AN ABSTRACT OF THE THESIS OF

Levi Fredrikson for the degree of Master of Science in Horticulture presented on 14 February 2011.

Title: Effects of Cover Crop and Vineyard Floor Management on Young Vine Growth, Soil Moisture, and Weeds in an Establishing Vineyard in the Willamette Valley of Oregon.

Abstract approved: ____

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Five vineyard floor management treatments were evaluated in a young vineyard in western Oregon to better understand the effects on vine growth and nutrition, soil moisture dynamics, and weed control during 2009 and 2010. Treatments included two mulched treatments where mowed alleyway residue was transferred in-row at rates of 1x and 3x of alleyway biomass, one treatment where residue was incorporated into alleyways, one treatment where residue was removed, and one unplanted treatment. Vine growth, root growth, and nutritional status of young vines were measured over two growing seasons, as was soil moisture from 0-76cm depth. Weed coverage was assessed visually and densities of broadleaf and grass weeds were determined. In-row volumetric and gravimetric soil moisture measured across 0-30 cm were greater in mulched than non-mulched treatments each year while the 3x level of mulch treatment had greater soil moisture than the 1x level of mulch treatment in 2010. Soil compaction in-row was lowest in mulched treatments each year. One-year old grapevines destructively harvested in fall each year had greater leaf and wood biomass in mulched treatments than non-mulched treatments. Shoot lengths were greater in mulched treatments than non-mulched treatments in 2010. Vines in mulched treatments had greater pruning weights by 43% in 2010 than the treatment in which residue was removed. Clusters per shoot were greater in vines under the 3x level of mulch in 2010. SPAD measures of leaf chlorophyll concentration were higher in mulched treatments than non-mulched treatments. Weed coverage and densities were substantially lower in-row of mulched treatments during 2009 and 2010, with nearly 100% weed suppression by the greater level of residue mulch. Alleyway weed coverage was lowest when residue was incorporated, and highest in the unplanted treatment at some sampling dates. These results indicate that cover crops can be managed effectively to increase shoot and leaf growth of one- to three-year old *V. vinifera* 'Chardonnay' vines and conserve soil moisture in a non-irrigated, cool climate vineyard. Further, this study indicates that mulching of mowed cover crop residue in-row can reduce weed growth, and incorporation of cover crop residues in alleyways can suppress alleyway weeds.

Effects of Cover Crop and Vineyard Floor Management on Young Vine Growth, Soil Moisture, and Weeds in an Establishing Vineyard in the Willamette Valley of Oregon.

by
Levi Fredrikson

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented 14 February 2011
Commencement June 2011

Master of Science thesis of Levi Fredrikson presented on 14 February 2011.

APPROVED:

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Levi Fredrikson, Author

ACKNOWLEDGEMENTS

I am deeply grateful first and foremost to Dr. Patricia A. Skinkis for supporting me through my entire graduate program, for challenging me to think critically, for teaching me to work efficiently and stand up for myself, and for supporting my wide array of academic interests. Secondly, Dr. R. Paul Schreiner taught me that I could be a meticulous, critically-minded, hard-working scientist and still have a lot of fun. I am very grateful for my other graduate committee members, Drs. Barbara Bond and James Osborne, for their communication and encouragement as I developed this thesis research and for being excellent role models as teachers. Deep thanks also go to Drs. John Luna and Ed Peachey for all their input and interest in this research and for their friendship.

Field research for this thesis would not have been possible without the helpful hands of fellow Viticulture Lab members Amanda, Alison, Abi, Karen, Kevin, Kim, Sunny, Xin and other eager students. Endless thanks to Dean Underwood for his support of our research as vineyard manager. My gratitude extends to the Olsen family and to the field crew that worked carefully and sonorously within the research site. Funding was provided by Agricultural Research Foundation and by Northwest Center for Small Fruits Research for which I am enormously grateful.

I would like to individually thank every member of our OSU-Horticulture family, though special thanks go to LeeAnn, Gina, Viki, and Wayne for their endless patience, support, and kind nature. Scott Robbins provided unwavering assistance at the early stages of this research and a solid friendship throughout. I cannot express through words how grateful I am to Dr. Anita Azarenko for her leadership, her encouragement, her clarity, her optimistic-pragmatist approach to life, and for her advocacy and mentorship of graduate students. Finally, thanks to each and every graduate student in our department over my years as part of the family.

