State University Central Analytical Laboratory using standard procedures for Western Oregon (Schreiner, 2005). Soil pH was determined in water extracts; $N0_3$ and NH_4 in 1M KCl extracts; P by Bray-1 method; K, Ca, Mg, Na and CEC in 1N ammonium acetate extracts; Fe, Zn, Mn and Cu in 0.025 M DTPA extracts; SO4-S in calcium phosphate extracts; B in hot-water extracts; and OM was determined by the loss on ignition method.

Weather data were obtained from a weather station (45°12'N, -123 ° 2'W), located in McMinnville, OR, about 19 km from either research site (Oregon Climate Service webpage, 2006). Historical precipitation data were also obtained from the station from 1910 to present and temperature data from 1961 to the present.

Cover Crop Treatments Applied

Seven cover crops treatments were applied on 23 and 24 September, 2003. Treatments were arranged in a randomized complete block design with four replicated plots per cover crop treatment. At each site, blocks were oriented east to west, with vine rows running north to south. Treatment plots were placed in the most uniform areas of each vineyard as determined by vine trunk diameter measurements that were recorded in the summer of 2003. Individual treatment plots consisted of four adjacent alleys with three rows of grapevines having the same treatment on both sides. Each plot included 24 vines at AS (8 vines per row) and 30 at JH (10 vine per row). Data were not collected from the first or last vine (border vines) in any row. Each block was separated by a single clean-tilled alleyway on either side, and no data was collected from vine rows bordering this clean alley.

All cover crop treatments consisted of mixtures of multiple plant species in order to ensure good overall establishment and a high degree of functional diversity. Treatments and seeding rates of mixtures were as follows: 1) Winter annuals (WA) 84.1kg/ha, 2) clover mix (CM) 22.4 kg/ha, 3) native grass mix (NGM) 33.6 kg/ha, 4) native meadow mix (NMM) 22.4kg/ha, 5) perennial grass + clover mix (PGCM) 22.4kg/ha and two controls, 6) resident vegetation (RV) and 7) clean cultivated (CC). The individual species and respective seeding rates are shown in Table 1. Cover crop species included within different treatments were selected based on consultation with local Willamette Valley researchers, wine grape growers, and seed company representatives. Species mixtures were chosen based on their function within the agro-ecological landscape. The WA treatment consisted of high-biomass-producing annuals

(legumes and cereal grains) that function to increase organic matter in the soil, establish quickly, and provide nectar resources for beneficial insects. The CM treatment consisted of annual subclovers and medic, chosen for its ability to fix atmospheric N, low-growth habit, tolerance to low mowing and traffic, self-seeding habit, fast establishment and pollen, and nectar resources for beneficial insects. The NGM consisted of perennial grasses native to upland prairie habitats in the Willamette Valley of Oregon, selected for their low-growth habit, summer dormancy, and tolerance to low mowing and traffic. The NMM consisted of the same native grass species from the NGM treatment with the addition of 14 native annual and perennial forbs chosen for their tolerance to low mowing and traffic, summer dormancy, lower growth habit, and nectar and pollen resources for beneficial insects. The PGCM consisted of three perennial turf grasses with the addition of some of the CM N-fixing species to reduce or eliminate the need for N fertilization of the grasses. The grasses in the PGCM treatment were chosen for their low growth habit, tolerance to low mowing and traffic, and summer dormancy. The RV treatment was characterized by a diverse assortment of annual and perennial grasses and forbs, largely of European origins. RV was considered weed biomass for the purposes of this study. The CC treatment was kept weed free during the growing season.

Table 1. Cover crop treatments and seeding rates applied at two N. Willamette Valley Vineyards in Sept. 2003

Treatment	Species	Common Name	Seeding Rate kg/ha
WA	*Secale cereale*	Cereal Rye	28
	Avena sativa	Oat 'Monida'	28
	Vicia sativa	Common Vetch	28/84.1
CM	*Trifolium. hirtum* 'Hykon'	Hykon Rose Clover	4.2
	T. subterraneum ssp. *subterraneum* 'Mt. Barker'	Mt. Barker Sub Clover	4.2
	T. subterraneum ssp. *yanninicum* 'Riverina'	Riverina Sub Clover	4.2
	T. subterraneum ssp. *subterraneum* 'Campeda'	Campeda Sub Clover	4.2
	T. resupinatum 'Nitro'	Nitro Persian Clover	4.2
	Medicago polymorpha 'Santiago'	Santiago Burr Medic	4.2/22.4
NGM	*Koeleria macrantha*	prarie junegrass	15.7
	Danthonia californica	California oatgrass	2.4
	Festuca roemeri	Roemer's fescue	13.5
	Elymus glaucus	blue wildrye	2.4/33.6
NMM	*Achillea millifolium*	common yarrow	0.5
	Lomatium utriculatum	spring gold	1.0
	Sidalcea malviflora ssp. virgata	rose checker mallow	1.4
	Eriophyllum lanatum	Oregon sunshine	1.0
	Prunella vularis var lanceolata	self heal	1.0
	Lupinus micranthus/bicolor	annual lupine	1.4
	Trifolium tridentatum	tomcat clover	1.4
	Madia elegans	showy tarweed	1.4
	Clarkia purpurea	purple godetia	0.5
	Clarkia amoena	fairwell to spring	0.5
	Agoseris grandiflora	large-flowered agoseris	1.4
	Gilia capitata	common gilia	1.0
	Lotus pershianus	Spanish clover	1.0
	Collomia grandiflora	large flowered collomia	1.4
	Koeleria macrantha	prarie junegrass	3.5
	Danthonia californica	California oatgrass	0.5
	Festuca roemeri	Roemer's fescue	13.5
	Elymus glaucus	blue wildrye	0.5/22.4

Table 1. (continued)

PGCM	*Lolium perenne* 'Essence'	dwarf elf ryegrass	5.2
	F. ovina var. duriuscula 'Ridu'	hard fescue 'Ridu'	5.2
	Festuca ovina 'Quatro'	sheep fescue 'Quatro'	5.2
	Trifolium. hirtum 'Hykon'	Hykon Rose Clover	1.1
	T. subterraneum ssp. *subterraneum* 'Mt. Barker'	Mt. Barker Sub Clover	1.1
	T. subterraneum ssp. *yanninicum* 'Riverina'	Riverina Sub Clover	1.1
	T. subterraneum ssp. *subterraneum* 'Campeda'	Campeda Sub Clover	1.1
	T. resupinatum 'Nitro'	Nitro Persian Clover	1.1
	Medicago polymorpha 'Santiago'	Santiago Burr Medic	1.1/22.4

All plots were cultivated in mid-September 2003 to prepare a seedbed. At AS, cultivation was accomplished by tilling with a spader to approximately 20 cm, followed by a shallow rototilling to a depth of 10 cm. At JH, alleyways in the CC treatment were disked to a depth of about 15 cm. Seeds were hand broadcast and incorporated by passing over the plots with the roller of an empty drop-seeder. Seeds in the WA treatment were also raked in by hand to achieve a greater planting depth (~2 cm). Legumes were inoculated with appropriate rhizobia in the first year. The WA treatment was cultivated and re-seeded on 7 Oct. 2004 as per 2003. Native annual forbs (*Clarkia amoena, C. purpurea, Collomia grandiflora, Madia elegans, Trifolium tridentatum, Gilia capitata* and *Lotus pershianus*) were also reseeded in the NMM treatment at AS in 2004 because flowers had been mowed during the growing season, preventing natural reseeding. Vine rows were kept weed free during the growing season at AS by cultivation with a grape hoe, and at JH by glyphosate (2004) or cultivation (2005).

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

Cover Crop Establishment and Percent Cover

Digital photographs of alleyway vegetation were taken one day prior to each mowing date, at a height of 1.5m above plots. The percentage of the soil surface area covered by vegetation within a 0.25 m^2 quadrat was estimated from these photos using a calibrated template representing 4% of the quadrat area. Weeds and cover crops were not differentiated in this process, and the CC treatment was not included.

Cover Crop Biomass and Nitrogen Content

Alleyway biomass was estimated just prior to each mowing date by cutting the vegetation at a height of 10 cm within two randomly placed 0.25 m^2 quadrats in adjacent alleys of each experimental plot. Weeds and cover crops (above 10 cm) from each quadrat were separated, dried at 70^o C for 48 hours, and weighed. Dried weed and cover crop residues from both quadrats were combined into a single sample and ground in a Wiley Mill to pass through a 20 mesh (850 μm) screen. The nitrogen concentrations of ground residues were determined by combustion analysis (TruSpec Elemental Determinator, Leco Inc., St Joseph, MI, USA). Total N content of mowed residue above 10 cm for each plot was determined by multiplying N concentration by dry mass. Weeds and cover crops were combined because this reflected the actual N made available in each plot.

Statistical Analysis

Percent cover was analyzed by ANOVA using a general linear model with cover crop treatment, year, and site as factors (See Table 21 in Appendix). Site was designated as a random factor. Means were compared using Tukey's post-hoc test at 95% confidence. All other variables violated assumptions of variance, and could not be corrected with transformations. These variables were analyzed using the nonparametric, Kruskal-Wallis ANOVA by ranks test. Since the primary interest was to test whether cover crop treatments affected vegetation in the alleyways, the effect of cover crop treatment on cover crop and weed biomass, percent weeds, total biomass and total N was assessed with sites and years combined. To test whether response to cover crop treatment was different between years, the effect of cover crop treatment on the change in these variables (cover crop and weed biomass, percent weeds, total biomass and total N) from 2004 to 2005 was tested. Because biomass sampling was not done with equal frequency at each site, and the second of two samples at AS in 2005 was lost in an oven fire, only the first sample date was used in the analysis of biomass (AS- 18 April 2004 and 1 April 2005; JH- 20 May 2004 and 1 May 2005). Although mowing dates differed at each site, the initial mowing date in each year reflected the majority of biomass accumulated over the winter and spring. For example, over 80% of the clover biomass was cut at the first mowing in a given year. Although the NGM, NMM, and PGCM treatments tended to have slightly higher biomass values later in the summer than in the first spring mowing, their biomass values were never substantial compared to the CM and WA treatments.

Results

Weather and Soil Analysis

Monthly rainfall and the average daily high temperatures for each month during the growing season in 2004 and 2005, along with the historical averages for these measurements are shown in Table 2. In 2004, rainfall was slightly lower than the historical average in June and July, higher than the historical average in August, and similar to the historical average in September. In 2005, rainfall was much higher than the historical average in June, average in July, and slightly lower than average in August, and September. However, the sum of June through Sept rainfall in both years of this study was very similar to the historical average. 2004 had warmer than average air temperatures in June, July and August but not in September. In 2005, temperatures were also warmer than average in July and August but June and September were slightly lower than average. Overall, for the months of June-September (the primary growth period for grapevines), both years in which this experiment was conducted had normal rainfall and normal temperatures.

Table 2. Summer rainfall and average daily high temperature at McMinnville, OR In 2004 and 2005

Year	Precip (in)					Max Temp (^{o}F)				
	Jun	Jul	Aug	Sept	Total	Jun	Jul	Aug	Sept	Average
2004	1.5	0.0	4.1	3.6	9.1	25.0	29.3	28.7	22.5	26.4
2005	6.6	0.7	0.5	0.7	8.5	21.4	29.4	30.1	24.1	26.3
Hist Avg*	2.8	1.0	1.3	4.0	9.1	23.9	28.0	28.2	25.1	26.3

* 1910-2005 for rainfall, 1961-2005 for temperature

Soil at the two sites were slightly different in chemical composition (Table 3). Most notably, K was 57% greater at AS than at JH. Levels of Ca and Mg were higher at JH than at AS. Soils were high in organic matter (OM) and low in available P, which is typical for western Oregon.

Table 3. Soil chemical properties at two north Willamette Valley vineyards

	AS	JH
P (ppm)	13	9
K (ppm)	366	223
Ca (meq/100g)	6.2	9.3
Mg (meq/100g)	3.5	3.4
Na (meq/100g)	<0.1	<0.1
B (ppm)	0.7	0.4
Cu (ppm)	1.3	1
Mn (ppm)	33	52.5
Fe (ppm)	24.4	34.3
Zn (ppm)	5.6	1.2
SO4-S (ppm)	24.5	7.8
pH	6.3	5.9
%OM	9.82	8.23
CEC	18.8	20.3
C (%)	1.68	1.56
N (%)	0.13	0.14

Percent Cover and Cover Crop Species Frequency

Percent vegetation cover in my plots was affected by an interaction between site and year (Table 4). The percentage of surface area covered by vegetation increased at JH from 2004 to 2005 and did not change at AS with years. Overall, the percent cover was high, ranging from 76% in the RV treatment at JH in year one, to100% in the CM, NGM and PGCM treatments at various times and sites. Percent vegetation cover was not significantly affected by treatment as a main effect.

The frequency of occurrence of individual species in the cover crop mixtures was never objectively quantified. However, the following subjective observations were made: Common vetch in the WA treatment was infrequently observed, though rye and oats did well. In the CM treatment, subclovers, medic and clovers performed equally well, producing abundant flowers in the spring and early summer. In the NGM treatment, *Festuca roemerii* and *Koeleria macrantha* dominated the mix, and Elymus species were occasionally observed although not identified to species. The slow-to-establish *Danthonia californica* was never identified, although this does not indicate with certainty that it did not establish at some level. Several native forbs (*Clarkia purpurea, C. amoena, Gilia capitata, Lotus pershianus, Madia elegans,* and *Lupinus micranthus*) in the NMM treatment bloomed abundantly in year one (2004) despite early mowing, although their establishment overall was variable across each site. Native annual forbs did not reestablish themselves well in the second year (2005) at JH, where they were allowed to go to seed naturally, or at AS, where supplemental annual seed was distributed in the fall of 2004. Commonly observed native forbs in the NMM treatment were; *Achillea millefolium*, *Prunella vulgaris var lanceolata*, *Lupinus bicolor*, *Clarkia amoena*,

Clarkia purpurea, *Gilia capitata*, and *Madia elegans*. Less frequently observed species were; *Lotus purshianus, Sidalcea virgata* and *Eriophyllum lanatum. Lomatium utriculatum* and *Collomia grandiflora* were rarely observed in any plots. All of the sown native forbs were identified in the vineyards except *Agoseris grandiflora* and *Trifolium tridentatum,* possibly due more to their similarity to common dandelion and clover-type weeds than to lack of establishment.

Table 4. Percent vegetation cover in alleyway at two N. Willamette Valley vineyards at first mowing

Treatment	AS		JH	
	2004	2005	2004	2005
WA	95.0 (2.9)	81.3 (3.1)	83.8 (9.0)	80.0 (4.6)
CM	100.0	98.8 (1.3)	100.0	100.0
NGM	98.8 (1.3)	100.0	85.0 (8.9)	97.5 (1.4)
NMM	92.5 (1.4)	98.8 (1.3)	82.5 (5.2)	95.0 (2)
PGCM	100.0	100.0	100.0	100.0
RV	98.8 (1.3)	96.3 (2.4)	76.3 (4.3)	91.3 (1.3)
Avg. Cover*	97.5 (0.8) a	95.8 (1.5) a	87.9 (2.8) b	94.0 (1.6) a

Means followed by standard errors in parenthesis. *Average value of all treatments, values followed by the same letter are not significantly different (Tukey's $p<0.05$).

