IMPACT OF UNDER-VINE MANAGEMENT IN A FINGER LAKES CABERNET FRANC VINEYARD

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ABSTRACT

Four under-vine management treatments were established in a Cabernet Franc vineyard to study their impact on vine growth and wine quality: glyphosate herbicide (GLY), cultivation (CULT), native vegetation (NV), and white clover (WC). Drainage lysimeters were installed in the under-vine treatments to monitor nutrient and pesticide concentrations in leachate. Smaller vine size and yields of NV cover crop in comparison to GLY vines suggested the potential for cover crops to limit vine vigor, whereas the greater yields of GLY vines, similarity in juice chemistry between treatments and the lack of sensory differences between treatments suggested that herbicide use promoted higher yields without a sacrifice in fruit quality. GLY leachate had greater concentrations of dissolved organic carbon, total nitrogen, and imidacloprid insecticide than NV leachate. These factors demonstrate the potential of cover crops to maintain soil quality and decrease the leaching of nutrients and agrochemicals in comparison to conventional practices.

BIOGRAPHICAL SKETCH

Adam Karl was born and raised in Lancaster, Pennsylvania. There he developed a passion for the outdoors and biology. After graduating from John Pierson McCaskey High School in 2004 he attended Bowdoin College, in Brunswick, Maine. At Bowdoin, Adam focused his studies on ecology and population biology. He graduated in 2008, majoring in biology and environmental studies, with a minor in Spanish. After college, he worked for the Cornell Lab of Ornithology researching songbird reproductive strategies in South and Central America, and co-founded a language institute in Lima, Peru.

While living in Lima, Adam became interested in viticulture and enology through his introduction to pisco, the clear aromatic brandy and national beverage of Peru. Believing he had found his calling, Adam returned to the United States to work as a harvest intern at Tres Sabores Winery in the Napa Valley. After working two more harvests, one in the Casablanca Valley of Chile, and another in Napa, Adam started his masters degree at Cornell University in the spring semester of 2013 in Dr. Justine Vanden Heuvel's lab. Upon graduation, Adam plans to travel to Spain in order to study management practices of dry-farmed vineyards as a recipient of the Frederick Dreer Award.

To all of the teachers and mentors throughout my life who helped shape my intellect and continue to provide me guidance.

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CHAPTER ONE

Literature Review

Introduction

The Finger Lakes American Viticulture Area of upstate New York is the largest producer of *Vitis vinifera* wine grapes in the state, and is experiencing rapid growth (USDA 2013). Total acres of *vinifera* cultivars planted in the AVA grew by 78% to 2,155 acres between 2001 and 2011 (USDA 2001; USDA2013). New York is the fourth largest producer of *vinifera* grapes in the country, behind California, Washington, and Oregon, making the Finger Lakes an increasingly important wine grape production area (USDA 2015).

While the Finger Lakes AVA encompasses approximately 940,000 hectares, the *vinifera* wine grape industry is concentrated on the hillsides directly adjacent to the larger, deeper Finger Lakes: primarily Keuka, Seneca, and Cayuga (Whitesell 2005). These deep glacial reservoirs have sufficient thermal mass to moderate the air temperature around them, reducing the frequency of extreme cold temperatures and frosts (Whitesell 2005). The range of this moderated mesoclimate is a function of elevation and distance from the lakes, and does not extend far from their shores (Lakso and Martinson 2005). The lake adjacent slopes provide good air and soil drainage, and the thermal moderation reduces the risk of extreme cold events and frost damage, making the propagation of cold-hardy *vinifera* cultivars feasible in this narrow strip of land (Lakso and Martinson 2005). Due to the proximity and increasing concentration of vineyards on slopes around the lakes, pollution of these water bodies with vineyard runoff and agrochemicals is of concern. Utilizing management practices that minimize soil erosion, and the leaching of nutrients and pesticides from vineyards into these bodies of water is therefore of particular importance.

Applying management practices that address the high vigor potential of vineyards in the Finger Lakes is also critical in economically producing a high quality crop. Grapevines have an indeterminate growth habit; vegetative growth is not curtailed by a shortening photoperiod, but continues as long as sufficient heat, nutrients, and moisture are available (Keller 2010). The fertile loam soils, in combination with ample precipitation averaging approximately 95 cm annually (Northeast Regional Climate Center 2014) make excessive vigor and vegetative growth a common challenge of grape growing in the region (Smart and Robinson 1991). Fruit shading and denser canopies resulting from excessive vegetative growth present a host of problems that diminish fruit quality and make vineyard management more difficult and expensive. Excessive shading can delay veraison and fruit maturation, reduce soluble solid and anthocyanin concentrations, and increase the concentration of undesirable flavor compounds such as methoxypyrazines (Chorti et al. 2010; Scheiner et al. 2011). Denser canopies also reduce air flow and light penetration in the canopy microclimate, increasing disease pressure, while at the same time reducing spray penetration and the effectiveness of fungicide applications (Austin et al. 2011). Hedging, leaf removal, lateral pulling, and shoot and cluster thinning are common practices to address these problems, but are temporary measures that require additional labor and funds, and do not address the cause of vine imbalance (Smart and Robinson 1991).

Management of the vineyard floor influences both vine growth and vineyard soils. The amount of vegetation on the vineyard floor and resultant competition with grapevines for water and nutrients impacts vine growth (Guerra and Steenwerth 2012). The amount of cover on soil, and the physical or chemical means of vegetation control has the capability to change the physical, chemical, and biological composition and characteristics of the soil (Oliveira and Merwin 2001). Given these factors, better understanding how groundcover management

practices impact vine growth and vineyard soils offers an opportunity to implement management decisions to improve grape production and maintain soil quality.

Efficacy of Vineyard Groundcover Management Practices

Current standard vineyard floor management practices in the Finger Lakes consist of herbicide application to control weed populations under vines in an approximately 1-m wide strip, with a sod alley between rows (Wolf 2008). In *vinifera* plantings, two tillage operations are conducted annually, one in the late fall to hill up soil around graft unions to protect scion buds from winter cold damage, and another in the spring to bring this soil down (Wolf 2008).

Herbicides are commonly used for weed suppression in vineyards because they effectively suppress weed growth, are cost effective, easy to apply, and provide much longer lasting weed suppression than cultivation (Tourte et al. 2008). Herbicides are the most widely applied pesticides in the United States, with the 201 million kg of herbicides applied in 2007 representing 65% of the total volume of pesticides applied to agricultural fields that year (Grube et al. 2011).

Herbicides are applied in both pre and post-emergent formulations in vineyards and vary widely in their mode of action, the plants they are effective against, and their persistence in the environment. The toxicity of herbicides is of concern for damaging vines, and contaminating watersheds (Tourte et al. 2008). Some herbicides can persist in soils for extended periods of time, prolonging this risk. The half-life of oxyfluorfen in soil was found to be 119 days in an Australian vineyard, raising concern for vines as well as consumers of wine made with grapes from the vineyard (Ying and Williams 2000). The leaching of some herbicides that do not rapidly degrade, such as diuron, pose risks for the safety of groundwater drinking sources (Field

et al. 2003). As a result of these concerns, there has been a shift away from herbicides with residual activity in the soil towards ones with more rapid breakdown (Dastgheib and Frampton 2000).

Glyphosate is the most commonly used herbicide in the United States (Gruber et al. 2011), and is popular due to its effectiveness as a non-selective postemergence systemic herbicide capable of killing annual and perennial grasses and broadleaf weeds (Baylis 2000). It is also popular due to its rapid breakdown and low risk of contamination within the environment (Duke and Powles 2008). It readily sorbs to soil and is degraded rapidly by soil microbes, diminishing its leaching potential (Rueppel et al. 1977). However, resistance of plants to herbicides is increasingly becoming a concern for the efficacy of herbicides for vineyard weed management. As of the end of 2014, there were 150 herbicide resistant weed species in the United States, 14 of them resistant to glyphosate (Heap 2015).

Cultivation, or tillage, involves the physical agitation and mixing of soil and surface vegetation. In vineyards, it is a means of mixing and incorporating floor litter, composts and amendments into the soil, as well as a means of weed control (Wolf 2008). It is a popular weed control method in organic vineyards where synthetic herbicide use is forbidden, and with vineyard managers looking to reduce chemical application in their vineyards (Bárberi 2002). When used as the sole means of weed control under vines, cultivation must be performed every several weeks during the growing season in temperate areas for adequate weed growth suppression (Wolf 2008). The labor and fuel costs associated with frequent passes can make cultivation an expensive weed control strategy. A study comparing the costs of weed management in a Californian vineyard over the course of four years found the average annual

cost of cultivation to be 71% greater than post-emergent herbicide application (Tourte et al. 2008).

Cultivation provides a short period of effective weed control because it provides no lasting impediment to weed growth. Some weeds, especially those with rhizomatic growth habits or deep rooted perennial structures, may survive and persist after cultivation, and the physical disruption of the soil profile also brings new seeds to the surface where they can germinate (Froud-Williams et al. 1984). The aeration and mixing of plant matter in the soil enhances short-term nitrogen mineralization, stimulating flushes of weed growth after cultivation (Bárberi 2002). The persistent use of cultivation for weed management favors the establishment and proliferation of species less susceptible to this management type, making weed control increasingly difficult and costly (Elmore et al. 1997).

Cover crops consist of resident vegetation or herbaceous plants deliberately seeded on the vineyard floor. They are comprised of a single or mix of species, representing a number of plant families, with annual, biennial, or perennial lifecycles (Guerra and Steenwerth 2012). Cover crops can be grown between rows and under vines, and maintained with a variety of management options that impact the cover crop's growth, and interaction with the vines and local agroecosystem. Cover crops inhibit the growth of weed species by outcompeting them for resources like water, space and light (Teasdale et al. 1998). Some cover crops in the Brassicaceae family, such as arugula (*Eruca* spp), and mustards (*Sinapis* spp), are often used for their allelopathic weed suppression (Olmstead 2006). However, because weeds are not actively killed from competition or antagonism with cover crops, weed populations are generally greater than with herbicide use or tillage. A study in a California vineyard found weed biomass to be two to 10 times greater in vineyard cover crops in comparison to cultivation and herbicide

application, but cover crops were effective at suppressing especially troublesome weed species such as sowthistle (*Sonchus* spp) and horseweed (*Conyza canadensis*) (Sanguankeo et al. 2009).

In Mediterranean climates, with wet winters and dry summers, cover crops are often planted over the winter when vines are dormant, and removed from all or part of the vineyard either by herbicides or cultivation during the growing season to limit competition with vines for water and nutrients (Tourte et al. 2008). If grown in the vineyard during the growing season, consideration of the phenology, vigor and demand for water are important considerations in cover crop selection and management strategies. Studies of cover crop and weed transpiration rates have found greatly varying values among species. A study conducted in a German Riesling vineyard found transpiration rates per unit of leaf area of the four weed species measured in the study to all be more than double the rate of grapevine leaves, with common mallow's (*Malva neglecta*) transpiration rate five times that of grapevine. A red fescue (*Festuca rubra*) cover crop had a lower transpiration rate than the grapevines, while a more vigorous cover crop, black medick (*Medicago lupulina*), had a transpiration rate nearly three times that of the grapevine (Lopes et al. 2004).

Cover crops have also garnered attention as a tool in integrated pest management. By increasing the species diversity within the vineyard, cover crops can provide habitat, as well as nectar and pollen food sources, for pest predators and parasitoids, increasing their abundance and diversity in comparison to bare ground controls (Costello and Daane 1998; Altieri and Schmidt 1985). In a New Zealand apple orchard, light-brown apple moth (*Epiphyas postvittana*) pupae were more abundant in an herbicide control than in two floral cover crops (*Lobularia mariitima*, and *Fagopyrum esculentum*). *E. postvittana* larvae damage in these treatments was decreased by as much as 29% in comparison to the control, and the density of *Dolichogenidea tasmanica*

cocoons, a parasite of *E. postvittana* pupae, was more than twice as abundant in these cover crops as in the control (Irvin et al. 2006). The species composition of the cover crop can also be important in supporting greater populations of predators and parasitoids. A study in Australian vineyards found that three different cover crops comprised of native grasses had greater abundance and diversity of pest predators and parasites than an oat (*Avena sativa*) cover crop. Predation of *E. postvittana* eggs, a common vineyard pest, were also greater in the native cover crops (Danne et al. 2010). Additionally, cover crops can provide an alternative food source for pests. Cutworms (Noctuidae *Xestia spp*), an early season predator of vine buds, prefer to feed on broadleaf plants rather than grasses. By providing an alternative food source, maintaining a broadleaf cover of plants can reduce cutworm damage in comparison to grass or bare ground (Olmstead 2006).

Impact of Groundcover on Soil Properties

While cover crops can suppress problematic weed populations and play a role in integrated pest management, one of their principal advantages over herbicide use and cultivation is in their maintenance of soil quality. Soil left bare, whether from herbicide application or cultivation, increases the intensity of runoff and erosion (Blavet et al. 2009). During precipitation events, erosion and runoff are increased with slope and lack of cover (Battany and Grismer 2000). Runoff occurs when precipitation rates exceed soil infiltration rates. Soil surface cover increases infiltration rates by slowing the velocity of water flowing downhill, giving it more time to enter the soil column, reducing the volume of runoff (Battany and Grismer 2000). This lowered velocity also reduces the volume of soil potentially carried by water, and its tendency to break apart aggregates and erode soils (Bradford and Huang 1994). Cover also prevents the

direct contact of raindrops with the soil surface, which weakens and breaks aggregates apart, contributing to the formation of surface crusts that reduce water infiltration (Epstein and Grant 1973). The lower volume of runoff water flowing down a slope, slower runoff velocities, and the reduction of splash erosion all contribute to reducing runoff and erosion in habitats with plant cover (Kamalu and Rickson 1994).

A study analyzing soil loss in tilled vs. cover cropped treatments in a Spanish hillside vineyard found 15 times greater soil loss in the tilled treatment (Marques et al. 2010). Water infiltration rates in cover cropped under-vine treatments have also been found to be more than double that of herbicide treated under-vine strips (Gulick et al. 1994). While not of particular concern in the Finger Lakes, cover crops also prevent wind erosion and reduce the amount of dust produced by agricultural machinery, both problems in arid and semi-arid climates (Baker et al. 2005).

High volumes of runoff are a concern for contamination for watersheds with pesticides because large quantities can be removed and rapidly transported from the soil surface to water bodies; in comparison, pesticides in leachate that pass through the soil column have a greater opportunity to be absorbed or degraded before reaching groundwater (Lourchart et al. 2001). A study measuring the movement of benomyl fungicide in an apple orchard with different groundcover management systems found concentrations of the fungicide in runoff greater than in leachate, regardless of groundcover management, and in concentrations as much as 17 times greater in runoff than leachate from residual herbicide plots without groundcover (Merwin et al. 1996).

Groundcover management can also influence the movement, and adsorption of pesticides and nutrients in leachate. Soil crusting resultant from exposure of the bare soil surface can result

in surface cracking. By forming channels into the soil, contact of infiltrating water with soil particles is decreased and the speed at which water passes through the soil column increased (Dekker and Ritsema 1996). This action can increase the concentrations of nitrates and pesticides in the resulting leachate water in comparison to non-crusted surfaces, posing concerns for local watersheds, and increasing the demand for more inputs into the vineyard (Merwin et al. 1996). Cultivation can temporarily alleviate soil crusting and cracking. It also reduces the presence of macropores present in undisturbed soil profiles formed by plant roots or soil macroorganisms such as earthworms (Magdoff and Van Es 2009). The lack of these pores can increase contact of leachate with soil particles by removing these preferential flow paths. Resultantly, herbicides such as atrazine have been found in concentrations four to five times greater in leachate from no-till in comparison to cultivated fields (Isensee et al. 1990).

While tillage operations can temporarily alleviate issues such as surface crusting, they degrade soil structure. The disruption of soil structure though the mixing, compacting, and breaking apart of aggregates from cultivation can increase the bulk density and penetrative resistance of soils, and diminish soil porosity and water holding capacity. Collectively, these factors can impede root growth, water storage, drainage, and gas exchange (Magdoff and Van Es 2009). Cultivation also stimulates the loss of soil organic matter (SOM) by disturbing the soil profile and exposing organic materials where they can be metabolized my microorganisms (Six et al. 1998), which impacts many soil properties.

Cover crops can provide benefits to protect and improve soil structure. The penetration of roots into the soil, in addition to aggregating soil to prevent erosion and runoff, also creates channels through the soil that decrease bulk density, and improve gas exchange and water drainage (McGourty and Reganold 2005). Some tap-rooted forb species, especially those in the

Brassicaceae family, such as mustards and radishes, are used to alleviate compaction in soils and to penetrate hard pan layers, preventing water logging and unrestricting root growth (Williams et al. 2004). As well as alleviating compaction, cover crops also make vineyard floors more durable and less susceptible to compaction from machinery traffic. The fibrous root matrices of grasses are especially effective at aggregating soil and limiting soil compaction from machinery, and are therefore commonly planted in vineyard alleyways to reduce both erosion and compaction (Kaspar et al. 2001).

Cover crops have the potential to stimulate microbial activity and promote SOM by adding organic residues to the soil (Sparling 1997). Vineyard studies have found sod cover crops to increase SOM in comparison to both cultivation (Steenwerth and Belina 2008) and herbicide groundcover management (Morlat and Jacquette 2003). SOM is a crucial component of soils that includes a wide variety of biologically derived material consisting of both living organisms and non-living residues. These materials are very heterogeneous in their composition and reactivity, ranging from readily decomposable labile pools to very stable and inert materials (Janzen et al. 1997). Collectively, SOM provides many benefits to the physical, chemical, and biological properties of soils. Organic materials are important components of soil aggregates, which helps provide a more stable soil structure and maintains pore spaces for gas exchange and water storage (Oads 1984). SOM is also a chelating agent that increases the cation exchange capacities of soils (Parfitt et al. 1995), and is an important source of mineralizable nitrogen, phosphorus, and sulfur for plants (Janzen et al. 1997).

By holding nutrients like nitrogen in stable forms in plant tissue, associated microorganisms, or labile organic matter, cover crops can prevent leaching of these nutrients. The use of a winter cover crop in a vegetable field in California reduced nitrate leaching by 65-

70% in comparison to a fallow control (Wyland et al. 1996). Greater vegetative groundcover has also been demonstrated to reduce nitrate leaching in vineyards (Steenwerth and Belina 2010). The varying C:N ratios of different cover crops impact their decomposition rates, addition of SOM, and plant available nitrogen. Grasses, with their extensive root systems and high C:N ratios typically have slow decomposition rates, and can add large amounts of organic matter to the soil over time (Magdoff and Van Es 2009). The nitrogen in their tissue does not become readily available to plants, and their decomposition may be initially nitrogen absorbing (Ingels 1998). Legumes have lower C:N ratios, decompose more rapidly, and are typically nitrogen releasing. Legumes can increase the availability of nitrogen to vines by fixing atmospheric nitrogen (King and Berry 2005).

The living fraction of SOM provides many services, including the mineralization of nitrogen to plant available forms (Sparling 1997), metabolizing pesticides (Liu et al. 2011), lowering plant pathogens and pest populations (Stone et al. 2004), and improving resistance to drought stress through the association of arbuscular mycorrhizal fungi (Gosling et al. 2006). Cover crops have been found to promote greater microbial respiration in vineyards than cultivation practices. A study in a vineyard in the Central Coast of California found the microbial biomass and carbon dioxide efflux of the soils from two grass cover cover crops to consistently be 1.5-4 times greater than a cultivation control (Steenwerth and Belina 2008). Increased microbial activity is also associated with greater microbial diversity and competition with soil born pests and pathogens. An Australian vineyard ground cover experiment at two vineyard sites found a permanent cover crop cover to increase the populations of beneficial omnivorous, bacterial feeding, fungal feeding, and predatory nematodes at both sites by a factor of 2-6 in comparison to the herbicide control; at the same time the population of plant parasitic nematodes

was decreased 3 fold over the course of the study in comparison to an herbicide control at one of the two vineyards (Rahman et al. 2009). Increased microbial activity and diversity associated with cover crops grown and then mulched under vines in New Zealand decreased botrytis bunch rot inoculum on the vineyard floor and resulting infection of fruit at harvest in comparison to an herbicide treated control (Jacometti et al. 2007). By promoting larger more robust microbial communities, groundcovers have the potential to help manage pests and pathogens in the soil.

Impact of Groundcover on Grapevine Growth, Yield, and Wine Quality

Grapevines growth can be impacted by groundcover management practices by controlling the amount of vegetation competing with vines for water and nutrients. Vine vigor is often controlled in arid regions through the amount of water delivered to vines by irrigation; increasing water stress has been shown to reduce vegetative growth and yields (Ginestar et al. 1998). Lower soil volumetric water content in cover crop treatments have been correlated with lower vine vegetative growth rates in several studies in both hot and cool climates (Monteiro and Lopes 2007; Lopes et al. 2008; Tesic et al. 2007; Wheeler et al. 2005). Lower mid-day stem water potentials in vines planted with cover crops have been correlated with lower vegetative growth rates as well (Centinari et al. 2015; Hatch et al. 2011; Lopes et al. 2008). Competition for water can therefore be a main factor by which cover crops limit vine growth. However, cover crops do not have consistent impacts on vine growth. Over the course of two years in a Willamette Valley Pinot noir vineyard, seven different inter-row cover crop treatments had no impact on vegetative growth, root density, yield, or sugar accumulation in comparison to a cultivation control (Sweet and Schreiner 2010). In a Finger Lakes Riesling vineyard, a buckwheat (*Fogapyrum esculentum*) cover crop had no impact on vine growth in comparison to an herbicide control, but a more

vigorous chicory (*Cichorium intybus*) cover crop reduced vegetative growth, yield, and titratable acidity of fruit in the second year of the study (Jordan 2014). The impact of cover crops on vine growth appears to vary with the vigor of the cover crop, the timing of establishment, and seasonal climactic variation.

Cover crops can also reduce vine growth by means other than direct competition for water. Celette et al. (2005) and Morlat and Jacquet (2003) found that vines grown with sod cover crops planted in alleyways had less vegetative growth than herbicide maintained treatments without impacting vine water status. In both of these studies, root growth was affected by cover crops, with vine roots growing in greater concentrations at deeper depths below the shallow regions dominated by cover crop roots. Celette et al. (2005) suggested that the observed decrease in vegetative growth may have been attributed to competition for nutrients with the cover crop. Subsequent studies in Celette et al. (2009) found that a permanent tall fescue (*Festuca arundinacea*) cover crop had smaller vines with lower concentrations of nitrogen in shoot tissue. The competition with the cover crop led the grapevines to more intensively exploit deeper soil profiles, beneath the surface layer where most nitrogen mineralization occurs, resulting in a reduction in nitrogen uptake by the vine and decreased vine size. Several other studies have found a correlation of reduced vine size and decreased nitrogen content in vines grown with cover crops as well (Ingels et al. 2005; Hatch et al. 2011; Sicher et al. 1993; Tesic et al. 2007). Cover crops may therefore impact vine growth by competition for nutrients in addition to water.

Water deficits at bloom and early stages of berry growth can limit potential crop and berry size (Ojeda et al. 2001). Flowering is also the time of most intensive nitrogen uptake by vines, and low nitrogen availability during this period can diminish fruit set (Keller et al. 1998). Competition from cover crops for resources at these sensitive stages of vine growth can

substantially decrease yield. Controlling the amount of competition with vines through the selection of cover crop species and management are important factors on its interaction with vines. In a study investigating the impact of cover crops on vine growth in semi-arid and temperate regions in Australia, a permanent cover crop reduced yields by 59% and 58% in the last two years of the study at the semi-arid site in comparison to the bare ground control (Tesic et al. 2007). At the temperate site, a difference in yield was only detected in the last year of the study when yield was decreased by 31%. Depending on management goals, the level of competition from the cover crop at the arid site may be excessive. Limiting cover crops to only part of the vineyard floor, mowing cover crops, or selecting less vigorous species are strategies for moderating the amount of competition with vines (Guerra and Steenwerth 2012).