There are endless folks in the Corvallis community to whom I am eternally grateful. They know who they are, but not just how grateful I am to them. Special thanks go to every individual and every animal involved with growing and providing food that nourished my mind and soul throughout these years. “Oh, to take what we love inside.” Likewise, eternal gratitude for all the folks that shared music and playing with me and for all the artists whose music inspired me through these years, especially Jack Rose, Townes van Zandt, Doc Watson, and Jackson C. Frank.

Finally, how can I hope to properly thank my family? Thanks to my mom for her boundless encouragement, unwavering acceptance, and unending interest in my life, to my dad for being the cornerstone of the person I am striving to be, for sharing his musical gifts, and for teaching me that “life is what you make of it,” to my brother Jake for understanding me more than anyone ever will and for laughing with me, to my grandparents for their wisdom, joy, faith, and love, and to Kala, Paul, Chris, and Becky for becoming family and riding alongside me.

CONTRIBUTION OF AUTHORS

Dr. Patricia A. Skinkis assisted with the experimental design, data analysis, data collection, and writing of each chapter. Dr. R. Paul Schreiner was involved with experimental design, data analysis, data collection, writing of chapter 3 and reviewing this thesis in entirety. Dr. Ed Peachey assisted with data collection and writing of chapter 2.

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Chapter 1

General Introduction

Vineyard floor management is critical for controlling competing vegetation when establishing a healthy vineyard. Vineyard producers generally assume cover crops compete too aggressively with young vines, particularly within the first three years after planting. In Oregon, young vineyards are often managed using soil cultivation or herbicides to control competing vegetation (Gold and Lombard 2003; William and Crisp, 2003). However, producers may choose not to use herbicides as misapplication can damage young grapevines or herbicides may be prohibited due to farming certification programs. Cover crops may serve as an alternative method of weed control and simultaneously provide benefits to vine growth and soil health. While many studies have been conducted on cover crop management in mature vineyards to meet management goals such as weed control (Fourie et al. 2006; Steinmaus et al. 2008), improving fruit quality (Ingels et al. 2005; Pinamonti, 1998; Tesic et al. 2007) and controlling vine vigor (Caspari et al. 1997), research in young vineyards is limited and not regionally defined. To address cover crop management in young vineyards in Oregon, a two-year study was designed to determine whether alleyway cover crops compete with young vines, and whether cover crops may be managed to conserve soil moisture, suppress weeds, and enhance young vine establishment.

Cover Crops as a Management Tool in Vineyards

A "cover crop" is defined here as any non-economic crop that is intentionally cultivated and grown in a production vineyard. Depending on plant species, cover crops have been used in vineyards to improve soil structure, decrease erosion and run-off, enhance crop nutrition, suppress weeds, pests and diseases, and increase worker and equipment traction. Both annual and perennial plant species may be grown as cover crops. Subcategories of cover crops include the following: legumes, grasses, and winter or summer annuals. These cover crops may be grown as a monoculture or as a blend of species, in either no-till or tilled systems. Naturally recruited plants, often termed "resident vegetation," may be managed as cover crops and can fulfill some of the aforementioned management goals (Ingels and Klonsky, 1998). Effective management of cover crops is based upon the management goals of the vineyard and the vineyard environment.

Cover cropping is viewed by many farmers as an investment in the longevity of the farm, both economically and in terms of soil and vine health. Sustainable management decisions are based on maximizing profits while preserving or increasing vineyard health for later years. Management may be governed by regulations set forth by the Oregon Department of Agriculture (ODA) and Soil and Water Conservation Districts (SWCD) among other regulatory bodies. Cover crops are an essential component of the Low Input Viticulture and Enology (LIVE) Program, a sustainable farming certification program, which mandates that at least 75 percent of the acreage be covered during winter (LIVE, 2010). Benefits of cover crops such as mitigation of erosion, building of soil tilth (Reicosky and Forcella, 1998), and the enhancement of biodiversity (especially beneficial predators) (Costello and Daane, 2003; Grafton-Cardwell et al. 1999) are difficult to assess economically. Still, these benefits are central tenets of sustainable production and ultimately may reduce further vineyard amendments and inputs.

Cover crop species selection and management depends upon the economic and ecological goals of the agricultural system. Regional suitability is based on the success rate of cover crop establishment in a given climate (Olmstead et al. 2001), soil fertility (Hirschfelt, 1998), cropping history (Doran and Smith, 1991), soil type (McGourty and Christensen, 1998), pest pressure (Keinath et al. 2003), and management of the economic crop being grown. However, a cover crop that establishes well and achieves management goals in one environment may not achieve management goals of a differing environment.