Cover Crop Biomass

Significant differences among cover crop treatments were found for cover crop biomass, total biomass (CC+ weeds), percent weeds, and total biomass N (Table 5). Weed biomass, however, was not different among treatments. Cover crop biomass above 10cm was greater in the WA and CM treatments compared to the NGM and NMM treatments. Total biomass (cover crops + weeds) above 10cm showed a similar trend, with WA and CM treatments producing more biomass than in NGM, NMM and RV treatments with the PGCM treatment falling between these groups (Table 5). Weeds as a percent of the total biomass were greater in the RV and NGM treatments than in the CM

or WA treatments. Biomass N was greater in the CM treatment than the NGM, NMM and RV treatments. At both sites, leguminous weeds (vetches and clovers) were common, with patchy distribution in all treatments, and may have made substantial contributions to biomass nitrogen measurements where present, although the RV treatment does not indicate this.

Cover crop treatment significantly effected the change in total biomass, cover crop biomass, percent weeds and biomass N from 2004 to 2005. The change in cover crop biomass from 2004 to 2005 showed that the PGCM and NGM increased to a greater degree than the WA treatment, which actually decreased. From 2004 to 2005, total biomass followed cover crop biomass trends, increasing in the PGCM, NGM and NMM treatments, and decreasing in the WA treatment. The percentage of biomass as weeds above 10 cm showed changes from 2004 to 2005 such that percent weed biomass in the NGM was reduced by 62%, which was a greater change than found in the NMM or the WA treatments, the latter having had a low percentage of weeds in year one. Biomass N increased in the PGCM and CM treatments from 2004 to 2005, which was significantly different from the decrease observed in the WA treatment.

Table 5. Cover crop and weed biomass, weeds as % of total, and biomass N in 2004 and 2005, and the change in these data from 2004 to 2005 (years and sites combined)

Variable	WA	CM	NGM	NMM	PGCM	RV	P value
CC biomass kg/ha	2247a	1668ab	316c	218c	887bc		<0.001
Δ CC biomass kg/ha	-2078b	148ab	632a	14ab	1077a		<0.001
weed biomass kg/ha	197	383	421	281	386	566	0.232
Δ weed biomass kg/ha	-211	-493	-281	95	-259	-577	0.135
Total biomass kg/ha	2444a	2051a	737b	498b	1272ab	566b	<0.001
Δ Total biomass kg/ha	-2289b	-345ab	351a	109a	818a	-577ab	<0.001
% weeds	6d	18cd	69ab	58abc	47bc	100a	<0.001
Δ % weeds	-4a	-14ab	-62b	9a	-35ab		<0.01
N kg/ha	36ab	66a	15bc	22bc	40ab	5c	<0.001
Δ N kg/ha	-25b	34a	12ab	-11ab	39a	1ab	<0.01

Means followed by the same letter for each variable (across rows) are not significantly different (Kruskall-Wallis $p<0.05$)

Discussion

There were clear differences between the two vineyards where I conducted this trial based on the soil analysis data. According to the OSU soil test guidelines (Marx et al. 1999), available phosphorus at both sites was low, with JH lower than AS. Potassium and sulfate-S were both high at AS and Mg was low at both sites. Boron and zinc were low at JH. Manganese levels were higher at JH than at AS, however both were within what is considered an adequate range.

Weather patterns during the 2004 and 2005 growing seasons were comparable to historical averages. The sum of rainfall during the summer of 2004 and 2005 growing seasons were very similar to historical averages (1910-2005), although these years may have been perceived of as wet years, due to the fact that the four previous years had been relatively dry. August rainfall in 2004 may have been high enough to regard that month as atypically wet for the northern Willamette Valley. June 2005 experienced an above average amount of rain, which may have charged the soil to a higher degree than normal, although this was followed by a September which was drier than the historical average.

Temperatures averaged over the summer were very similar to the historical averages (1961-2005). In 2004, June, July and August were slightly warmer than average, while September was cooler. In 2005, June and September were slightly cooler than average and July and August were slightly warmer. Based on these data, it can be argued that the 2004 and 2005 growing seasons were fairly typical for the northern Willamette Valley.

Soil surface coverage showed variation by an interaction between site and year. The fact that average cover increased from 2004 to 2005 at JH but not at AS may have been due to 1) less weed pressure at JH as indicated by the average RV values, 2) less vigor in general at JH leading to slower establishment, or a combination of these factors .

In this study, biomass produced by the WA treatment ranged from $\bar{x}$ 1000-3500 kg/ha averaged across plots at a given site and year (data not shown), with biomass values much lower in the second year than the first. The poorer establishment of the WA treatment in 2005 was likely due to the cool weather at the time of reseeding (Oct 7), which was unfavorable for germination. Generally it is recommended that cover crops be sown no later than the third week of September in western Oregon (Sattell, 1998), however, coordination with growers at the time of harvest was difficult and that goal was missed. Our WA biomass values were lower than values from the same species when grown in monoculture in California vineyards, which averaged about 10,000 kg/ha (Bugg et al. 1996). However, treatments were irrigated in that study in order to encourage germination. Winter annual cover crop values in this study were slightly lower than those reported in the Willamette Valley of 3000-9000 kg/ha (Sattell et. al. 1998). Our clover mix treatment produced biomass with a range of $\bar{x}$ 900-2600 kg/ha averaged across plots at a given site and year. Subclovers and medics have been reported to accumulate an

average 8000 kg/ha (Bugg et al. 1998), while 5600 kg/ha has been reported for subclovers in the Willamette Valley (Sattell et al. 1998). It is unsurprising that biomass accumulation was lower in this experiment than those reported elsewhere due to the likelihood of substantial fertility differences between hillside vineyard soils and valley soils where most cover crop research has been conducted.

The NGM, NMM, and PGCM treatments accumulated very little cover crop biomass above 10 cm in the first year, which was not surprising given that they were perennials and chosen for their short stature. The establishment of the NGM, NMM and PGCM treatments is more appropriately discussed in terms of weed biomass and percent cover rather than cover crop biomass production alone. The percentage of total alleyway biomass attributed to weeds was significantly less in 2005 than in 2004 within the NGM treatment only. Weed biomass went from 100% to 52% at AS, and from 100% to 22% at JH. This pattern in which native grasses produce very little biomass in the first year and more in the second due to their slow growth rates is similar to observations made in upland prairie restoration efforts in the Willamette Valley (Wilson, B., pers comm). The NMM treatment ranked highest among all treatments in percentage of weed biomass in 2005 at both sites, with AS containing 74% weeds and JH containing 51% weeds. The PGCM treatments at AS went from 68% to 8% weeds and at JH from 57% to 25% between 2004 and 2005. Much of the biomass in the PGCM treatment consisted of clovers at both sites, due to the highly successful establishment of this portion of the seeded treatments. This is supported by observations made in the field and by the higher N contribution of this treatment than expected for perennial grass alone. The percent cover in the PGCM treatment was 100% in both years at both sites.

Patterns in total alleyway biomass (cover crops + weeds) above 10cm were similar to those in cover crop biomass data. Additionally, in most cases, total kg N/ha accumulated in each treatment paralleled the total biomass measured, and likely reflected the species composition of each treatment. For example, had the vetch portion of the WA treatment established more successfully, the N content of that treatment would have probably been greater. Likewise, had the clover component of the PGCM treatment not established itself so successfully in contrast to the perennial grasses, the overall N content would probably have been less. Leguminous weeds were abundant at each site, which likely contributed to unexpectedly high N values, such as in the native meadow treatment at JH. It was not surprising to find that the CM treatment contributed the largest amount of N at both sites.

The highest cover crop + weed biomass N values at AS (clovers $\bar{x} = 86$ kg/ha; and winter annuals $\bar{x} = 51$ kg/ha) are slightly lower than other reported N values for these species of 129kg/ha and 85kg/ha, respectively (Sattell et al. 1998). This may be explained by the lower fertility of hillside soils in contrast to the valley soils where that work was conducted. Recommended N fertilization rates for grapevines in Oregon are 5.6-11.2 kg N/ha/year to maintain vigor and 11.2-33.6 kg N/ha/year to increase vigor (Campbell and Fey, 2003). Other guidelines suggest fertilizing in proportion to annual crop removal and vine growth, ranging from 3.5-20.6 kg N/ha/year (LIVE, 2006). Of the cover crop treatments in this trial, only the resident vegetation (5 kg N/ha) fell into the lower end of the recommended levels. The native grass and native meadow treatments fell into the mid range (15 kg N/ha), and the winter annual and clover treatments provided N in excess of this recommendation (31.5 and 53.5 kg/ha). However, only a

small portion of the N contained in cover crop residues becomes available for vine uptake and quantities are difficult to predict.

Conclusions

Despite differences in site soil characteristics, cover crop treatment was the most important factor in dictating the amount of biomass and the total N contributed to plots. The two highest biomass producers were the WA and CM treatments, although the WA treatment was more susceptible to unsatisfactory seed germination conditions which resulted in lower biomass values for that treatment in year two. In addition, even when the WA biomass values were highest among all other treatments, the percent cover was not necessarily the greatest, ranging from 84-95% cover. This indicates that although the WA treatment can be an excellent biomass contributor, it may not function as well at reducing erosion. The CM treatment reestablished itself very well without reseeding, and produced more biomass even than the WA treatment in the second year at AS. In both years and at both sites the CM treatment provided excellent coverage of the ground surface. The CM treatment contributed the most N per hectare of all treatments at each site, which could potentially provide N in excess of recommended fertilization rates for Oregon vineyards.

The perennial treatments (NGM, NMM and PGCM) were better established in year two than in year one, as indicated by lower weed biomass. The NGM treatment had established itself very well by the second year, indicating that it may be a viable new cover crop option for vineyards in western Oregon. In the NMM treatment, of the eighteen species of native grasses and forbs sown, sixteen were observed between the two

sites over both years. These were observed with highly variable degrees of frequency, however, with native annuals generally less frequent in year two than in year one. The NMM treatment was the least effective in out-competing weeds. The PGCM treatment provided excellent ground coverage at both sites in both years and contained a moderate percentage of weeds compared to the other treatments. The RV treatment ranked the lowest among all treatments in biomass production and in N contribution to the vineyard.

CHAPTER 3. SOIL WATER AND VINE RESPONSE

Materials and Methods

Soil Water Content

Volumetric soil water content was determined every two weeks from late June to early September in each year using time domain reflectometry (TDR, Trase System, Soil Moisture Equip. Corp., Santa Barbara, Ca). In the spring, two sets of 45 cm wave guides were installed in all treatment plots at both sites except the RV treatment, and left in place throughout the growing season. One set of wave guides was located in the vine row (25cm from the vine trunk at AS and 30 cm from the vine trunk at JH), and the other set was located in the middle of the alley (directly across from the vine row set).

Vine Water Status

Midday leaf water potential was measured biweekly during the growing season, weather permitting, using a pressure chamber (Model 610, PMS Instrument Company, Corvallis, OR, USA). Between 1230 and 1430h, one fully expanded leaf with full sun exposure per plot was located in the canopy. A plastic bag was placed over the leaf and the petiole was cut near the shoot with a razor blade. The leaf was immediately secured in the pressure chamber. The chamber was then slowly pressurized until sap flowed out of the cut petiole. Readings were recorded at the instant sap became visible on the cut surface.

Vine Nutrient Status

Vine leaves were collected from 15 vines per replicate treatment (five vines per treated row) from opposite-cluster nodes at bloom and veraison. Leaf blades were separated from petioles and both tissues were rinsed in distilled water, dried at 70 ^{o} C for

48 hours, and ground separately in a Wiley mill to pass through a 40 mesh screen for nutrient analysis. Carbon and N was determined via combustion analysis (TruSpec Elemental Determinator, Leco Inc., St Joseph, MI, USA). P, K, S, Ca, Mg, Mn, Cu, B, Zn, Fe were measured by ICP-OES after dry-ashing samples (Perkin Elmer Optima 3000DV, Wellesley, MA, USA) by the Central Analytical Lab (Oregon State University). Due to the high cost of analysis, ICP analysis was conducted only on leaf and petiole samples collected from AS in 2005, where cover crop establishment was more uniform.

Vine Vigor and Phenology

Grapevine phenological stages (budbreak, bloom, veraison, harvest, leaf-fall) were recorded throughout the year at both sites. Shoot lengths were determined twice in each season (AS: 4 May and 17 June 2004, 1 June and 27 June 2005. JH:13 May and 17 June 2004, 9 June 2005) on three vines per replicated treatment, one in each treated row, before hedging. In 2005 at JH, shoot lengths were measured only once before hedging occurred. Two shoots per vine were measured at the 2^{nd} and 6^{th} nodal position from the trunk head. Successive measurements were always conducted on the same vines. Dormant season pruning weights from nine vines per replicate treatment were determined in the winter of 2004 at both sites. In 2005, crews at each site pruned prior to our knowledge. In that year at JH, all pruned biomass was immediately removed after pruning and was therefore not measured. At AS, prune weights were obtained by averaging the weights of pruned shoots from five adjacent vines per treatment plot giving one measurement per plot.

Roots and AMF colonization

Vine root samples were collected at bloom and after fruit harvest from three treatments (WA, PGCM and CC) and two locations (vine row and alley) at each site. Three soil cores (5.7 cm diameter, 0-45 cm depth) were removed from the vine row and from the alley in each plot and pooled. Soil from each location was stored at 4^{o} C for up to 5 weeks before processing.

Two methods were used to obtain roots from the soil. In 2004, grapevine roots were carefully hand-picked from small aliquots of soil and stored in cold tap water until all of the soil was processed. In 2005, roots were retrieved by a wet-sieving method (Böhm, 1979) in an effort to improve recovery of fine roots. Soil samples were placed in a large bucket and covered with cold tap water. The soil-water suspension was stirred vigorously and one-third of the suspension was poured over a 1mm sieve at a time. Roots and other organic debris caught on the sieve was gently rinsed and then transferred to a white tray where grapevine roots were removed with tweezers. Roots obtained by handpicking from soil (2004) or from washed soil samples (2005) were sonicated for 30 seconds in a water bath sonicator (Ultrasonic LC 60, Lab-Line Instruments Inc., Melrose Park, IL, USA) and rinsed over a 500μm sieve to remove adhering soil particles. Roots were then separated into woody and fine root fractions under a stereomicroscope in water. Vine roots were distinguished from roots of other plants based on size, texture and color. All woody roots were included in a single fraction, with small diameter roots being distinguished from fine roots by the loss or collapse of the cortex. Fine roots were defined as primary roots with an intact cortex varying in color from white to brown. Both woody and fine root fractions were blotted dry on paper towels and fresh weights were

recorded. The length of woody roots was measured with a ruler. Fine roots were stored in FAA (formaldehyde/acetic acid/ethanol, 5%:10%:50%) for up to two months before clearing and staining to evaluate AMF colonization. Roots were cleared using KOH and H_2O_2 and stained with trypan blue, as in Schreiner (2003).

Fine root length was determined by the gridline intercept method (Newman, 1966). Colonization of fine roots by AMF was determined on randomly selected root fragments using the method of McGonigle et al. (1990) as modified by Schreiner (2003). The proportion of fine root length containing AMF hyphal structures was counted, with a separate count of arbuscules.

Fruit Yield and Quality

Fruit samples were collected 1 to 3 days before commercial harvest. All fruit clusters were removed from six vines per plot, counted, and weighed. Average cluster weights were calculated by dividing the total yield per vine by the number of clusters. Representative subsamples were transported to the laboratory in coolers, stored at 4^{o} C, and processed within 2 days. Three representative clusters per plot were used to assess juice quality. Berries were removed by hand and pressed with a small hand-crank press to obtain 0.625 ml juice/g cluster weight. Juice soluble solids (^{o}BRIX) were measured with a hand-held refractometer (Leica Microsystems, Buffalo, NY) and pH was determined with a pH meter. Titratable acidity was determined by pipetting 10 mL juice into 40 mL distilled water in 100 mL beaker and titrating with 0.133 N NaOH to an endpoint pH of 8.1. Normality of NaOH solution was checked by titrating a KH_2Phthalate solution to a final pH of 8.1. Subsamples of juice were stored at -20 ^{o} C for analysis of yeast assimilable N content (YANC). In year one (2004), YANC was determined only at AS,

while YANC was determined at both sites in 2005. Ammonia-N in the must was determined by the enzymatic ammonia method as described by Bergmeyer and Beutler (1990). Amino-N in the must was determined by the NOPA method as described by Dukes and Butzke (1998). YANC is the sum of ammonia-N and NOPA-N.