In many circumstances, especially in regions with fertile soils and ample precipitation, moderate devigoration of grape vines can be beneficial (Smart and Robinson 1991). By growing smaller less dense canopies, cover crops have increased beneficial characteristics in canopy architecture such as fewer leaf layers and internal clusters (Tesic et al. 2007). A study in Virginia with a red fescue under-vine cover crop reduced pruning weights by 47% in comparison to an herbicide control; the resulting canopy had fewer occlusion layers and increased plant available radiation to both clusters and leaves (Hatch et al. 2011). Smaller less dense canopies of vines grown with cover crops have reduced the observed incidence of botrytis bunch rot as well (Morlat and Jacquet 2003; Sicher et al. 1993). Increased sun exposure, airflow, and spray penetration through the fruit zone can decrease the incidence of fungal pathogens such as powdery mildew (Austin et al. 2011). Improved sunlight penetration through the canopy and moderate shoot diameter have also been correlated with improved bud fruitfulness and periderm formation (Smart 1985). Competition with cover crops has also improved the balance of overly

vegetative vines, lowering yield/pruning weight ratios to within recommended levels (Monteiro and Lopes 2007; Sicher et al. 2003). Cover crops therefore offer a tool to limit excessive vine vigor, providing a number of benefits.

Cover crops can influence juice and wine quality through manipulating conditions in the fruit zone, and the supply of resources to developing fruit. Increased sunlight exposure can increase total skin monomeric anthocyanins in red grape varieties (Spayd et al. 2002). Greater cluster sunlight exposure from reduced canopy densities in several cover crop studies has been correlated with increases in anthocyanins and tannin levels in juice and wine (Lopes et al. 2008; Morlat and Jacquet 2003; Wheeler et al. 2005). Water stress imparted by cover crop competition can also reduce berry size, increasing the skin-to-pulp ratio, which may also contribute to greater anthocyanin and tannin levels (Morlat and Jacquet 2003). Cover crops have been observed to increase soluble solids in juice (Morlat and Jacquet 2003). A study in New Zealand found a chicory cover crop to reduce pruning weights of Cabernet sauvignon vines by approximately half of a cultivated control, without impacting yield (Wheeler et al. 2005). Fruit from vines in the chicory cover crop had advanced ripening in comparison to the control, with increased soluble solids and decreased titratable acidity, as well as wines that scored higher on a sensory quality evaluation. Cool viticultural regions like the Finger Lakes where ripening periods are often limited by climatic conditions would benefit from decreased juice acidity, increased anthocyanin accumulation, and accelerated sugar accumulation.

Conclusion

Different groundcover management strategies have their benefits and drawbacks. Determining the optimal means to manage vineyard groundcover is largely dependent on the

climate and production goals of the vineyard. Especially in regions with appreciable rainfall throughout the growing season, cover crops offer benefits in both managing soil quality, and providing benefits from devigorating vines.

Due to the potential interactions and consequences that vineyard groundcovers have, continued multiyear studies are warranted to further understand these relationships. While many studies have examined the impact of vineyard groundcovers on soil quality parameters, vine growth, or sensory attributes of resultant wines, there has not been a single comprehensive evaluation of how vineyard groundcover impacts all of these factors in a cool climate vineyard. Due to the growing prominence of viticulture in the Finger Lakes, and potential of groundcover management practices to improve the management practices of vineyards in the region, the aim of this study was to understand the impact of different under-vine groundcovers in a Finger Lakes vineyard over the course of several years on the vine growth, wine sensory properties, soils, and leachate composition.

REFERENCES

Altieri, M.A., and L.L. Schmidt. 1985. Cover crop manipulation in northern California orchards and vineyards: effects on arthropod communities. Biological Agriculture and Horticulture. 3:1-24.

Austin, C.N., and W.F. Wilcox. 2011. Effects of fruit-zone leaf removal, training systems, and irrigation on the development of grapevine powdery mildew. American Journal of Enology and Viticulture. 62:193-198.

Baker, J. B., R.J. Southard, and J.P. Mitchell. 2005. Agricultural dust production in standard and conservation tillage systems in the San Joaquin Valley. Journal of Environmental Quality. 34:1,260-1,269.

Bárberi, P. 2002. Weed management in organic agriculture: are we addressing the right issues?. Weed Research. 42:177-193.

Battany, M.C., and M.E. Grismer. 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. Hydrological processes. 14:1,289-1,304.

Baylis, A.D. 2000. Why glyphosate is a global herbicide: strengths, weaknesses and prospects. Pest Management Science. 56:299-308.

Blavet, D., G. De Noni, Y. Le Bissonnais, M. Leonard, L. Maillo, J.Y. Laurent, J. Asseline, J.C. Leprun, M.A. Arshad, and E. Roose. 2009. Effect of land use and management on the early stages of soil water erosion in French Mediterranean vineyards. Soil and Tillage Research. 106:124-136.

Bradford, J.M., and C.H. Huang. 1994. Interrill soil erosion as affected by tillage and residue cover. Soil and Tillage Research. 31:353-361.

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

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

Centinari, M., J.E. Vanden Heuvel, M. Goebel, M. Smith, and T. Bauerle. 2015. Root-zone management practices impact above and below-ground growth in Cabernet Franc grapevines. Australian Journal of Grape and Wine Research. Accepted June 2015.

Chorti, E., S. Guidoni, A. Ferrandino, and V. Novello. 2010. Effect of different cluster sunlight exposure levels on ripening and anthocyanin accumulation in Nebbiolo grapes. American Journal of Enology and Viticulture. 61:23-30.

Costello, M.J., and K.M. Daane. 1998. Influence of ground cover on spider populations in a table grape vineyard. Ecological Entomology. 23:33-40.

Danne, A., L.J. Thomson, D.J. Sharley, C.M. Penfold, and A.A. Hoffmann. 2010. Effects of native grass cover crops on beneficial and pest invertebrates in Australian vineyards. Environmental Entomology. 39:970-978.

Dastgheib, F., and C. Frampton. (2000). Weed management practices in apple orchards and vineyards in the South Island of New Zealand. New Zealand Journal of Crop and Horticultural Science. 28:53-58.

Dekker, L.W., and C.J Ritsema. 1996. Preferential flow paths in a water repellent clay soil with grass cover. Water Resources Research 32:1,239-1,249.

Duke, S.O., and S.B. Powles. 2008. Glyphosate: a once-in-a-century herbicide. Pest Management Science. 64:319-325.

Elmore, C., J. Roncoroni, L. Wade, and P. Verdegaal. 1997. Four weed management systems compared: Mulch plus herbicides effectively control vineyard weeds. California Agriculture. 51:14-18.

Epstein, E., and W.J. Grant. 1973. Soil crust formation as affected by raindrop impact. *In* Physical Aspects of Soil Water and Salts in Ecosystems. Hadas, A., D. Swartzendruber, P.E. Rijtema, M. Fuchs, and B. Yaron (eds.), pp. 195-201. Springer, Heidelberg, NY.

Field, J.A., R.L. Reed, T.E. Sawyer, S.M. Griffith, and P.J. Wigington. 2003. Diuron occurrence and distribution in soil and surface and ground water associated with grass seed production. Journal of Environmental Quality. 32(1): 171-179.

Froud-Williams, R.J., R.J. Chancellor, and D.S.H. Drennan. 1984. The effects of seed burial and soil disturbance on emergence and survival of arable weeds in relation to minimal cultivation. Journal of Applied Ecology. 21:629-641.

Ginestar, C., J. Eastham, S. Gray, and P. Iland. 1998. Use of sap-flow sensors to schedule vineyard irrigation. Effects of post-veraison water deficits on water relations, vine growth, and yield of Shiraz grapevines. American Journal of Enology and Viticulture. 49:413-420.

Gosling, P., A. Hodge, G. Goodlass, and G.D. Bending. 2006. Arbuscular mycorrhizal fungi and organic farming. Agriculture, Ecosystems and Environment. 113:17-35.

Grube, A., D. Donaldson, T. Kiely, and L. Wu. 2011. Pesticides industry sales and usage. US EPA, Washington, DC.

Guerra, B., and K. Steenwerth. 2012. Influence of floor management technique on grapevine growth, disease pressure, and juice and wine composition: a review. American Journal of Enology and Viticulture. 62:149-164

Gulick, S. H., D.W. Grimes, D.A. Goldhamer, and D.S. Munk. 1994. Cover-crop-enhanced water infiltration of a slowly permeable fine sandy loam. Soil Science Society of America Journal. 58:1,539-1,546.

Hatch, T.A., C.C. Hickey, and T.K Wolf. 2011. Cover crop, rootstock, and root restriction regulate vegetative growth of Cabernet Sauvignon in a humid environment. American Journal of Enology and Viticulture. 63:298-311.

Heap, I. The International Survey of Herbicide Resistant Weeds. Available online at http://weedscience.org/summary/countrysummary.aspx/. Accessed 10 February 2015.

Ingels, C. A. 1998. Cover cropping in vineyards: a grower's handbook. University of California Division of Agriculture and Natural Resources. Oakland, CA.

Irvin, N.A., S.L. Scarratt, S.D. Wratten, C.M. Frampton, R.B. Chapman, and J.M. Tylianakis. 2006. The effects of floral understoreys on parasitism of leafrollers (*Lepidoptera: Tortricidae*) on apples in New Zealand. Agricultural and Forest Entomology. 8:25-34.

Isensee, A.R., R.G. Nash, and C.S. Helling. 1990. Effect of conventional vs. no-tillage on pesticide leaching to shallow groundwater. Journal of Environmental Quality. 19:434-440.

Jacometti, M.A., S.D. Wratten, and M. Walter. 2007. Management of understorey to reduce the primary inoculum of *Botrytis cinerea*: Enhancing ecosystem services in vineyards. Biological Control. 40:57-64.

Janzen, H.H., Campbell, C.A., Ellert, B.H. and Bremer, E. 1997. Soil organic matter dynamics and their relationship to soil quality. *In* Soil quality for crop production and ecosystem health: Developments in soil science. Vol. 25. Gregorich, E.G. and M.R. Carter (eds.), pp. 277-291. Elsevier Publishing, Amsterdam.

Jordan, L.M. 2014. Evaluating the effects of using annually established under-vine cover crops in northeastern Riesling vineyards. M.S. thesis. Cornell University, Ithaca, NY.

Kamalu, C., and R.J. Rickson. 1994. The effect of slope length and inclination on the separate and combined actions of rainsplash and runoff. *In* Conserving soil resources: European perspectives. Selected papers from the First International Congress of the European Society for Soil Conservation. Rickson, R.J. (ed.), pp. 143-149. CAB International, Oxfordshire, UK.

Kaspar, T.C., J.K. Radke, and J.M. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. Journal of Soil and Water Conservation. 56:160-164.

Keller, M. 2010. The science of grapevines: anatomy and physiology. Academic Press. London, UK.

Keller, M., K.J. Arnink, and G. Hrazdina. 1998. Interaction of nitrogen availability during bloom and light intensity during veraison: Effects on grapevine growth, fruit development, and ripening. American Journal of Enology and Viticulture. 49:333-340.

King, A.P., and A.M. Berry. 2005. Vineyard δ 15 N, nitrogen and water status in perennial clover and bunch grass cover crop systems of California's central valley. Agriculture, Ecosystems and Environment. 109:262-272.

Lakso, A.N., and T.E. Martinson. 2005. The Basics of Vineyard Site Evaluation and Selection. Cornell University Department of Horticulture. Geneva, New York.

Liu, Z., Dai, Y., Huang, G., Gu, Y., Ni, J., Wei, H., & Yuan, S. 2011. Soil microbial degradation of neonicotinoid insecticides imidacloprid, acetamiprid, thiacloprid and imidaclothiz and its effect on the persistence of bioefficacy against horsebean aphid *Aphis craccivora* Koch after soil application. Pest Management Science. 67:1,245-1,252.

Lopes, C., A. Monteiro, F.E. Ruckert, B. Gruber, B. Steinberg, and H.R. Schultz. 2004. Transpiration of grapevines and co-habitating cover crop and weed species in a vineyard. Vitis-Geilweilerhof. 43:111-118.

Lopes, C.M., A. Monteiro, J.P. Machado, N. Fernandes, and A. Araujo. 2008. Cover cropping in a sloping non-irrigated vineyard: Effects on vegetative growth, yield, berry and wine quality of 'Cabernet Sauvignon'grapevines. Ciência e Técnica Vitivinícola. 23:37-43.

Louchart, X., M. Voltz, P. Andrieux, and R. Moussa. 2001. Herbicide transport to surface waters at field and watershed scales in a Mediterranean vineyard area. Journal of Environmental Quality. 30:982-991.

Magdoff, F., and H. Van Es. 2009. Building soils for better crops: sustainable soil management 3rd ed. Sustainable Agriculture Network handbook series.

Marques, M.J., S. García-Muñoz, G. Muñoz-Organero, and R. Bienes. 2010. Soil conservation beneath grass cover in hillside vineyards under Mediterranean climatic conditions (Madrid, Spain). Land Degradation and Development. 21(2): 122-131.

Merwin, I.A., J.A. Ray, T.S. Steenhuis, and J. Boll. 1996. Groundcover management systems influence fungicide and nitrate-N concentrations in leachate and runoff from a New York apple orchard. Journal of the American Society for Horticultural Science. 121: 249-257.

Monteiro, A., and C.M. Lopes. 2007. Influence of cover crop on water use and performance of vineyard in Mediterranean Portugal. Agriculture Ecosystems and Environment. 121:336-342.

Morlat, R., and A. Jacquet. 2003. Grapevine root system and soil characteristics in a vineyard maintained long-term with or without interrow sward. American Journal of Enology and Viticulture. 54:1-7.

Northeast Regional Climate Center. The Climate of Ithaca, NY. Available at http://www.nrcc.cornell.edu/climate/ithaca/. Accessed August 5 2014.

Oades, J.M. 1984. Soil organic matter and structural stability: mechanisms and implications for management. Plant and Soil. 76: 319-337.

Ojeda, H., A. Deloire, and A. Carbonneau. 2001. Influence of water deficits on grape berry growth. Vitis-Geilwilerhof. 40:141-146.

Oliveira, M.T. and I.A. Merwin. 2001. Soil and physical conditions in a New York orchard after eight years under different groundcover management systems. Plant and Soil. 234:233-237.

Olmstead, M.A. 2006. Cover crops as a floor management strategy for Pacific Northwest vineyards. Washington State University Extension. Prosser, WA.

Parfitt, R. L., Giltrap, D. J., & Whitton, J. S. 1995. Contribution of organic matter and clay minerals to the cation exchange capacity of soils. Soil Science and Plant Analysis. 26:1,343-1,355.

Rahman, L., M.A. Whitelaw-Weckert, R.J. Hutton, and B. Orchard. 2009. Impact of floor vegetation on the abundance of nematode trophic groups in vineyards. Applied Soil Ecology. 42:96-106.

Rueppel, M.L., B.B. Brightwell, J. Schaefer, and J.T. Marvel. 1977. Metabolism and degradation of glyphosate in soil and water. Journal of Agricultural and Food Chemistry. 25:517-528.

Sanguankeo, P.P., R.G. Leon, and J. Malone. 2009. Impact of weed management practices on grapevine growth and yield components. Weed Science. 57:103-107.

Scheiner, J.J., J.E. Vanden Heuvel, B. Pan, and G.L. Sacks. 2011. Modeling impacts of viticultural and environmental factors on 3-isobutyl-2-methoxypyrazine in Cabernet franc grapes. American Journal of Enology and Viticulture. 63:94-105.

Sicher, L., A. Dorigoni, and G. Stringari. 1993. Soil management effects on nutritional status and grapevine performance. Mineral Nutrition of Deciduous Fruit Plants. 383:73-82.

Six, J., E.T. Elliott, K. Paustian, and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Science Society of America Journal. 62:1367-1377.

Smart, R. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality, a review. American Journal of Enology and Viticulture. 36:230-239.

Smart, R., and M. Robinson. 1991. Sunlight into wine: a handbook for winegrape canopy management. Winetitles.

Sparling, G.P. 1997. Soil microbial biomass, activity and nutrient cycling. Soil health: its relationship to ecosystem health. *In* Biological indicators of soil health. Pankhurst, C., Doube, B.M. and Gupta, V.V.S.R. (eds.), pp. 97-119. Wallingford, UK.

Spayd, S.E., J.M. Tarara, D.L. Mee, and J.C. Ferguson. 2002. Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. American Journal of Enology and Viticulture. 53:171-182.

Steenwerth, K. L., and K.M Belina. 2008. Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. Applied Soil Ecology. 40:359-369.

Steenwerth, K.L., and K.M Belina. 2010. Vineyard weed management practices influence nitrate leaching and nitrous oxide emissions. Agriculture Ecosystems and Environment. 138:127-131.

Stone, A.G., S.J. Scheuerell, and H.M. Darby. 2004. Suppression of soilborne diseases in field agricultural systems: organic matter management, cover cropping, and other cultural practices. *In* Soil Organic Matter in Sustainable Agriculture. F. Magdoff, and R.W. Ray (eds.). pp. 131-177. CRC Press, Boca Raton, FL.

Sweet, R.M., and R.P Schreiner. 2010. Alleyway cover crops have little influence on Pinot noir grapevines (*Vitis vinifera* L.) in two western Oregon vineyards. American Journal of Enology and Viticulture. 61:240-252.

Teasdale, J. R. 1998. Cover crops, smother plants, and weed management. *In* Integrated Weed and Soil Management. Hatfield, J.L., D.D. Buhler, B.A. Stewart (eds.), pp. 247-270. Ann Arbor Press, Chelsea, MI.

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

Tourte, L., R. Smith, L. Bettiga, T. Bensen, J. Smith, and D. Salm. 2008. Post-emergence herbicides are cost effective for vineyard floor management on the Central Coast. California Agriculture. 62:19-23.

(USDA) United States Department of Agriculture. 2001. Fruit Tree and Vineyard Survey, 2001. National Agricultural Statistics Service: New York Field Office. Albany, NY.

(USDA) United States Department of Agriculture. 2013. New York Vineyard Survey, January 2013. National Agricultural Statistics Service: New York Field Office. Albany, NY.

(USDA) United States Department of Agriculture. 2015. Noncitrus Fruits and Nuts 2014 Preliminary Summary. National Agricultural Statistics Service. Washington, DC.

Wheeler, S.J., A.S. Black, and G.J Pickering. 2005. Vineyard floor management improves wine quality in highly vigorous Vitis vinifera 'Cabernet Sauvignon' in New Zealand. New Zealand Journal of Crop and Horticultural Science. 33:317-328.

Whitesell K. (2005). The Lake Effect on the Surrounding Climate of the Finger Lakes in New York. 18th Annual Keck Symposium. L Bettison-Varga (ed.), 58-61. Colorado College, CO.

Williams, S.M., and R.R. Weil. 2004. Crop cover root channels may alleviate soil compaction effects on soybean crop. Soil Science Society of America Journal. 68:1,403-1,409.

Wolf, T.K. 2008. Wine Grape Production Guide for Eastern North America. Natural Resource, Agriculture, and Engineering Service, Ithaca, NY.

Wyland, L.J., L.E. Jackson, W.E. Chaney, K. Klonsky, S.T. Koike, and B Kimple. 1996. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, pests and management costs. Agriculture Ecosystems and Environment. 59:1-17.

Ying, G.G., and B. Williams. 2000. Dissipation of herbicides in soil and grapes in a South Australian vineyard. Agriculture Ecosystems and Environment. 78:283-289.

CHAPTER TWO

Impact of Under-Vine Management in a Finger Lakes Cabernet Franc Vineyard: Vine Growth, Fruit Composition, and Wine Sensory Analyses

Introduction

Fertile soils, in combination with ample precipitation, make excessive vegetative growth a common challenge for vineyard management in cool climates such as the Northeast United States. These vineyards are characterized by large, dense canopies and heavily shaded fruit zones. These conditions can increase disease pressure by inhibiting airflow, light exposure, and spray penetration in the canopy (Austin et al. 2011). Excessively shaded canopies can also reduce fruit and wine quality by decreasing sugar accumulation and anthocyanin production, and promoting higher concentrations of undesirable flavor compounds (Smart 1985; Ryona et al. 2008). In order to reduce shading and improve fruit quality, growers frequently perform practices such as hedging, leaf removal, lateral pulling, and shoot and cluster thinning.

The standard vineyard floor management practice in the Northeastern United States is to maintain a weed-free strip under the trellis using herbicides or cultivation, and sod alleyways between rows (Wolf 2008). The soil left bare from these treatments increases the incidence of erosion and runoff (Battany and Grismer 2000), and eliminates competition from non-vine plant species for water and nutrients (Wheeler et al. 2005). Planting cover crops under vines has the potential to mitigate the environmentally detrimental features of herbicide application and cultivation, while increasing competition with vines to reduce vigor. This competition could help reduce management costs and improve fruit quality by competing with the vine for water and nutrients, decreasing the need for practices to manage overly vigorous canopies. Cover crops planted under vines have been effective in decreasing metrics of vine vigor, including pruning

weights, yield, shoot growth, leaf area, canopy density, and fruit shading (Hatch et al. 2011; Tesic et al. 2007; Wheeler et al. 2005).

The objective of this study was to determine the impact of under-vine management in a Cabernet Franc vineyard on vine growth, fruit composition, and wine characteristics.

Materials and Methods

Vineyard Site and Experimental Design

The study was conducted from 2011-2013 in an approximately 0.25 ha research vineyard located about 350 m from the eastern shore of Cayuga Lake, in Lansing, NY, in the Finger Lakes American Viticultural Area (42°34'15"N, 76°35'39"W, 124 meters elevation). The vineyard soils are classified as a Hudson-Cayuga silt loam (Soil Survey Staff 1987), on a 5-8% westward facing slope. The vines, *Vitis vinifera* L. cv. Cabernet Franc cl. 1 grafted on 3309C rootstock, were planted in 2008 with 2.8-m row spacing.

The vines were planted 1.8-m apart, cane-pruned, and trained on a two-tier flat bow vertical shoot positioned trellis. The vineyard was equipped with a pressure compensating drip irrigation system (UniRam, Trickl-eez Company, Biglerville, PA) with emitters spaced 61 cm apart with a discharge rate of 2.3 L/hour. This system was run for six hours on 29 June and 2 July 2012 due to perceived vine water stress. Disease pressure was controlled by standard spraying practices for *V. vinifera* (Wolf 2008).

Four under-vine groundcover treatments were established in 1-m wide strips under vines in 2011. The vineyard consisted of 17 rows, with each row consisting of six panels, with four vines per panel. The interior four panels of even numbered rows were designated as treatment panels. Odd numbered rows, and end panels of treatment rows were maintained with glyphosate

herbicide when needed as guard (buffer) panels. Each treatment panel contained a drainage lysimeter used to collect leachate water for analysis of nutrient and agrochemical content, discussed in Chapter Three. In rows 2, 8, 12, and 16, lysimeters were placed between vines. In rows 4, 6, 10, and 14 a vine was planted in a lysimeter. Due to poor growth as a result of being planted in a drainage lysimeter, these vines were omitted from the present study. With the omission of these vines, the study contained 112 experimental vines (Figure 2.1).

Alleyways were planted with either fine-leaf fescue (*Festuca duriuscula* L.) or tall fescue (*F. arundinacea* Schreb.) in the spring of 2010, and maintained by periodic mowing. The study was arranged in a split-plot design with four replicates. Alley sod type was the main plot, and under-vine treatment the split-plot. Analysis of sod type effects found few and inconsistent differences. Anecdotally, there was no visual difference in sod type. Since alley-type had essentially no impact on the study, the statistical analyses were then run as a randomized complete block design, with eight replicates of each treatment.