While selection of optimal cover crop types or species is important to a specific region or farming system, an understanding of how to manage cover crops is also essential in meeting best management practices. Ingels et al. (2005) concluded that differences in vine nutrient status between cover crop treatments were more likely due to tillage or non-tillage of the cover crop rather than to the species used. Similarly, Baumgartner et al. (2008) found that tillage practices, not species of cover crop, significantly influenced weed biomass and community structure in a California vineyard.

While cover crops can serve to meet production goals, they may negatively impact production systems due to mismanagement. Reduced vine growth and yields due to cover crop competition for water and nutrients has been observed (Rodriguez-Lovelle et al. 2000; Tesic et al. 2007). In certain cases, this competition between cover crops and grapevines is desirable to control vine vigor (Caspari et al. 1997; Ferrini et al. 1996). Excessive vine vigor can delay fruit ripening (Spayd et al. 1994) and reduce fruit quality (Ingels et al. 2005).

Pest and disease pressures may be aggravated by cover crops, such as an increase in *Pythium* disease incidence following an oat and vetch cover crop (Grünwald et al. 2000), though this would be of greater concern to establishing subsequent cover crops rather than to vine health. Increased gopher populations were observed with cover crops in California vineyards (Ingels et al. 2005; Wolpert et al. 1993). Increases of parasitic nematodes can occur with cover crops (Westerdahl et al. 1998). In addition to biotic problems, abiotic problems may result from cover crops as well. Risk of spring frost damage may be increased in vineyards that maintain vegetation during the winter and early spring as opposed to a vegetation-free or mowed vineyard floor (McGourty and Christensen, 1998). The potentially negative impacts of using cover crops exemplify the importance of understanding effective management practices in a vineyard production system.

One form of cover crop management that is being used commercially is the transfer of mown cover crop biomass into the vine row using a side-discharge mower. Commercially, this practice is known as "mow and throw." This technique has been shown to suppress weeds, increase crop yield, and generate higher capital returns than herbicide or cultivated controls in a North Coast California vineyard (Steinmaus et al. 2008). Mowing cover crops at the time of bud break can reduce early season competition between vines and cover crops (Monteiro and Lopes, 2007). In the case of "mow and throw," early season mowing is desirable because the mulch can be applied before weed seeds begin germinating (Elmore et al. 1998), and while cover crops reach peak concentrations of N (e.g. before flowering) (Hirschfeldt, 1998). Precipitation and irrigation enhance the breakdown of mulched cover crop residues making nutrients available through decomposition (Elmore et al. 1998). Composition of mulched residue in terms of plant species and C:N ratio will determine decomposition rates and nutrient release (Ranells and Wagger, 1997). When legume residues are mulched into the vine row, earthworms are able to incorporate the leguminous matter faster than matter with a high C:N ratio such as a grass residue (Scow and Werner, 1998). Cheng et al. (2008) concluded that legume residues should be placed near the highest root densities, such as in the vine row, in order to maximize breakdown and vine N uptake. Grass residue will persist on the soil surface longer than legume residue, offering benefits of mulch such as weed control and soil moisture conservation (Elmore et al. 1998).

Effects of Cover Crops on Weed Suppression

Weeds can compete with vines for soil moisture and nutrients to a degree that they may reduce fruit quality, yield, and vine growth (Byrne and Howell, 1978). Control of weeds prior to seed development is important in reducing the weed seed bank (Fourie et al. 2006; Moonen and Bárberi, 2004). Weed control in vineyards is often managed in different ways when considering the vine row and the alleyway. Three methods are generally used by grape growers for weed control: herbicide sprays, tillage, and/or cover crops. Using alleyway cover crops to effectively control weeds has been achieved in young (Fourie et al. 2006) and mature (Bugg et al. 1996) vineyards. A variety of cover crop management techniques including annual species, perennial species, tilled, and non-tilled systems, have been demonstrated to reduce weeds as compared to herbicide controls (Baumgartner et al. 2008; Gago et al. 2007). Alternatives to herbicides are fundamental to low-input, integrated, and organic farming systems which seek to reduce contamination of groundwater and reduce synthetic inputs, among other objectives (Bond and Grundy, 2001; Clements et al. 1994).

Cover crops may control weeds through several mechanisms, sometimes providing multiple levels of control. Allelopathic control of weeds has been observed upon decomposition of legume residues, such as clovers (*Trifolium spp.*) (Dyck and Liebman, 1994; Liebman and Davis, 2000), as well as non-leguminous residues, such as rye (*Secale cereale*) (Weston, 1996) and certain *Brassicaceae* species (Haramoto and Gallandt, 2005; Petersen et al. 2001). Physical control of weeds may be obtained through "smothering," where the ecological niches of weeds are filled through competition from a cover crop. In this case, the cover crop outcompetes weeds and is termed "living mulch" (Teasdale, 1998). A caveat to cover crop-mediated weed control is that the cover crop must not be allowed to become a weed itself (Bugg, 1991). To control cover crop growth and weeds simultaneously, the mow and throw technique may be used. This method of mulching has been shown to reduce germination of weed seeds in the vine row and reduce overall weed biomass more than either herbicide or cultivated controls (Steinmaus et al. 2008).