Data Analysis

All data were analyzed by ANOVA using the general linear model with site regarded as a random factor, and with block included in the model as a main effect only. Variables that violated assumptions of homogeneity of variance (Cochran's), even after various transformations, were analyzed using the non-parametrics Kruskal-Wallis ANOVA by ranks (main effects only). Soil water in the vine row and alley, leaf Ψ, and leaf N were analyzed using date, site, and cover crop treatment as factors (see Tables 22-26 in Appendix). Data on vine leaf blade nutrients at bloom and veraison, besides N, were analyzed by ANOVA with date, treatment and block as factors. Grapevine shoot lengths and pruning weights were analyzed three separate ways due to imbalanced data sets. In order to evaluate the effect of year, data from both years at AS were evaluated by ANOVA with date (shoot lengths) or year (pruning weights), treatment, and block as factors. To look at the effect of site, data from both sites in 2004 were evaluated by ANOVA with date (shoot lengths), treatment, site and block as factors (Tables 27-30 in Appendix). Finally, to see if treatment affected shoot lengths or pruning weights on any given sample date at either site, ANOVA was used to evaluate each date at each site individually, with treatment and block as factors. Grapevine fruit yield per vine and cluster weights were evaluated two ways; with Kruskall-Wallis ANOVA by ranks with site, year and treatment as factors (Table 40 in Appendix) and with ANOVA at each site

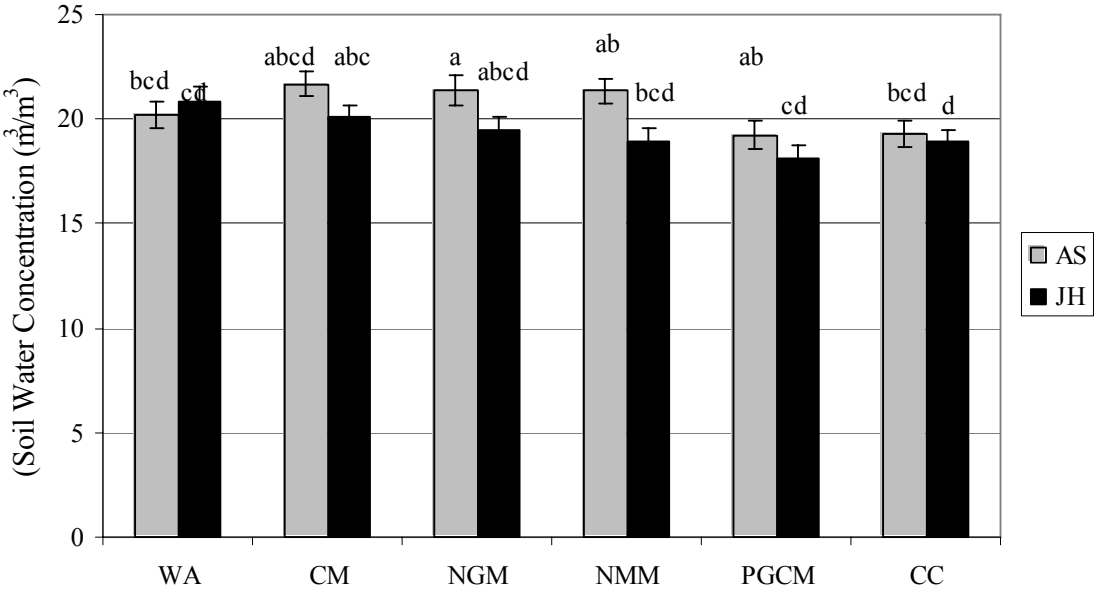
in each year. Fruit soluble solids (BRIX), titratable acidity (TA) and pH were all analyzed with ANOVA, with site, year, treatment and block as factors (Tables 31-33 in Appendix). Juice NH_4, N-OPA and YANC were all analyzed two ways due to imbalanced sampling; ANOVA was conducted using 2004+2005 data at AS only to evaluate the effect of year (year, treatment and block as factors), and ANOVA was conducted using AS+JH data in 2005 only to assess the effect of site (site, treatment and block as factors; Tables 34-39 in Appendix). Additional single-factor ANOVAs were used on soil water, shoot length and pruning weight data on single date/site combinations with treatment as a factor. Measurements of grapevine roots and AMF colonization in the vine row and in the alley were evaluated by Kruskall-Wallis with date, year, site, treatment and block as factors. The vine row and alley locations were compared with a separate Kruskall-Wallis analysis with location as a factor. Post hoc comparisons were made with Tukey's test (ANOVA) or multiple comparisons of mean ranks for all groups (Kruskall-Wallis). Correlation analyses were performed on leaf nutrient, cover crop N, vine pruning weight, vine cane length, and vine AMF colonization data to identify significant relationships between treatments and vine parameters. For all figures and text, weighted mean values and the standard error of the mean are presented.

Results

Soil Water Content

Soil water content in the alley was significantly influenced by interactions between site and cover crop treatment, and between site and date. The main effect of cover crop treatment on soil water content was not significant. Soil water content did not respond to treatments in a similar fashion between the two sites in the alley ($p<0.05$, Fig1.). Soil water content in the CM treatment at AS was higher than the CC treatment at both sites. In addition, soil in the CM treatment contained more water than the NGM, NMM, and PGCM treatments at JH. Volumetric soil water in the alley also varied by site and date, with soil water at JH generally being lower than AS, although JH was higher than AS in the early part of 2004 ($p<0.001$).

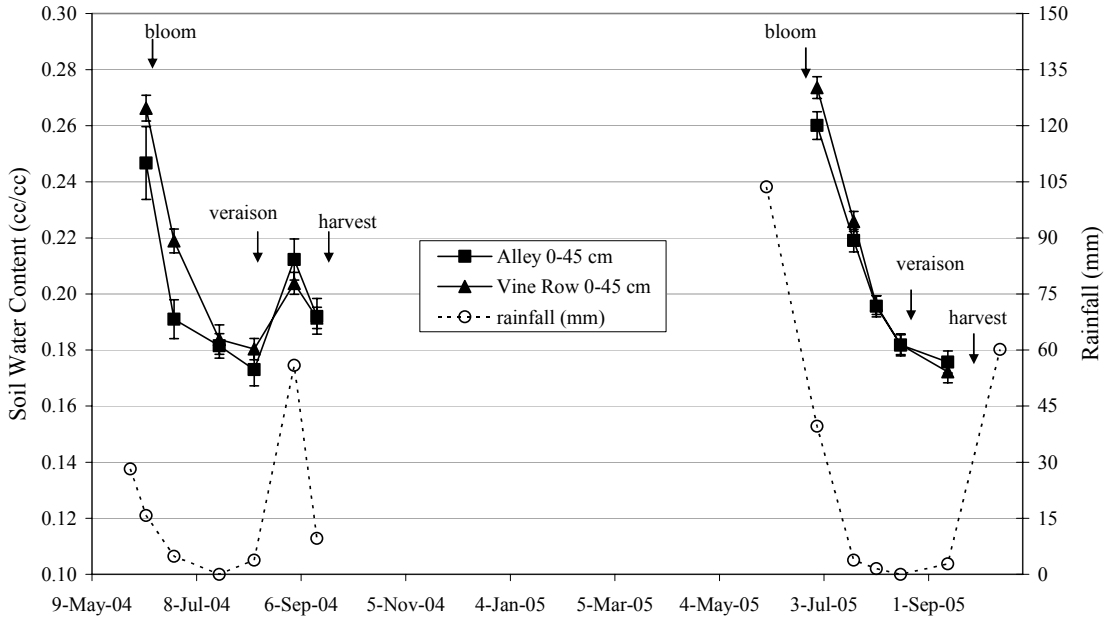
Figure 1. Volumetric soil water content in alleyway at two N. Willamete Valley vineyards, all sample dates combined over 2004 and 2005 growing seasons



Bars indicate standard error of the mean. Means with the same letter are not statistically different (Tukey's $p<0.05$)

Soil water in the vine row was most strongly affected by date. Within vine rows, soil water content was not significantly different among cover crop treatments. However, a treatment by date interaction ($p<0.05$) revealed that soil water content responded differently to some treatments depending on the date, although differences were minor and fell well within the 2% margin of error of the measurement technique, as defined by the manufacturer of the instrument (Trase TRD Operating Instructions). An additional interaction between treatment and site indicated higher soil water content in the CM treatment at AS than at JH ($p<0.001$) in the vine row, although again these differences were small (AS CM $\overline{x}$ =0.25cc/cc, JH CM $\overline{x}$ =0.19cc/cc). Vine row soil water showed a significant site by date interaction ($p<0.001$), such that soil water content was higher in the beginning of the season at JH than at AS, but by the end of the season soil water content was lower at JH than at AS. Again, differences were small and likely fell well within the margin of measurement error. Overall, water content decreased in all treatments in both locations over the season, but the late season rainfall in 2004 caused a spike in soil water content (Fig 2). It is noteworthy that volumetric soil water content was never significantly different among cover crop treatments at either site in the vine row or alley on any given sample date, and that the CC treatment did not have higher soil water content than any cover cropped treatment.

Figure 2. Soil Moisture & Rainfall Patterns at two N. Willamette Valley vineyards in 2004 & 2005 (sites & treatments combined)

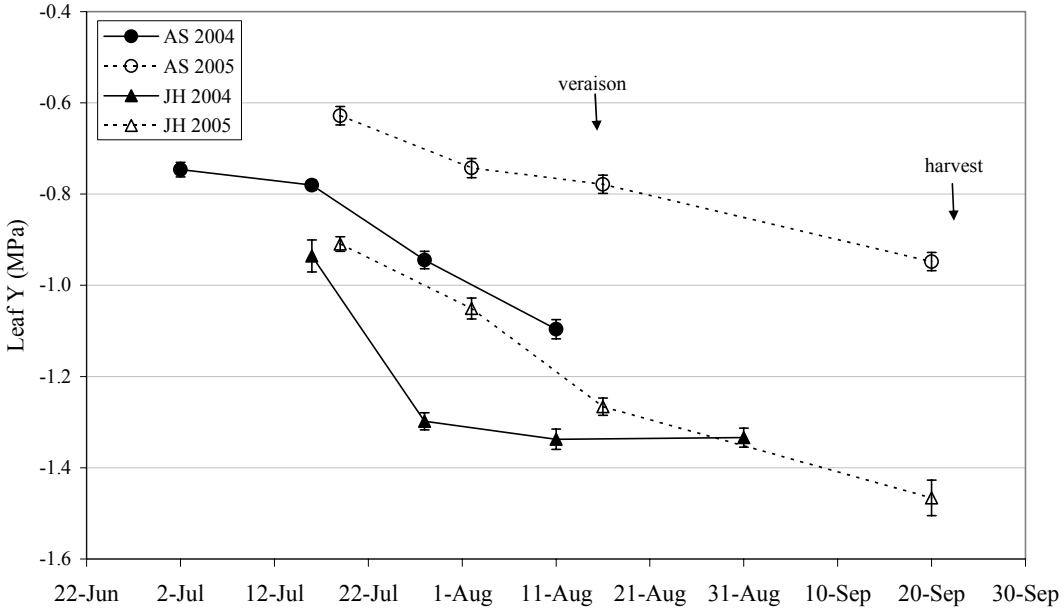


Bars indicate standard error of the mean.

Vine Water

Midday vine leaf water potential (Ψ) was affected by an interaction between site and date, indicating that water stress developed more quickly and was more severe at JH than at AS in both years (Fig 3). Cover crop treatment did not influence vine water stress as measured by midday vine leaf water potential. Average leaf Ψ values for each treatment, sample date and site are shown in Tables 16a-b in the appendix.

Figure 3. Midday leaf water potential at two N. Willamette Valley vineyards in 2004 and 2005



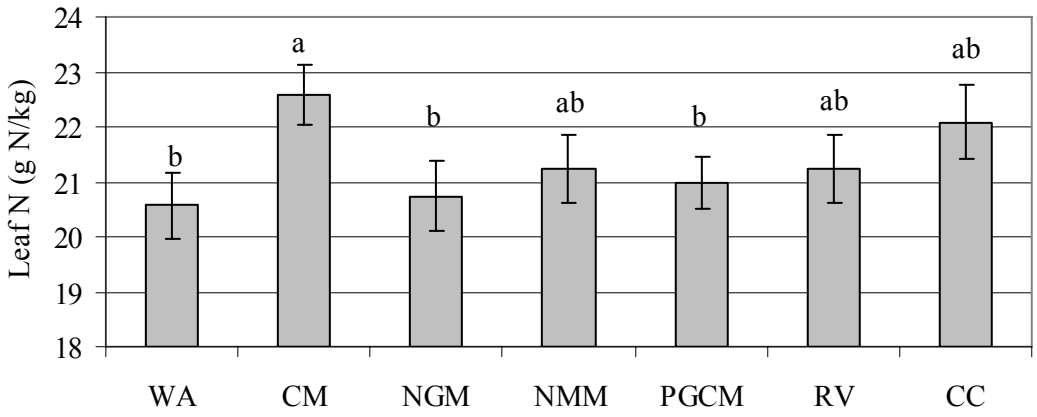
Bars indicate standard error of the mean

Vine Nutrients

Vine leaf N concentrations at bloom varied by year, such that 2004 N concentrations were higher than in those in 2005 (2004 $\overline{x}$ =35.3±0.3 gN/kg, 2005 $\overline{x}$ =28.7±0.3 g N/kg, $p<0.01$). At veraison, vine leaf N concentrations were significantly affected by cover crop treatment (Fig.4), such that the N concentration of vine leaves in the CM treatment was higher than the NGM, PGCM or WA treatments ($p<0.05$). Leaf N concentrations were correlated to dormant season pruning weights at both sites in 2004 (AS bloom time $R^2=0.50$, $p<0.05$; AS at veraison, $R^2=0.7668$, $p<0.001$; JH at bloom, $R^2=0.49$, $p<0.05$). Leaf N was also correlated to pruning weights in 2005 at AS, the only site where pruning weights were available ($R^2=0.47$, $p<0.05$). Also, in 2005 AS leaf N at bloom correlated with the contribution of N by cover crop biomass at AS in that same

year (R^2= 0.7229, p<0.001).

Figure 4. Average leaf N by treatment at veraison at two N. Willamette Valley vineyards in 2004 and 2005 (sites and years combined)



Bars indicate standard error of the mean. Means with the same letter are not statistically different (Tukey's p<0.05)

Cover crop treatment significantly affected leaf blade concentrations of P, K, and Zn at bloom at AS in 2005 (Table 6a-b). Leaf P concentrations were higher in the PGCM treatment compared to CC, WA and RV treatments (p<0.01). Leaf K concentrations were higher in the CC treatment than in the WA, NMM, PGCM and RV treatments (p<0.01). Concentrations of Zn in the leaf were highest in the CC and NGM treatments, which were different from the CM and PGCM treatments (p<0.01).