A few scion buds on each vine are often protected from cold temperatures in the Northeastern United States by hilling soil over the graft union (Wolf 2008): however due to the buried drainage lysimeters in this study, hilling was not an option. In the winters of 2010-11 and 2011-12 rye (*Secale cereale* L.) straw was placed in a strip in the center of the under-vine row and removed in the spring. However, rye produces benzoxazinones that are allelopathic to both monocots and dicots and prevent seed germination (Barnes and Putnam 1986) and we subsequently noted suppressed vegetative growth where rye straw was spread. To avoid further impact of the straw on vegetation growth, bags filled with gravel in the winter of 2012-13, and bags filled with sawdust in the winter of 2013-14 were placed around graft unions to protect scion buds.

The four under-vine treatments included glyphosate herbicide application (GLY), cultivation (CULT), native vegetation (NV), and white clover cover crop (WC) maintained in a 1-m wide strip under the vines. Representing conventional vineyard practices, glyphosate herbicide was applied twice per year in the GLY treatment, once in late May or early June and again in late July or early August. Makaze glyphosate (Loveland Products, Greeley, CO), N-(phosphonomethyl)glycine in the form of its isopropylamine salt, was diluted to a 2% solution, and applied at a rate of 2.9 kg ai/ha with a backpack sprayer. In the CULT treatment, cultivation was performed over the entire treatment area with a grape hoe by hand to a depth of approximately 10 cm when average vegetation height reached about 30 cm. Vegetation disturbed by cultivation was left in place on the soil surface. In the WC treatment, white clover (*Trifolium. repens* L. cv. Dutch White) was seeded at 10 kg/ha in mid to late April each year and mowed when average vegetation height reached approximately 30 cm. The NV treatment consisted of allowing naturally occurring vegetation to grow, which was mowed using a push mower when average height reached approximately 30 cm. A list of species found in native vegetation towards the end of the experiment can be found in Table 2.1. Herbicide application, cultivation, and mowing dates can be found in Table 2.2.

When average shoot length reached approximately 10 cm, secondary and tertiary shoots were removed, and primary shoots thinned to 28 per vine in 2011 and 2012, and 30 in 2013. The canopy was managed by vertical shoot positioning throughout the growing season. Vines were not hedged, and long shoots were wrapped around the top fruiting wire in order to preserve accurate vine pruning weights.

Figure 2.1. Randomized complete block design layout for experimental Cabernet Franc vineyard located in Lansing, NY.

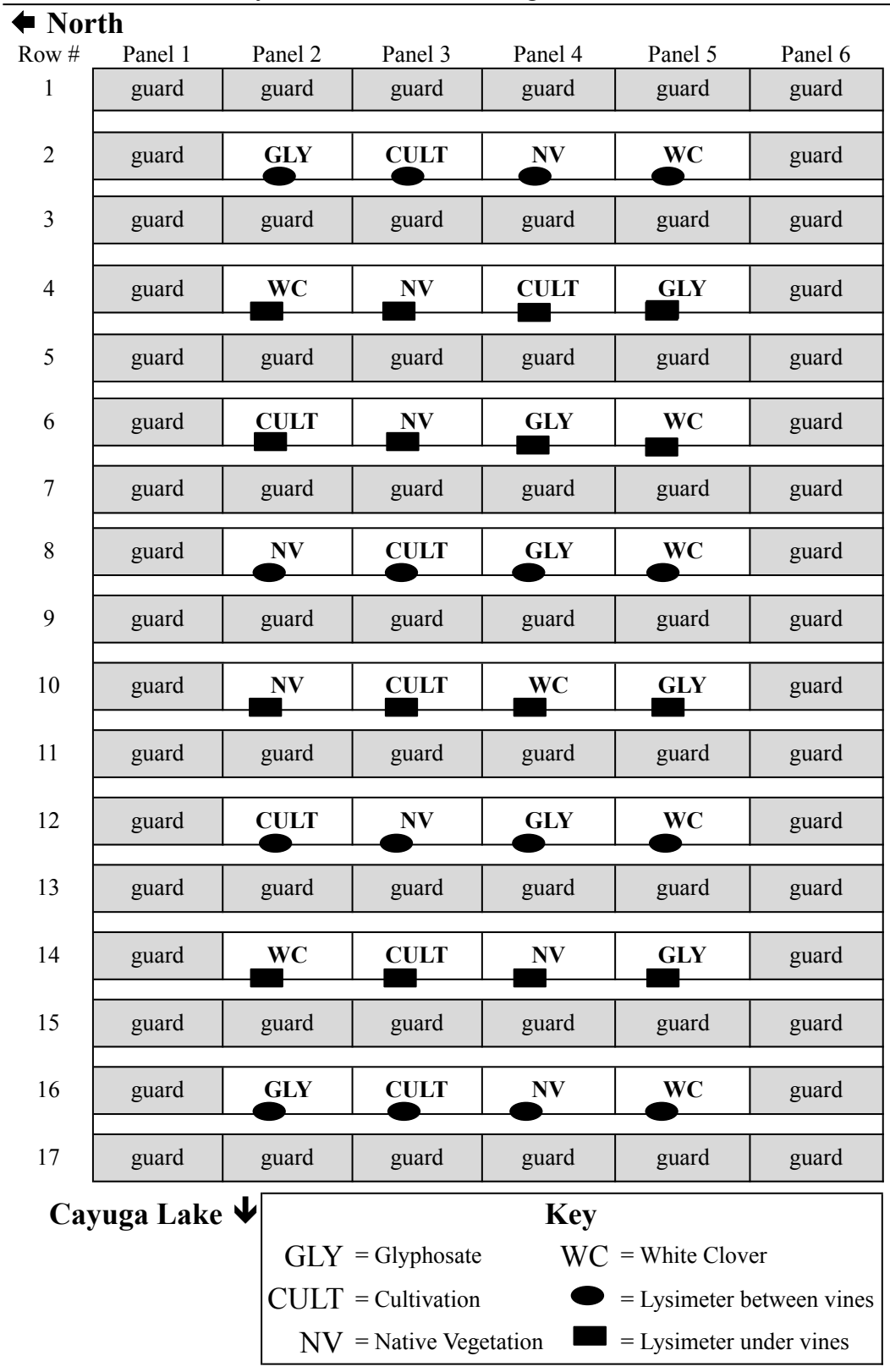

Table 2.1. Plant species identified within the Native Vegetation under-vine treatments in August 2014.

Family	Species	Common Name
Amaranthaceae	*Amaranthus albus* L.	Tumble pigweed
	Amaranthus powellii S. Wats.	Powell amaranth
Apiaceae	*Daucus carota* L.	Wild carrot
Asteraceae	*Arctium minus* Bernh.	Common burdock
	Cichorium intybus L.	Chicory
	Conyza canadensis L.	Horseweed
	Solidago spp.	Goldenrod
	Sonchus arvensis L.	Perennial sowthistle
	Symphyotrichum ericoides L.	White aster
	Taraxacum officinale F.H. Wigg	Dandelion
Chenopodiaceae	*Chenopodium album* L.	Common lambsquarters
Convolvulaceae	*Convolvulus arvensis* L.	Field bindweed
Fabaceae	*Trifolium pratense* L.	Red clover
	Trifolium repens L.	White clover
Lamiaceae	*Glechoma hederacea* L.	Ground Ivy
	Prunella vulgaris L.	Healall
Oxalidaceae	*Oxalis stricta* L.	Yellow woodsorrel
Plantagonaceae	*Plantago lanceolata* L.	Buckhorn plantain
	Plantago major L.	Broadleaf plantain
Polygonaceae	*Polygonum aviculare* L.	Prostrate knotweed
	Polygonum persicaria L.	Ladysthumb
Portulacaceae	*Portulaca oleracea* L.	Common purslane
Poaceae	*Digitaria ischaemum* Schreb.	Smooth crabgrass
	Digitaria sanguinalis L.	Large crabgrass
	Echinochloa crus-galli L.	Barnyardgrass
	Festuca arundinacea Schreb.	Tall fescue
	Festuca duriuscula L.	Fine-leaf fescue
	Panicum capillare L.	Witchgrass
	Setaria glauca L.	Yellow foxtail
Scrophulariaceae	*Linaria vulgaris* Mill.	Yellow toadflax
	Verbascum thapsus L.	Common mullein
Simaroubaceae	*Ailanthus altissima* Mill.	Tree of heaven

Table 2.2. Date of groundcover treatments: glyphosate herbicide application in the Glyphosate treatment (GLY), hand cultivation in the Cultivation treatment (CULT), and mowing in Native Vegetation (NV) and White Clover (WC) treatments.

Treatment	2011	2012	2013	2014
GLY	May, July	May, July	27 May, 2 August	6 June, 1 August
CULT	May	June	16 May, 4 July, 7 September	19 May, 29 July
NV	June, August	June, August	17 June, 7 September	19 May, 10 September
WC	-	-	17 September	13 June, 10 September

Weather Data

Weather data for the site was recorded from the Cornell University Network for Environment and Weather Applications (NEWA) Lansing station (newa.cornell.edu), located approximately 150 m north of the vineyard at a similar elevation. In 2011, the precipitation gauge was not functioning from 6 May through 18 May, 28 May through 3 June, and from 30 July through 31 October. During these dates, precipitation data from a weather station being used by our research program in another viticultural study located 9.2 km north of the research site was used. In 2013, the precipitation gauge was not functioning from 1 August through 12 September. On these dates, precipitation data from a Trumansburg, NY Weather Underground weather station, located approximately 6.3 km southeast of the site was used. Precipitation and temperature data from 1 April through 31 October was used to estimate rainfall and growing degree-days for the growing season (with a base threshold of 10°C) for each growing season.

Pruning Weights

In late March or early April each year dormant vines were pruned to four canes with 10 nodes per cane, leaving 40 nodes per vines. The pruning weights from individual vines were weighed with a hanging scale accurate to 0.1 kg (Salter Brecknell, SA3N340, Fairmont, MN). These masses and the yields from the previous year were then used to calculate Ravaz indices (yield/pruning weight).

Bud Survival

After a variable and cold winter in 2013/2014, there was severe cold damage to many *V. vinifera* vineyards in the Finger Lakes. To calculate bud survival, emergence of primary buds from cane nodes was counted for each vine on 17 May 2014. Due to high levels of bud mortality within the vineyard, viticultural data were not collected for the experiment during the 2014 growing season.

Stem Water Potential

Vine stem water potential was measured with a pressure bomb (Soil Moisture Equipment Corporation, model 3005F01, Santa Barbara, CA) during the growing season of 2012 and 2013. Fully expanded and exposed healthy leaves between the 5th and 7th node were selected. Predawn stem water potential ($\Psi_{Predawn}$) measurements were taken between 0330 and 0500 hr. Midday stem water potential (Ψ_{Midday}) measurements were taken within $\pm$1.5 hours of solar noon. For Ψ_{Midday} measurements, leaves were placed within 250 cm^2 plastic bags wrapped in foil one hour before measurements were taken. Stem water potential was calculated by cutting the petiole with a razor and placing leaves in the pressure chamber with the petiole extending from the grommet

seal, and pressurizing the chamber until a small droplet of xylem fluid began to protrude from the tip of the cut petiole (Scholander et al. 1965). In 2012, a single leaf was measured per treatment panel. In 2013, a single leaf per panel for predawn, and two leaves per panel for midday measurements were taken. In 2012, only a single predawn measurement was taken on 10 July, and midday measurements were taken on 10 July, 25 July, 7 August, and 30 August. In 2013, a midday measurement was taken on 5 July, and both predawn and midday measurements were taken on 22 July, 6 August, 19 August, 5 September, and 17 September.

Enhanced Point Quadrant Analysis

Vine canopy structure and light environment were characterized on a per-vine basis using enhanced point quadrant analysis (EPQA) at approximately 50% veraison on 26 August 2013 (Meyers and Vanden Heuvel 2008). To characterize canopy structure, point quadrant analysis (PQA) was performed by inserting a thin rod through the fruiting zone perpendicular to the vine row at 20 cm intervals, recording the sequence of leaves and clusters the rod contacted (Smart and Robinson 1991). This data was used to calculate leaf layer numbers, percent interior clusters, and percent interior leaves. The light environment in the canopy interior was characterized by recording photon flux measurements using a ceptometer (Decagon, model AccuPAR LP-80, Pullman, WA) between 1200 and 1400 hr. The ceptometer, 90 cm long, containing 80 photosensors, was inserted within the fruit zone parallel to the row with the sensors directed upward, while a point photosynthetically active radiation (PAR) point sensor was held above the canopy. The ratio of PAR intensity within and above the canopy was used to calculate in-canopy flux. An in-canopy flux value was calculated for each vine by averaging 10 in-canopy flux measurement over 10 seconds. Canopy structure and photon in-canopy flux data were analyzed

using Canopy Exposure Mapping Tools, version 1.7 (available free of charge from Jim Meyers, jmm533@cornell.edu) developed to calculate occlusion layer number, cluster exposure layers, and cluster exposure flux availability (Meyers and Vanden Heuvel 2008).

Petiole Nutrient Analysis

Petiole samples were collected at approximate veraison and analyzed for nutrient content by dry ash extraction at the Cornell Nutrient Analysis Laboratory. Samples were collected on 9 September 2011, 17 August 2012, and 29 August 2013. Petioles were taken from the 5th to 7th leaf position of fully expanded non-damaged leaves. Twenty petioles from each treatment were collected and combined for analysis in 2011 and 2012; a single petiole from each vine was collected in 2013. Samples were analyzed through combustion analysis of C and N and dry ash extraction of Al, B, Ca, Cu, Fe, K, Mg, Mo, Mn, Na, P, and Zn.

Harvest and Yield Components

Harvest was based on an average 21°Brix threshold for the GLY treatment determined by the random sampling of 100 berries from each treatment, measured with a temperature-compensating digital refractometer (SPER Scientific, 300053, Scottsdale, AZ). Harvest was conducted on 13 October 2011, 21 September 2012, and 16 October 2013. On a per-vine basis, clusters were hand-harvested, counted, and weighed with a hanging scale accurate to 0.1 kg (Salter Brecknell, SA3N340, Fairmont, MN). Two hundred berries per treatment panel were collected and weighed at harvest to determine average berry weight.

Plant Cover and Biomass

At berry set and veraison in 2013 and 2014, a square framed area of 0.06 m^2 divided into 100 identical subunits using a string grid was used to estimate percent plant coverage of soil in the under-vine treatments. Each subunit was evaluated for the presence of living plant tissue to calculate the percent coverage. Living plant tissue occupying more than 50% of a subunit was recorded as having plant cover. Three framed areas were randomly selected within each treatment block during each measurement period. Aboveground biomass was collected within two of these squares during veraison. Samples were dried for 48 hours at 60°C and weighed (Santorius ELT103, accuracy ±0.001, Goettingen, Germany). In 2013, clover in the biomass samples was separated from other plant tissue and weighed separately in the WC treatment. In 2014, this separation was performed with all samples.

Soil Moisture

A soil moisture data probe (Decagon EC-5, Decagon Devices, Pullman, WA) was installed in each treatment panel in rows 2, 8, 12, and 16 in the fall of 2010. The probes were installed in the middle of the under-vine row between two treatment vines to a depth of approximately 20 cm. From 1 April to 31 October each year of the study, mid-day measurements taken at 1400 hr were used to record soil volumetric water content during the growing season. In 2011, soil moisture data were not recorded from 4 June to 6 June, 24 June to 8 July, 2 August to 20 August, and 12 September to 31 October due to datalogger malfunctions. In 2012, soil moisture was not recorded between 22 September and 4 October, and in 2013, between 17 October and 21 October due to datalogger malfunctions.

Winemaking and Juice Chemistry

The grapes from each harvest were brought to the Cornell Vinification and Brewing Technology Laboratory in Geneva, NY immediately after harvest, where the fruit from each treatment was combined, stored in a temperature-controlled cooler, crushed within 24 hours of arrival, given an addition of 50 ppm SO_2 and divided into duplicate lots for fermentation. In 2011, the must from the NV, GLY, and CULT treatments was chaptalized to 21 °Brix. After crushing, must was placed in 30-gallon stainless steel jacketed fermenters, and inoculated with *Sacharomyces cerevisiae* strain GRE yeast (Scott Laboratories, Petaluma, CA) at 1g/L. Yeast available nitrogen (YAN) was brought up to 200 mgN/L using a combination of Go-Ferm Protect®, Fermaid® K, and diammonium phosphate. Wines were kept between 20-30°C for the first 24 hours of fermentations, 27-32°C between 24-60 hours, 25-30°C between 60-84 hours, and between 20-30°C after 84 hours and the end of alcoholic fermentation. Wines were pressed once residual sugar levels were less than 0.5%, determined using Clinitest tablets (Bayer, West Haven, CT). Once dry, wines were pressed, racked and inoculated with *Oenococcus oeni* strain Alpha (Lallemand, Petaluma, CA) at 1g/L to undergo malolactic fermentation at 20°C. After malolactic fermentation, SO_2 was added to achieve 40 ppm free SO_2, and wines were cold stabilized at 2°C for approximately four months prior to bottling. After cold stabilization, TA was adjusted with the addition of tartaric acid to 6.2±0.4 g/L, 7.1±0.4 g/L, and 6.6±0.2 g/L in 2011, 2012, and 2013, respectively. Prior to bottling, wines were tasted for faults, bottled in 750 mL green glass bottles with screw caps, and stored at 16°C.

In 2011 and 2012 Brix, pH, titratable acidity (TA), and YAN were measured from juice samples of each experimental fermentation lot immediately after crushing at the Brewing Technology Laboratory in Geneva, NY. In 2013, 15 random clusters from each experimental

panel were analyzed for Brix, pH, TA, and YAN. Brix was determined with a temperature compensating digital refractometer, pH measured with a benchtop pH meter (VWR Symphony pH Meter, model SB80RI, Radnor, PA), TA measured by titrating a 50 mL aliquot of juice against 0.10 M NaOH to pH 8.2, and YAN measured by using a Chemwell 2910 Multianalyzer to measure ammonia and spectrophotometry to measure primary amino nitrogen (Nisbet et al. 2013).

Wine Sensory Sorting Trial

Wines from the 2011, 2012, and 2013 vintages were evaluated for sensory similarities in the spring and summer of 2014. The 2011 vintage sorting occurred on 15 April and 18 April 2014; the 2012 vintage sorting occurred on 18 April, 22 April and 25 April 2014; and the 2013 vintage sorting occurred on 7 July and 9 July 2014. A sensory sorting panel, consisting of 75 individuals between the ages 21 and 70 who reported they drank red wine at least once per month, participated in each vintage. Panelists, who were compensated $5 for participating, were seated at a table separated by white partitions, in a room illuminated with fluorescent lighting. Wines were poured in 30 mL servings at room temperature in clear tulip shaped (ISO) 220 mL wine glasses covered with plastic lids, for each panelist. Wines from both fermentations of groundcover treatments (eight glasses total) were simultaneously presented to panelists in a randomized order. The glasses were coded with a three-digit identification number. Panelists were given no information about the wines and asked to smell and taste the wines and then sort them into groups based on the similarities of their overall sensory properties (Lawless and Heymann 1998; Preszler et al. 2013).

The wine sensory sorting trial data were analyzed by giving wines grouped together a similarity score of one, and wines not grouped together a score of zero, from each panelist's grouping sheet. The sum of the similarity scores for each possible combination of wines was used to form an 8x8 similarity square matrix for each vintage. This matrix was analyzed using multidimensional scaling (MDS) analysis (Kraskal 1964) in SAS (version 9.4, Cary, NC). This analysis creates a two dimensional perceptual map of the similarity among samples by placing more frequently paired samples closer together, and less frequently paired samples farther apart on a coordinate plane (Nestrud and Lawless 2010). A squared correlation value (R^2) quantified how well the mapping in two dimensions accounted for variance among samples. This method is useful for visually representing differences in sensory attributes among subjects even when underlying characteristics are not well understood or defined (Lawless and Heyman 1998). The MDS method has been widely used in the study of sensory attributes of food (Lawless et al. 1995), as well as with wine aroma (Lee and Noble 2006; Jordan 2014; Preszler et al. 2013), and taste (Parr et al. 2007).

Economic Analysis

A partial budget analysis of groundcover management cost was calculated for each vintage during the study to estimate the financial implications of adopting different under-vine groundcover treatments. Estimates for the cost of different groundcover maintenance methods were subtracted from projected crop values for each vintage to project the financial implications of adopting different groundcover practices. Statistical analysis was performed by calculating the revenue generated on a per-vine basis and comparing these values among treatments. These

values were determined by calculating the monetary value of the yield from each vine and subtracting the fraction of the cost of under-vine management on a per-vine basis.

The partial budget estimated two glyphosate herbicide sprays and a spot application for GLY, four cultivation passes for CULT, a single seeding of white clover seed for WC, and four mowing passes using a Fischer Mulchgeräte double headed mower (model GL460) that can simultaneously mow the under-vine row and alleyways for NV and WC. Available estimates for the cost of groundcover maintenance and Cabernet Franc grape prices in the Finger Lakes region were used (Table 2.3). An estimate for the additional cost of under-vine mowing was produced by calculating the cost of labor and machinery to operate an under-vine mower and subtracting this value from the cost of traditional alleyway mowing. A private grape grower in Long Island, New York supplied data on machinery costs, and labor use to estimate the time and cost needed to mow the under-vine area of their *V. vinifera* vineyards. The same estimates of capital interest rates, repairs, fuel cost, and wages from Yeh et al. (2014) were used to complete this calculation. Because both the under-vine area and alleyway are mowed at the same time, an estimate for the cost of traditional alleyway mowing was subtracted from this estimate to reflect the additional cost of under-vine mowing.

Table 2.3. Summary of under-vine partial budget model variables and parameters.

Description	Unit	Value	Rate per Season	Source
Glyphosate Spray	$/ha	232	2	Yeh et al. 2014
Glyphosate Spot Application	$/ha	84	1	Yeh et al. 2014
Cultivation	$/ha	259	4	Yeh et al. 2014
Seed Spreading	$/ha	51	1	Yeh et al. 2014
White Clover Seed	$/kg	10.40	3.3	ARS Staff 2014
Under-Vine Mowing	$/ha	21	4	Calculated
2011 Cabernet Franc Price	$/t	1,378	-	FLGP 2011
2012 Cabernet Franc Price	$/t	1,392	-	FLGP 2012
2013 Cabernet Franc Price	$/t	1,451	-	FLGP 2013

Statistical Analysis

Viticultural, juice, and economic data were analyzed using JMP Pro version 10.0.2 (SAS Institute, Cary, NC). A logit transformation of percentage data was performed prior to analysis. Data were analyzed using a mixed model ANOVA, with treatment as a fixed variable and row as a random variable. A Tukey HSD test at a 5% significance level was used to compare means among treatments.

Results

Weather Data

The 2012 growing season was the warmest of the study (Table 2.4). The 2011 and 2013 growing seasons were cooler than 2012 and had similar heat accumulations to one another. The 2014 growing season was the coolest of the study. The 2011 and 2014 growing seasons were the driest of the study and had similar accumulations of precipitation, while the 2013 growing season was the wettest of the study.

Table 2.4. Accumulation of growing degree days (GDD) base 10°C, and precipitation (mm) from April through October in 2011 to 2014.

Month	GDD Base 10°C				Precipitation (mm)			
	2011	2012	2013	2014	2011	2012	2013	2014
April	46	36	37	32	46	76	67	78
May	201	244	209	183	41	59	52	63
June	301	308	282	297	57	49	113	149
July	412	423	411	346	19	79	115	108
August	315	365	333	316	89	93	104	64
September	251	225	197	224	172	105	135	23
October	77	98	117	101	79	136	68	9
Total	1604	1699	1585	1498	503	597	654	496

Plant Cover and Biomass

The GLY control treatment effectively suppressed vegetation growth in the under-vine row throughout both the 2013 and 2014 growing seasons (Table 2.5). Samples were not collected to quantify vegetative growth in the treatments in the earlier years of the study, but we observed that the GLY treatments were essentially clear of vegetation through most of the previous growing seasons. Percent cover was under 10% for both measurement dates in 2013 and under 1% for both dates in 2014. Vegetative dry mass was also under 1 g/m^2 for all dates in 2013 and 2014.