Effects of Cover Crops on Vineyard Soil Moisture and Soil Structure

Protecting vineyard soils from erosion is one of the foremost reasons cover crops are used. Cover crops can substantially reduce hillside erosion (Kaspar et al. 2001; Malik et al. 2000). Cover crops provide groundcover by which to reduce soil compaction by precipitation and a root system that can increase water infiltration relative to tilled or herbicide-treated surfaces (Kaspar et al. 2001; Krohn and Ferree, 2005). Increased water infiltration has been directly correlated with decreased runoff and reduced soil erosion (Franzluebbers, 2002; Mitra et al. 2006). Erosion mitigation and improvement of soil structure are essential to the long-term productivity of a vineyard.

In Oregon, where most precipitation occurs during the dormant period and early part of the growing season, a cover crop is likely to be maintained during this period to prevent erosion without competing with vines. Competition with vines for water may be reduced by killing the cover crop with herbicide or mowing at strategic times (Monteiro and Lopes, 2007) or through increased supplemental irrigation to the vines (Prichard, 1998). Morlat and Jacquet (2003) found that vineyard soil moisture increased under a mowed cover crop treatment as compared to the herbicide treated control; similar results were obtained by Celette et al. (2005). Morlat and Jacquet (2003) ascribed the increased soil moisture to improved water holding capacity of soils with cover crops. Conversely, other studies have noted a reduction in vineyard soil moisture under cover crop treatments due uptake of soil moisture by the cover crop (Rodriguez-Lovelle et al. 2000; Tesic et al. 2007). These contextual differences emphasize the importance of cover crop management in manipulating soil water dynamics based on regional climates.

Soil moisture may be conserved by applying mulch from cover crop residues (Elmore et al. 1998). Mulches derived from cover crop residues have been shown to conserve more moisture in summer than the cover crop depletes while growing in spring (Clark et al. 1997). Hostetler et al. (2007) found greater in-row soil moisture in vine rows under organic mulch than in cultivated vine rows. Similarly, research on plastic mulches in vineyards has shown increased growth of grapevines due to water conservation by the synthetic mulch (Hegazi 2000; Hostetler et al. 2007; Reynolds et al. 2008). Soil moisture conservation by mulches may prove important to vine growth in vineyards in Oregon's Willamette Valley that are dry-farmed

Vineyard soils benefit from the addition of organic matter as nutrient-holding capacity and water infiltration are increased. Incorporation of cover crop biomass increases organic carbon and nitrogen (Sainju et al. 2002) and improves aggregate stability (Hermawan and Bomke, 1997). Pinamonti (1998) demonstrated that increased organic matter addition from compost mulch improved soil structure and may have improved nutrient availability to grapevines. Total soil microbial activity and diversity have been shown to increase due to various cover cropping systems (Ingels et al. 2005; Scow and Werner, 1998), though how this directly benefits vine health is unclear.

Effects of Cover Crops on Vine Development and Nutrition

Increased vine growth in the first years of vineyard establishment allows managers to train vines to the trellis and begin producing a harvestable crop earlier than poorly managed vines. Generally, vines are not cropped for the first two years after planting. The first crop is often harvested in year three or four and full production potential is realized in year four or five. During the establishment of a young vineyard, proper nutrition and soil moisture must be provided to vines in order to support healthy root and shoot development. Nutrient availability to young vines may be increased by effective weed control and nutrient amendments to the soil or foliage. Soil moisture may be increased through regular irrigation and maintained through soil water conservation practices such as mulching.

Research in vineyards has produced conflicting results regarding the impact of cover crops on vine physiology and development. Vine response is heavily dependent on the species of cover crop being grown, management of the cover crop, and environmental variables such as climate, soil type, and soil moisture. Grapevines require water and nutrients to differing degrees according to environment, cultivar, vine age, and phenological stage of development (Campbell and Fey, 2003; Keller 2005; Schreiner et al. 2006). In some cases, an actively growing cover crop competes with vines for water and/or nutrients enough to reduce vine growth and affect fruit quality (Caspari et al. 1997; Tesic et al. 2007).