At veraison in 2005, cover crop treatment significantly affected leaf blade concentration of S, B, Zn and Fe at AS (Table 6. c-d). Leaves from the NMM treatment had a higher concentration of S than did the RV treatment (p<0.05). In the CC treatment, there were higher concentrations of B than in the NMM and RV treatment (p<0.05). Leaf Zn was higher in the CC treatment than in the PGCM and the RV

($p<0.01$). Fe concentrations were greatest in the leaf blades in the PGCM, different from CM, NGM, NMM, and RV treatments ($p<0.01$). Values for Cu were elevated at veraison due to application of Cu as a fungicide. While significant differences between cover crop treatments were found for some nutrients, effects were not consistently expressed at both bloom and veraison. The only exception was that Zn was higher at both bloom and veraison in the CC treatment than in the PGM treatment.

Table 6a. AS leaf blade macro nutrients (g/kg) sampled at bloom 2005

TRT	P	K	S	Ca	Mg
WA	2.4 (0.1) b	11.2 (0.3) b	2.9 (0.1)	17.1 (0.5)	2.6 (0.1)
CM	2.9 (0.3) ab	11.8 (0.0) ab	3.0 (0.1)	17.4 (0.6)	2.6 (0.2)
NGM	3.6 (0.5) ab	11.9 (0.8) ab	3.3 (0.2)	19.5 (0.8)	2.6 (0.0)
NMM	3.1 (0.3) ab	11.3 (0.4) b	3.4 (0.1)	19.0 (0.8)	2.6 (0.1)
PGCM	4.1 (0.3) a	11.6 (0.3) b	3.5 (0.4)	19.3 (0.4)	2.7 (0.1)
RV	2.7 (0.2) b	11.0 (0.3) b	3.3 (0.3)	18.5 (0.4)	2.4 (0.0)
CC	2.3 (0.2) b	13.4 (0.0) a	3.3 (0.3)	17.7 (1.0)	2.6 (0.1)
P value	<0.01	<0.01	NS	NS	NS

Table 6b. AS leaf blade micro nutrients (mg/kg) sampled at bloom 2005

TRT	Mn	Cu	B	Zn	Fe
WA	157.0 (5.0)	9.8 (0.3)	57.5 (7.8)	24.8 (1.8) ab	120.3 (6.7)
CM	160.5 (21.5)	11.0 (0.4)	60.5 (1.5)	21.0 (1.4) b	106.3 (6.1)
NGM	162.8 (6.3)	12.0 (1.1)	62.0 (2.9)	28.0 (1.8) a	99.3 (5.8)
NMM	157.8 (3.4)	12.3 (0.5)	57.3 (3.1)	23.5 (0.3) ab	100.3 (6.1)
PGCM	173.5 (4.8)	11.8 (0.8)	67.0 (5.8)	20.3 (1.9) b	151.3 (30.0)
RV	170.3 (14.7)	11.8 (1.1)	54.0 (3.9)	23.0 (2.2) ab	108.3 (13.2)
CC	167.0 (8.2)	11.0 (0)	60.3 (6.6)	28.5 (0.9) a	112.0 (10.1)
p value	NS	NS	NS	<0.01	NS

Table 6c. AS leaf blade macro nutrients (g/kg) sampled at veraison 2005

TRT	P	K	S	Ca	Mg
WA	1.7 (0.1)	14.9 (0.7)	3.2 (0.1) ab	24.0 (0.7)	2.9 (0.2)
CM	2.4 (0.2)	15.0 (0.8)	3.3 (0.2) ab	25.0 (1.0)	3.0 (0.2)
NGM	2.3 (0.2)	15.2 (0.6)	3.5 (0.2) ab	24.5 (0.8)	2.8 (0.2)
NMM	2.4 (0.1)	13.9 (0.4)	3.6 (0.1) a	26.9 (0.9)	2.9 (0.1)
PGCM	2.5 (0.6)	15.2 (0.6)	3.3 (0.2) ab	25.1 (0.6)	2.8 (0.1)
RV	2.1 (0.2)	14.0 (0.6)	3.0 (0.1) b	26.9 (0.4)	3.0 (0.1)
CC	1.9 (0.1)	15.5 (0.8)	3.5 (0.1) ab	24.2 (1.0)	2.9 (0.1)
p value	NS	NS	<0.05	NS	NS

Table 6d. AS leaf blade micro nutrients (mg/kg) sampled at veraison 2005

TRT	Mn	Cu	B	Zn	Fe
WA	176.8 (15.9)	298.8 (15.4)	22.0 (0.9) ab	22.3 (0.9) ab	322.5 (32.3) ab
CM	172.5 (10.1)	292.3 (12.0)	23.0 (1.2) ab	22.3 (1.7) ab	255.8 (9.5) b
NGM	168.5 (8.8)	333.0 (15.2)	22.5 (1.3) ab	23.8 (1.3) ab	274.0 (11.3) b
NMM	177.3 (5.7)	335.0 (28.0)	20.5 (1.0) b	24.5 (2.2) ab	271.8 (13.0) b
PGCM	200.0 (15.4)	326.8 (26.2)	22.0 (1.0) ab	19.5 (1.7) b	404.5 (61.7) a
RV	191.8 (11.1)	297.8 (14.1)	21.3 (1.7) b	19.0 (1.2) b	237.3 (12.2) b
CC	180.3 (8.3)	308.5 (24.0)	27.3 (2.4) a	26.5 (1.0) a	297.8 (13.9) ab
p value	NS	NS	<0.05	<0.01	<0.01

Values in parenthesis are SE of the mean, values within a column followed by the same letter are not significantly different (Tukey's $p < 0.05$)

Vine Roots and AMF

The amount of fine roots found in the alley was effected by year (2004<2005, $p<0.001$), and by date (bloom<post harvest, $p<0.001$, Table 7a). The percentage of fine roots colonized by AMF in the alley was effected by site only (JH<AS, $p<0.05$). Arbuscular colonization of roots was effected by treatment, year (2004<2005, $p<0.01$) and date (bloom<post harvest, $p<0.001$). Roots in the CC treatment were more highly colonized by arbuscules than either the PGCM or WA treatments ($p<0.05$).

Roots were generally more abundant in the vine row, and therefore more consistent results were obtained here than in the alley. In the vine row, fine root density and AMF colonization were both affected by site. Fine root density was greater at AS than at JH ($p<0.001$). Conversely, total and arbuscular colonization was greater at JH than at AS ($p<0.001$).

A separate analysis comparing the vine row and alley locations at each site revealed significant affects of location on fine root density and AMF colonization. Fine root density was significantly higher in the vine row than the alley at AS ($p<0.001$) but not different between the two locations at JH. In fact, there was an opposite trend at JH, where fine root density was generally greater in the alley than in the vine row (Alley $\overline{x}$ =0.2 g/mm; Vine Row $\overline{x}$ =0.16 g/mm; $p=0.13$). Total and arbuscular colonization were both higher in the vine row than the alley at both sites (AS total $p<0.05$, ARB $p<0.05$; JH total $p<0.001$, ARB $p<0.001$). There were negative relationships between leaf and petiole P concentrations at veraison and arbuscular colonization at post harvest (R^2= -0.60 $p<0.05$, R^2=-0.66, $p<0.05$, respectively).

Table 7a. Root length and AMF colonization in the alley at two N. Willamette Valley vineyards in 2004 and 2005

Factor/Treatment	Fine Root Length mm/g	Total AMF %	Arbuscules %
Cover Crop			
WA	0.23 (0.06)	49 (4)	15 (2)
PGCM	0.25 (0.05)	49 (4)	16 (3)
CC	0.31 (0.05)	54 (3)	21 (2)
p value	NS	NS	<0.05
Site			
AS	0.32 (0.05)	55 (3)	18 (2)
JH	0.20 (0.03)	46 (3)	17 (2)
p value	NS	<0.05	NS
Year			
2004	0.14 (0.03)	50 (3)	14 (2)
2005	0.38 (0.05)	51 (2)	21 (2)
p value	<0.001	NS	<0.01
Date			
Bloom	0.13 (0.02)	50 (3)	13 (2)
Post Harvest	0.40 (0.05)	52 (2)	22 (2)
p value	<0.001	NS	<0.001

Means followed by standard errors of the mean in parenthesis

Table 7b. Root length and AMF colonization in the vine row at two N. Willamette Valley vineyards in 2004 and 2005

Factor/Treatment	Fine Root Length mm/g	Total AMF %	Arbuscules %
Cover Crop			
WA	0.41 (0.07)	66 (3)	28 (2)
PGCM	0.36 (0.06)	70 (3)	30 (3)
CC	0.34 (0.05)	70 (2)	26 (2)
p value	NS	NS	NS
Site			
AS	0.58 (0.05)	64 (2)	22 (2)
JH	0.16 (0.03)	73 (2)	34 (2)
p value	<0.001	<0.001	<0.001
Year			
2004	0.40 (0.06)	68 (2)	26 (2)
2005	0.35 (0.03)	70 (2)	30 (2)
p value	NS	NS	NS
Date			
Bloom	0.29 (0.03)	70 (2)	30 (2)
Post Harvest	0.45 (0.06)	68 (2)	26 (2)
p value	NS	NS	NS

Means followed by standard errors of the mean in parenthesis

Vine Phenology and Vigor

Relevant grapevine phenological dates are shown in Table 8. Bloom, veraison and harvest were later in 2005 than in 2004 at both sites. At AS, the interval between veraison and harvest was 38 days in 2004 and 47 days in 2005. At JH, the veraison-harvest interval was 46 days in 2004 and 31 days in 2005.

Table 8. Dates of significant grapevine phenological stages at two N. Willamette vineyards for 2004 and 2005 in the N. Willamette Valley

	AS		JH	
	2004	2005	2004	2005
Budbreak	March 26	March 19	March 30	March 18
Bloom	June 7	June 22	June 4	June 21
Veraison	Aug 10	Aug 26	Aug 8	Aug 20
Harvest	Sept 17	Oct 12	Sept 23	Sept 30

Shoot lengths at AS were significantly affected by date and treatment (Table 27 in the Appendix). Shoot lengths increased from the first to the second measurement dates in a given season. Shoot lengths in the CC treatment were higher than those in the PGCM treatment (CC $\overline{x}$ = 116.9cm, ±6.5, and PM $\overline{x}$ = 104.0cm ±6.3, p=0.004). In 2004, sites were significantly different (AS, 103.2, 3.5cm > JH, 90.4, 3.2cm, $p<0.05$). One-way ANOVAs of shoot lengths for each treatment at each sample date and site revealed no differences in shoot lengths between treatments. The only exception was at the first sample date in 2004 at JH (Table 9), where shoot lengths in the NGM treatment were greater than those in the WA and RV. However, the NGM grasses were not well established in year one.

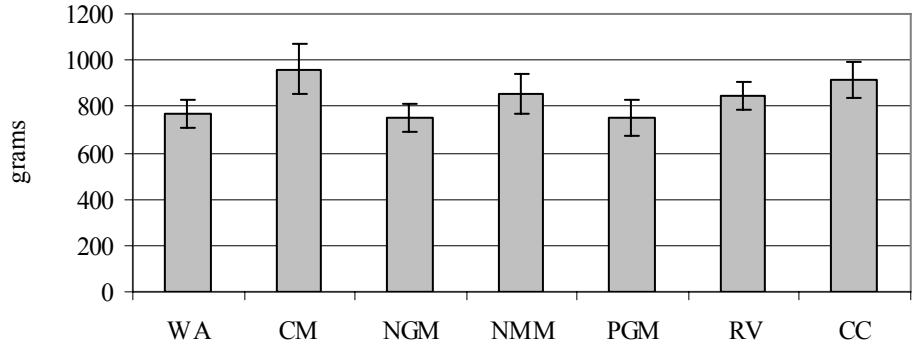
Table 9. Average shoot lengths (cm) at two N Willamette Valley vineyards in 2004 and 2005

	AS				JH		
	2004		2005		2004		2005
	14 May	17 June	1 June	27 June	13 May	17 June	9 June
WA	64.0(3.9)	127.3(9.0)	83.1(5.1)	158.9(9.5)	46.4(3.0) c	120.5(4.4)	83.5(3.8)
CM	61.0(3.5)	148.3(7.9)	86.2(4.0)	166.4(6.0)	49.8(2.3) abc	122.4(6.6)	73.0(7.0)
NGM	65.6(3.2)	156.2(4.4)	81.5(3.0)	156.1(6.4)	61.3(2.4) a	126.4(4.2)	87.3(4.7)
NMM	57.1(2.7)	138.57.5)	86.7(3.1)	162.1(6.8)	58.8(3.1) ab	128.7(9.1)	88.2(4.6)
PGCM	56.2(3.5)	140.4(6.3)	76.8(4.3)	142.8(8.6)	51.2(2.4) abc	124.3(6.8)	83.5(3.1)
RV	63.9(3.8)	148.7(8.3)	85.5(2.8)	158.5(6.4)	49.0(2.9) bc	131.0(10.0)	80.5(3.0)
CC	65.7(2.1)	151.4(7.5)	85.8(2.4)	164.7(4.8)	52.0(2.4) abc	143.5(4.3)	81.0(4.4)
p value	NS	NS	NS	NS	<0.01	NS	NS

Means followed by standard errors of the mean in parenthesis
Values followed by the same letter are not significantly different (Tukey's , $p<0.05$)

Pruning weights at AS alone were different among treatments ($p<0.05$), and between years (2004<2005, $p<0.01$, Table 29 in the Appendix). However, a Tukey's post-hoc comparison did not show any significant differences between treatment means (Fig 5). Pruning weights from AS were higher than those at JH (AS $\bar{x}$ = 690g; JH $\bar{x}$ = 350 g, $p<0.001$). There were no significant differences in pruning weights between treatments in 2004. Individual one-way ANOVAs for each sample date and site showed no effect of cover crop treatment on pruning weights (Table 10).

Figure 5. Average pruning weights by treatment AS, 2004 and 2005 combined



Bars indicate standard error of the mean

Table 10. Average shoot pruning weights (g/vine) at two N Willamette Valley vineyards in 2004 and 2005

	AS		JH
	2004	2005	2004
WA	592.2 (46.9)	948.5 (67.6)	291.7 (25.7)
CM	755.3 (119.5)	1168.0 (122.0)	283.9 (13.0)
NGM	694.4 (89.5)	810.5 (86.4)	420.4 (36.3)
NMM	676.1 (70.1)	1035.5 (99.1)	358.1 (57.5)
PGCM	579.4 (33.7)	920.5 (73.7)	325.3 (18.6)
RV	741.9 (36.8)	948.0 (102.1)	355.6 (56.7)
CC	773.6 (46.0)	1052.5 (33.8)	400.3 (30.8)
p value	NS	NS	NS

Means followed by standard errors of the mean in parenthesis

Fruit Yield and Quality

Fruit yield was affected by cover crop treatment and site (Table 40 in Appendix). Yields per vine were lower in the CM treatment than the PGCM ($p<0.05$), and yield was higher at AS than at JH over the two years ($p<0.001$). ANOVAs conducted on site and years separately revealed a significant treatment affect at AS in 2005 where yield in the CM treatment was lower than any other treatment (Table 11a, $p<0.001$).

Average cluster weight was affected by site and year. AS had larger clusters than

JH ($p<0.001$), and clusters were larger in 2004 than in 2005 ($p<0.001$). There was no difference among cover crop treatments in cluster weights. One-way ANOVAs of cluster weights run on site and years separately revealed a significant treatment affect at AS in 2005, where cluster weight in the CM treatment was lower than the CC, NMM, PGCM, and RV treatments (Table 11b).