The cover crops NV and WC established nearly complete ground cover of the under-vine area, with over 95% cover in September of 2013 and both quantification dates in 2014. In June of 2013 however, cover was lower in both treatments, with 69% and 56% cover in the NV and WC treatments, respectively. Vegetative dry mass ranged between 15.8 and 46.5 g/m^2 for the cover crops, which were not different from one another except for the June 2014 measurement, when the NV treatment's vegetative dry mass was 57% greater than that of WC. However, the WC treatment had been mowed 10 days previously, in comparison to the NV treatment being

mowed 36 days previously. In 2013, the white clover cover crop in WC did not establish well, and clover only made up 23% of vegetative dry mass in the WC treatment. In 2014, the cover crop established more successfully, with approximately 52% of the vegetative biomass clover on both sampling dates. The poor establishment may have resulted from white clover seed being dispersed into plots with pre-existing resident vegetation that inhibited the growth of newly germinated seeds.

The CULT treatment maintained a moderate suppression of vegetative growth, between the low level of plant growth achieved in the GLY control and the high degree of cover in the NV and WC treatments. Percent cover and dry mass for the CULT treatment ranged between 21% and 58% cover and 2.5 and 10.1 g/m^2 across treatment dates.

Table 2.5. Vegetative cover, vegetative dry mass, and proportion of clover in vegetation mass in under-vine groundcover treatments in 2013 and 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

	% Surface Area Cover	Dry Mass (g/m^2)	% Dry Mass Clover	% Surface Area Cover	Dry Mass (g/m^2)	% Dry Mass Clover
Treatment	27 June 2013			23 June 2014		
GLY	5±2 b	-	-	1±0 c	0.3±0.1 d	0.0±0.0 c
CULT	54±5 a	-	-	49±4 b	6.3±0.9 c	0.0±0.0 c
NV	69±4 a	-	-	99±1 a	24.8±1.3 a	24.5±4.3 b
WC	56±7 a	-	-	96±1 a	15.8±1.8 b	51.6±5.6 a
P-value	<0.001	-	-	<0.001	<0.001	<0.001
Treatment	7 September 2013			27 August 2014		
GLY	8±2 c	0.6±0.1 c	-	0±0 c	0.2±0.0 b	0.0±0.0 c
CULT	58±7 b	10.1±1.4 b	-	21±3 b	2.5±0.5 b	0.0±0.0 c
NV	98±1 a	31.7±2.4 a	-	100±0 a	46.4±5.1 a	17.1±4.0 b
WC	98±1 a	31.7±3.1 a	23.3	100±0 a	38.7±3.5 a	51.9±5.8 a
P-value	<0.001	<0.001	-	<0.001	<0.001	<0.001

Vegetative and Reproductive Growth

GLY treatment vines were the largest, most vigorous vines in the study. In 2011 the average pruning weights for NV and WC vines were 30% less than GLY vines (Table 2.6). In 2012, NV pruning weights were 43% less, and CULT and WC vines were 57% less than GLY vines. In 2013, pruning weights for CULT, NV, and WC vines were 36%, 57%, and 43% less than GLY vines.

GLY vines produced the greatest yields in the study as well. In 2011, WC vines yielded 29% and 22% less than GLY and CULT vines, respectively. The lower yields of WC compared to GLY vines were attributed to 20% lower cluster weight and 7% lower berry weight. In 2012, CULT, NV, and WC vines yielded 45%, 49%, and 41% less than GLY vines. The greater yield in GLY was largely attributed to heavier clusters with more berries; WC, CULT, and NV clusters were 29%, 39%, and 42% smaller than GLY clusters, respectively. WC cluster number/vine was also 15% less than in GLY. In 2013, NV vines yielded 22% less than GLY vines. and 19% less than WC vines. NV berry weight in 2013 was 6% less than GLY. There was a difference in Ravaz indices between NV and GLY in 2011, with the NV Ravaz index 45% greater than GLY vines. In 2013, NV and WC had Ravaz indices 121% and 102% greater than GLY vines. In 2012, vines in tall fescue planted alleyway rows had smaller cluster weights at harvest than those in fine-leaf fescue rows ($p=0.014$).

There was no statistical analysis of juice chemistry in 2011 and 2012 because must was sampled at crush after field plots had been combined. In 2013, the pH of GLY treatment juice, 3.47, was higher than the pH of juice from the other treatments, which ranged between 3.39 and 3.42. YAN was 38% lower in the NV treatment compared to GLY.

Table 2.6. Harvest data and fruit composition of Cabernet Franc grapevines with different under-vine groundcover treatments from 2011 to 2013. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, and WC=White Clover. Values are averages ± standard error.

	Pruning Weight (kg/vine)			Ravaz Index (yield/pruning weight)		
Treatment	2011	2012	2013	2011	2012	2013
GLY	1.0±0.1 a	0.7±0.1 a	1.4±0.1 a	6.2±0.5 b	10.0±1.3	6.2±1.5 b
CULT	0.8±0.1 ab	0.3±0.0 b	0.9±0.1 b	8.5±1.1 ab	15.1±3.6	9.9±1.5 ab
NV	0.7±0.1 c	0.4±0.1 b	0.6±0.1 c	9.0±0.7 a	14.3±3.8	13.7±1.5 a
WC	0.7±0.1 bc	0.3±0.4 b	0.8±0.1 bc	7.0±0.8 ab	14.9±2.6	12.5±1.6 a
P-value	<0.001	<0.001	<0.001	0.018	0.433	<0.001
	Yield (kg/vine)			Cluster Weight (g/cluster)		
Treatment	2011	2012	2013	2011	2012	2013
GLY	5.9±0.4 a	5.1±0.2 a	7.7±0.4 a	124.4±6.7 a	64.2±1.8 a	121.0±6.5 a
CULT	5.4±0.4 a	2.8±0.8 b	6.5±0.4 ab	109.7±5.2 ab	39.1±1.4 bc	102.1±3.5 b
NV	5.2±0.3 ab	2.6±0.1 b	6.0±0.4 b	109.6±4.4 ab	37.1±1.8 c	106.3±4.6 ab
WC	4.2±0.3 b	3.0±0.1 b	7.4±0.3 a	99.7±5.0 b	45.4±1.8 b	118.2±4.4 ab
P-value	0.004	<0.001	0.001	0.003	<0.001	0.015
	Cluster Number/Vine			Berry Weight (g/berry)		
Treatment	2011	2012	2013	2011	2012	2013
GLY	46.0±2.5	79.4±2.5 a	65.6±2.9	1.5±0.0 a	1.3±0.0	1.7±0.0 a
CULT	49.5±2.7	70.4±2.8 ab	65.0±2.7	1.4±0.0 b	1.3±0.0	1.6±0.0 ab
NV	47.4±2.0	70.3±2.4 ab	56.5±2.9	1.3±0.0 b	1.3±0.0	1.6±0.0 b
WC	41.9±3.1	67.2±2.6 b	64.0±3.3	1.4±0.0 b	1.3±0.0	1.6±0.0 ab
P-value	0.225	0.009	0.141	<0.001	0.437	<0.001
	Soluble Solids (°Brix)			pH		
Treatment	2011	2012	2013	2011	2012	2013
GLY	20.3	21.8	21.4±0.3	3.40	3.28	3.47±0.02 a
CULT	20.4	21.6	21.7±0.1	3.35	3.31	3.39±0.01 b
NV	20.6	21.5	21.3±0.1	3.36	3.32	3.42±0.01 b
WC	21.0	21.1	21.3±0.2	3.40	3.28	3.42±0.02 b
P-value	-	-	0.060	-	-	<0.001
	Titratable Acidity (g/L)			Yeast Assimilable Nitrogen (mg/L)		
Treatment	2011	2012	2013	2011	2012	2013
GLY	7.3	6.4	8.0±0.2 a	84	51	91.1±11.4 a
CULT	6.7	6.4	7.7±0.2 a	34	55	66.2±2.8 ab
NV	6.4	6.2	7.1±0.2 b	35	52	56.2±6.0 b
WC	6.6	6.5	7.7±0.3 a	52	65	77.2±10.1 ab
P-value	-	-	<0.001	-	-	0.010

Enhanced Point Quadrant Analysis

Under-vine treatment had an impact on many characteristics of canopy structure and density as revealed by EPQA analysis in 2013 (Table 2.7). Overall, GLY canopies were the densest, and NV canopies were the least dense as reflected by leaf layer number, occlusion layer, and cluster exposure flux availability. Leaf layer numbers were 19% fewer in CULT and WC treatments and 41% fewer in the NV treatment than GLY. NV also had 27% fewer leaf layer numbers than CULT and WC vines. NV had 24%, 21% and 20% fewer interior clusters than GLY, CULT, and WC, and also had greater penetration of plant available radiation through the canopy, with 98%, 43%, and 49% greater cluster exposure flux availability than GLY, CULT, and WC.

Table 2.7. Enhanced Point Quadrant Analysis (EPQA) characteristics of Cabernet Franc grapevines with different under-vine groundcover treatments measured on 26 August 2013 at veraison. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

Treatment	Leaf Layer Number	Occlusion Layer Number	% Interior Leaves	% Interior Clusters
GLY	3.7±0.2 a	6.0±0.3 a	49.6±2.7 a	91.4±1.9 a
CULT	3.0±0.1 b	5.0±0.2 b	40.5±2.5 b	87.3±1.2 a
NV	2.2±0.2 c	4.2±0.2 c	36.7±3.2 b	69.2±4.6 b
WC	3.0±0.2 b	5.2±0.2 b	43.2±2.3 ab	86.4±2.4 a
P-value	<0.001	<0.001	0.003	<0.001

Treatment	Cluster Exposure Layer	Cluster Exposure Flux Availability (%)
GLY	1.6±0.1 a	14.6±0.8 c
CULT	1.3±0.1 b	20.3±1.4 b
NV	0.9±0.1 c	28.9±2.8 a
WC	1.3±0.1 b	19.4±3.0 bc
P-value	<0.001	<0.001

Vine Water Status

Under-vine treatments did not have an impact on predawn leaf water potential in either 2012 or 2013 (Table 2.8). There was no observed impact of under-vine treatment on midday stem water potential in 2013 either. Stem water potential differed among treatments in 2012, but values never exceeded -1.06 MPa, suggesting that vines were not water stressed even during that hot dry summer (Centeno et al. 2010). On 25 July 2012, vines in tall fescue planted alleyway rows had lower midday stem water potential than those in fine-leaf fescue rows ($p=0.014$).

Petiole Nutrients

Petiole nutrient concentrations were measured at veraison in non-replicated samples from each treatment each year of the study (Table 2.9). Nutrient levels were within acceptable ranges according to recommended nutrient guidelines for the Northeast, except for nitrogen (Wolf 2008). Nitrogen levels were at suboptimal levels for CULT in 2012 and all treatments in 2013. However, the vines displayed no visible symptoms of nitrogen deficiency and were highly vegetative with pruning weights as great as 1.4 kg/vine in 2013.

Bud Survival

After a very cold and variable winter, with temperatures reaching a high of 11°C on 13 January and a low of -23°C in the early morning of 22 January 2014 at the research vineyard, there was extensive bud mortality. NV and CULT treatment vines had greater primary bud survival, with 52% and 48% survivorship (respectively), than GLY treatment vines with 28% . NV also had significantly greater bud survival than WC, which had 40% survivorship (Figure 2.2). There was greater vine bud survival in the fine-leaf fescue rows than tall fescue rows

(p=0.023). This difference in bud survival was attributed to greater bud mortality in the two outermost treatment rows, which were both planted with tall fescue, but were also located in the flattest parts of the vineyard and had the poorest air drainage.

Soil Moisture

CULT treatment soils had the highest moisture contents during the study. During the growing season of 2011, CULT soils had 10% more moisture than GLY and WC treatment soils (Table 2.10). In 2012, the largest difference in soil moisture was between CULT and WC. In 2013, CULT soils had 14% more moisture than WC soils while NV and GLY soils had 11% more soil moisture than WC soil.

Differences in soil moisture among treatments shifted throughout the growing seasons as well (Figure 2.3). Although CULT had the wettest soils for the entire growing season in 2012, GLY had greater soil moisture content from late May to late June, followed by CULT, NV, and WC. This period also had the greatest separation of treatments soil water content during the growing season. From 20 May through 31 June, CULT, NV, WC had 7%, 15%, and 26% less soil moisture than GLY. In late June, GLY soil moisture decreased relative to the other treatments, becoming lower than CULT. In mid-July, the differences in soil moisture levels among treatments decreased.

In 2013, differences among treatments were less pronounced than 2012. CULT maintained the moistest soils from mid May through the end of the growing season. Similar to 2012, early June through late July saw the largest differences in soil moisture among treatments. After this point, differences among treatments were minimal until the end of the growing season.

Table 2.8. Predawn leaf water potentials ($\Psi_{Predawn}$) and midday stem water potentials (Ψ_{Midday}) of Cabernet Franc grapevines with different under-vine groundcover treatments from 2012 and 2013. $\Psi_{Predawn}$ measurements were taken between 0330-0500 hr and Ψ_{Midday} were taken ±1.5 hours of solar noon. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

2012

$\Psi_{Predawn}$ (MPa)

Treatment	10 July
GLY	-0.55±0.03
CULT	-0.59±0.03
NV	-0.64±0.03
WC	-0.59±0.06
P-value	0.510

Ψ_{Midday} (MPa)

Treatment	10 July	25 July	7 August	30 August
GLY	-0.95±0.07	-0.92±0.04	-0.93±0.03 ab	-1.05±0.03 a
CULT	-1.03±0.04	-0.85±0.07	-0.76±0.04 b	-0.85±0.04 b
NV	-1.06±0.04	-0.85±0.08	-0.83±0.06 ab	-0.87±0.05 b
WC	-1.02±0.08	-0.88±0.06	-0.94±0.04 a	-0.91±0.06 ab
P-value	0.501	0.757	0.022	0.019

2013

$\Psi_{Predawn}$ (MPa)

Treatment	22 July	6 August	19 August	5 September	17 September
GLY	-0.19±0.02	-0.11±0.01	-0.10±0.01	-0.11±0.01	-0.06±0.01
CULT	-0.17±0.02	-0.11±0.01	-0.11±0.01	-0.10±0.01	-0.06±0.01
NV	-0.18±0.02	-0.11±0.02	-0.11±0.01	-0.11±0.01	-0.06±0.01
WC	-0.17±0.02	-0.11±0.01	-0.11±0.00	-0.11±0.01	-0.06±0.01
P-value	0.744	0.983	0.498	0.652	0.805

Ψ_{Midday} (MPa)

Treatment	5 July	22 July	6 August	19 August	5 September	17 September
GLY	-0.34±0.01	-0.52±0.04 ab	-0.35±0.02	-0.26±0.01	-0.21±0.01	-0.25±0.01
CULT	-0.34±0.01	-0.49±0.03 b	-0.37±0.02	-0.29±0.01	-0.22±0.01	-0.27±0.01
NV	-0.35±0.03	-0.52±0.03 ab	-0.39±0.02	-0.28±0.01	-0.22±0.01	-0.26±0.01
WC	-0.35±0.01	-0.61±0.04 a	-0.40±0.01	-0.28±0.01	-0.22±0.01	-0.26±0.01
P-value	0.820	0.028	0.174	0.171	0.637	0.169

Table 2.9. Concentrations of nutrients from petioles samples at veraison of Cabernet Franc grapevines with different under-vine groundcover treatments from 2011 to 2013. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, and WC=White Clover.

	% C			% N			P (ppm)		
Treatment	2011	2012	2013	2011	2012	2013	2011	2012	2013
GLY	39.6	38.4	27.6	1.0	0.9	0.7	2270	2688	4533
CULT	40.1	34.9	32.1	0.8	0.7	0.5	2905	4678	6599
NV	40.5	38.8	27.7	0.8	0.9	0.5	2152	2595	5491
WC	40.4	46.9	29.8	0.9	1.3	0.5	2295	2325	3403
	K (ppm)			Ca (ppm)			Mg (ppm)		
Treatment	2011	2012	2013	2011	2012	2013	2011	2012	2013
GLY	26778	25363	25345	30296	22984	22203	9261	7645	8324
CULT	22662	29412	22720	24258	23730	22889	9624	7283	9024
NV	22652	25452	21593	25778	23736	23114	9855	7958	8483
WC	26892	25817	20762	24899	21923	23144	8532	7254	9285
	Fe (ppm)			Mn (ppm)			B (ppm)		
Treatment	2011	2012	2013	2011	2012	2013	2011	2012	2013
GLY	61.4	29.7	63.8	237.0	187.2	143.8	35.8	38.8	32.3
CULT	31.4	19.9	78.0	236.0	133.6	190.9	35.1	35.5	32.5
NV	40.0	18.3	55.6	447.8	286.3	220.8	34.6	39.5	36.4
WC	154.4	20.6	75.4	344.9	210.4	190.0	41.0	35.4	33.4
	Zn (ppm)			Cu (ppm)			Na (ppm)		
Treatment	2011	2012	2013	2011	2012	2013	2011	2012	2013
GLY	86.5	85.8	74.9	8.0	9.4	45.1	232.9	311.5	477.3
CULT	74.5	89.8	74.1	7.6	8.9	51.2	227.5	349.6	496.1
NV	81.2	98.6	75.7	7.1	8.9	59.7	255.2	493.0	516.0
WC	68.8	90.2	78.8	7.6	8.3	55.8	255.4	350.0	507.6
	Al (ppm)								
Treatment	2011	2012	2013						
GLY	25.7	17.1	50.9						
CULT	22.5	15.0	34.4						
NV	22.7	18.0	44.0						
WC	35.4	15.0	44.2						

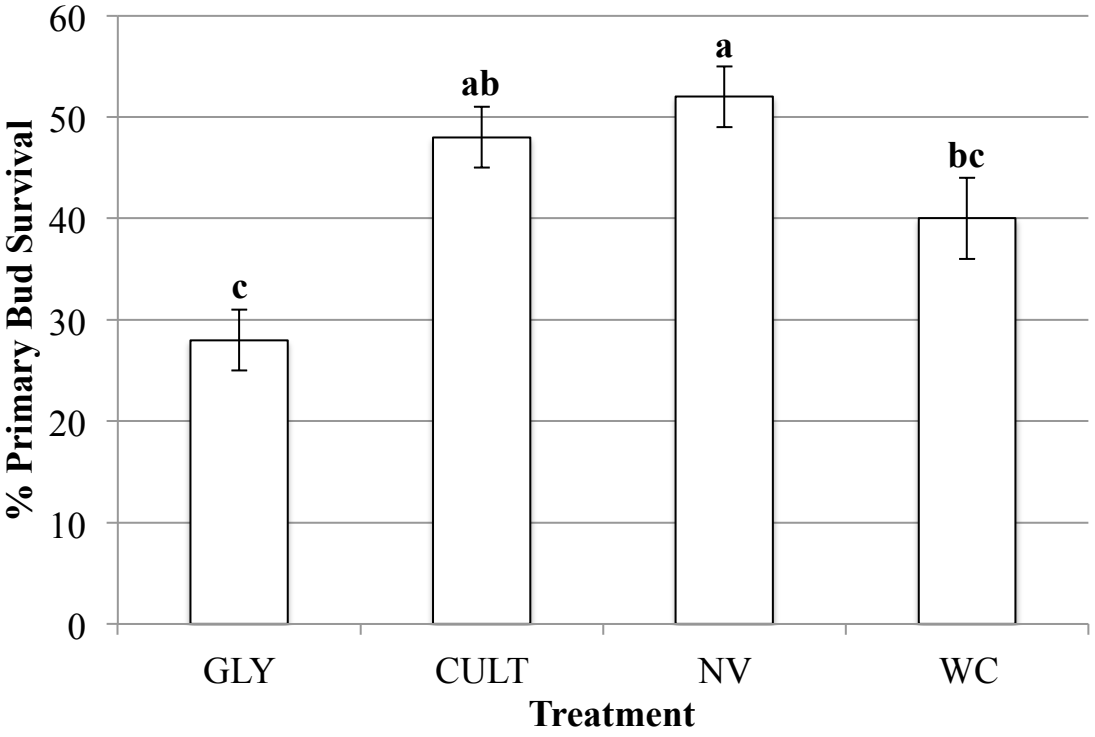

Figure 2.2. Primary bud survival of Cabernet Franc grapevines with different under-vine groundcover treatments measured on 17 May 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

Table 2.10. Soil volumetric water content (g/cm^3) of under-vine groundcover treatments between 1 April and 31 October in 2011, 2012, and 2013. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are an average of mid-day measurements ± standard error.

Treatment	2011[a]	2012[b]	2013[c]
GLY	0.21±0.00 b	0.18±0.00 b	0.21±0.00 b
CULT	0.23±0.00 a	0.19±0.00 a	0.22±0.00 a
NV	0.22±0.00 ab	0.17±0.00 c	0.21±0.00 b
WC	0.21±0.00 b	0.16±0.00 d	0.19±0.00 c
P-Value	<0.001	<0.001	<0.001

[a], data missing for 94 days in 2011 growing season.
[b], data missing for 35 days in 2012 growing season.
[c], data missing for 5 days in 2013 growing season.

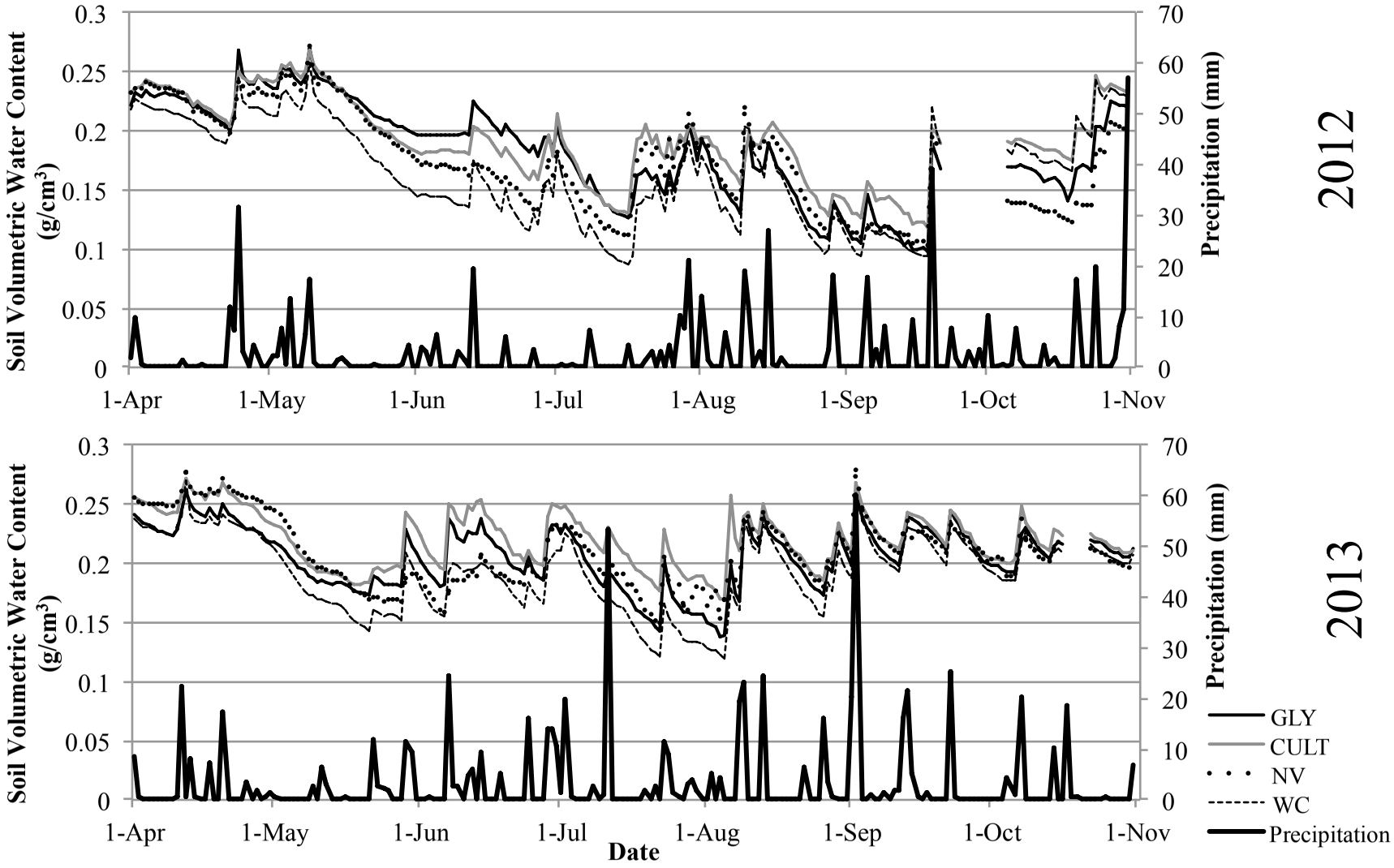

Figure 2.3. Average soil volumetric water content (g/cm^3) of under-vine groundcover treatments and precipitation (mm) during the growing seasons of 2012 and 2013 (1 April to 31 October). GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Soil water content values are an average of daily mid-day measurements and precipitation values daily accumulation of rain at the research vineyard.