The vine root system is essential to nutrient and water uptake, therefore, development of a healthy root system is often the central goal of management in the first three years after planting (Gold and Lombard, 2003). Over time, vine roots will avoid growing into cover-cropped alleyways which can result in deeper rooting and greater in-row root densities than alleyways kept free of vegetation (Morlat and Jacquet, 2003; Smart et al. 2006). While a cover crop may impede vine growth upon initial introduction into a vineyard system, it may alter root architecture in a way that mitigates competition over time. Morlat and Jacquet (2003) found that a permanent grass cover crop in alleyways, as compared to herbicide, reduced the amount of grapevine roots in the alleyway and increased the amount of roots in the vine row and root density at greater depths.

Subterranean competition between vines and cover crops has been strongly linked to available soil moisture (Morlat and Jacquet, 2003; Tesic et al. 2007), suggesting that proper irrigation management could mitigate competition between vines and cover crops. Though irrigation can meet these needs, some vineyard sites may have limited or no access to irrigation water. For economic reasons, an irrigation system may not be installed in the first years of a vineyard, particularly in regions where mature vineyards can be grown without supplemental irrigation. Organic mulches have been shown to increase vine root branching, length, and overall biomass through conserving soil moisture and buffering temperature fluctuations near the soil surface (Eastham et al. 1996; Elmore et al. 1998; Van Huysteen, 1988).

Arbuscular mycorrhizal fungi (AMF), which colonize grapevine roots, are critical to healthy vine development (Linderman and Davis 2001; Schreiner, 2005). AMF affect vine nutrient uptake, especially P (Biricolti et al. 1997). P is often deficient in Oregon vineyards due to low soil mobility (Campbell and Fey, 2003). AMF have been shown to increase root uptake of Mn, Zn, Fe (Karagiannidis and Nikolaou, 1999), and Cu (Biricolti et al. 1997) to some degree as well. Vines colonized with AMF have exhibited a more branched root system (Schellenbaum et al. 1991) and greater root growth (Biricolti et al. 1997), as well as greater shoot growth (Linderman and Davis, 2001) compared to non-colonized vines. Certain vineyard cover crops such as cereal rye (*Secale cereale*) and burclover (*Medicago polymorpha*) have been shown to increase colonization of grapevine roots (Baumgartner et al. 2005; Cheng and Baumgartner, 2006). Conversely, Sweet and Schreiner (2010) found no effect of cover crops on vine root AMF colonization. Living cover crop stands have been observed to increase AMF colonization (Deguchi et al. 2007), while killed cover crop residues may decrease AMF colonization (Ortiz-Ceballos et al. 2007). AMF mediate the transfer of N from legume (*Medicago polymorpha*) and grass (*Bromus hordeaceus*) cover crop residues to grapevines (Cheng and Baumgartner, 2004, 2006), though low rates of mineral N fertilizer will reduce uptake of legume residue N by vine roots and AMF hyphae (Cheng et al. 2008). Cover crops provide management alternatives to practices such as tillage and herbicides, which can reduce AMF populations (Oehl et al. 2003).

Soil moisture and nutrient competition between cover crops and vines is determined by numerous environmental factors and should be adjusted according to vineyard management goals. Altering the width of the vegetation-free strip in vine rows can moderate competition between cover crops and vines (Ingels et al. 2005; Zabadal and Dittmer, 2001). Cover crop-derived competition may also be moderated by the type or species grown (Ingels et al. 2005) and timing of mowing, irrigation, or tillage (Hartwig and Ammon, 2002; Ingels et al. 2005). Cover crops may actually increase nutrient availability to vines as leguminous cover crops can provide fixed N (Patrick et al. 2004; Ranells and Wagger, 1997). Certain cover crops, such as cereal rye (*Secale cereale*) have been shown to immobilize soil nutrients such as phosphorus (Kamh et al. 1999; Scow and Werner, 1998). However, it has been shown that certain cover crops planted in-row, particularly grasses, can substantially reduce young vine growth due to water and nutrient competition (Bordelon and Weller, 1997).

Tesic et al. (2007) found that increasing grass cover of vineyard alleyways corresponded to reductions in yield of up to 2.4-fold in a hot, dry climate whereas yield was unaffected and fruit maturity was improved with increasing grass cover in a cool climate. These effects were attributed to competition for moisture and nutrients by the grass cover in both climates. However, the degree of competition in the cool climate was enough to reduce vegetative vigor without negatively impacting yield (Tesic et al. 2007). The reduction in vegetative vine growth was ascribed to reduced soil moisture from cover crop competition, which in turn reduced nutrient availability, especially N (Tesic et al. 2007). Rodriguez-Lovelle et al. (2000) observed that increased alleyway vegetation resulted in decreased vegetative vine growth, N status, and crop yields when alleyway grass cover crops were not disked in spring and allowed to grow throughout the season. Caspari et al. (1997) observed limited vine growth during the period of rapid shoot growth due to early season competition for moisture by chicory, an aggressive perennial cover crop. In two Willamette Valley (Oregon) vineyards, Sweet and Schreiner (2010) observed no measurable competition between vines and six different alleyway cover crop mixes studied over two years.