Table 11a. Average yield per vine (g/vine) at two N. Willamette Valley vineyards in 2004 and 2005

	AS		JH	
	2004	2005	2004	2005
Winter Annuals	1213 (70)	1062 (92) a	891 (176)	913 (166)
Clover Mix	1154 (80)	720 (112) b	885 (61)	928 (114)
Native Grass Mix	1154 (40)	1108 (72) a	795 (44)	1171 (120)
Native Meadow Mix	1113 (39)	1180 (51) a	967 (100)	965 (107)
Perennial Grass/Clover Mix	1220 (41)	1171 (103) a	942 (37)	1037 (108)
Resident Vegetation	1098 (40)	1257 (152) a	862 (72)	965 (189)
Clean Cultivated	1063 (38)	1146 (88) a	942 (56)	1122 (223)
p value	NS	<0.001	NS	NS

Means followed by standard errors of the mean in parenthesis
Values followed by the same letter are not significantly different (Tukey's, $p<0.05$)

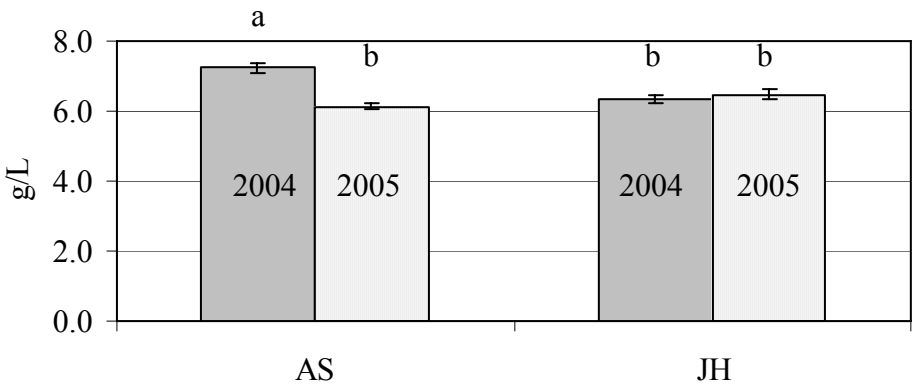
Table 11b. Average cluster weights (g/cluster) at two N. Willamette Valley vineyards in 2004 and 2005

	AS		JH	
	2004	2005	2004	2005
Winter Annuals	79 (4)	49 (3) ab	66 (5)	35 (2)
Clover Mix	75 (5)	39 (5) b	65 (3)	42 (3)
Native Grass Mix	77 (3)	50 (2) ab	61 (2)	43 (2)
Native Meadow Mix	75 (3)	55 (3) a	64 (4)	39 (2)
Perennial Grass/Clover Mix	80 (2)	52 (4) a	67 (3)	39 (2)
Resident Vegetation	73 (3)	54 (5) a	67 (4)	39 (3)
Clean Cultivated	71 (3)	51 (2) a	77 (6)	43 (3)
p value	NS	<0.01	NS	NS

Means followed by standard errors of the mean in parenthesis
Values followed by the same letter are not significantly different (Tukey's, $p<0.05$)

Analysis of juice quality measurements by ANOVA revealed significant affects of site on soluble solids (BRIX), an interaction between site and year on juice pH, and interactions between site and year, site and treatment, and treatment and year on juice TA. There were no cover crop treatment effects on juice soluble solids or pH based on ANOVA. Juice soluble solids at JH were higher than AS (JH $\bar{x}$=25.3, AS $\bar{x}$ = 23.4, $p<0.01$). Juice pH was lower at AS in 2005 than at the same site in 2004 ($p<0.001$). Juice titratable acidity (TA) showed significant interactions between cover crop treatment and site and between treatment and year. However, within a given site or year, there were no differences between cover crop treatments. The site by year interaction accounted for the most variability among the three significant interactions: Titratable acidity at AS was higher in 2004 than in 2005, and also higher than JH in either year (Fig 6, $p<0.001$).

Figure 6. Average titratable acidity (TA) at two N. Willamette Valley vineyards

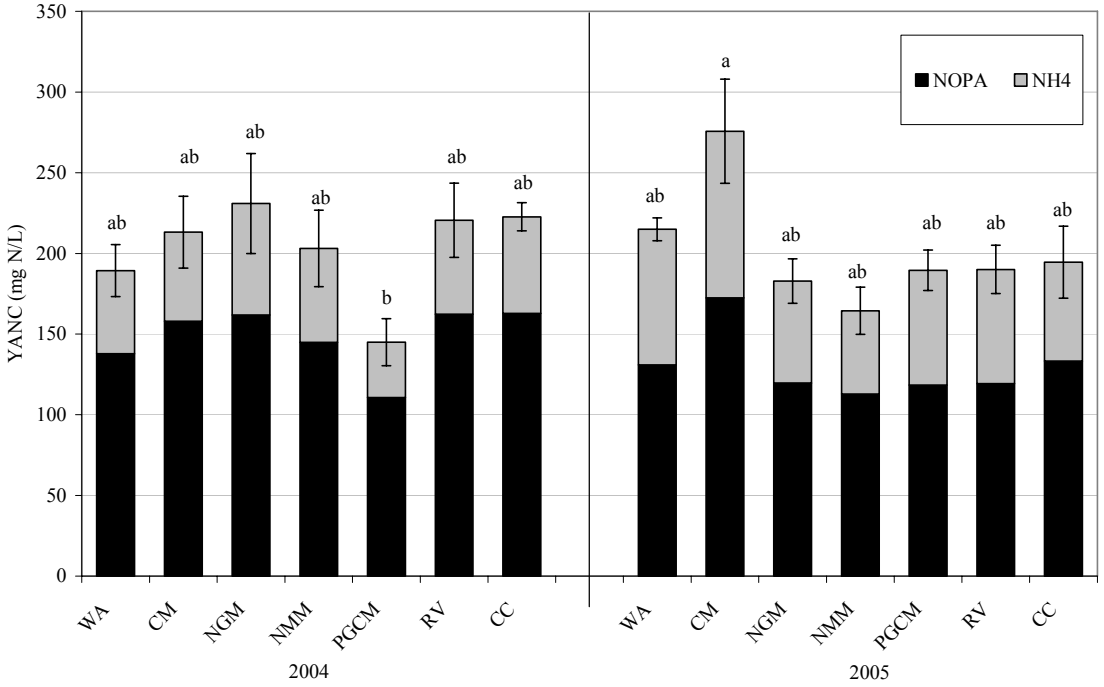


Bars indicate standard error of the mean. Means followed by the same letter are not statistically different (Tukey's, $p<0.05$)

Juice N concentrations were affected by treatment, year and site, as demonstrated by two separate analyses. At AS (2004 and 2005 combined), ANOVA showed a treatment by year interaction for yeast assimilable nitrogen content (YANC) of the juice, as well as a significant treatment main effect. YANC was higher in the CM treatment in 2005 than in PGCM in 2004, and than the NMM treatment in 2005 (Fig 7 a-b, $p<0.05$). NH_4-N was affected by a treatment by year interaction as well as by year as a main effect (2005>2004, $p<0.001$). The interaction pattern of NH_4-N content between treatment and year was similar to that of YANC (Fig 7 a-b, $p<0.01$). N-OPA levels were significantly affected by treatment (CM>PGCM, $p<0.05$) and by year (2004>2005, $p<0.05$).

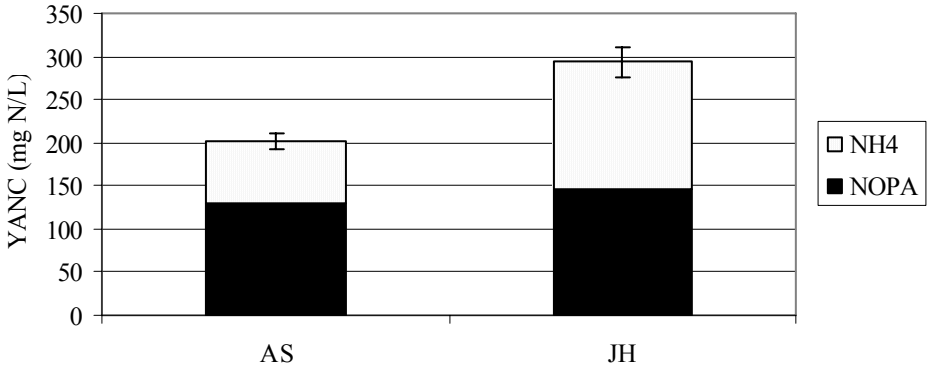
In 2005 with both sites combined, YANC and NH_4-N were significantly affected by site, and NH_4-N was also affected by cover crop treatment. JH had higher YANC ($p<0.001$) and NH_4-N ($p<0.001$) contents than did AS (Fig 8). Although ANOVA indicated that NH_4-N levels were different among treatments, Tukey's test showed no differences among means (juice N means for each year and site are shown in Tables 20a-b in the appendix).

Figure 7. Juice N Concentration at AS in 2004 and 2005



Bars indicate standard error of the YANC mean.

Figure 8. Average juice N 2005 at two N. Willamette Valley Vineyards



Bars indicate standard error of the YANC mean.

Discussion

Soil Water

In no case did cover crop treatment affect soil water content in the vine row, nor did the CC treatment contain more water than any of the vegetated treatments. Cover crop treatments had only minor effects on soil water in the alley, where the WA and CM treatments were slightly higher compared to the PGCM treatment. In both the alley and vine row locations, soil water content decreased over the growing season. Where differences were observed, with the exception of date, they were inconsistent and just beyond the limits of accuracy of the time domain reflectometry technique (±1%). In addition, time domain reflectometry can produce variable results in soils where the electrical conductivity is unusually high, due to high clay contents such as those observed at JH (Trase, 2006). When these high clay soils at JH reached a certain point of dryness in late summer, surface cracking was observed, often extending to about 30cm. Where these cracks occurred adjacent to wave guides, effective soil contact may have been compromised, potentially reducing the accuracy of volumetric soil water content measurements. Because of this and the inconsistent effects of treatment on soil moisture from site to site, it is possible that the interactions I observed in soil water were due to chance.

The CC treatment did not contain more water in the alley or vine row compared to any of the cover crop treatments during the summer months. These results suggest that evaporation from cultivated soil surfaces, combined with possible lower water infiltration into CC soils roughly equal the water lost via cover crop transpiration in our study. Another possible explanation is that vines growing in CC treatments experienced less

nutrient competition, and therefore used more water themselves. However, my shoot length, prune weight, nor yield data support this, as the CC treatment was not greater than any other treatment in any of these measurements. Similar results were found in a drip-irrigated San Joaquin Valley vineyard. Soil water in the vine row bordered by nodding needlegrass (*Nassella cernua*), a California native perennial, contained more water during the growing season than did the clean cultivated treatment. Measurements of pruning weights in that study did not show more vigorous growth in the clean cultivated treatment, supporting our data (Costello, 1999).

Vine Water

Vine leaf water potential varied by site and sample date but not by treatment. Vines at JH showed increasing levels of water stress earlier than vines at AS. Differences between sites can probably be attributed to the younger vines at JH having less drought tolerance due to less expansive root systems in the vine row, as demonstrated by our root data. The high clay content of the soils at JH may have also restricted root penetration and reduced the amount of water available to vines, leading to greater stress. The trend for higher levels of water stress observed at JH compared to AS is supported by lower soil water contents at JH compared to AS.

Effects of cover crop treatments on leaf water potential of grapevines have been irregular in past studies. In a south coast California vineyard, predawn leaf water potential was significantly less in vines with 'Berber' orchardgrass (*Dactylis glomerata* L. 'Berber') than in clean cultivated treatments in June, July and Sept but not in Aug (Wolport et al. 1993). However, Celette et al. (2005) found no difference in predawn leaf Ψ comparing vines with perennial grass alleys to chemically weeded alleys. In a review

of several vineyard cover crop trials in the North Coast of California, Blake (1991) suggests that soil type, especially those with high clay contents or limiting soil depth, may play a larger role than cover crop species in increasing vine stress under no-till floor management.

Vine Nutrients

Macro and micro nutrient concentrations in the vine leaf at AS 2005 were not consistent between sample times. In general, most nutrients were within or exceeded the reported "adequate" levels for vines from other grape growing regions (Campbell and Fey, 2003), with the exception of leaf P at bloom and leaf Zn at veraison which were slightly below adequate. The only treatment effect that was consistent between bloom and veraison was that Zn was lower in the PGCM treatment than the CC treatment. Our findings do not support those of Tan and Crabtree (1990), who found Fe, S, Ca, B, and Mn to be reduced in vine leaves from 'Chardonnay' vines grown with perennial grass cover crops compared to herbicide-treated alleyways in the Willamette Valley. Nor do our findings support those of Sicher et al. (1995), who studied the nutrient concentrations of 'Merlot' vine leaves in Northern Italy. They found that K, Ca and Mg concentrations were lower in vine leaves with vegetated alleyways (resident vegetation or perennial grass) compared to bare soil (tilled or herbicide-treated). Our findings also do not support those of Hanna et al. (2003), who found higher levels of K in 'Thompson Seedless' vines in cover cropped versus clean cultivated vineyards in California's central valley.

Grapevine leaf N concentrations were affected by the CM treatment at veraison, but not at bloom in this study. At veraison, leaf N concentrations were higher in the CM

treatment than the NGM, PGCM and WA treatments. There was no year by cover crop treatment interaction, indicating that this response was similar in both 2004 and 2005. It was somewhat surprising to see increased N in the CM treatment in the first year, especially considering the fact that the plant residues were never mechanically incorporated. Increases in leaf N in the CM treatment coincided with slight increases in pruning weights, indicating that the leaf N increase was probably not due to a concentrating effect. It is possible that the low leaf N in 2005 at bloom time was due to high rainfall in June of that year, which may have leached available N from the soil. In general, there were good correlations found between leaf N and juice N (YANC) at bloom in both 2004 and 2005.

Our vine nitrogen data are consistent with some studies but not with others. King and Berry (2005) demonstrated that grapevine leaves contained greater N concentrations when grown for four years with strawberry clover (*Trifolium fragiferum L.* 'Palestine') in alternate alleys, compared to bunchgrasses in a California vineyard. This is consistent with our findings of higher leaf N in the CM treatment compared to the NGM, PGCM and WA treatments. However, Sicher et al. (1995) found higher vine leaf N in clean cultivated and chemically weeded treatments than in vegetated treatments, which is inconsistent with my data which show no difference in vine leaf N concentration between the CC treatment and any other. Tan and Crabtree (1990) demonstrated a reduction in vine leaf N in perennial grass cover cropped versus tilled alleys in Oregon's Willamette Valley, a finding that was not observed in this study.

Roots and AMF

In the alley, there were more fine roots in 2005 than in 2004. This is likely due

to the change in methods between 2004 and 2005 used to recover fine roots from the soil. However, the same trend was not observed in the vine row. The only observed treatment effect in the alley was a higher rate of arbuscular frequency in roots in the CC treatment compared to cover cropped treatments (PGCM and WA), which was in contrast to expectations. This might have been an indirect result of a more photosynthetically active canopy improving carbohydrate availability in the roots, thereby supporting the colonization of AMF. Comparing locations, it was surprising to observe more fine roots in the alley than in the vine row at JH, suggesting that cover crops could potentially impose a more competitive affect at this site. In the vine row, there were fewer fine roots at JH than at AS, but higher rates of AMF colonization. This suggests that vines at JH may be more reliant on mycorrhizal fungi to expand the effective rooting area than those at AS. However, the rate of AMF colonization in roots in the alley was greater at AS than at JH. The fact that there was a greater rate of arbuscule colonization in the alley in 2005 than 2004 was surprising, due to the fact that there was more water stress in 2004, as indicated by the leaf water potential data. One would expect greater arbuscule colonization under high water stress conditions, as found by Schreiner (2005b). The negative correlation between leaf and petiole P at veraison and arbuscule frequency post harvest indicates that vines with adequate levels of P may have allocated fewer resources to the maintenance of mycorrhizal symbionts.