Wine Chemistry

There were no large differences among treatments or fermentation replications in soluble solids at the onset of alcoholic fermentation, or in TA and pH of wines at bottling (Table 2.11). In 2011, WC was harvested at 21.0 °Brix and GLY, CULT, and NV wines were all chaptalized to this same concentration in soluble solids.

Table 2.11. Soluble Solids, Titratable Acidity, and pH of wines at bottling made from Cabernet Franc grapes with different under-vine groundcover treatments from 2011 to 2013. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, and WC=White Clover.

		Soluble Solids (°Brix) at Onset of Fermentation			Titratable Acidity (g/L) at Bottling		
Treatment	Rep	2011	2012	2013	2011	2012	2013
GLY	1	21.0	21.8	22.0	6.1	7.2	6.6
GLY	2	21.0	21.8	22.4	6.3	6.7	6.8
CULT	1	21.0	21.6	21.2	6.4	7.0	6.6
CULT	2	21.0	21.6	21.8	6.2	7.2	6.6
NV	1	21.0	21.5	21.9	6.3	7.5	6.5
NV	2	21.0	21.5	21.4	6.4	7.2	6.5
WC	1	21.0	21.1	21.5	6.0	7.2	7.2
WC	2	21.0	21.1	22.3	5.8	7.1	7.1

		pH at Bottling		
Treatment	Rep	2011	2012	2013
GLY	1	3.43	3.44	3.60
GLY	2	3.40	3.58	3.62
CULT	1	3.26	3.53	3.64
CULT	2	3.22	3.53	3.58
NV	1	3.28	3.50	3.62
NV	2	3.24	3.52	3.65
WC	1	3.33	3.50	3.57
WC	2	3.35	3.52	3.57

Wine Sensory Sorting

The R^2 values of MDS consensus plots, between 0.89 in 2011 and 0.92 in 2012, indicated that the relationships among the wines were acceptably represented in a two-dimensional model.

However, there were not any groupings of wines from the same treatment with one another in any of the vintages, or any separation or grouping of under-vine treatments with one another, indicating that panelists did not perceive different sensory attributes from the wines of different groundcover treatments in any of the vintages (Figure 2.3).

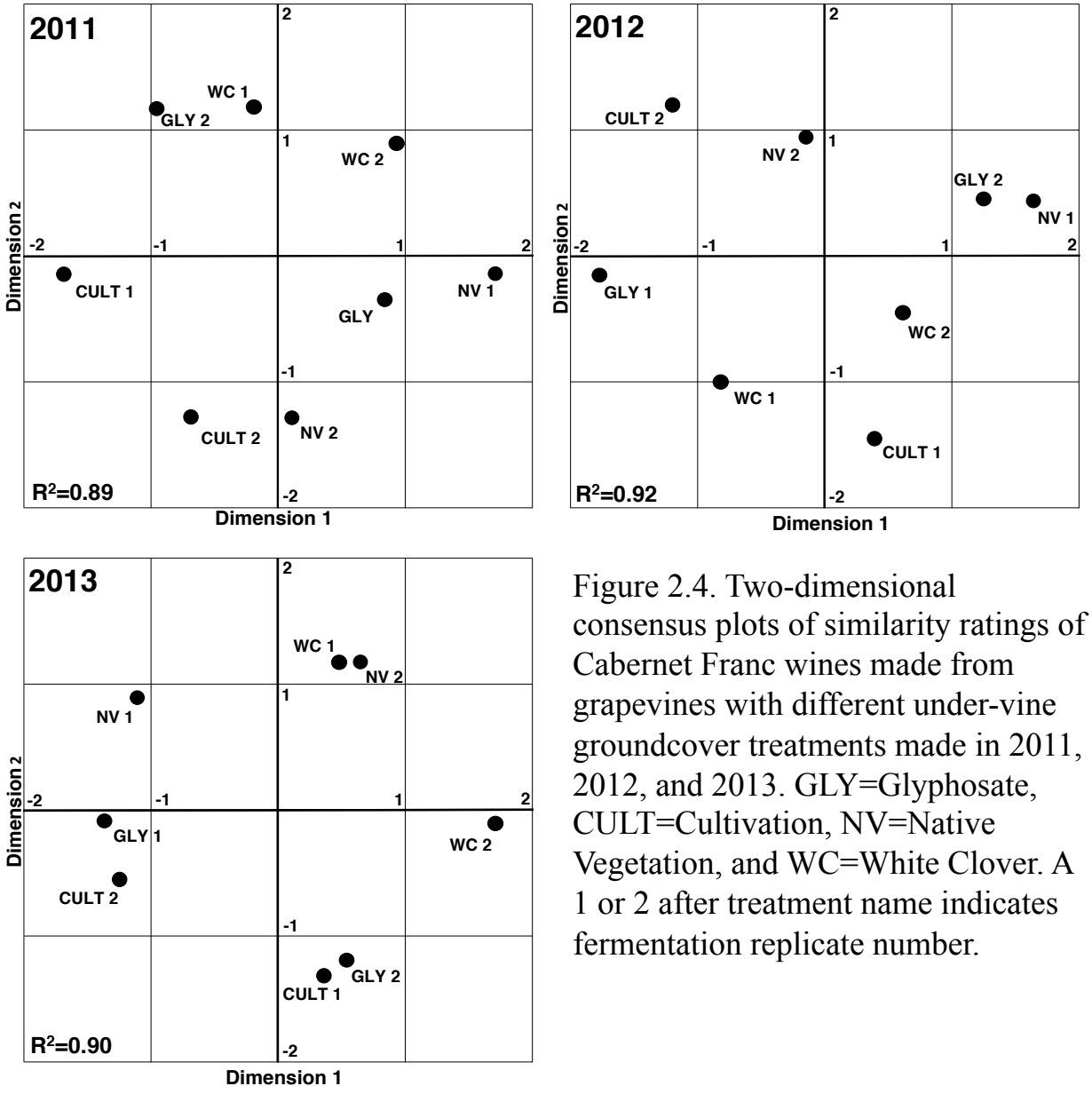

Figure 2.4. Two-dimensional consensus plots of similarity ratings of Cabernet Franc wines made from grapevines with different under-vine groundcover treatments made in 2011, 2012, and 2013. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, and WC=White Clover. A 1 or 2 after treatment name indicates fermentation replicate number.

Economic Analysis

The partial budget revealed that the GLY treatment typically generated more revenue than the other treatments (Table 2.12). The difference between GLY and other treatments was mostly driven by the greater yields of GLY compared to the other treatments rather than the cost of under-vine cultivation, cover crop seeding, and/or maintenance. This impact was most pronounced in 2012 when difference in yields between GLY and other treatments was greatest. In 2011 WC generated 26% less revenue than GLY. In 2012, CULT, NV, and WC generated 50%, 48%, and 40% less revenue than GLY. In 2013, CULT and NV generated 18% and 20% less revenue than GLY. The cover crops were the least expensive of under-vine treatments to maintain, with NV and WC costing $84 and $169 annually per hectare, respectively. GLY herbicide sprays cost $548 per hectare, and cultivation passes in CULT were the most expensive in the study, with an average estimated cost of $1,036 per hectare to maintain.

Figure 2.12. Partial budget analysis comparing the impact of under-vine groundcover on yield and management cost from 2011-2013. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover.

Treatment	Year	Cost of Under-vine Groundcover Maintenance ($/ha)	Yield (t/ha)	Crop Value ($/ha)	Crop Value Minus Cost of Under-vine Groundcover Maintenance ($/ha)	Reduced Revenue in Comparison to GLY (%)
GLY	2011	548	11.6	15,985	15,437 a	-
CULT	2011	1,036	10.8	14,882	13,846 ab	10
NV	2011	84	10.4	14,331	14,247 ab	8
WC	2011	169	8.4	11,575	11,406 b	26
p-value		-	-	-	0.011	-
GLY	2012	548	10.2	14,198	13,650 a	-
CULT	2012	1,036	5.6	7,795	6,759 b	50
NV	2012	84	5.2	7,238	7,154 b	48
WC	2012	169	6.0	8,352	8,183 b	40
p-value		-	-	-	<0.001	-
GLY	2013	548	15.3	22,200	21,652 a	-
CULT	2013	1,036	13.0	18,863	17,827 bc	18
NV	2013	84	12.0	17,412	17,328 c	20
WC	2013	169	14.7	21,330	21,161 ab	2
p-value		-	-	-	0.001	-

Discussion

This study demonstrates the capability of under-vine groundcovers to impact vine growth and yield. In all three years of the study GLY vines had larger pruning weights than the cover crop treatments NV and WC. In the last two years of the study, GLY vines were larger than CULT vines as well. GLY vines also had greater yields, producing more fruit than WC in 2011, NV in 2013, and all three treatments in 2012. The GLY under-vine treatment area was nearly bare throughout the study, with very little cover and plant biomass. The NV and WC cover crops had nearly complete cover of the vineyard floor, and CULT had variable and intermediate plant

coverage and biomass on the vineyard floor. This trend of decreased vegetative and reproductive growth of grapevines has been observed with an increase in vineyard floor plant coverage in other studies (Celette et al. 2005; Hatch et al. 2011; Jordan 2014; Wheeler et al. 2005). However, due to the allelopathic properties of rye and its inhibition of seed germination, the rye straw spread in the under-vine rows to protect graft unions in the winters of 2010-11 and 2011-12 likely reduced the amount of vegetative growth in the under-vine treatments than would have normally grown in the 2011 and 2012 seasons (Barnes and Putnam 1986).

Previous research has correlated decreases in vine growth and yield in cover cropped vineyards with decreases in soil moisture and vine water status (Centinari et al. 2015; Tesic et al. 2007; Hatch et al. 2011). The present study did not demonstrate any consistent differences in vine water status among treatments. Measurements of stem water potential in 2012 and 2013 never went below the limit of -1.1 MPa that Baeza et al. (2007) found to be a threshold, which vines could reach before exhibiting evidence of water deficit. However we do not have stem water potential data from July 2011, the driest month of the study.

There were differences in soil volumetric water content within the study; in all three years CULT had the highest soil moisture over the entire growing season, but this did not correlate with greater vine size. In 2013, WC also had drier soils than NV, but a greater yield. However, the moisture probes were located at a relatively shallow depth (20 cm). Hatch et al. (2011) found inconsistent and small differences among soil moisture levels at shallow depths between 10-40 cm soil depth in Cabernet Franc vineyards in Virginia with sod cover crop and herbicide under-vine treatments, but found herbicide treatment soils at 60 cm to have consistently higher soil moisture than sod treatment soils, correlating with greater vine size and yields in the herbicide treatment. It is possible that in our study the probes did not detect different

patterns in soil moisture at deeper depths among treatments. Grapevines have one of the deepest rooting pattern distributions among plants, and extract moisture from much greater depths than where soil moisture probes were located in this study (Smart et al. 2006). Additionally, cultivation has been shown to diminish the presence of grapevine roots within the top 20 cm of soil in comparison to herbicide weed control (Smart et al. 2006). However, other studies have shown greater vine root growth in the top 20 cm of the soil with cultivation weed management in comparison to cover crops (Centinari et al. 2015). In combination with suppressing weed growth, decreased vine rooting at this depth may have contributed to the higher soil moisture levels of the CULT treatment while not correlating with greater vine size.

Differences in rooting patterns among vine roots in the cover crop treatments NV and WC may have also have impacted vine growth in 2013. A number of studies have found the presence of cover crop roots to decrease vine root presence in shallow depths in competition with cover crop roots (Cellette et al. 2009; Morlat and Jacquette 2003; Smart et al. 2006). Centinari et al. 2014 found decreased presence of fine roots in the top 20 cm of the soil profile and reduced root lifespan with annual ryegrass (*Lolium multiflorum*) and buckwheat (*Fagopryrum esculentum*) cover crops than a cultivated control, but not with a less aggressively growing turnip (*Brassica rapa var. rapa*) cover crop. White clover grows best in cooler moist conditions, typical of the spring in the Finger Lakes, and may have been less competitive during the warmer weather in the summer than more competitive plant species in the NV treatment (Hall 1993). Decreased competitiveness from clover roots may have increased vine root densities in WC at shallower depths, or decreased root mortality in comparison to vine roots in NV, helping to contribute to the greater yields and denser canopy of WC than NV in 2013.

The 2012 growing season had the driest soils of the study, the lowest vine stem water potentials, and the greatest differences in pruning weights and yield, with GLY vines being larger and producing more fruit than all other treatments. The differences in soil moisture among treatments were greatest between late-May through the end of June. During this time GLY soils had greater soil moisture than the other treatments. This time period also coincided with bloom, which occurred on approximately 5 June. Grapevines are most susceptible to decreases in reproductive yield from water stress during the first three weeks after bloom (Hardie and Considine 1976). This period of greater difference in soil moisture potentially contributed to the greater yield of GLY vines in 2012. Pre-dawn and mid-day vine water measurements starting earlier in the growing season may have revealed differences in water potentials among treatments.

While vine water status is often related closely with vine growth, other factors, such as the availability of nitrogen, can limit growth as well. A study by Celette et al. (2005) found that vine growth in a vineyard with tall fescue inter-rows was less than in a bare ground herbicide control, but that predawn leaf water potential and mid-day stomatal conductance did not differ, suggesting that direct competition for water did not impact vine growth. Celette et al. (2009) found that grapevines with a tall fescue inter-rows grew roots at deeper depths than a bare ground herbicide control, under the profile of the cover crop roots, to extract water from deeper unexploited depths. By extracting water from deeper depths below the shallow regions where most nitrogen mineralization occurs, grapevine growth and yield was reduced related to a significant reduction in nitrogen uptake. It is not clear if nitrogen limitations played a role in impacting vine size or yield in our study or if the spatial distribution of root growth differed among treatments, as has been shown by Centinari et al. (2015), and Morlat and Jacquet (2003).

Petiole samples collected at veraison were not replicated, so we cannot infer treatment differences in nitrogen availability. Petiole nitrogen levels from 2013 suggested that vines were nitrogen deficient, but vines were highly vegetative and showed no evidence of nitrogen deficiency. Other studies of *V. vinifera* in the Finger Lakes region of New York state have also found petiole nitrogen concentrations considered deficient according to nutrient guidelines, without observing any symptoms of nitrogen deficiency (Centinari et al. 2015; Jordan 2014). The higher concentration of YAN in GLY than NV juice in 2013 suggests that GLY vines may have had greater uptake of nitrogen than NV, which may have partially contributed to the difference in vine size and yield between the two treatments.

There was no evidence of increased nitrogen concentrations in petioles from vines in the WC treatment, even though they were planted in a leguminous cover crop that had greater nitrogen leaching than other treatments (Chapter 3). However, a study measuring the uptake of nitrogen from decomposing clover and grass litter tissue enriched with ^{15}N to grapevines in a Chardonnay vineyard in Bologna, Italy found that while the litter lost 80% of its nitrogen within 16 weeks, less than 4% of this nitrogen was present in above ground grapevine tissue at the time of harvest (Brunetto et al. 2011). Brunetto et al. speculated that the low absorbance of ^{15}N may have been due to the low nitrogen requirements of mature grapevines, the failure of the recently released nitrogen to reach the entire root system, or competition with plants and microorganisms for nitrogen. A similar occurrence may have taken place within this study, resulting in similar petiole nitrogen concentrations among treatments, despite WC being planted in a leguminous cover crop.

The low and variable temperatures during the winter of 2013-2014 inflicted large amounts mid-winter cold damage to buds, but also revealed an impact of groundcover treatments

on bud survival. The greater survival of CULT and NV compared to GLY primary buds was likely related to differences in vine size and canopy architecture among treatments. Bud cold hardiness is reportedly increased by more exposure of shoots to sunlight during the growing season, moderate cane diameter, and a lack of persistent lateral canes (Howell and Shaulis, 1980). The greater number of leaf layers as revealed by EPQA analysis, and more vigorous cane growth indicated by larger pruning weights of GLY vines, showed that these canopies were larger and denser than in CULT and NV. The greater light penetration and more moderate cane growth of the CULT and NV vines likely contributed to greater bud cold hardiness. Similarly, the more dense canopies of WC than NV likely contributed to the greater bud mortality of WC vines than NV.

Whereas there were differences in vine size and yield among treatments, there was little impact on juice chemistry. The Ravaz indices of NV and WC in 2013 were above the range of 5-10 recommended by Kliewer and Dokoozlian (2005), but ripened fruit to similar soluble solids and acid levels as GLY, which fell within this range. The lower TA levels of NV than GLY can be attributed to the greater exposure of clusters to sunlight, which has been shown to more rapidly degrade tartaric acid in grapes (Spayd et al. 2002). Whereas GLY vines had more YAN than NV grapes, all treatments were deficient by enological industry standards, and supplementation of must with yeast nutrients would be recommended for healthy fermentations (Bell and Henschke 2005). There may have been other differences in fruit composition among treatments that were not measured, such as anthocyanin content and secondary metabolites.

Due to the similarity of juice and wine chemistry among treatments and fermentation replicates, it is not surprising that there were no perceived sensory differences among treatments in the MDS sensory analyses of the wines for all three vintages. However, other studies have

found an impact of vine size and yield on red wine quality. Scheiner et al. (2011) found that lower vine water status, lower vigor, and smaller cane weights correlated with greater herbaceous aromas in Cabernet Franc wine from the Finger Lakes. Studies on Cabernet Sauvignon have found an increase in vegetal descriptors of wines from vines with lowered crop yields implemented by pruning (Chapman et al. 2004). Leaf and cluster shading of Cabernet Sauvignon has also been demonstrated to impact the sensory properties of juice and wine (Morrison and Noble 1990). The goal of the winemaking protocol in our study was to standardize fermentations, and not introduce factors that could impact the sensory qualities of the wines. The resulting wines differed from commercial red wines that the untrained panelists in our study are accustomed to consuming, in that no additions or treatments such as oak, or barrel aging had been made. Because of these differences from commercial wines that the sensory profile panelists were accustomed to, it may have been more difficult for panelists to discern differences from these wines. The lack of discernable sensory differences among treatments can also be interpreted to mean that, even though there were impacts on vine size, canopy density, and yields, the treatments did not impact the sensory properties of resulting wines.

The partial budget analysis determined that GLY typically generated more revenue than other treatments, mostly due to the greater yields of GLY resulting in more fruit to sell. Even though the application of herbicides was more expensive than maintaining -s, the increased revenue from greater yields offset this cost in most instances. Because of the lack of sensory differences among wines and the similarity of juice chemistry among treatments, grape prices were estimated to be the same among treatments. Due to thin profit margins and the projections of *V. vinifera* prices not meeting long-term projected production costs in the Finger Lakes, large reductions in revenue from decreased yields is not economically sustainable (Yeh et al. 2014).

The greatest reductions in revenue in comparison to GLY occurred in 2012 when all other treatments produced less revenue than GLY by as much as 40-50%. The 2012 growing season was the warmest year of the study and also had the lowest yields. In the other years of the study, differences in yield and revenue between GLY and other treatments were not as large as 2012, or as consistent. In 2011, only WC generated significantly less revenue than GLY, and in 2013, CULT and NV generated significantly less revenue. Given the impact that year had on the variability of yield among treatments, adaptively managing cover crops may be a feasible means of limiting their impact on yield in order to reduce losses in revenue by more intensively mowing or applying herbicide to cover crops in especially dry or warm years. In more temperate, wetter years, cover crops may be a competitive under-vine management alternative to herbicides. Additionally, while we did not find appreciable differences in fruit quality during this study, GLY vines did produce larger, denser canopies than other treatments. In a commercial setting, growers likely would have spent more time and resources leafing, cluster thinning, and hedging the GLY treatment than the cover crop treatments, potentially increasing the economic viability of cover crops in comparison to current standard herbicide application.

Conclusion

Conventional practices of herbicide use under vines to prevent competition from vegetation with grapevines are an effective means of promoting growth and limiting water stress in arid regions. In cooler more temperate climates such as the Finger Lakes, excessive vine vigor necessitates practices such as cluster thinning, leafing, and hedging. The reduction in vine size and yield of cover crop treatment vines in comparison to those in the herbicide treatment in our study demonstrates the ability of cover crops to reduce vine size, providing a tool for growers to

reduce vigor. Native vegetation cover crop was effective in limiting vine vigor, but the difficulty of re-establishing a white clover cover crop suggested that it was not a practical cover crop to out-compete other plant species. The use of periodic cultivation, while clearing vegetation from vineyard floor, did not promote vine vigor, perhaps since weed growth was allowed to persist until it reached a height of about 30 cm. The greater yields in the herbicide treatment, the similarity in juice chemistry among treatments, and the lack of sensory differences among treatments suggest that herbicide use promoted higher yields without a sacrifice in fruit quality. The greater yields of the herbicide treatment also generated more revenue than the other treatments in 2012, a particularly dry and warm growing season, despite herbicide application costing more than cover crop maintenance. In more temperate years, cover crops may provide a competitive alternative to herbicide application. However, the greater bud hardiness of cultivation and native vegetation vines could have important implications for the industry as more variable temperatures are anticipated with climate change.

REFERENCES

ARS (Agricultural Research Service) Staff. 2014. Cover Crops for the Southeast: Cover Crop Costs. U.S.D.A. National Soil Dynamics Laboratory, Auburn, AL.

Austin, C.N., and W. F. Wilcox. 2011. Effects of fruit-zone leaf removal, training systems, and irrigation on the development of grapevine powdery mildew. American Journal of Enology and Viticulture. 62:193-198.

Baeza, P., P. Sánchez-de-Miguel, A. Centeno, P. Junquera, R. Linares, and J.R. Lissarrague. 2007. Water relations between leaf water potential, photosynthesis and agronomic vine response as a tool for establishing thresholds in irrigation scheduling. Scientia Horticulturae. 114:151-158.

Barnes, J.P., and A.R. Putnam. 1986. Evidence for allelopathy by residues and aqueous extracts of rye (*Secale cereale*). Weed Science. 34:384-390.

Battany, M.C., and M.E. Grismer. 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. Hydrological Processes. 14:1,289-1,304.

Bell, S.J., and P.A. Henschke. 2005. Implications of nitrogen nutrition for grapes, fermentation and wine. Australian Journal of Grape and Wine Research. 11:242-295.