Justification for Vineyard Cover Crop Management Research

Research on cover crop management is an area of integrated and applied viticulture that needs to be refined for different regions and for different stages of vine development within a vineyard of a given region. There is potential to enhance young vine establishment through innovative use of cover crop residues, which can provide weed control, conservation of soil moisture, improvement of soil structure, and vine nutrition. A two year-study was conducted to determine how to best manage cover crops to enhance vine growth in a new vineyard in Oregon's Willamette Valley. This research focused on the effects of various cover crop management regimes on weed control, soil moisture, root system development, vegetative growth of vines, and vine nutrient status. Since a winter annual cover crop is not expected to compete with young vines in this region, it was hypothesized that the cover crop could be grown and mowed residue be used to control weeds, conserve soil moisture, and increase vegetative- and root growth of young vines as compared to an unplanted treatment.

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CHAPTER 2

Effect of cover crop and floor management on weed coverage and density in an establishing vineyard in Oregon's Willamette Valley

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Abstract

Five vineyard floor management treatments were evaluated for effects on weed control over two growing seasons in an establishing *Vitis vinifera* 'Chardonnay' wine grape vineyard in the Willamette Valley of Oregon. Four cover crop management treatments and an unplanted treatment were compared to assess effects on vine row and alleyway weed coverage and densities of broadleaf and grass weeds. A winter annual cover crop was grown in alleyways of the cover-cropped treatments and was mowed in spring. The mowed residue was managed as follows: 1. Residue transferred in-row as mulch representing the industry practice of "mow-and-throw." 2. Residue transferred in-row as mulch at three-times the rate of the prior treatment. 3. Mowed residue incorporated into alleyways. 4. Removal of mowed cover crop residue from the vineyard. Weed coverage was assessed visually within a 1.0-m^2 quadrat placed randomly in alleyways and vine rows, and densities of broadleaf and grass weeds were determined by counting and grouping individual weeds within each quadrat. Vine row weed coverage and densities were lower in treatments with residue mulch at each sampling date in 2009 and 2010 with nearly 100% in-row weed suppression by the heavier mulch treatment. Alleyway weed coverage was lowest when residue was incorporated, and highest in the unplanted treatment at some sampling dates. Grass weed densities in alleyways were similar between treatments at all sampling dates. Results of this study indicate that in-row

mulch of cover crop residues at fresh weight densities of 2.5-15.0 kg·m^{-2} provided effective weed control in a non-irrigated vineyard in western Oregon. Also, alleyway weed coverage may be reduced through incorporation of mowed cover crop residues.

Introduction

Weeds can compete with young *Vitis vinifera* grapevines for soil moisture and nutrients and can impact yield and fruit quality (Byrne and Howell, 1978). Root systems of young vines are small and subject to greater suppression of vine growth due to weed competition compared to established or mature vines (Balerdi, 1972). Three weed management methods are generally used by grape growers: herbicide sprays, tillage, and/or cover crops. The majority of weed management in vineyards is focused within the vine row where weeds may compete directly for water and nutrients. However, management of weeds in the alleyway is important in reducing the weed seed bank and can reduce the need for in-row management over time (Fourie et al., 2006; Moonen and Bárberi, 2004).

While herbicide sprays are widely used to manage weeds in young and mature vineyards, some common herbicides have been observed to damage shoot and root tissue of grapevines at standard concentrations (Balerdi, 1972; Lee and Cahoon, 1981). Tillage as a means of weed management has been shown to lead to increased erosion, creates a more favorable environment for germination of some weed species, and may not be effective in controlling rhizomatous weed species (Gago et al., 2007).

Alternatives to herbicides are fundamental to low-input, integrated, and organic farming systems which seek to reduce contamination of groundwater and herbicide-resistant weeds, among other objectives (Bond and Grundy, 2001; Clements et al., 1994). Alternatives to tillage are important in reducing erosion and dust, maintaining populations of beneficial soil microbes (Ingels et al., 2005; Larson et al., 2001), and reducing fuel and tractor inputs. Certain cover crop management systems have been used as an alternative to herbicides and tillage to control weeds, thereby reducing the amount of adventitious weeds in vineyard alleyways (Baumgartner et al., 2008; Gago et al., 2007).