It is typical to find a greater density of fine roots within the vine row in vineyards compared to the alleys, especially when the alley is vegetated (Morlat and Jacquet, 2003; Schreiner, 2005b). Therefore it was surprising to find that there was no difference in fine root density between the vine row and alley locations at JH. This may be due to the

presence of a restrictive clay layer that we encountered during root sampling, which probably forced vine roots to grow horizontally into the alley rather than vertically within the row. The greater colonization rate of arbuscule in the alley at the post harvest date versus the bloom date is not supported by Schreiner (2005b), who showed that AMF colonization in the vine row increased to a peak in early summer, remained high throughout the growing season, and declined in the fall at a rate that varied with rainfall.

Vine Vigor

Shoot lengths differed by cover crop treatment at AS when both years were included in the analysis. Shoots in the CC treatment were longer than those in the PGCM treatment by an average of 12.9 cm. However, it is questionable as to the biological significance of this due to the early sample dates and lack of correlation with the pruning weight data. Additional vigor data such as canopy density, nodal length or leaf area was not collected. Shoot lengths in the NGM treatment were greater than those in the WA and RV at JH at the first sample date in 2004. This indicates that the NGM treatment was the least, and the WA treatment the most competitive at that time. It is noteworthy that shoot lengths in the CC treatment were never statistically greater than any other treatments at any given sample date.

Pruning weights did not statistically differ among cover crop treatments, although it was interesting to note the following trends among treatments; CM>CC>NMM>WA>RV>PGCM>NGM. Although this trend shows the CM and CC treatments had the greatest pruning weights, the shoot lengths were longest in these treatments in only one sample time at one site (CM at AS on 27 June 2005, and CC at JH on 17 June 2004), indicating that cane diameter may have been greater in these

treatments. Given a third year of cover crop establishment, differences in vine vigor between treatments may have become more distinct.

Our shoot length results are not supportive of a cover crop study in the Willamette Valley of Oregon (Tan and Crabtree, 1990). That study found that shoot lengths on two and three year old grapevines were reduced by perennial grasses in alleys versus chemically weeded alleys. The difference in vine ages between this study and ours may be one reason for the different findings. Our pruning weight results are partially supportive of work done in California by Ingels et al. (2005), who found vine pruning weights to be greater in all treatments (green manure, clovers, cereals and clean cultivated) than the native perennial grass in years two and three after cover crop establishment. However, Ingels et al. (2005) found no differences in shoot length among the five vineyard cover treatments after four years of establishment. The trends observed in our pruning weights are unsupportive of another trial in California, where reduced pruning weights were found on vines with a 'Berber' orchardgrass cover crop compared to clean cultivated in years two (difference of 2.9 lb/vine) and three (difference of 2.5 lb/vine) of cover crop establishment (Wolpert et al. 1993).

Fruit Yield and Quality

Grapevine fruit yield was lower in the CM treatment compared to the PGCM treatment. This effect was most evident in 2005, when yield in the CM treatment was lower than all other treatments at AS, and was among the lowest at JH. Cluster weights were also lowest in the CM treatment at AS in 2005. One possible explanation for the reduced yield in the CM treatment is that the N provided by the cover crop induced inflorescence necrosis or bunch stem necrosis. Inflorescence necrosis, has been

described as the partial or complete breakdown of the rachis or pedicels near bloom (Jackson and Coombe, 1988). Excess NH_4 in combination with shading is believed to cause inflorescence necrosis (Gu et al. 1996). Shading reduces the carbohydrate status of the vine, thereby limiting carbon substrates necessary for assimilation of NH_4 into amino acids. This may allow the buildup of NH_4 to toxic levels within the rachis, leading to necrosis. It is possible that the CM treatment resulted in dense, shady canopies and also provided N at levels exceeding the capacity of the vines' ability to assimilate it. These two factors alone or in combination may have induced inflorescence necrosis and subsequently lowered yield.

There were no treatment effects on juice soluble solids or juice pH. In 2005, titratable acidity of the juice was much lower at AS than at JH, which was likely a result of a longer hang time (difference of 12 days). The higher Brix values in 2005 than 2004 can be attributed to weather conditions at the time of harvest, which lead to later harvest dates in 2005. Brix values were higher at JH than at AS, which may be an indirect result of lower yields at JH than AS, or may have been due to dehydration of berries at JH. Our findings support those of Ingels et al. (2005), who found no differences in Brix, TA or pH associated with any of five cover crop treatments over four seasons with a few exceptions. However, grassed versus weed-free alleys have frequently been reported to result in increased juice Brix, although this was likely an indirect result of lower yields (Rodriguez-Lovelle et al. 2000; Sicher et al. 1995; Wolpert et al. 1993).

Yeast assimilable nitrogen content (YANC) was elevated in the CM treatment (276 mg (N)/L) at AS in 2005 in comparison to all other treatments, although it was statistically different only from the NGM treatment (183 mg (N)/L) within that same

year. The fact that the increase in fruit N in the CM treatment occurred only in the second year indicates that either 1) more N was available in 2005 in the soil at the right time for accumulation in the fruit or 2) N taken up in 2004 had accumulated in the vine's reserves and, in combination with the soil N in 2005, contributed to higher levels of N in the fruit. The increase in fruit YANC is best explained by the fact that there was a simultaneous reduction in yield; the vines essentially concentrated the same amount of N into a smaller amount of fruit. There is a wide range of recommended yeast assimilable N levels for "healthy" fermentations, from 140 to 500 mg N/L (Butzke 1998; Spayd, 1998). The lowest mean YANC value was in the PGCM at AS in 2004 ($\overline{x}$=145 mg N/L), just above the lowest recommended level of yeast assimilable N for "healthy" fermentations. Rodriguez-Lovelle et al. (2000b) has also reported a low juice N in fruit from vines with grass sod in every alley, compared to tilled or chemically-weeded treatments.

Conclusions

Over two years of establishment, cover crop treatments in two Oregon vineyards had minor affects on soil moisture, vine water status, or vine growth and yield responses. In addition, sites often did not respond similarly to treatments. Soil moisture in the alley was slightly higher in WA and CM treatments as compared to the PGCM treatment, and the clean cultivated treatment was not different from any cover crop treatment at either location (vine row or alley). Midday vine leaf water potential was unaffected by any treatment. Vine leaf nutrients were inconsistently affected by treatment, except that Zn was lower in the PGCM treatment than the CC treatment at both sample times (bloom and veraison). In addition, most nutrient values were within acceptable ranges for optimal

vine health. Patterns of colonization of vine roots by AMF indicated that vines under more water stress have greater colonization, and that vines with adequate levels of P possibly allocate fewer resources to support AMF. Early season vine shoot lengths were slightly greater in the CC treatment compared to the PGCM treatment, although it is questionable if the differences were biologically significant. There was no affect of treatment on dormant season pruning weights.

Grapevines in this experiment were affected by the N provided by the CM treatment. Leaf N at veraison was greater in the CM treatment compared to the WA and NGM treatments. Other treatments, including CC, were not different from CM, WA and NGM. Reduction of fruit yield in the CM treatment was an effect that was possibly due to excess N inducing inflorescence necrosis. The effects of the CM treatment on yield and leaf and juice N were more obvious in year two than in year one. It was surprising to see responses in the vine resulting from the CM treatment after just two years without mechanical incorporation of cover crop residues.

General Conclusions

The cover crops selected for this experiment generally established themselves well, but they affected the vineyard ecosystem only in subtle ways. The WA and CM treatments tended to produce the most biomass and to contain the fewest weeds. However, the WA treatment was susceptible to poor germination conditions, and in this case did not provide maximum coverage of the vineyard alley floor. In year two, the perennial treatments, NGM, NMM and PGCM, were better established than in year one, as indicated by lower weed presence in the treatments in 2005. Despite the wide range of biomass produced, cover crops, including the CC treatment, did not affect soil water content (although soil moisture in the alley was slightly higher in WA and CM treatments as compared to the PGCM treatment), nor did they influence water status of the vine. Rather, the predominant influences over soil and vine water status were time of year and site. For example, midday leaf water potential declined at both sites over the summer, and JH developed much greater water stress than AS in both years, which may be because of the younger vines at JH.

Vine vegetative growth (early season shoot lengths and dormant season prune weights) was largely unaffected by cover crop treatments, including the CC treatment. Fine root length of vines and the colonization rate by AMF were not different among the CC, WA, or PGCM treatments in either the vine row or alley. Rather, site had a major influence on roots and AMF in the vine row. Root length was significantly greater in the older vines at AS, while colonization by AMF was significantly greater in the younger vines at JH.

The CM treatment had the greatest influence on grapevines in this experiment. Vine leaf N concentration at bloom (but not at veraison) and juice YANC both increased, and yield per vine and cluster weights both decreased in the CM treatment. This effect was greater at AS, which was a more vigorous site in general than JH. The higher concentration of leaf N at bloom in 2005 in the CM treatment correlated with total cover crop biomass N at in that same year. It is customary for winter annual cover crops to be flail mowed and then mechanically incorporated into the soil in order to make nutrients more readily available. However, we saw a clear nutrient response in this study despite the lack of residue incorporation.

Each cover crop treatment has its own merits and drawbacks. The WA treatment accumulated a large amount of biomass and excluded weeds well, which may be desirable in vineyards that need to increase soil organic matter or to decrease weeds. However, it requires reseeding annually and may not provide maximum soil coverage in order to reduce erosion. The CM treatment can provide a good deal of N to the vineyard as well as out-compete weeds, although how to manage the amount and timing of N provided is not well understood, especially in no-till systems. The NGM proved to be promising as a vineyard cover crop, as it established itself well and did not compete with the vines for water after two years of establishment. However, the cost of native grass seed is higher than that of standard turf grass seed and it can be difficult to find sources. The NMM bloomed profusely in the first year, and although many perennial forbs bloomed in the second year, annual forbs did not appear to reestablish themselves. This treatment would be the most expensive to establish. The PGCM performed well all-around; it established itself well, competed well with weeds and did not compete with the

vines for water. The RV treatment would be the easiest and lowest cost ground cover to establish, although if the resident weeds of a particular vineyard were noxious or otherwise undesirable, this ground cover management strategy may not be desirable. However, because RV provided the least % cover, it may be a poor choice where erosion is a concern. Finally, the CC treatment may be a good ground management approach if the vineyard is on very shallow soils, is very young or otherwise weak. Over the two years of this study, however, there was no apparent advantage to cultivating the alleys between grape vine rows in either vineyard.

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APPENDIX

Means Tables

Table 12. Average cover crop biomass (kg/ha) >10cm at AS and JH in 2004 and 2005 on the first mowing

	AS			JH		
TRT	2004	2005	04-05 Mean	2004	2005	04-05 Mean
WA	3074 (117)	988 (57)	2031 (398)	3496 (1038)	1426 (329)	2461 (638)
CM	1421 (246)	2587 (277)	2004 (279)	1766 (348)	897 (259)	1331 (259)
NGM	0 (0)	253 (109)	126 (69)	0 (0)	1010 (455)	505 (284)
NMM	242 (99)	151 (141)	196 (82)	179 (60)	297 (128)	238 (69)
PGCM	130 (97)	1779 (662)	954 (439)	566 (97)	1071 (341)	819 (190)
RV	1141 (199)	72 (33)	607 (223)	185 (388)	482 (293)	525 (226)

Means followed by standard errors in parenthesis

Table 13a. Average weed biomass (kg/ha) >10cm and % of total ground biomass attributed to weeds at AS in 2004 and 2005 on first mowing

Treatment	2004	% of TOT 04	2005	% of TOT 05	04-05 Mean
WA	202 (67)	6.2 (2.1)	0.0	0.0	101.4 (49)
CM	255 (106)	15.2 (3.2)	41.2 (36)	1.6 (1.4)	148.3 (65)
NGM	124 (78)	100.0 (0)	271.0 (76)	51.6 (7.6)	197.6 (57)
NMM	116 (32)	32.4 (18.9)	167.3 (109)	52.5 (24.6)	141.7 (53)
PGCM	270 (60)	67.5 (17.9)	154.8 (31)	8.0 (2.3)	212.6 (38)
TRT Average	194 (32)		127 (36)		

Means followed by standard errors in parenthesis.

Table 13b. Average weed biomass (kg/ha) >10cm and % of total ground biomass attributed to weeds at JH in 2004 and 2005 on first mowing

Treatment	2004	% of TOT	2005	% of TOT	04-05 Mean
WA	403 (139)	10.3 (3.5)	183 (127)	17.0 (3.7)	293 (96.)
CM	1003 (210)	36.2 (4.1)	231 (87)	20.5 (6.2)	617 (180)
NGM	997 (411)	100.0	289 (121)	22.3 (3.9)	643 (239)
NMM	350 (148)	66.2 (11.3)	489 (367)	62.2 (13.3)	419 (185)
PGCM	759 (211)	57.3 (6.3)	357 (177)	25.0 (16.4)	558 (148)
TRT p value	NS	NS	NS	NS	NS
TRT Average	703 (117)		310 (84)		

Means followed by standard errors in parenthesis

Table 14. Average total biomass (cover crops + weeds, kg/ha) > 10cm at AS and JH in 2004 and 2005 on first mowing

	AS			JH		
TRT	2004	2005	2004-2005	2004 †	2005	2004-2005
WA	3278 (111)	989 (58)	2133 (436)	3311 (1158)	1610 (457)	2755 (721)
CM	1677 (345)	2628 (276)	2153 (272)	2609 (488)	1129 (352)	1949 (412)
NGM	124 (78)	525 (171)	324 (115)	677 (411)	1300 (572)	1149 (331)
NMM	358 (106)	319 (133)	339 (79)	426 (154)	786 (470)	658 (234)
PGCM	400 (52)	1934 (665)	1167 (424)	1268 (232)	1429 (301)	1378 (177)
RV	1141 (199)	72 (33)	607 (223)	185 (388)	482 (293)	525 (226)

Means followed by standard errors in parenthesis.