Brunetto, G., M. Ventura, F. Scandellari, C.A. Ceretta, J. Kaminski, G.W. de Melo, and M. Tagliavini. 2011. Nutrient release during the decomposition of mowed perennial ryegrass and white clover and its contribution to nitrogen nutrition of grapevine. Nutrient Cycling in Agroecosystems. 90:299-308.

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

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

Centeno, A., P. Baeza, and J.R. Lissarrague. 2010. Relationship between soil and plant water status in wine grapes under various water deficit regimes. Hort Technology. 20:585-593.

Centinari, M., J.E. Vanden Heuvel, M. Goebel, M. Smith, and T. Bauerle. 2015. Root-zone management practices impact above and below-ground growth in Cabernet Franc grapevines. Australian Journal of Grape and Wine Research. Accepted June 2015.

Chapman, D.M., M.A. Matthews, and J.X. Guinard. 2004. Sensory attributes of Cabernet Sauvignon wines made from vines with different crop yields. American Journal of Enology and Viticulture. 55:325-334.

FLGP (Finger Lakes Grape Program). 2011. Grape Harvest Prices. Cornell University Cooperative Extension, Penn Yan, NY.

FLGP (Finger Lakes Grape Program). 2012. Grape Harvest Prices. Cornell University Cooperative Extension, Penn Yan, NY.

FLGP (Finger Lakes Grape Program). 2013. Grape Harvest Prices. Cornell University Cooperative Extension, Penn Yan, NY.

Hall, M.V. 1993. Agronomy Facts: White Clover. Penn State Extension, State College, PA.

Hardie, W.J., and J.A. Considine. 1976. Response of grapes to water-deficit stress in particular stages of development. American Journal of Enology and Viticulture. 27:55-61.

Hatch, T.A., C.C. Hickey, and T.K Wolf. 2011. Cover crop, rootstock, and root restriction regulate vegetative growth of Cabernet Sauvignon in a humid environment. American Journal of Enology and Viticulture. 63:298-311.

Howell, G. S., and N. Shaulis. 1980. Factors influencing within-vine variation in the cold Resistance of cane and primary bud tissues. American Journal of Enology and Viticulture. 31:158-161.

Jordan, L.M. 2014. Evaluating the effects of using annually established under-vine cover crops in northeastern Riesling vineyards. M.S. thesis. Cornell University, Ithaca, NY.

Kliewer, W.M., and N.K. Dokoozlian. 2005. Leaf area/crop weight ratios of grapevines influence on fruit composition and wine quality. American Journal of Enology and Viticulture 56:170-181.

Kraskal, J.B. 1964. Nonmetric multidimensional scaling: a numerical method. Psychometrika. 29:115-120.

Lawless, H., and H. Heymann. 1998. Sensory evaluation of food: principles and practices, 2nd edition. Chapman Hall, NY.

Lawless, H.T., N. Sheng, and S.S. Knoops. 1995. Multidimensional scaling of sorting data applied to cheese perception. Food Quality and Preference. 6:91-98.

Lee, S.J., and A.C. Noble. 2006. Use of partial least squares regression and multidimensional scaling on aroma models of California Chardonnay wines. American Journal of Enology and Viticulture. 57:363-370.

Meyers, J.M., and J.E. Vanden Heuvel. 2008. Enhancing the precision and spatial acuity of point quadrat analyses via calibrated exposure mapping. American Journal of Enology and Viticulture. 59:425-431.

Morlat, R., and A. Jacquet. 2003. Grapevine root system and soil characteristics in a vineyard maintained long-term with or without interrow sward. American Journal of Enology and Viticulture. 54:1-7.

Morrison, J.C., and A.C. Noble. 1990. The effects of leaf and cluster shading on the composition of Cabernet Sauvignon grapes and on fruit and wine sensory properties. American Journal of Enology and Viticulture. 41:193-200.

Nestrud, M.A., and H.T. Lawless. 2010. Perceptual mapping of apples and cheeses using projective mapping and sorting. Journal of Sensory Studies. 25:390-405.

Nisbet, M.A., T.E. Martinson, and A.K. Mansfield. 2013. Preharvest prediction of yeast assimilable nitrogen in Finger Lakes Riesling using linear and multivariate modeling. American Journal of Enology and Viticulture. 64:485-494.

Parr, W.V., J.A. Green, K.G. White, and R.R. Sherlock. 2007. The distinctive flavor of New Zealand Sauvignon blanc: Sensory characterisation by wine professionals. Food Quality and Preference. 18:849-861.

Preszler, T., T.M. Schmit, and J.E. Vanden Heuvel. 2013. Cluster thinning reduces the economic sustainability of Riesling production. American Journal of Enology and Viticulture. 65:407-416.

Ryona, I., B.S. Pan, D.S. Intrigliolo, A.N. Lakso, and G.L. Sacks. 2008. Effects of cluster light exposure on 3-isobutyl-2-methoxypyrazine accumulation and degradation patterns in red wine grapes (*Vitis vinifera* L. cv. Cabernet Franc). Journal of Agricultural and Food Chemistry. 56:10,838-10,846.

Scheiner, J.J., J.E. Vanden Heuvel, B. Pan, and G.L. Sacks. 2011. Modeling impacts of viticultural and environmental factors on 3-isobutyl-2-methoxypyrazine in Cabernet franc grapes. American Journal of Enology and Viticulture. 63:94-105.

Scholander, P.F., E.D. Bradstreet, E.A. Hemmingsen, and H.T. Hammel. 1965. Sap pressure in vascular plants: negative hydrostatic pressure can be measured in plants. Science. 148:339-46.

Smart, R.E. 1985. Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review. American Journal of Enology and Viticulture. 36:230-239.

Smart, D.R., E. Schwass, A. Lakso, and L. Morano. 2006. Grapevine rooting patterns: A comprehensive analysis and a review. American Journal of Enology and Viticulture. 57:89-104.

Smart, R., and M. Robinson. 1991. Sunlight into wine: a handbook for winegrape canopy management. Winetitles.

Soil Survey Staff, N.R.C.S., U.S.D.A. 1987. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed 8 May 2013.

Spayd, S.E., J.M Tarara, D.L. Mee, and J.C. Ferguson. 2002. Separation of sunlight and temperature effects on the composition of *Vitis vinifera* cv. Merlot berries. American Journal of Enology and Viticulture. 53:171-182.

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

Wheeler, S.J., A.S. Black, and G.J. Pickering. 2005. Vineyard floor management improves wine quality in highly vigorous *Vitis vinifera* 'Cabernet Sauvignon' in New Zealand. New Zealand Journal of Crop and Horticultural Science. 33:317-328.

Wolf, T.K. 2008. Wine Grape Production Guide for Eastern North America. Natural Resource, Agriculture, and Engineering Service, Ithaca, NY.

Yeh, A.D., M.I Gomez, and G.B. White. 2014. Cost of Establishment and production of *V. vinifera* grapes in the Finger Lakes region of New York-2013. Cornell University Department of Applied Economics, Ithaca, NY.

CHAPTER THREE

Impact of Under-Vine Management in a Finger Lakes Cabernet Franc Vineyard: Soil Properties and Leachate Composition

Introduction

There is interest in the use of under-vine cover crops in viticultural regions with ample precipitation to compete with vines for water and nutrients to help limit excessive vigor (Centinari et al. 2015; Hatch et al. 2011). In addition to the potential benefits of reduced vine vigor, cover crops are being investigated for their potential to protect and improve soils that are normally kept weed-free from herbicide applications or cultivation (Novara et al. 2011). This could be particularly advantageous in regions like the Finger Lakes of New York where vineyards are predominantly located on slopes in close proximity to lakes, and pollution from runoff and leaching of nutrients and agrochemicals is of increased concern.

Weed control in the under-vine row is important for the production of high quality grapes. Tall or climbing weeds can block sunlight from reaching leaves in the canopy, reduce carbohydrate production, or interfere with harvest (Wolf 2008). Competition from weeds for light, water and nutrients can be particularly severe in newly planted vineyards while young vines are establishing canopies and root systems (Bordelon and Weller 1997). Herbicide application in the under-vine row is common due to its high degree of efficacy and relative low cost of weed control; cultivation is another popular chemical-free method of weed control but it is more labor intensive due to the frequency with which it must be performed (Wolf 2008).

While herbicide application and cultivation are effective at controlling weed populations, they can also negatively impact soil quality. Erosion and runoff rates increase with a lack of soil cover, raising concern with these weed control strategies to conserve vineyard soil and prevent

pollution of local watersheds (Battany and Grismer 2000). Exposure of bare soil also results in greater impact from raindrops, which weakens and breaks aggregates apart, increasing the erosivity of soils, and contributing to the formation of surface crusts (Epstein and Grant 1973). Weed management strategies that do not leave soil bare therefore offer the potential to prevent erosion and runoff. Cultivation stimulates the loss of soil organic matter by disturbing the soil profile and exposing organic materials where they can be metabolized my microorganisms (Six et al. 1998), and the application of glyphosate herbicide is capable of lowering populations of some soil microbes (Schnürer et al. 2006).

Cover crops offer a means of groundcover management that suppresses weed populations by outcompeting them for resources like space or light, and maintains cover over the vineyard floor, reducing the negative impacts of exposing bare soil (Teasdale et al. 1998). Unlike cultivation and herbicide application, cover crops add organic residues to the soil and have the potential to stimulate more microbial activity and promote greater accumulation of soil organic matter (Steenwerth and Belina 2008; Sparling 1997). Collectively, soil organic matter provides many benefits to the physical, chemical, and biological properties of soils, making management practices that conserve it crucial for the long-term sustainability of vineyard soils.

By potentially increasing organic matter concentrations and altering the leaching in soils, cover crops may also impact the movement of pesticides such as imidacloprid in the vineyard. Imidacloprid leaching is lower in soils with greater organic matter due to the sorption of imidacloprid to organic matter, providing a potential means of reducing leaching by increasing soil organic matter (Cox et al. 1998). Additionally, there are no known studies that investigate the influence of cover crops on imidacloprid leaching, but other studies have found groundcover to impact the rate and concentration of pesticide leaching in soils (Merwin et al. 1996).

Imidacloprid is a systemic neonicotinoid insecticide, and the second most widely applied agrochemical in the world (Goulson 2013). Its popularity is largely due both to its effectiveness against a wide range of insect pests, and the long-term protection from pests it provides (Jeschke et al. 2010). Low concentrations between 5-10 ppb are considered sufficient to provide protection from most insect pests (Castle et al. 2005). By distributing throughout the plant, imidacloprid can provide lasting protection to all plant tissue, including from both root and foliage feeding pests. A single application of imidacloprid to grapevines can provide effective control of glassy winged sharp shooters for over three months (Byrne and Toscano 2006); applications in maple trees have provided protection from insect pests for as long as four years (Oliver et al 2010). However, imidacloprid can be lethal to non-target insects and aquatic invertebrates, and reduce the foraging ability of pollinators, raising concern for its movement and persistence (Alexander et al. 2007: Stoughton et al. 2008: Yang et al. 2008).

The objective of this study was to determine if cover crops planted in the under-vine row of a vineyard could improve the physical, chemical, and biological properties of soil in comparison to conventional weed management practices.

Materials and Methods

Vineyard Site, Experimental Design, Ground Cover, and Soil Moisture

The vineyard site, under-vine treatments, plant cover and biomass data collection, soil moisture probe data collection, and weather data collection of this study are described in Chapter Two. The experiment was arranged in a randomized complete block design. For soil analysis, each experimental unit was a treatment panel managed with one of the four under-vine treatments, with eight replicates of each treatment, resulting in 32 experimental units. In 2011,

only four experimental units per treatment, from rows 2, 8, 12, and 16, were used for soil analysis. The study was conducted from 2011-2014.

Soil Sampling Procedure

Soil samples were collected on 5 September of 2011, 9 August of 2012, 10 August 2013, and 7 August 2014. Bulk composite soil samples were used to analyze soil organic matter, nutrients, pH, wet aggregate stability, and soil respiration. These samples were collected by mixing three random samples of approximately 1 L from the top 15 cm of soil within each experimental unit. These samples were then spread out on a countertop and dried overnight before being submitted for analysis or prepared for measurement of soil respiration.

An intact soil core was taken from each experimental unit on soil sampling dates as well. Two stainless steel rings each measuring 60 mm tall x 73 mm in diameter were taped together and driven into the soil using a wooden block and hammer. An empty ring was placed on top of the upper ring when its top was almost full and used to push the stacked rings slightly below the surface. The stacked rings were then dug out, excess soil cut away with a trowel, and the ends protected with plastic caps. These cores were used to measure porosity, penetration resistance, and bulk density.

Soil Organic Matter, Nutrients, and pH

Dried soil samples were submitted to the Cornell Nutrient Analysis Laboratory (Ithaca, NY) for measurement of soil organic matter, nutrients, and pH. Soil organic matter was calculated by loss on ignition after being heated for 2 hours at 550°C. Macronutrients and micronutrients were measured using inductively coupled argon plasma (ICP) spectrophotometry

after extraction in Morgan's solution (1:5 soil to solution ratio). P was measured by colorimetric methods (Soil Survey Staff 2014). pH was measured in a 1:1 dilution (by volume) of soil and water (Soil Survey Staff 2014).

Aggregate Stability

Aggregate stability of bulk soil samples were measured in 2013 and 2014, beginning in the fourth season of experimental treatment applications. Dried bulk soil samples were passed through a 2 mm sieve, then placed on a 0.25 mm sieve and the aggregates that did not pass through were retained. These aggregates, between 0.25 and 2 mm, were spread on a 200 mm diameter 0.25 mm sieve and placed 50 cm below a rainfall simulator. Over the course of five minutes, the rainfall simulator delivered 12.5 mm of water in droplets on each sample (Gugino et al. 2009). The soil remaining on the sieve and the lost material that fell through during the simulated rain were individually collected, dried, and weighed. The proportion of the soil retained on the sieve was calculated to determine aggregate stability.

Soil Respiration

Each bulk soil sample was passed through a 2 mm sieve, placed in metal cylinders with nylon mesh bottoms on a sand tension table under vacuum pressure, and removed when water tension equilibrated to $\Psi = -10$ kPa. 50 g of soil was placed in a 250 mL airtight jar along with 20 mL of 0.5 NaOH in a plastic vial (Fisher Scientific, Pittsburg, PA) and kept in the dark at 30°C. Over the course of six weeks, weekly measurements of the electrical conductivity of the NaOH samples were compared to two blank samples (50 g of autoclaved sand) and a fully CO_2

saturated standard (0.25 M Na_2CO_3) to calculate weekly respiration of CO_2 (Rodella and Saboya 1999). Soil was dried at 105°C and then weighed after the experiment to determine dry weight.

Porosity, Penetration Resistance, and Bulk Density

Top and bottom soil cores were separated from one another, and the bottoms of both cores were covered with nylon gauze attached with rubber bands. These samples were placed in water reaching to the top rim of the cores to fully saturate the soil over the course of 24 hours. Cores were equilibrated to three water tensions in order to estimate the volume and distribution of pore diameters for the top (0-6 cm) and bottom (6-12 cm) soil depths of the under-vine treatments (Moebius-Clune et al. 2008). Macroporosity (pore diameters > 1,000 μm) was calculated gravimetrically by measuring the loss in water mass after saturated cores drained freely for 3 hours (Ψ = -0.3 kPa). Mesoporosity (pore diameters 1,000-30 μm) was calculated from the loss in water mass after cores previously equilibrated to Ψ = -0.3 kPa were then placed on a sand tension table under vacuum pressure and equilibrated to Ψ = -10 kPa. To determine total porosity and bulk density, cores were then oven dried at 105°C. Microporosity (pore diameters 30-0.2 μm) was determined using subsamples of re-saturated oven dried soil equilibrated to Ψ = -1500 kPa on a ceramic high-pressure apparatus. Available water capacity was calculated from the loss of water from -10 kPa to -1500 kPa.

Penetration resistance was measured on the top surfaces of each core immediately after they were equilibrated to -10 kPa using a 30° angle, 4-mm-diameter cone micro-penetrometer pushed into the soil to a depth of 50 mm at a rate of 8 mm/s (Moebius-Clune et al. 2008).

Soil Water Infiltration

Infiltration rates of water into the soil of under-vine treatments was measured using Cornell Sprinkle Infiltrometers (Ogden et al. 1997) on 1 September 2011, 5 October 2012, 10 October 2013, and 28 August 2014. The infiltrometers consisted of a portable rainfall simulator positioned on top of a 235-mm inner diameter metal ring inserted 7 cm into the soil, with an overflow hole flush with the down-slope soil surface. The rainfall simulator then dripped water onto the soil surface until a consistent rate of runoff was achieved. The infiltration rate was calculated by subtracting the rate of runoff exiting the ring from the rate of water entering from the rainfall simulator (Oliveira and Merwin 2001).

Lysimeter Placement and Design

Sixteen sub-soil drainage lysimeter troughs were installed in the vineyard in the summer of 2010, one in each experimental unit in rows 2, 8, 12, and 16 (Figure 2.1). The lysimeters were Tuff Stuff (Terra Bella, CA) plastic catchment basins measuring 107x61x33 cm with a 152 L volume, buried between vines with the top rim of the basin level with the vineyard floor. A 1.9-cm diameter flexible drainage pipe was attached to a drainage hole drilled in the lower bottom rim of the lysimeter which drained under the between row alley and terminated at a collection station buried in the adjacent downhill vine row. The drainage hole was covered with piece of plastic mesh and gravel. The collection station consisted of a 90° plastic elbow that was fitted to screw cap with an overflow mechanism that attached to a 250 mL high-density polyethylene collection bottle (Fisher Scientific, Pittsburg, PA).

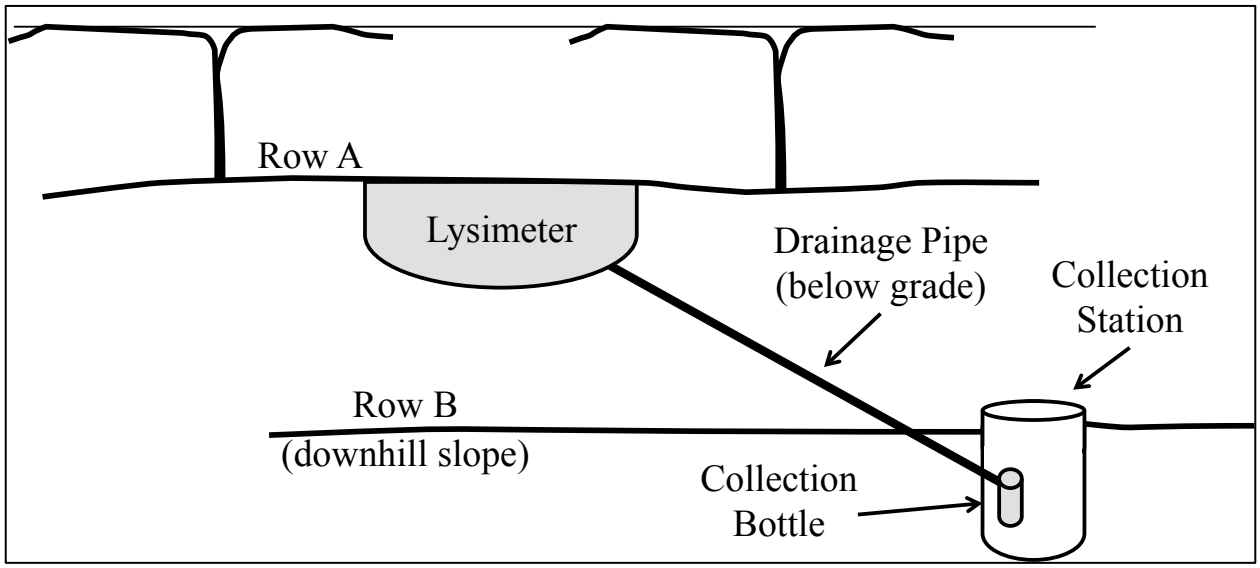

Figure 3.1. Drainage lysimeter and collection station placement and design.

Leachate Collection and Filtration

Beginning in 2011 and continuing until the end of 2014, leachate samples were collected after precipitation events and stored in a -15°C freezer. For analysis, samples were first filtered into a vacuum flask through a glass fiber filter with a .45 μm pore diameter (G6 Glass Fiber Filter Circle, Fisher Scientific, Waltham, MA).

Dissolved Organic Carbon and Total Nitrogen Leachate Chemical Analyses

Filtered samples were analyzed for dissolved organic carbon (DOC) and total nitrogen (TN) concentrations. Analyses were performed using a TOC-V (CPH) with an attached Total Nitrogen 1 unit (Shimadzu Scientific Instruments, Columbia, MD) at Pennsylvania State University in State College, PA. DOC was measured using high temperature catalytic oxidation, using the methodology described by Sugimura and Suzuki (1988). TN was measured using chemiluminescence detection after high temperature catalytic combustion at 720°C, using the methodology described by Clesceri et al. (1998).

The DOC and TN concentrations of leachate samples were compared for differences among treatments for each calendar year of the study. In 2011, 77, 77, 68 and 69 leachate samples from GLY, CULT, NV, and WC treatments were analyzed (respectively); and in 2012 81, 89, 64, and 70 leachate samples from GLY, CULT, NV, and WC treatments were analyzed (respectively). In 2013, 82, 73, 67, and 64 leachate samples from GLY, CULT, NV, and WC treatments (respectively) were analyzed. In 2014, 40, 34, 35, and 28 leachate samples from GLY, CULT, NV, and WC treatments were analyzed (respectively).

Imidacloprid Application and Leachate Analysis

On 16 July 2012 imidacloprid insecticide was sprayed on the vines at a rate of 112 g of ai/ha in the form of Provado® 1.6 flowable insecticide (Bayer Crop Science, Triangle Park, North Carolina). Over a period of two to 43 days after the application, and on ten different dates, 66 leachate samples (15 from GLY, 18 from CULT, 17 from NV, and 16 from WC) were collected (Table 3.1). These were filtered and sent to the USDA National Science Laboratories in Gastonia, NC for analysis of imidacloprid and its metabolites: imidacloprid des nitro HCl, imidacloprid olefin, imidacloprid olefin des nitro, and imidacloprid urea. Samples were measured with the Association of Analytical Community's Official Method 2007.01, which uses an acetonitrile and water solution to analyze samples with liquid chromatography and tandem mass spectrometry detection (Lehotay 2007).

Imidacloprid was applied on August 6 2013 in the same manner and rate as in 2012. Thirty-nine samples were collected over a period of three to 47 days after the application on four dates. However, a large rainstorm with an accumulation of 5.4 cm on August 8 and 2.2 cm on August 9 removed most of the imidacloprid from vineyard. Few detections of imidacloprid and

no detections of its metabolites were recorded after these storms. Analysis of this data found no impact of treatment on leaching and is not included in this study.

Table 3.1. Number of leachate samples analyzed per treatment for imidacloprid and its metabolites during 2012, and the volume of precipitation recorded on collection dates. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover.

Collection Date	Days After Spray	mm Precipitation	Number of Samples Analyzed per Treatment			
			GLY	CULT	NV	WC
18 July	2	-	-	1	1	1
21 July	5	3	3	3	3	3
24 July	8	5	-	1	1	1
26 July	10	10	1	1	1	1
27 July	11	8	1	1	1	1
31 July	15	14	4	4	4	3
2 August	17	1	1	1	1	1
13 August	28	3	4	4	4	4
20 August	35	-	-	1	-	-
28 August	43	18	1	1	1	1
Total	-	-	15	18	17	16

Statistical Analysis

Soil and leachate data were analyzed using JMP Pro version 10.0.2 (SAS Institue, Cary, NC). Soil respiration, organic matter, pH, nutrient analysis, infiltration, aggregation, penetration, bulk density, and porosity data was measured using a single sample from each experimental unit and analyzing for differences using a mixed model ANOVA, with treatment as a fixed variable and row as a random variable. In 2011, only four experimental units per treatment, from rows 2, 8, 12, and 16, were used for soil respiration, infiltration, penetration, bulk density, and porosity measurements. A logit transformation of percentage data was performed prior to analysis. Leachate samples were analyzed for differences in DOC and TN concentrations among treatments by comparing samples collected during the calendar year using a mixed model

ANOVA, with treatment as a fixed variable and collection date and row as a random variable. DOC and TN data were transformed with a natural log in order to achieve a normal distribution of data. Tukey HSD test at a 5% significance level was used to compare means among treatments.