Cover crops can be used to manage weeds through several mechanisms. Competition between weeds and cover crops will occur to varying degrees based on the vineyard environment and management. Allelopathic suppression of weeds has been observed upon decomposition of legume residues, such as clovers (*Trifolium*) (Dyck and Liebman, 1994; Liebman and Davis, 2000), as well as non-leguminous residues such as cereal rye (*Secale cereale*) (Weston, 1996) and certain Brassicaceae species (Haramoto and Gallandt, 2005; Petersen et al., 2001). Physical suppression of weeds may be obtained when alleyway vegetation is mowed at strategic times during vine development and the residue transferred into vine rows as mulch. This method of mulching, known as “mow-and-throw,” has been shown to reduce germination of weed seeds in the vine row (Elmore et al., 1998) and reduce overall weed biomass more than herbicides or cultivation (Steinmaus et al., 2008). Many studies on vineyard weed management have been conducted using mature vines of five years of age or more, and more research is needed on the effect of these methods in young vineyards.

A two year study was developed to determine the effect of alleyway cover crop and management on weed coverage/density in an establishing vineyard. The study was ancillary to a systemic study evaluating the effects of these treatments on vine growth, nutrition, soil moisture and structure (Fredrikson, 2011). It was hypothesized that mowed alleyway residues transferred into the row would suppress weed emergence compared to non-mulched treatments.

Materials and Methods

Experimental design and vineyard floor management treatments.

This trial was conducted over 2 years at a commercial wine grape vineyard 7 miles south of Independence, OR (lat. 44.77'N, long. -123.18'W, elevation 90 m). The 10-acre vineyard was planted in July 2008 with 'Chardonnay' (Dijon clone 96 on rootstock 3309-C) grapevines. Vines were spaced 7 ft (across alleyways) by 5 ft (in-row) and planted in north-south oriented rows. The soil is an Amity series (Fine-silty, mixed, superactive, mesic Argiaquic Xeric Argialboll) silty clay loam with a 0% to 3% slope across the experimental site. The total size of the experimental plot used within the site was 140 ft (east to west) x 330 ft (north to south). The site was non-irrigated throughout the experiment.

Five vineyard floor management treatments (Table 2.1) were spatially distributed amongst 5 replicates across the site for a total of 25 experimental plots arranged in a completely randomized design. Each replicate plot included 20 vines and was 100 ft long. Replicate plots were 11 ft wide and included 3-ft-wide grape rows (i.e., in-row) and the adjacent 4-ft-wide alleyways on either side of the vine row. A buffer vine row separated each replicate plot from other plots.

A winter annual cover crop mix of cereal rye and crimson clover (*Trifolium incarnatum*) was planted in Sept. 2008 and 2009 in each plot with the exception of the unplanted treatment. The cover crop was seeded at a rate of 30 lb/acre cereal rye and 20 lb/acre crimson clover. The crimson clover seed had been pre-inoculated with rhizobium to ensure proper nodulation of roots for nitrogen (N) fixation. A double-roller drop-seeder (Brillion® Sure-Stand™ SSP-5; Brillion Farm Equipment, Brillion, WI) was used to plant the cover crop seed into a 4-ft-wide seedbed which had been prepared by harrowing once and rolling twice before planting. No fertilizer or irrigation was applied to the cover crop or grapevines throughout the duration of the experiment.

There were five treatments included in the study, including four that used cover crop residues and one that was left unplanted (Table 2.1). Cover crop plots were mown when crimson clover reached 90% flowering in May each year, when it was at the highest potential N contribution based on total biomass and percent N (Ranells and Wagger, 1992). The unplanted treatment plots were not seeded to cover crop and were kept at minimal vegetative coverage using glyphosate (Bronco®; Monsanto Company, St. Louis, MO) applied at a rate of 1.0 lb/acre (acid equivalent) in January each year.