Table 15. Average total biomass N (weeds +cover crops) at AS and JH in 2004 and 2005 (kg N/ha)

	AS			JH		
Treatment	2004	2005	2004-2005	2004	2005	2004-2005
WA	76 (1)	25 (2)	51 (1)	21 (10)	23 (5)	22 (6)
CM	48 (1)	125 (15)	87 (1)	50 (23)	41 (13)	46 (16)
NGM	4 (2)	16 (6)	10 (1)	15 (5)	26 (13)	21 (8)
NMM	12 (1)	13 (5)	13 (1)	43 (21)	21 (15)	32 (17)
PGCM	11 (1)	77 (25)	44 (2)	30 (4)	44 (12)	37 (6)
RV	5 (1)	3 (1)	4 (1)	3 (1)	8 (4)	6 (2)

Means followed by standard errors in parenthesis

Table 16a. Average leaf water potential at two N Willamette Valley vineyards in 2004 (MPa)

	15 July		27 July		10 Aug	
TRT	AS	JH	AS	JH	AS	JH
WA	-0.81 (0.31)	-0.96 (0.52)	-0.99 (0.02)	-1.30 (0.04)	-1.09 (0.04)	-1.41 (0.04)
CM	-0.80 (0.35)	-1.03 (1.59)	-0.95 (0.07)	-1.31 (0.04)	-1.23 (0.04)	-1.39 (0.04)
NGM	-0.76 (0.24)	-0.81 (0.43)	-0.95 (0.05)	-1.25 (0.09)	-1.06 (0.02)	-1.21 (0.03)
NMM	-0.83 (0.14)	-0.95 (1.06)	-0.98 (0.04)	-1.28 (0.06)	-1.04 (0.02)	-1.34 (0.10)
PGCM	-0.78 (0.25)	-0.98 (0.48)	-0.93 (0.07)	-1.29 (0.07)	-1.11 (0.07)	-1.39 (0.04)
RV	-0.74 (0.13)	-0.98 (1.56)	-0.95 (0.06)	-1.36 (0.01)	-1.14 (0.09)	-1.35 (0.05)
CC	-0.75 (0.35)	-0.85 (0)	-0.88 (0.05)	-1.30 (0)	-1.01 (0.02)	-1.28 (0.03)

Means followed by standard errors of the mean in parenthesis

Table 16b. Average leaf water potential at two N Willamette Valley vineyards in 2005 (MPa)

TRT	18 July		2 Aug		15 Aug		19 Sept	
	AS	JH	AS	JH	AS	JH	AS	JH
WA	-0.73	-0.93	-0.76	-1.01	-0.73	-1.32	-0.91	-1.50
	(0.05)	(0.01)	(0.05)	(0.06)	(0.09)	(0.04)	(0.06)	(0.16)
CM	-0.63	-0.90	-0.78	-1.11	-0.86	-1.29	-0.92	- 1.4
	(0.06)	(0.02)	(0.07)	(0.05)	(0.06)	(0.02)	(0.06)	(0.05)
NGM	-0.59	-0.94	-0.69	-0.94	-0.74	-1.14	-0.92	-1.43
	(0.06)	(0.07)	(0.07)	(0.06)	(0.03)	(0.07)	(0.08)	(0.06)
NMM	-0.60	-0.93	-0.74	-1.08	-0.79	-1.30	-0.99	-1.59
	(0.02)	(0.04)	(0.04)	(0.09)	(0.01)	(0.07)	(0.05)	(0.08)
PGCM	-0.71	-0.86	-0.81	-1.06	-0.84	-1.30	-1.00	-1.33
	(0.06)	(0.04)	(0.04)	(0.04)	(0.07)	(0.02)	(0.02)	(0.11)
RV	-0.56	-0.93	-0.79	-1.13	-0.74	-1.26	-0.97	-1.50
	(0.04)	(0.04)	(0.07)	(0.05)	(0.02)	(0.04)	(0.05)	(0.16)
CC	-0.59	-0.89	-0.64	-1.04	-0.76	-1.26	-0.94	-1.44
	(0.03)	(0.06)	(0.03)	(0.06)	(0.06)	(0.04)	(0.03)	(0.06)

Means followed by standard errors of the mean in parenthesis

Table 17. Average grapevine leaf N (g N/kg) at two N Willamette Valley vineyards

TRT	AS				JH			
	2004		2005		2004		2005	
	Bloom	Veraison	Bloom	Veraison	Bloom	Veraison	Bloom	Veraison
WA	32 (0)	22 (1)	26 (1)	18 (1)	35 (1)	22 (1)	30 (1)	20 (0)
CM	36 (1)	24 (1)	32	21 (1)	36 (1)	24 (1)	30	22 (0)
NGM	34 (1)	23 (1)	26 (1)	18 (1)	36 (0)	22 (1)	29 (1)	19 (1)
NMM	32 (1)	23 (1)	27 (1)	19 (0)	38 (1)	23 (1)	31 (0)	20 (1)
PG	33 (0)	22 (0)	30 (1)	20 (1)	36 (0)	23 (0)	30 (0)	19 (1)
RV	36 (1)	24 (1)	27 (0)	19 (0)	35 (1)	23 (1)	30 (1)	19 (0)
CC	36 (1)	24 (1)	26 (0)	19 (1)	37 (1)	25 (1)	30 (1)	21 (0)

Means followed by standard errors of the mean in parenthesis

Table 18a. Average fine root density, AMF and arbuscule colonization in the Alley at two N. Willamette Valley vineyards in 2004 and 2005

Year	Date	Site	TRT	FR mm/g	VAM	ARB
2004	Bloom	AS	Clean	0.049 (0.029)	73.04 (7.17)	22.52 (7.77)
2004	Bloom	AS	Per Grass	0.046 (0.008)	60.94 (6.53)	8.75 (1.37)
2004	Bloom	AS	Winter Ann	0.055 (0.018)	46.89 (15.55)	11.59 (6.39)
2004	Bloom	JH	Clean	0.000011 (0.00004)	50.82 (9.56)	13.56 (2.78)
2004	Bloom	JH	Per Grass	0.000015 (0.000004)	42.11 (15.21)	3.98 (0.69)
2004	Bloom	JH	Winter Ann	0.000016 (0.000008)	25.60 (8.82)	5.84 (5.03)
2004	PH	AS	Clean	0.389 (0.111)	43.27 (2.8)	15.16 (5.96)
2004	PH	AS	Per Grass	0.231 (0.04)	59.16 (5.82)	13.77 (3.99)
2004	PH	AS	Winter Ann	0.173 (0.084)	68.93 (2.05)	23.79 (8.78)
2004	PH	JH	Clean	0.419 (0.175)	51.85 (13.06)	28.36 (10.85)
2004	PH	JH	Per Grass	0.174 (0.058)	40.56 (7.89)	10.10 (2.35)
2004	PH	JH	Winter Ann	0.166 (0.054)	42.10 (11.51)	5.01 (1.09)
2005	Bloom	AS	Clean	0.251 (0.087)	53.50 (9.11)	18.84 (7.28)
2005	Bloom	AS	Per Grass	0.204 (0.093)	31.67 (11.05)	5.84 (2.53)
2005	Bloom	AS	Winter Ann	0.163 (0.084)	48.65 (12.11)	5.20 (1.76)
2005	Bloom	JH	Clean	0.353 (0.018)	53.29 (8.58)	21.86 (8.92)
2005	Bloom	JH	Per Grass	0.187 (0.077)	47.96 (8.58)	17.82 (7.09)
2005	Bloom	JH	Winter Ann	0.229 (0.074)	60.99 (7.97)	14.73 (3.44)
2005	PH	AS	Clean	0.597 (0.163)	56.62 (2.58)	21.56 (0.77)
2005	PH	AS	Per Grass	0.827 (0.159)	64.52 (12.39)	35.00 (12.51)
2005	PH	AS	Winter Ann	0.881 (0.297)	57.32 (6.44)	28.85 (6.79)
2005	PH	JH	Clean	0.412 (0.09)	51.69 (2.79)	26.54 (3.23)
2005	PH	JH	Per Grass	0.305 (0.07)	45.44 (6.05)	28.84 (5.33)
2005	PH	JH	Winter Ann	0.174 (0.034)	43.39 (7.84)	22.06 (7.49)

Mean values followed by SE in parenthesis, PH= Post Harvest

Table 18b. Average fine root density, AMF and arbuscule colonization in the Vine Row at two N. Willamette Valley vineyards in 2004 and 2005

Year	Date	Site	TRT	FR (mm/g)	AMF (%)	ARB (%)
2004	Bloom	AS	Clean	0.506 (0.061)	71.28(134)	31.78 (1.68)
2004	Bloom	AS	Per Grass	0.450 (0.015)	67.73 (3.94)	34.14 (1.29)
2004	Bloom	AS	Winter Ann	0.477 (0.068)	55.87 (5.13)	31.98 (1.88)
2004	Bloom	JH	Clean	0.0000050 (0.000002)	83.69 (6.35)	23.09 (3.57)
2004	Bloom	JH	Per Grass	0.0000060 (0.000002)	83.40 (3.96)	38.77 (4.11)
2004	Bloom	JH	Winter Ann	0.0000050 (0.000001)	54.14 (11.32)	25.60 (8.91)
2004	PH	AS	Clean	0.795 (0.150)	60.75 (7.93)	14.44 (5.32)
2004	PH	AS	Per Grass	1.090 (0.142)	59.17 (11.68)	19.23 (6.21)
2004	PH	AS	Winter Ann	1.151 (0.195)	65.86 (5.79)	17.14 (7.78)
2004	PH	JH	Clean	0.105 (0.031)	73.40 (4.11)	24.01 (2.53)
2004	PH	JH	Per Grass	0.122 (0.058)	70.74 (4.73)	23.24 (4.5)
2004	PH	JH	Winter Ann	0.049 (0.02)	65.86 (10.3)	28.76 (5.34)
2005	Bloom	AS	Clean	0.386 (0.033)	67.46 (8.06)	17.25 (1.77)
2005	Bloom	AS	Per Grass	0.396 (0.06)	68.25 (0.86)	20.83 (3.63)
2005	Bloom	AS	Winter Ann	0.384 (0.126)	65.60 (6.01)	14.00 (4.35)
2005	Bloom	JH	Clean	0.200(0.058)	67.22 (2.86)	35.80 (4.66)
2005	Bloom	JH	Per Grass	0.318(0.083)	76.25 (10.08)	45.25 (12.4)
2005	Bloom	JH	Winter Ann	0.416(0.134)	76.15 (4.74)	39.49 (3.43)
2005	PH	AS	Clean	0.503(0.199)	56.68 (5.64)	17.01 (3.92)
2005	PH	AS	Per Grass	0.365(0.045)	63.91 (6.77)	16.51 (3.95)
2005	PH	AS	Winter Ann	0.468(0.233)	71.39 (2.51)	30.11 (3.74)
2005	PH	JH	Clean	0.223(0.060)	82.23 (5.57)	44.14 (2.87)
2005	PH	JH	Per Grass	0.148(0.051)	70.30 (7.43)	41.87 (10.17)
2005	PH	JH	Winter Ann	0.346(0.191)	74.61 (3.72)	39.46 (5.32)

Mean values followed by SE in parenthesis, PH= Post Harvest

Table 19a. Average grape juice BRIX, pH, TA at AS in 2004 and 2005

TRT	2004			2005		
	BRIX	pH	TA	BRIX	pH	TA
WA	22.8 (0.1)	3.29 (0.02)	7.08 (0.22)	23.8 (0.2)	3.06 (0.04)	6.24 (0.15)
CM	23.0 (0.3)	3.36 (0.04)	6.91 (0.34)	23.8 (0.2)	3.13 (0.03)	5.90 (0.37)
NGM	23.5 (0.3)	3.30 (0.04)	6.91 (0.42)	23.6 (0.3)	3.03 (0.05)	6.16 (0.23)
NMM	23.1 (0.3)	3.25 (0.06)	7.66 (0.50)	23.6 (0.1)	3.06 (0.02)	5.90 (0.37)
PGCM	23.1 (0.2)	3.24 (0.04)	7.20 (0.46)	23.4 (0.1)	3.01 (0.03)	6.35 (0.21)
RV	23.3 (0.2)	3.31 (0.05)	7.06 (0.38)	23.4 (0.2)	3.06 (0.10)	6.07 (0.47)
CC	23.2 (0.4)	3.38 (0.02)	7.80 (0.40)	23.5 (0.2)	3.05 (0.03)	6.35 (0.17)

Mean values followed by SE in parenthesis

Table 19b. Average grape juice BRIX, pH, TA at JH in 2004 and 2005

TRT	2004			2005		
	BRIX	pH	TA	BRIX	pH	TA
WA	25.2 (0.5)	3.50 (0.08)	6.22 (0.16)	26.0 (0.3)	3.43 (0.09)	6.39 (0.30)
CM	24.0 (0.8)	3.45 (0.05)	6.08 (0.18)	25.2 (0.5)	3.43 (0.05)	6.53 (0.39)
NGM	26.0 (0.6)	3.46 (0.04)	6.46 (0.13)	26.0 (0.1)	3.34 (0.04)	6.72 (0.41)
NMM	24.2 (0.5)	3.41 (0.07)	6.37 (0.10)	25.5 (0.4)	3.45 (0.11)	6.37 (0.52)
PGCM	24.7 (0.9)	3.40 (0.06)	6.37 (0.29)	26.2 (0.5)	3.33 (0.07)	6.65 (0.32)
RV	24.8 (0.6)	3.50 (0)	6.18 (0.24)	25.2 (0.5)	3.33 (0.05)	6.11 (0.46)
CC	25.5 (0.3)	3.48 (0.01)	6.79 (0.29)	25.5 (0.5)	3.26 (0.02)	6.58 (0.31)

Mean values followed by SE in parenthesis

Table 20a. Average grape juice N (mg/L) at AS in 2004 and 2005

TRT	2004			2005		
	NOPA	NH4	YANC	NOPA	NH4	YANC
WA	137.9 (10.0)	51 (8)	189.3 (16.2)	130.9 (3.3)	84 (4)	214.9 (7.0)
CM	157.9 (17.1_	55 (6)	213.2 (22.2)	172.5 (19.6)	103 (15)	275.7 (32.3)
NGM	161.8 (18.6)	69 (14)	231.0 (31.0)	119.7 (2.7)	63 (11)	182.9 (13.8)
NMM	145.0 (12.8)	58 (13)	203.1 (23.7)	112.8 (10.6)	52 (8)	164.5 (14.6)
PGCM	110.6 (16.3)	34 (8)	145.0 (14.6)	118.5 (4.3)	71 (9)	189.6 (12.5)
RV	162.4 (22.7)	58 (6)	220.5 (23.0)	119.4 (8.4)	71 (11)	190.0 (15.0)
CC	162.8 (8.5)	60 (7)	222.7 (8.7)	133.3 (11.1)	61 (12)	194.6 (22.3)

Mean values followed by SE in parenthesis

Table 20b. Average grape juice N (mg/L) at JH in 2005

TRT	NOPA	NH4	YANC
WA	186.1 (46.0)	149 (18)	335.4 (63.8)
CL	160.1 (29.4)	165 (23)	325.1 (51.5)
NG	123.2 (16.1)	131 (14)	253.7 (29.7)
NM	165.9 (40.3)	143 (31)	308.4 (71.3)
PG	119.6 (22.2)	147 (12)	266.6 (31.6)
RV	139.0 (23.8)	141 (8)	280.2 (31.5)
CC	136.2 (18.3)	149 (13)	285.2 (29.7)

Mean values followed by SE in parenthesis

ANOVA Tables

Table 21. ANOVA Average % soil surface vegetative cover

Univariate Tests of Significance for % cover Over-parameterized model Type III decomposition

	Effect	SS	Degr. Of freed	MS	Den.Syn. Errr df	Den.Syn. MS	F	p
Intercept	Fixed	844687	1	844687	1	787.760	1072.26	0.019435
Block	Fixed	457	3	152.3	69	39.6626	3.841	0.013268
TRT	Fixed	2648.2	5	529.6	5	115.8854	4.57	0.060424
SITE	Random	787.8	1	787.8	1.41401	429.0104	1.836	0.351928
YEAR	Fixed	114.8	1	114.8	1	356.5104	0.322	0.671357
TRT*SITE	Random	579.4	5	115.9	5	43.3854	2.671	0.152369
TRT*YEAR	Fixed	889.8	5	178	5	43.3854	4.102	0.073751
SITE*YEAR	Random	356.5	1	356.5	5	43.3854	8.217	0.035135
TRT*STE*YR	Random	216.9	5	43.4	69	39.6626	1.094	0.371722
Error		2736.7	69	39.7				

Table 22. ANOVA Soil Water Vine Row

Univariate Tests of Significance for water cc/cc (SoilWaterRowOnly) Over-parameterized model Type III decomposition

	Effect	SS	Deg Freed	MS	Den.Syn. Err df	Den.Syn. MS	F	p
Intercept	Fixed	20.0995	1	20.0995	1	0.002236	8988.90	0.006714
Block	Fixed	0.00829	3	0.00276	357	0.00071	3.896	0.009237
Site	Random	0.00224	1	0.00224	6.5679	0.007312	0.306	0.59858
TRT	Fixed	0.01459	5	0.00292	5	0.006322	0.462	0.791868
Date	Fixed	0.38265	9	0.04252	9	0.00115	36.986	0.000005
Site*TRT	Random	0.03161	5	0.00632	45	0.000159	39.692	0
Site*Date	Random	0.01035	9	0.00115	45	0.000159	7.217	0.000002
TRT*Date	Fixed	0.01373	45	0.00031	45	0.000159	1.915	0.015814
Site*TRT*Date	Random	0.00717	45	0.00016	357	0.00071	0.224	1
Error		0.25335	357	0.00071				