Leachate samples tested for concentrations of imidacloprid and its metabolites in 2012 were analyzed for differences among treatments using a nominal logistic fit model. An odds ratio test at a 5% significance level was used to compare means among treatments. Treatments were compared by the proportion of samples testing positive for imidacloprid, with trace (<1pbb), or measurable (>1pbb), concentrations of imidacloprid. Treatments were also compared by the proportion of samples with measurable imidacloprid concentrations (>1pbb), and the proportion of samples testing positive for imidacloprid metabolites (trace or measurable concentrations).

Results

Soil Respiration

Soil from treatments planted with under-vine cover crops had the greatest soil respiration rates during laboratory analysis over the course of the study (Table 3.2). NV soil respiration was as great as 43% greater than GLY and 45% greater than CULT. WC soil respiration was as great as 36% more than GLY and 39% more than CULT. In 2013 and 2014 NV soil respiration was 31% and 28% greater than WC microbial respiration, respectively.

Table 3.2. Average weekly respiration of CO_2 per gram of soil in different under-vine treatments over the course of six weeks. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

	Cumulative CO_2 Respiration (mg CO_2/g soil)			
Treatment	2011	2012	2013	2014
GLY	0.35±0.02 b	1.46±0.10 b	0.96±0.04 b	0.67±0.05 b
CULT	0.33±0.02 b	1.42±0.10 b	0.98±0.05 b	0.70±0.04 b
NV	0.48±0.03 a	1.61±0.10 ab	1.23±0.06 a	0.96±0.06 a
WC	0.44±0.02 a	1.98±0.12 a	0.94±0.04 b	0.75±0.05 b
P-value	<0.001	0.001	<0.001	<0.001

Soil Organic Matter, Nutrients and pH

There were few differences in soil nutrient concentrations (Table 3.3). In 2011 and 2014, WC soil had lower P levels than GLY: 41% less in 2011 and 46% less in 2014. In 2012, CULT soils had 37% less K than WC. In 2013, NV soils had 27% and 24% less K than GLY and CULT. In 2014, NV soils had 50% more Zn than GLY. However, all soil nutrient concentrations were within adequate ranges, except for P, which was found to be deficient according to soil nutrient recommendations for vineyards (Wolf 2008), and these differences were not consistent among years. In 2014, WC soils had 3.4% organic matter, 21% more than CULT soils, with 2.8% organic matter.

Table 3.3. Organic matter, pH, P, K, Mg, and Ca concentrations in bulk soil from under-vine groundcover treatments from 2011 to 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

	Organic Matter (%)				pH			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	2.6±0.3	4.8±0.3	3.6±0.2	3.0±0.2 ab	7.2±0.2	7.1±0.1 ab	6.8±0.1	6.6±0.1
CULT	2.5±0.3	4.6±0.3	3.6±0.3	2.8±0.2 b	7.0±0.3	7.2±0.1 a	6.8±0.1	6.5±0.1
NV	3.1±0.1	4.9±0.1	3.6±0.2	3.2±0.1 ab	7.0±0.2	7.1±0.1 ab	6.8±0.1	6.4±0.1
WC	3.2±0.2	5.5±0.1	3.8±0.2	3.4±0.2 a	7.0±0.2	7.0±0.1 b	6.7±0.1	6.4±0.1
P-value	0.149	0.089	0.836	0.042	0.704	0.009	0.297	0.254
	P (ppm)				K (ppm)			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	3.2±0.9 a	7.7±1.2	2.7±0.5	3.7±0.5 a	116±13	245±19 ab	142±6 a	201±36
CULT	2.3±0.6 ab	4.6±0.5	4.4±1.0	2.7±0.3 ab	85±13	169±22 b	136±11 a	161±16
NV	2.6±1.0 ab	5.7±0.8	3.6±0.8	2.8±0.4 ab	103±9	221±13 ab	104±10 b	179±28
WC	1.9±0.8 b	5.5±1.0	3.2±0.5	2.0±0.3 b	112±11	270±33 a	131±8 ab	174±23
P-value	0.046	0.067	0.389	0.003	0.105	0.021	0.013	0.347
	Mg (ppm)				Ca (ppm)			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	246±9	244±12	203±12	196±14	1800±259	1764±295	1532±153	1283±127
CULT	219±27	236±17	191±13	182±11	1625±270	1868±295	1486±141	1169±111
NV	249±7	243±6	202±9	197±7	1734±251	1744±116	1447±88	1203±63
WC	254±22	252±14	201±12	198±13	1822±177	1747±130	1520±110	1272±105
P-value	0.516	0.854	0.802	0.637	0.806	0.908	0.887	0.708

Table 3.3 continued. Fe, Mn, Zn, and Al concentrations in bulk soil from under-vine groundcover treatments from 2011 to 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

	Fe (ppm)				Mn (ppm)			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	1.1±0.1	2.5±0.1	1.4±0.1	0.7±0.1	14.3±1.3	8.3±0.6	6.5±0.5	10.6±0.6
CULT	1.8±0.3	2.6±0.2	1.6±0.2	0.7±0.0	12.2±1.7	8.1±0.8	7.1±0.3	10.0±0.6
NV	1.4±0.2	2.8±0.2	1.5±0.2	0.8±0.1	14.6±1.3	8.3±0.4	6.9±0.5	11.5±0.6
WC	1.3±0.3	2.8±0.2	1.4±0.2	0.7±0.1	14.8±1.6	9.7±0.7	6.7±0.7	12.1±0.8
P-value	0.209	0.182	0.397	0.626	0.163	0.131	0.759	0.094
	Zn (ppm)				Al (ppm)			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	0.6±0.1	2.0±0.8	0.9±0.1	0.4±0.0 b	7.7±1.4	11.5±0.7	8.3±1.3	7.8±1.5
CULT	0.5±0.0	1.2±0.3	0.7±0.1	0.4±0.1 ab	15.1±3.7	13.4±1.1	9.5±1.6	8.8±0.8
NV	0.7±0.0	0.9±0.1	0.8±0.1	0.6±0.1 a	11.4±2.8	13.8±1.34	10.5±1.6	9.7±1.3
WC	0.6±0.0	1.2±0.2	0.7±0.1	0.5±0.0 ab	8.4±2.9	14.0±2.0	9.2±1.8	8.7±2.0
P-value	0.134	0.300	0.170	0.023	0.157	0.408	0.336	0.772

Soil Water Infiltration

There were no differences in saturated soil infiltration rates among treatments during all four years of the study (Table 3.4).

Table 3.4. Saturated infiltration rate (mm/minute) from under-vine groundcover treatments from 2011 to 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

Treatment	2011	2012	2013	2014
GLY	5.1±0.6	3.5±0.4	4.5±0.4	2.9±0.5
CULT	3.9±0.8	3.4±0.3	4.1±1.0	4.5±1.3
NV	4.7±0.6	3.7±0.5	3.4±0.7	3.8±1.2
WC	5.0±0.6	3.8±0.4	5.0±0.5	4.4±0.8
P-value	0.686	0.734	0.217	0.455

Aggregate Stability

In 2013, there was no difference in aggregate stability among treatments. In 2014, WC soils had 36% greater aggregate stability than GLY and 23% greater than CULT, with WC soil maintaining 74.8% of aggregate mass after a simulated rain event (Table 3.5).

Table 3.5. Aggregate stability of bulk soil samples from under-vine groundcover treatments from 2013 and 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

Treatment	2013	2014
GLY	59.0±3.7	55.1±4.6 b
CULT	69.7±3.0	60.8±3.0 b
NV	65.2±3.9	64.9±4.4 ab
WC	68.3±2.7	74.8±4.2 a
P-value	0.146	0.003

Porosity, Penetration Resistance, and Bulk Density

There was no impact of treatment on soil core variables from 2011-2013 (Tables 3.6). In 2014, bulk density of the CULT upper depth was 13% greater than in the WC upper depth. Total porosity was 16% less, and available water capacity was 12% less in the CULT upper depth soil than in WC. Total porosity was 11% less in the CULT upper depth than in NV in 2014 as well.

Leachate Dissolved Organic Carbon and Total Nitrogen

Average dissolved organic carbon (DOC) concentrations were greater in GLY and CULT leachate samples than NV and WC samples over the calendar years of 2011, 2012, and 2013 (Table 3.7). In 2014, GLY and CULT DOC concentrations were greater than in WC, and CULT DOC concentrations were greater than NV. Yearly average GLY DOC leachate concentrations were as much as 32% and 39% greater than NV and WC DOC concentrations, respectively. Yearly average CULT DOC leachate concentrations were as much as 33% and 36% greater than NV and WC DOC concentrations, respectively.

There was a pattern of DOC leachate concentrations increasing during the spring in April and May, and a period of the highest leaching of the year during autumn in September and October for all treatments, but with DOC concentrations leaching from CULT and GLY greater than from NV and WC plots (Figure 3.2). Spikes in DOC leaching in the cover crops NV and WC followed mowing events.

Total nitrogen (TN) leachate concentrations varied among treatments and years (Table 3.6), and were generally higher in GLY and the WC treatments, and lower in CULT and NV. In 2011, NV samples had 59% lower, and CULT samples had 38% lower TN concentrations than GLY. In 2012, CULT, and NV TN concentrations were 79%, and 80% lower than WC. Both

CULT and NV leachate were 62% lower in TN than GLY. In 2013, CULT, NV, and WC had TN concentrations 81%, 86%, and 40% less than GLY. The TN concentration of CULT and NV leachate was 68% and 77% less than WC. In 2014 the TN concentration of CULT and NV leachate was 78% and 44%less than GLY, and 77% and 42% less than WC.

Similar to DOC leaching, TN leaching increased in the spring, beginning in April or May of each year (Figure 3.3). The year 2012 exhibited two periods of high TN leaching from the WC treatment, in mid-April and from August through October. In 2013 there was a jump in TN leaching from GLY and WC in late June, despite the fact that white clover did not account for a large proportion of vegetation in WC plots that year due to difficulty in establishment. GLY experienced another period of elevated TN leaching in September through October of the same year.

Table 3.6. Bulk density, penetration resistance, total porosity and available water capacity in soils of different under-vine treatments. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

	Bulk Density (g/cm^3)				Penetration Resistance (MPa)			
	Upper Depth 0-6 cm				Upper Depth 0-6 cm			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	1.19±0.07	1.26±0.05	1.29±0.04	1.34±0.03 ab	0.44±0.09	0.39±0.03	0.52±0.06	0.53±0.05
CULT	1.21±0.05	1.33±0.03	1.33±0.06	1.40±0.03 a	0.40±0.07	0.63±0.08	0.58±0.08	0.54±0.04
NV	1.20±0.03	1.22±0.03	1.29±0.03	1.28±0.03 ab	0.45±0.13	0.61±0.07	0.56±0.04	0.50±0.08
WC	1.25±0.05	1.22±0.06	1.27±0.05	1.24±0.02 b	0.48±0.09	0.64±0.13	0.53±0.08	0.50±0.06
P-value	0.858	0.218	0.715	0.008	0.885	0.133	0.921	0.969
	Lower Depth 6-12 cm				Lower Depth 6-12 cm			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	1.43±0.06	1.40±0.06	1.44±0.04	1.48±0.06	0.47±0.03	0.65±0.07	0.82±0.07	0.88±0.11
CULT	1.38±0.02	1.47±0.04	1.46±0.05	1.52±0.05	0.50±0.11	0.82±0.09	0.77±0.06	0.83±0.09
NV	1.35±0.04	1.45±0.04	1.40±0.03	1.51±0.05	0.63±0.12	0.88±0.05	0.75±0.07	0.76±0.11
WC	1.29±0.05	1.42±0.04	1.43±0.06	1.41±0.03	0.51±0.14	0.71±0.11	0.78±0.09	0.63±0.08
P-value	0.149	0.599	0.670	0.400	0.351	0.150	0.917	0.326

	Total Porosity (% volume)				Available Water Capacity (% volume)			
	Upper Depth 0-6 cm				Upper Depth 0-6 cm			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	48.0±1.9	39.1±2.1	42.1±1.8	42.0±1.0 ab	38.8±2.3	35.4±2.1	37.3±1.6	36.9±1.2 ab
CULT	48.0±1.7	39.0±1.2	41.5±2.1	39.2±1.0 b	41.3±1.9	36.1±1.2	38.8±2.0	35.6±0.9 b
NV	49.8±1.5	41.6±1.0	43.4±4.2	44.2±1.4 a	43.5±2.1	38.8±3.6	39.6±1.2	38.6±1.3 ab
WC	50.3±1.8	41.5±1.5	43.4±2.9	46.6±1.2 a	44.0±0.7	38.0±1.8	39.3±2.5	40.3±0.8 a
P-value	0.223	0.150	0.755	0.002	0.067	0.572	0.558	0.023
	Lower Depth 6-12 cm				Lower Depth 6-12 cm			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	39.0±4.1	35.1±1.6	36.0±1.1	35.9±2.1	32.8±3.7	31.9±1.8	32.6±1.0	31.9±2.0
CULT	39.8±1.6	34.5±1.3	37.9±2.0	35.2±1.8	35.5±0.9	30.9±1.2	34.6±1.7	30.2±1.5
NV	40.5±1.3	33.3±0.8	39.5±1.3	37.1±2.0	38.8±1.3	30.6±0.8	35.4±1.1	32.8±1.8
WC	44.8±2.7	35.3±1.9	39.9±1.7	39.1±1.5	38.5±0.9	32.0±2.1	37.0±1.6	34.5±1.4
P-value	0.330	0.76	0.148	0.525	0.180	0.104	0.108	0.422

Table 3.6 continued. Macroporosity, mesoporosity, and microporosity in soils of different under-vine treatments. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

	Macroporosity (% volume >1mm)				Mesoporosity (% volume 1,000-10μm)			
	Upper Depth 0-6 cm				Upper Depth 0-6 cm			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	9.3±1.3	3.9±0.4	4.8±0.7	5.2±0.5	27.3±2.1	24.3±1.9	26.1±1.6	24.7±0.9
CULT	6.8±1.1	3.0±0.3	2.5±0.4	3.7±0.4	29.8±1.7	23.8±1.2	26.0±2.4	23.0±1.3
NV	6.3±1.7	2.6±1.1	4.1±0.6	5.6±0.6	30.0±2.8	26.3±0.9	27.9±1.1	25.0±1.5
WC	6.3±1.7	3.6±0.4	4.0±0.7	6.4±0.7	27.8±1.5	25.9±1.8	28.8±1.7	27.1±1.3
P-value	0.465	0.140	0.116	0.073	0.277	0.299	0.208	0.193
	Lower Depth 6-12 cm				Lower Depth 6-12 cm			
Treatment	2011	2012	2013	2014	2011	2012	2013	2014
GLY	6.3±1.0	3.4±0.6	3.4±0.3	4.0±0.5	21.5±2.3	20.4±1.5	19.4±1.1	18.8±1.8
CULT	4.3±1.2	3.5±0.5	3.3±0.5	5.0±0.8	22.0±0.7	18.0±1.2	21.3±1.6	17.6±1.3
NV	1.8±0.3	2.4±0.2	4.0±0.8	4.4±0.6	23.0±2.0	17.1±0.8	21.9±0.7	19.0±1.5
WC	6.3±2.1	3.4±0.7	3.0±0.4	4.6±0.6	25.3±0.8	18.4±1.9	23.3±1.8	22.1±1.4
P-value	0.078	0.772	0.538	0.737	0.397	0.055	0.059	0.212

	Microporosity (% volume 10-0.2μm)			
	Upper Depth 0-6 cm			
Treatment	2011	2012	2013	2014
GLY	11.5±0.3 b	11.0±0.7	11.1±0.9	12.2±0.6
CULT	11.5±0.6 b	12.5±0.5	12.8±0.7	12.6±0.7
NV	13.5±1.6 ab	12.5±0.3	11.8±0.6	13.6±0.6
WC	16.3±1.0 a	12.4±0.9	10.5±1.1	13.2±0.7
P-value	0.030	0.861	0.337	0.455
	Lower Depth 6-12 cm			
Treatment	2011	2012	2013	2014
GLY	11.3±1.6	11.6±0.7	13.3±0.8	13.1±0.7
CULT	13.5±0.9	12.9±0.5	13.4±0.3	12.6±0.9
NV	15.8±1.3	13.8±0.6	13.5±0.6	13.7±0.7
WC	13.3±0.5	13.3±1.0	13.8±1.5	12.3±1.0
P-value	0.069	0.400	0.979	0.645

Table 3.7. Dissolved organic carbon (mg C/L) and total nitrogen (mg N/L) concentrations in leachate water samples from different under-vine groundcover treatments from 2011 to 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. Values are averages ± standard error.

	Dissolved Organic Carbon (mg C/L)			
Treatment	2011	2012	2013	2014
GLY	13.77±0.56 a	11.68±0.47 a	12.17±0.35 a	10.60±1.01 ab
CULT	13.90±0.62 a	11.38±0.44 a	12.23±0.48 a	10.13±0.76 a
NV	9.31±0.51 b	8.08±0.55 b	9.78±0.52 b	8.92±0.88 b
WC	9.17±0.35 b	8.59±0.50 b	9.40±0.48 b	6.49±0.73 c
P-value	<0.001	<0.001	<0.001	<0.001
	Total Nitrogen (mg N/L)			
Treatment	2011	2012	2013	2014
GLY	8.74±1.18 a	9.36±1.02 a	8.21±1.07 a	7.39±1.80 a
CULT	5.41±0.93 b	3.59±0.37 b	1.57±0.19 c	1.65±0.23 b
NV	3.59±0.68 c	3.54±0.55 b	1.11±0.18 c	4.12±1.42 b
WC	4.73±0.63 b	17.37±2.75 a	4.92±1.12 b	7.10±2.82 a
P-value	<0.001	<0.001	<0.001	<0.001

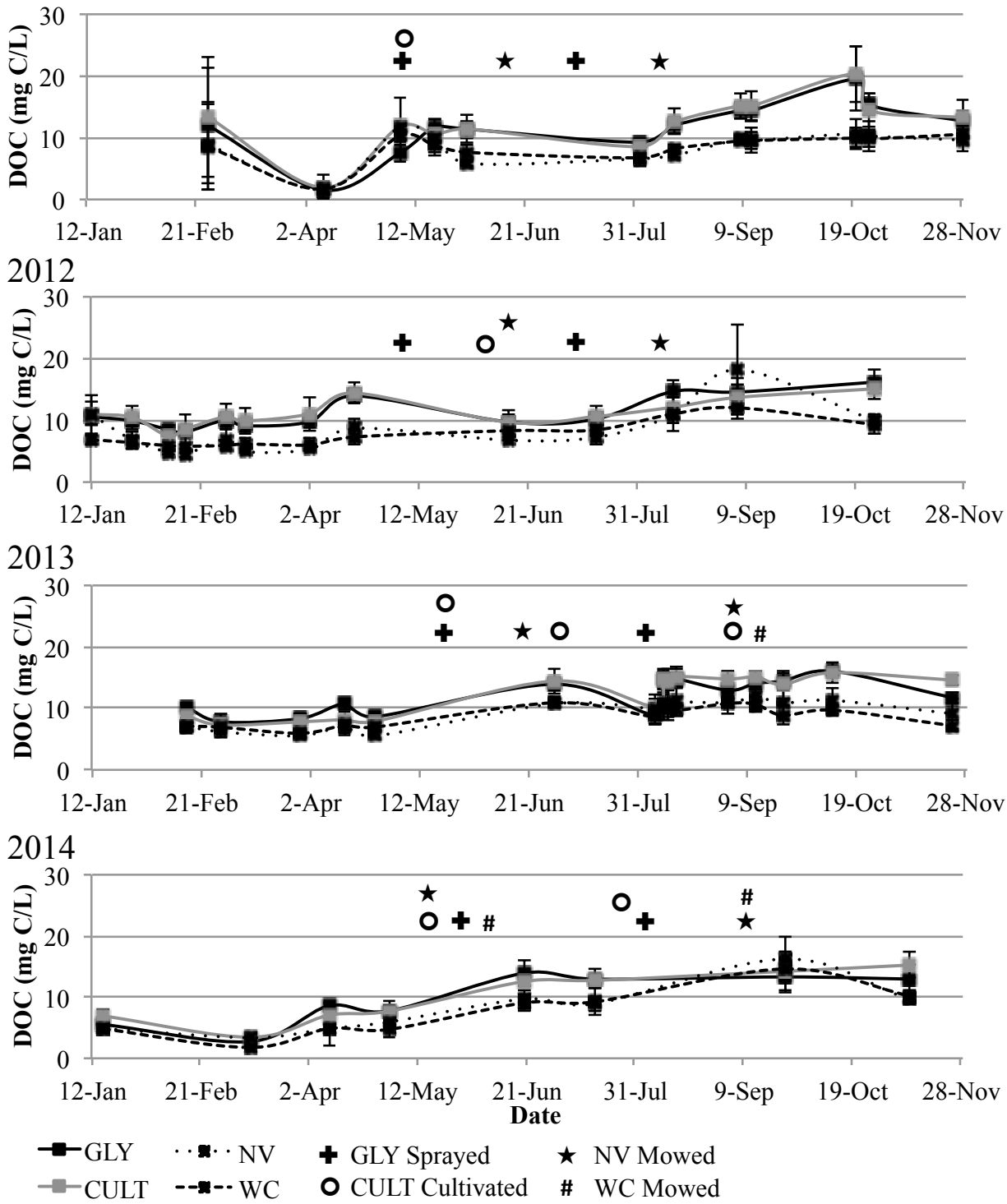

Figure 3.2. Dissolved Organic Carbon (DOC) concentrations (mg C/L) of leachate samples from under-vine groundcover treatments from 2011 to 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. DOC concentrations are averages ± standard error.