Table 23. ANOVA Soil Water Alley

Univariate Tests of Significance for water cc/cc (SoilWaterAlleyOnly) Over-parameterized model Type III decomposition

	Effect	SS	Degr of Freed	MS	Den.Syn. Err df	DenSyn MS	F	p
Intercept	Fixed	18.8651	1	18.8651	1	0.01633	1154.6	0.018729
Block	Fixed	0.0083	3	0.00278	353	0.00087	3.166	0.024582
Site	Random	0.0163	1	0.01634	10.1063	0.00376	4.342	0.063496
TRT	Fixed	0.0294	5	0.00589	5	0.00191	3.078	0.121356
Date	Fixed	0.3006	9	0.03341	9	0.00244	13.685	0.000304
Site*TRT	Random	0.0095	5	0.00191	45.1322	0.00059	3.239	0.013909
Site*Date	Random	0.0219	9	0.00244	45.1352	0.00059	4.133	0.000626
TRT*Date	Fixed	0.0384	45	0.00085	45	0.00059	1.447	0.109579
Site*TRT*Date	Random	0.0265	45	0.00059	353	0.00087	0.672	0.947832
Error		0.3099	353	0.00088				

Table 24. ANOVA Vine Leaf Water Potential

Univariate Tests of Significance for Mpa (All Leaf Water Potential) Over-parameterized model Type III decomposition

	Effect	SS	Deg of Freed.	MS	Den.Syn Err df	DenSyn MS	F	p
Intercept	Fixed	402.340	1	402.340	1	10.9969	36.5866	0.10430
Block	Fixed	0.051	3	0.0173	291	0.01496	1.1530	0.32799
TRT	Fixed	0.381	6	0.0635	6	0.01585	4.0070	0.05770
Site	Random	10.996	1	10.9969	6.3414	0.24472	44.9359	0.00042
Date	Fixed	10.542	6	1.757	6	0.23749	7.3982	0.01401
TRT*Site	Random	0.095	6	0.0159	36	0.00862	1.8392	0.11890
TRT*Date	Fixed	0.327	36	0.0091	36	0.00862	1.0555	0.43605
Site*Date	Random	1.424	6	0.2375	36	0.00862	27.5561	0
TRT*Site*Date	Random	0.310	36	0.0086	291	0.01496	0.5760	0.97645
Error		4.353	291	0.015				

Table 25. ANOVA Leaf N (log transformed) at Bloom

Univariate Tests of Significance for %N (all CN) Over-parameterized model Type III decomposition
Include cases: 1:112

	Effect (F/R)	SS	DegOf Freed	MS	Den.Syn Err df	Den.Syn Err MS	F	p
Intercept	Fixed	1148	1	1147.763	1	1.0903	1052.62	0.0196
Block	Fixed	0.07	3	0.024	81	0.0332	0.70	0.5499
YEAR	Fixed	12.04	1	12.047	1	0.0026	4594.70	0.0093
SITE	Random	1.09	1	1.09	0.88436	0.0549	19.82	0.1648
TRT	Fixed	0.46	6	0.077	6	0.1239	0.62	0.7090
YEAR*SITE	Random	0.01	1	0.003	6	0.0715	0.03	0.8545
YEAR*TRT	Fixed	0.61	6	0.102	6	0.0715	1.42	0.3392
SITE*TRT	Random	0.74	6	0.124	6	0.0715	1.73	0.2605
YEAR*SITE*TRT	Random	0.43	6	0.072	81	0.03324	2.15	0.0561
Error		2.69	81	0.033				

Table 26. ANOVA Leaf N (log transformed) at Veraison

Univariate Tests of Significance for %N (all CN) Over-parameterized model Type III decomposition Include cases: 113:224

	Effect	SS	DegOf Freed	MS	DenSyn Err df	DenSyn MS	F	p
Intercept	Fixed	510.586	1	510.59	1	0.08750	5834.9	0.00833
Block	Fixed	0.195	3	0.065	81	0.02133	3.04	0.03353
YEAR	Fixed	3.615	1	3.615	1	0.08186	44.15	0.09508
SITE	Random	0.088	1	0.088	0.996	0.08217	1.06	0.49054
TRT	Fixed	0.513	6	0.086	6	0.01550	5.51	0.02835
YEAR*SITE	Random	0.082	1	0.082	6	0.01519	5.38	0.05934
YEAR*TRT	Fixed	0.112	6	0.019	6	0.01519	1.22	0.40673
SITE*TRT	Random	0.093	6	0.016	6	0.01519	1.02	0.49041
YEAR*SITE*TRT	Random	0.091	6	0.015	81	0.02133	0.71	0.64080
Error		1.728	81	0.021				

Table 27. ANOVA Shoot Length (log transformed) at AS, 2004 and 2005 combined

Univariate Tests of Significance for logcm (Shoot Lengths) Sigma-restricted parameterization Effective hypothesis decomposition Include cases: 1:336

	SS	Degr. Of Freedom	MS	F	p
Intercept	1359.776	1	1359.776	236351.5	0
Block	0.124	3	0.041	7.2	0.000115
Trt	0.112	6	0.019	3.3	0.004043
date	9.544	3	3.181	553	0
Trt*date	0.096	18	0.005	0.9	0.54107
Error	1.755	305	0.006		

Table 28. ANOVA Shoot Length (log transformed) in 2004, AS and JH combined

Univariate Tests of Significance for logcm (Shoot Lengths 05) Over-parameterized model Type III decomposition Include cases: 1:168,337:504

	Effect	SS	Degr. Of Feedom	MS	Den.Syn. Err df	Den.Syn. MS	F	p
Intercept	Fixed	1260.67	1	1260.67	1	0.315226	3999.253	0.010066
Rep	Fixed	0.064	3	0.021	305	0.006792	3.122	0.026275
Trt	Fixed	0.157	6	0.026	6	0.008058	3.258	0.088212
site	Random	0.315	1	0.315	0.0031	0.000572	551.361	0.03268
date	Fixed	11.938	1	11.938	1	0.007619	1566.777	0.01608
Trt*site	Random	0.048	6	0.008	6	0.015105	0.533	0.768123
Trt*date	Fixed	0.033	6	0.006	6	0.015105	0.365	0.877148
site*date	Random	0.008	1	0.008	6	0.015105	0.504	0.504226
Trt*site*date	Random	0.091	6	0.015	305	0.006792	2.224	0.040782
Error		2.072	305	0.007				

Table 29. ANOVA Pruning Weights at AS, 2004 and 2005 combined

Univariate Results for Each DV (Prune Wt AS 2005) Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. of	g/vine	g/vine	g/vine	g/vine
Intercept	1	39088403	39088403	2050.923	0
Block	3	309338	103113	5.41	0.003285
TRT	6	327037	54506	2.86	0.020922
Year	1	1224783	1224783	64.263	0
TRT*Year	6	128136	21356	1.121	0.368403
Error	39	743298	19059		
Total	55	2732593			

Table 30. ANOVA Pruning Weights at 2004, AS and JH combined

Univariate Tests of Significance for g/vine (All Shoot Length and Pruning Weights) Over-parameterized model Type III decomposition Include cases: 1:56

	Effect	SS	Degr. Of Freedom	MS	Den.Syn. Err df	Den.Syn. MS	F	p
Intercept	Fixed	15010378	1	15010378	1	1615568	9.2911	0.201812
Block	Fixed	132444	3	44148	39	10129	4.3587	0.009676
TRT	Fixed	138795	6	23133	6	11428	2.0243	0.205927
site	Random	1615568	1	1615568	6	11428	141.3751	0.000021
TRT*site	Random	68565	6	11428	39	10129	1.1282	0.364198
Error		395022	39	10129				

Table 31. ANOVA Juice Soluble Solids (BRIX) (AS+JH, 2004+2005)

Univariate Tests of Significance for BRIX (BRIX) Over-parameterized model Type III decomposition

	Effect	SS	DegOf Freed	MS	Den.Syn Err df	Den.Syn MS	F	p
Intercept	Fixed	66193.21	1	66193.21	1	103.9501	636.778	0.02521
Block	Fixed	0.52	3	0.17	81	0.7167	0.239	0.86847
TRT	Fixed	6.13	6	1.02	6	0.8389	1.218	0.40822
SITE	Rand	103.95	1	103.95	2.6349	1.1199	92.822	0.00398
YEAR	Fixed	9.84	1	9.84	1	0.5858	16.799	0.15234
TRT*SITE	Rand	5.03	6	0.84	6	0.3049	2.751	0.12171
TRT*YEAR	Fixed	3.98	6	0.66	6	0.3049	2.176	0.18318
SITE*YEAR	Rand	0.59	1	0.59	6	0.3049	1.921	0.21500
TRT*SITE*YEAR	Rand	1.83	6	0.3	81	0.7167	0.425	0.86005
Error		58.05	81	0.72				

Table 32. ANOVA Juice pH (AS+JH, 2004+2005)

Univariate Tests of Significance for pH (pH) Over-parameterized model Type III decomposition

	Effect	SS	DegOf Freed	MS	Den.Syn Err df	Den.Syn. MS	F	p
Intercept	Fixed	1216.58	1	1216.58	1	1.49272	815.008	0.02229
Block	Fixed	0.161	3	0.054	81	0.01005	5.330	0.00211
TRT	Fixed	0.088	6	0.015	6	0.00973	1.509	0.31493
SITE	Rand	1.493	1	1.493	1.0679	0.17305	8.626	0.19595
YEAR	Fixed	0.801	1	0.801	1	0.16740	4.783	0.27301
TRT*SITE	Rand	0.058	6	0.01	6	0.00408	2.385	0.15712
TRT*YEAR	Fixed	0.079	6	0.013	6	0.00408	3.231	0.08963
SITE*YEAR	Rand	0.167	1	0.167	6	0.00408	40.987	0.00068
TRT*SITE*YEAR	Rand	0.025	6	0.004	81	0.01005	0.406	0.87297
Error		0.815	81	0.01				

Table 33. ANOVA Juice titratable acidity (TA) (AS+ JH, 2004+2005)

Univariate Tests of Significance for TA (TA) Over-parameterized model Type III decomposition

	Effect	SS	DegrOf Freed	MS	Den.Syn Err df	Den.Syn MS	F	p
Intercept	Fixed	4806.2	1	4806.25	1	2.0360	2360.57	0.01310
Block	Fixed	14.513	3	4.838	81	0.2857	16.92	0
TRT	Fixed	3.362	6	0.56	6	0.2355	2.37	0.15774
SITE	Random	2.036	1	2.036	1.0366	10.600	0.19	0.73498
YEAR	Fixed	6.47	1	6.47	1	10.4109	0.62	0.57501
TRT*SITE	Random	1.413	6	0.236	6	0.0462	5.09	0.03402
TRT*YEAR	Fixed	1.224	6	0.204	6	0.0462	4.41	0.04685
SITE*YEAR	Random	10.411	1	10.411	6	0.0462	225.18	0.00001
TRT*SITE*YEAR	Random	0.277	6	0.046	81	0.2857	0.16	0.98604
Error		23.148	81	0.286				

Table 34. ANOVA Juice N by OPA AS Only (2004+2005)

Univariate Results for Each DV (All Fruit Data) Sigma-restricted parameterization
Effective hypothesis decomposition

	Deg Of Freed	SS	MS	F	p
Intercept	1	1081530	1081530	1436.663	0
Block	3	466	155	0.206	0.891414
TRT	6	11957	1993	2.647	0.02989
Year	1	4929	4929	6.548	0.014496
TRT*Year	6	6762	1127	1.497	0.204726
Error	39	29359	753		
Total	55	53474			

Table 35. ANOVA Juice N as NH4 AS Only (2004+2005)

Univariate Results for Each DV (All Fruit Data) Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. Of Freed	SS	MS	F	p
Intercept	1	227082.9	227082.9	768.7598	0
Block	3	4338.3	1446.1	4.8956	0.005539
TRT	6	3779.6	629.9	2.1326	0.071239
Year	1	4032.9	4032.9	13.6527	0.000674
TRT*Year	6	5863.4	977.2	3.3083	0.009941
Error	39	11520.2	295.4		
Total	55	29534.3			

Table 36. ANOVA Juice N as YANC AS Only (2004+2005)

Univariate Results for Each DV (All Fruit Data) Sigma-restricted parameterization Effective hypothesis decomposition

	Degr. Of Freedom	SS	MS	F	p
Intercept	1	2299768	2299768	1499.43	0
Block	3	5820	1940	1.265	0.299808
TRT	6	27316	4553	2.968	0.017456
Year	1	45	45	0.029	0.864977
TRT*Year	6	24080	4013	2.617	0.031473
Error	39	59817	1534		
Total	55	117077			

Table 37. ANOVA Juice N by OPA 2005 Only (AS+JH)

Univariate Tests of Significance for NOPA (All Fruit N) Over-parameterized model Type III decomposition Include cases: 29:84

	Effect	SS	DegrOf Freed	MS	Den.Syn Err df	Den.Syn. MS	F	p
Intercept	Fixed	1072226	1	1072226	1	4319.847	248.2093	0.040354
Block	Fixed	3965	3	1322	39	2048.881	0.645	0.590768
TRT	Fixed	15545	6	2591	6	1422.736	1.821	0.242172
Site	Random	4320	1	4320	6	1422.736	3.0363	0.132054
TRT*Site	Random	8536	6	1423	39	2048.881	0.6944	0.655508
Error		79906	39	2049				

Table 38. ANOVA Juice N as NH4 2005 Only (AS+JH)

Univariate Tests of Significance for NH4 (All Fruit N) Over-parameterized model Type III decomposition Include cases: 29:84

	Effect	SS	DegOf Freed	MS	Den.Syn Err df	Den.Syn MS	F	p
Intercept	Fixed	668529.8	1	668529.8	1	77061.67	8.6753	0.208368
Block	Fixed	2217.8	3	739.3	39	911.83	0.8108	0.495638
TRT	Fixed	8023.9	6	1337.3	6	253.08	5.2842	0.03129
Site	Random	77061.7	1	77061.7	6	253.08	304.4937	0.000002
TRT*Site	Random	1518.5	6	253.1	39	911.83	0.2776	0.944135
Error		35561.3	39	911.8				

Table 39. ANOVA Juice N as YANC 2005 Only (AS+JH)

Univariate Tests of Significance for YANC (All Fruit N) Over-parameterized model Type III decomposition Include cases: 29:84

	Effect	SS	DegrOf Freed	MS	Den.Syn Err df	Den.Syn. MS	F	p
Intercept	Fixed	3434055	1	3434055	1	117872.3	29.13369	0.116623
Block	Fixed	11062	3	3687	39	5234	0.70452	0.5551
TRT	Fixed	41002	6	6834	6	2001.3	3.4146	0.080317
Site	Random	117872	1	117872	6	2001.3	58.89721	0.000256
TRT*Site	Random	12008	6	2001	39	5234	0.38237	0.885798
Error		204124	39	5234				

Table 40. Kruskall-Wallis ANOVA by ranks analyses for fruit yield, vine root density, and AMF and ARB colonization (p values)

	yield	yield	alley			vine row		
Factor	(g/vine)	(g/cluster)	root length	%AMF	%ARB	root length	%AMF	%ARB
TRT	0.0424	0.7265	0.1963	0.6219	0.0318	0.9373	0.562	0.4458
SITE	0	0	0.1595	0.0231	0.6708	0	0.0004	0
YEAR	0.5314	0	0	0.9737	0.0063	0.5479	0.8403	0.3812
DATE			0	0.6575	0.0008	0.2102	0.8432	0.1584