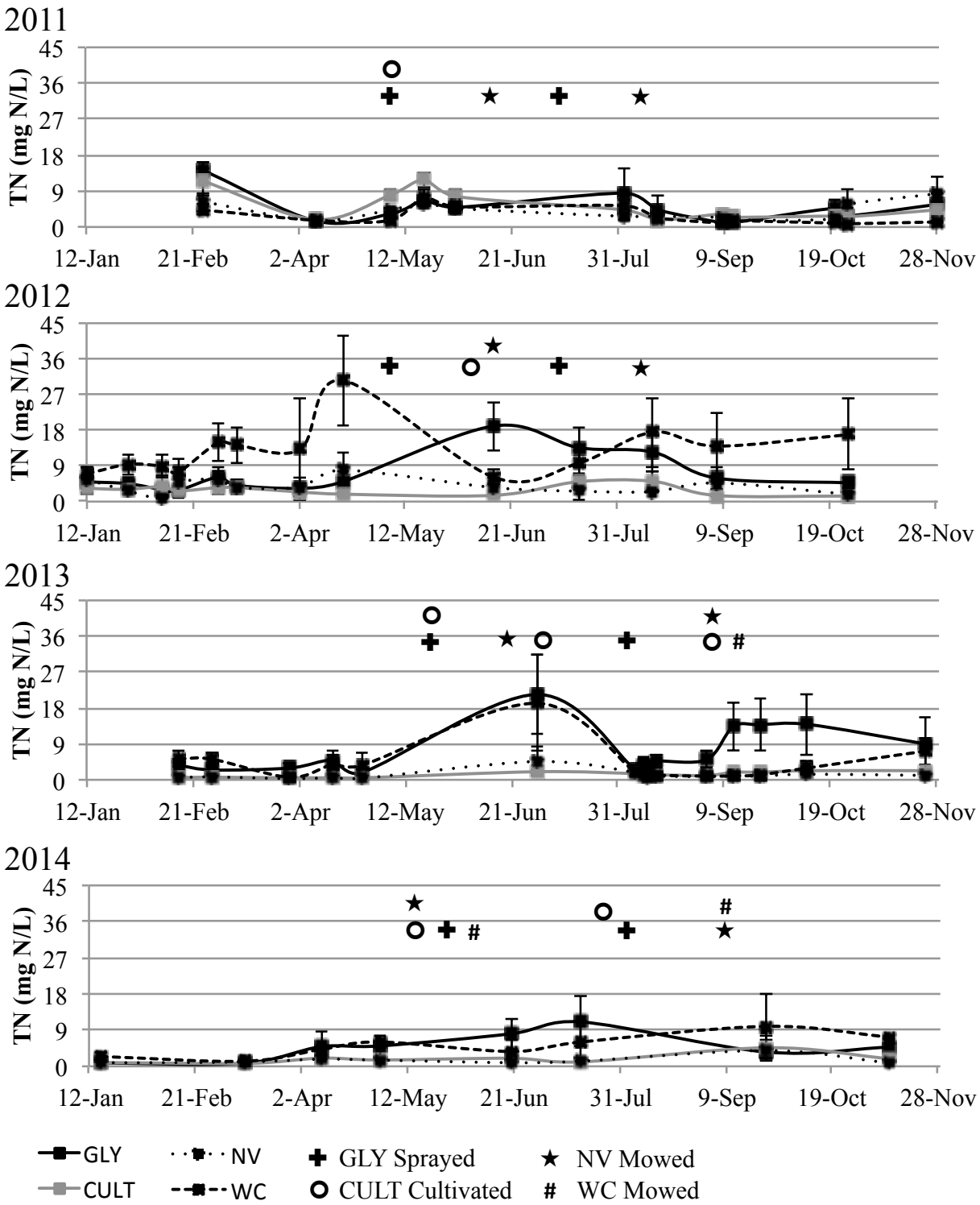

Figure 3.3. Total Nitrogen (TN) concentrations (mg N/L) of leachate samples from under-vine groundcover treatments from 2011 to 2014. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover. TN concentrations are averages ± standard error.

Imidacloprid

Imidacloprid was found in either trace (<1pbb) or in measurable (>1pbb) concentrations in half or more of all samples over a 43-day period after imidacloprid application (Table 3.8). Imidacloprid was found most frequently in GLY and NV, with almost every GLY and NV leachate sample testing positive for imidacloprid. CULT had the lowest number of positive test results, with only half of CULT samples containing detectable imidacloprid. While nearly all GLY and NV leachate samples tested positive for imidacloprid, a third of GLY leachate samples contained imidacloprid in measurable concentrations. In contrast, imidacloprid was not found in measurable concentrations in any NV samples. GLY had more samples with imidacloprid in measurable quantities than CULT and WC as well. GLY also had more samples with imidacloprid metabolites (imidacloprid des nitro HCL and or imidacloprid urea) than all other treatments. Some 40.0% of GLY leachate samples contained imidacloprid metabolites, while 5.6%, 0.0%, and 6.3% of CULT, NV, and WC, respectively, samples contained these metabolites.

Table 3.8. Percent of leachate samples with imidacloprid found in trace (<1pbb) or measurable (>1pbb) concentrations, and either trace or measurable concentrations of two imidacloprid metabolites: imidacloprid des nitro HCl or imidacloprid urea. GLY=Glyphosate, CULT=Cultivation, NV=Native Vegetation, WC=White Clover.

Treatment	% Samples with Trace Imidacloprid Concentrations	% Samples with Measureable Imidacloprid Concentrations	% Samples with Imidacloprid Metabolites
GLY	93.3 a	33.3 a	40.0 a
CULT	50.0 b	5.6 b	5.6 b
NV	94.0 a	0.0 b	0.0 b
WC	68.8 ab	6.3 b	6.3 b
P-value	0.004	0.016	0.013

Discussion

The implementation of different under-vine management practices over the course of four years impacted biological properties of soils as well as leachate composition. An impact of under-vine management on the physical structure of soil only became evident in the final year of the study.

In 2014, the bulk density of soil in the top 6 cm of CULT was greater than all other treatments. Compaction of soils through the disruption of soil structure from cultivation is one of the disadvantages of this practice (Lagacherie et al. 2006). The bulk density of CULT was above optimum ranges for field-crop production in clay-loam soils, and entering the spectrum where root elongation could become severely restricted (Reynolds et al. 2003). In addition to potential rooting problems, increased bulk density from soil compaction reduces the pore volume of soils, decreasing gas exchange and available water capacity (Archer et al. 1972). Consistent with these findings, measurements in soil porosity revealed that the top layer of CULT soil had lower total porosity than NV and WC and lower available water capacity than WC. Because these differences were found in the last year of the study, it is possible that this was the beginning of a long-term trend in soil physical structure associated with management practices.

In addition to having greater porosity and water holding capacity, WC soils had greater soil organic matter than CULT in 2014. The decline in organic matter and porosity in CULT were likely connected. Shukla et al. (2006) found that soil organic matter was the most important parameter indicating the degree of soil aeration. The physical action of cultivation makes many organic residues vulnerable to microbial attack and helps promote the loss of organic matter (Six et al. 1998). By not stimulating the metabolism of organic matter, and providing a greater input of organic materials, the WC cover crop promoted soils with more organic matter. Other

vineyard studies have also found cover crops to increase soil organic matter in comparison to cultivation as well (Steenwerth and Belina 2008).

Soil respiration rates are affected by substrate availability, soil moisture, and temperature (Sparling 1997). In a laboratory setting, with controlled moisture and temperature, they are most reflective of the respiratory potential of the soil and the availability of biodegradable substrates, not necessarily of respiration rates occurring in the field (Doran et al. 1997). Measures of microbial activity are invaluable in that they respond quickly to changes in management practices, and can indicate changes in the flux of labile carbon before differences in soil organic matter can be detected (Sparling 1997), which often take many years to become detectible (Smith 2004). The decrease of labile carbon additions to soils, such as with herbicide use or tillage, has been shown to decrease soil microbial respiration rates (Cleveland et al. 2007). The general trend of greater soil respiration under the cover crops NV and WC than in the bare ground treatments GLY and CULT indicates that herbicide application and tillage were decreasing the input of biodegradable substrates to the soil, diminishing microbial activity, and potentially lowering soil organic matter. Greater levels of microbial respiration are also associated with increased rates of nitrogen mineralization to plant available forms (Rustad et al. 2001). Increased rates of nitrogen mineralization can limit the need for fertilizers and soil amendments, as well as help diminish nitrogen competition of cover crops with grapevines.

DOC is an important source of carbon, nitrogen, phosphorous and sulfur for soil microbial metabolism, and influences the physical chemical, and biological properties of soil (Haynes and Beare 2000). Because much of it is bound to or incorporated within soil aggregates, disturbance of the soil structure, and increased erosivity of soils are reported to increase the leaching of DOC to surface and below-ground water bodies (Kalbitz et al. 2000; Amezketa 1999;

Brye et al. 2001). Plant cover, as well as greater microbial activity, has also been linked with immobilizing DOC, and preventing its leaching (Qualls and Richardson 2003; Tripolskaja et al. 2013). The pattern of greater DOC leaching from GLY and CULT soils in comparison to NV and WC soils is consistent with these reports that less disturbed soils with more cover limiting DOC leaching. Leaching of DOC out of the soil is indicative of carbon loss from the agroecosystem. It has been suggested that increases in DOC from changes in land management could be used, similarly to microbial biomass and respiration, as early indicators of soil organic matter loss (Silveira 2005).

Under-vine treatments also impacted total nitrogen leaching of soils throughout the study. There was a general trend of greater nitrogen leaching in GLY and WC treatment soils than in CULT and NV. Other vineyard ground cover studies have found greater nitrogen leaching in herbicide treated under-vine rows than in cultivated treatments (Steenwerth and Belina 2010). A greater presence of soil carbon, microbial biomass, and plant residues has been associated with reduced nitrogen leaching in cropping systems (Kramer et al. 2006; Steenwerth and Belina 2008). It is likely that the relative absence of plant cover and associated root systems in the GLY treatment in comparison to CULT and NV treatments reduced the immobilization of nitrogen (Weinert et al. 2002). The greater nitrogen leaching in the WC treatment can be attributed to the decomposition of nitrogen rich clover tissue, which has been observed in other cover crop studies (McCracken et al. 1994). The high concentrations of TN in the WC treatment in April of 2012 can likely be attributed to the decomposition of clover tissue from 2011 following the thawing of the soil. Greater leaching of nitrate can lead to increased emissions of nitrous oxide, a powerful greenhouse gas, from agricultural soils (Steenwerth and Belina 2010), as well as entering local bodies of water.

In addition to providing insight about the movement of DOC and TN in the vineyard under different under-vine ground management treatments, there was an observed impact of groundcover management on imidacloprid insecticide movement and persistence within the vineyard. Over the course of 43 days after imidacloprid was applied to the vines, it was found in at least half of all leachate samples, regardless of treatment, and in nearly all NV and GLY samples. However, imidacloprid and its breakdown metabolites were found in greater concentrations in GLY treatment leachate, than in other treatments. The lack of plant cover in the GLY treatment may have introduced more imidacloprid directly to the soil (through dripping from vine foliage) where it was not absorbed by plants, helping explain why imidacloprid was found in higher concentrations, and its metabolites detected more frequently in GLY than in other treatments (Goulson 2013). Testing groundcover vegetation for concentrations of imidacloprid and its metabolites would have helped elucidate the movement of these chemicals through the agroecosystem. Krupke et al. (2012) found imidacloprid in non-target vegetation in the borders of fields planted with imidacloprid-treated row crops in concentrations as high as 9 pbb.

The degradation of imidacloprid within soils is dependent on microbial activity (Liu et al. 2011). Additionally, imidacloprid has a high leaching potential, which is increased with greater concentrations of DOC in leachate water due to greater competition for sorption sites on soil particles (Flores-Céspedes et al. 2002). More of the imidacloprid that entered soil may have been leached from GLY plots than in the NV and WC treatments, due to lower microbial activity and or greater DOC concentrations in GLY. Preferential macropore flowpaths from soil cracking in GLY may have increased the leaching of imidacloprid as well; soil cracking from persistent herbicide application has been associated with more rapid and increased rates of nitrate and

benomyl fungicide in similar soil types to those in our study (Merwin et al. 1996). Imidacloprid also resists leaching by sorbing to organic matter in the soil (Cox et al. 1998). If rapidly transported through the soil column though soil cracks, which we observed in the GLY treatment, imidacloprid leaching may have increased due to fewer opportunities to sorb to soil particles. Imidacloprid is highly toxic to many aquatic and soil dwelling invertebrates (Stoughton et al. 2008; Cox 2001), making the reduction of imidacloprid leaching by preventing its contact with bare soil a priority. However, if imidacloprid is absorbed or taken up by groundcover vegetation, including flowering cover crops such as white clover, it may prove problematic for non-target organisms, such as honeybees, *Apis mellifera*, whose foraging and homing ability can be reduced by ingesting sub-lethal doses of imidacloprid from pollen and nectar sources (Yang 2008).

Conclusion

Management practices that maintain soil quality are paramount for the long-term sustainability of a vineyard. Over a relatively short period, herbicide application and cultivation displayed trends suggesting that these practices are diminishing soil organic matter and microbial activity within vineyard soils in comparison to cover crop treatments. Preserving soil organic matter is crucial for maintaining the physical, chemical, and biological functions of a healthy soil. The increased leaching of DOC from CULT and GLY treatments, in addition to removing more carbon from these vineyard soils, also poses as a potential source of contamination to the local watershed, as does leaching of imidacloprid from GLY soils. However, potential absorption of imidacloprid by ground vegetation may pose a threat to non-target insects. Cumulatively, these factors demonstrate the potential of under-vine cover crops to maintain soil quality and

decrease the leaching of nutrients and agrochemicals in vineyards in comparison to conventional practices.

REFERENCES

Alexander, A.C., J.M. Culp, K. Liber, and A.J. Cessna. 2007. Effects of insecticide exposure on feeding inhibition in mayflies and oligochaetes. Environmental Toxicology and Chemistry. 26:1,726-1,732.

Amezketa, E. 1999. Soil aggregate stability: a review. Journal of Sustainable Agriculture. 14:83-151.

Archer, J.R., and P.D. Smith. 1972. The relation between bulk density, available water capacity, and air capacity of soils. Journal of Soil Science. 23:475-480.

Battany, M.C., and M.E. Grismer. 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. Hydrological Processes. 14:1,289-1,304.

Bordelon, B.P., and S.C. Weller. 1997. Preplant cover crops affect weed and vine growth in first-year vineyards. Hort Science. 32:1,040-1,043.

Brye, K.R., J.M. Norman, L.G. Bundy, and S.T. Gower. 2001. Nitrogen and carbon leaching in agroecosystems and their role in denitrification potential. Journal of Environmental Quality. 30:58-70.

Byrne, F.J., and N.C. Toscano. 2006. Uptake and persistence of imidacloprid in grapevines treated by chemigation. Crop Protection. 25:831-834.

Castle, S.J., F.J. Byrne, J.L. Bi., and N.C. Toscano. 2005 Spatial and temporal distribution of imidacloprid and thiamethoxam in citrus and impact on *Homalodisca coagulata* (Say) populations. Pesticide Management Science. 61:75–84.

Centinari, M., J.E. Vanden Heuvel, M. Goebel, M. Smith, and T. Bauerle. 2015. Root-zone management practices impact above and below-ground growth in Cabernet Franc grapevines. Australian Journal of Grape and Wine Research. Accepted June 2015.

Clesceri, L. S., A.E. Greenberg, and A.D. Eaton. 1998. Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC.

Cleveland, C.C., D.R. Nemergut, S.K. Schmidt, and A.R. Townsend. 2007. Increases in soil respiration following labile carbon additions linked to rapid shifts in soil microbial community composition. Biogeochemistry. 82:229-240.

Cox, L., W.C. Koskinen, R. Celis, M.C. Hermosin, J. Cornejo, and P.Y. Yen. 1998. Sorption of imidacloprid on soil clay mineral and organic components. Soil Science Society of America Journal. 62:911-915.

Cox, C. (2001). Insecticide factsheet: imidacloprid. Journal of Pesticide Reform. 21:15-21.

Doran, J.W. M. Safley. 1997. Defining and assessing soil health and sustainable productivity. *In* Biological Indicators of Soil Health. Pankhurst, C., B.M. Doube, and V.V.S.R. Gupta (eds.), pp. 1–28. CAB International, Wallingford, UK.

Epstein, E., and W.J. Grant. 1973. Soil crust formation as affected by raindrop impact. Physical Aspects of Soil Water and Salts in Ecosystems. Hadas, A., D. Swartzendruber, P.E. Rijtema, M. Fuchs, and B. Yaron (eds.), pp. 195-201. Springer-Verlag, Berlin.

Flores-Céspedes, F., E. González-Pradas, M. Fernández-Pérez, M. Villafranca-Sánchez, M. Socias-Viciana, and M.D. Urena-Amate. 2002. Effects of dissolved organic carbon on sorption and mobility of imidacloprid in soil. Journal of Environmental Quality. 31:880-888.

Goulson, D. (2013). Review: An overview of the environmental risks posed by neonicotinoid insecticides. Journal of Applied Ecology. 50:977-987.

Gugino, B.K., G.S. Abawi, O.J. Idowu, R.R. Schindelbeck, H.M. van Es, D.W. Wolfe, B.N. Moebius-Clune, J.E. Thies, and G.S. Abawi. 2009. Cornell soil health assessment raining manual. Cornell University College of Agriculture and Life Sciences. Ithaca, NY.

Hatch, T.A., C.C. Hickey, and T.K Wolf. 2011. Cover crop, rootstock, and root restriction regulate vegetative growth of Cabernet Sauvignon in a humid environment. American Journal of Enology and Viticulture. 63:298-311.

Haynes, R.J., M.H. Beare. 1996. Aggregation and organic matter storage in mesothermal, humic soils. Structure and Organic Matter Storage in Agricultural Soils. Carter, M.R., and B.A. Stewart (eds.), pp. 213-262. CRC Press, Boca Raton, FL.

Jeschke, P., R. Nauen, M. Schindler, and A. Elbert. 2010. Overview of the status and global strategy for neonicotinoids. Journal of Agricultural and Food Chemistry. 59:2,897-2,908.

Kalbitz, K, and J.H. Park. 2000. Controls on the dynamics of dissolved organic matter in soils: a review. Soil Science 165: 277-304.

Kramer, S.B., J.P. Reganold, J.D. Glover, B.J. Bohannan, and H.A. Mooney. 2006. Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils. Proceedings of the National Academy of Sciences of the United States of America 103:4,522-4,527.

Krupke, C.H., G.J. Hunt, B.D. Eitzer, G. Andino, and K. Given. 2012. Multiple routes of pesticide exposure for honey bees living near agricultural fields. PLoS one. 7:1-8.

Lagacherie, P., G. Coulouma, P. Ariagno, P. Virat, H. Boizard, and G. Richard. 2006. Spatial variability of soil compaction over a vineyard region in relation with soils and cultivation operations. Geoderma. 134:207-216.

Lehotay, S. 2007. AOAC Official Method 2007.01 Pesticide Residues in Foods by Acetonitrile Extraction and Partitioning with Magnesium Sulfate. Journal of AOAC International. 90:485-520.

Liu, Z., Y. Dai, G. Huang, Y. Gu, J. Ni, H. Wei, and S. Yuan. 2011. Soil microbial degradation of neonicotinoid insecticides imidacloprid, acetamiprid, thiacloprid and imidaclothiz and its effect on the persistence of bioefficacy against horsebean aphid *Aphis craccivora* Koch after soil application. Pest Management Science. 67:1,245-1,252.

McCracken, D.V., M.S. Smith, J.H. Grove, R.L. Blevins, and C.T. MacKown. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. Soil Science Society of America Journal. 58:1,476-1,483.

Merwin, I.A., J.A. Ray, T.S. Steenhuis, and J. Boll. 1996. Groundcover management systems influence fungicide and nitrate-N concentrations in leachate and runoff from a New York apple orchard. Journal of the American Society for Horticultural Science. 121:249-257.

Moebius-Clune, B.N., H.M. van Es, O.J. Idowu, R.R. Schindelbeck, D.J. Moebius-Clune, D.W. Wolfe, and R. Lucey. 2008. Long-term effects of harvesting maize stover and tillage on soil quality. Soil Science Society of America Journal. 72:960-969.

Novara, A., L. Gristina, S.S. Saladino, A. Santoro, and A. Cerdà. 2011. Soil erosion assessment on tillage and alternative soil managements in a Sicilian vineyard. Soil and Tillage Research. 117:140-147.

Oliveira, M.T. and I.A. Merwin 2001. Soil and physical conditions in a New York orchard after eight years under different groundcover management systems. Plant and Soil. 234:233-237.

Oliver, J.B., D.C. Fare, N. Youssef, S.S. Scholl, M.E. Reding, C.M. Ranger, J.J. Moyseenko, and M.A. Halcomb. 2010. Evaluation of a single application of neonicotinoid and multi-application contact insecticides for flatheaded borer management in field grown red maple cultivars. Journal of Environmental Horticulture. 28:135-149.

Qualls, R.G., C.J. Richardson. 2003. Factors controlling concentration, export, and decomposition of dissolved organic nutrients in the Everglades of Florida. Biogeochemistry. 62:197-229.

Reynolds, W.D., X.M Yan, C.F. Drury, T.Q. Zhang, and C.S. Tan. 2003. Effects of selected conditioners and tillage on the physical quality of a clay loam soil. Canadian Journal of Soil Science. 83(4): 381-393.

Rodella, A.A., and L.V. Saboya. 1999. Calibration for conductimetric determination of carbon dioxide. Soil Biology and Biochemistry. 31:2,059-2,060.

Rustad, L.E., J.L. Campbell, G.M. Marion, R.J. Norby, M.J. Mitchell, A.E. Hartley, J.H.C. Cornelissen, and J. Gurevitch. 2001. A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. Oecologia. 126:543-562.

Schnürer, Y., P. Persson, M. Nilsson, A. Nordgren, and R. Giesler. 2006. Effects of surface sorption on microbial degradation of glyphosate. Environmental Science and Technology. 40:4,145-4,150.

Shukla, M.K., R. Lal, and M. Ebinger. 2006. Determining soil quality indicators by factor analysis. Soil and Tillage Research. 87:194-204.

Silveira, M.L.A. 2005. Dissolved organic carbon and bioavailability of N and P as indicators of soil quality. Scientia Agricola. 62:502-508.

Six, J., E.T. Elliott, K. Paustian, and J.W. Doran. 1998. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. Soil Science Society of America Journal. 62:1,367-1,377.

Smith, P. 2004. How long before a change in soil organic carbon can be detected?. Global Change Biology. 10:1,878-1,883.

Soil Survey Staff. 2014. Kellogg Soil Survey Laboratory Methods Manual. *In* Soil Survey Investigations Report No. 42, Version 5.0. R. Burt and Soil Survey Staff (eds.). USDA NRCS.

Sparling, G.P. 1997. Soil microbial biomass, activity and nutrient cycling. *In* Soil health: its relationship to ecosystem health. Pankhurst, C., B.M. Doube, B.M. and V.V.S.R. Gupta, (eds.), pp. 97-119. CAB International, Wallingford, UK.

Steenwerth, K., and K.M. Belina. 2008. Cover crops enhance soil organic matter, carbon dynamics and microbiological function in a vineyard agroecosystem. Applied Soil Ecology. 40:359-369.

Steenwerth, K. L., and Belina, K. M. 2010. Vineyard weed management practices influence nitrate leaching and nitrous oxide emissions. Agriculture, Ecosystems and Environment. 138:127-131.

Stoughton, S.J., K. Liber, J. Culp, and A. Cessna. 2008. Acute and chronic toxicity of imidacloprid to the aquatic invertebrates *Chironomus tentans* and *Hyalella azteca* under constant-and pulse-exposure conditions. Archives of Environmental Contamination and Toxicology. 54:662-673.

Sugimura, Y., and Y. Suzuki. 1988. A high-temperature catalytic oxidation method for the determination of non-volatile dissolved organic carbon in seawater by direct injection of a liquid sample. Marine Chemistry. 24:105-131.

Teasdale, J. R. 1998. Cover crops, smother plants, and weed management. *In* Integrated Weed and Soil Management. Hatfield, J.L., D.D. Buhler, B.A. Stewart (eds.), pp 247-270. Integrated Weed and Soil Management. Ann Arbor Press, Chelsea, MI.

Tripolskaja, L., C.A. Booth, and M.A. Fullen. 2013. A lysimeter study of organic carbon leaching from green manure and straw into a sandy loam Haplic Luvisol. Žemdirbystė (Agriculture). 100:3-8.

Weinert, T.L., W.L. Pan, M.R. Moneymaker, G.S. Santo, and R.G. Stevens. 2002. Nitrogen recycling by nonleguminous winter cover crops to reduce leaching in potato rotations. Agronomy Journal. 94:365-372.

Wolf, T.K. 2008. Wine Grape Production Guide for Eastern North America. Natural Resource, Agriculture, and Engineering Service, Ithaca, NY.

Yang, E.C., Y.C. Chuang, Y.L. Chen, and L.H. Chang. 2008. Abnormal foraging behavior induced by sublethal dosage of imidacloprid in the honey bee (Hymenoptera: *Apidae)*. Journal of Economic Entomology. 101:1,743-1,748.