In 2009, mowed alleyway residue was applied to the in-row area as mulch in the mulch1 treatment in the quantity of 5 $kg \cdot m^{-2}$ fresh weight to an approximate thickness of 10 cm and width of 1 m. The mulch3 treatment received residue density at three-fold that of mulch1 with 15 $kg \cdot m^{-2}$ fresh weight at an approximate thickness of 30 cm and width of 1 m. Residue was applied by hand to ensure even distribution across each treatment replicate. Mowed residue was managed in the same manner in 2010. However, residue applied in-row and incorporated between-row in 2010 was lower due to reduced growth of the cover crop. The mulch1 and mulch3 treatments received 2.5 $kg \cdot m^{-2}$ and 7.5 $kg \cdot m^{-2}$ fresh weight residue in-row, respectively in 2010. Weather data was collected (Table 2.2) from an on-site weather station (Vantage Pro2™; Davis Instruments, Hayward, CA) and regional weather station for Corvallis, OR (AgriMet, Pacific Northwest Cooperative Agricultural Weather Network). Soil temperature data was recorded in the vine row using dataloggers (HOBO™ micro station; Onset, Pocasset, MA) for mulched and non-mulched treatments at depths of 15 and 30 cm.

Weed management.

One week prior to treatment application, weeds in the vine rows were desiccated using 0.67% glyphosate. Alleyway biomass samples were collected before treatments were applied and used to estimate total weed biomass in each treatment. During the season, weeds in the alleyway were controlled by disking based on commercial vineyard management practices in 2009 (14 July and 1 Sept.) and 2010 (7 Aug.). In-row weeds were controlled as needed in summer with applications of glyphosate on 27 May, 14 July, and 31 Aug. in 2009 and on 16 June in 2010. The overall reduced growth of weeds in 2010 resulted in less need for control and only one sampling date was possible. Weeds were assessed 1 d prior to each disking or spray application.

Sampling weed biomass in cover crop stands.

Cover crop and weed biomass was sampled in all treatments except the unplanted, 1 d prior to implementing treatments. The sampling procedure did not include the unplanted treatment as minimal vegetative coverage was maintained (Table 2.1). Biomass was sampled by randomly throwing a 1.0-m^2 quadrat into the alleyway and harvesting all aboveground biomass 5 cm above the soil surface to simulate mowing. One sample was taken from the east and one from the west alleyway of each plot. Weed and cover crop biomass were separated by hand and fresh weights were measured separately for each biomass sample. Cereal rye, crimson clover, and weed biomass were oven-dried separately to determine percent moisture content.

Weed densities and estimation of coverage.

Coverage of weeds in alleyways was estimated using a method similar to the procedure described by Gago et al. (2007), though a 1.0-m^2 quadrat was used instead of 0.25-m^2 and six replicates per plot instead of 12. The quadrat was placed randomly in the alleyway east of each treatment vine row three times and then three times in the west alleyway. Within the 1.0-m^2 quadrat, weed coverage was visually estimated as a percent of total ground coverage (Vitta and Quintanilla, 1996) by the same trained assessor each time. Weeds within the quadrat were then counted individually and grouped as either "broadleaf" or "grass" species. While weeds were not quantified by species in this study, individual weeds that comprised weed biomass, percent coverage, and count data were photographed and visually identified and classified according to genus and species when possible. Alleyway weeds were assessed on 30 June, 13 July (percent coverage only), and 31 Aug. 2009 and on 6 Aug. 2010.

In-row weeds were assessed by the same visual and counting methods with a 1.0-m^2 quadrat placed at six different predetermined positions across a replicate. Predetermined positions were used to prevent assessing areas that had been compromised by other measurements (e.g. soil cores). The mulch layer of mulch1 and mulch3 plots was removed for weed assessment and then put back into place. After in-row weeds were assessed, glyphosate was applied at a rate of 1.0 lb/acre (acid equivalent) in-row with a tractor-mounted sprayer. In-row weeds were assessed on 26 May, 13 July, 31 Aug. 2009 and on 16 June 2010. In-row and alleyway weeds were assessed at different sampling dates due to differences in weed control dates as determined by the vineyard management.

Data Analysis.

Data was analyzed with SAS (version 9.2; SAS Institute, Cary, NC) using proc ANOVA, GLM, and MIXED procedures where appropriate. Levene's test was used to check for homogeneity of variance in the data and residuals were examined for skew or lack of normality. Data violating assumptions of Analysis of Variance (ANOVA) were transformed prior to analysis using the log, square root, or arcsine transformations with addition of a constant to meet the assumptions, and the data were re-checked to ensure assumptions were met post-transformation. Back-transformed means are presented in the tables where transformed values were used. Percent coverage data were transformed prior to analysis using the square root or arcsine transformations with addition of a constant to meet the assumptions of analysis of variance. Dry weights of weeds in alleyway biomass samples were converted to a percent of total alleyway biomass and transformed using the square root transformation. ANOVA type III sums of squares were used to assess effects of treatment, sampling date, and interactions between treatment*date. Years were analyzed independently because cumulative effects of treatments from 2009-10 could have violated the assumption of independence between years. Tukey's Honestly Significant Difference (HSD) test was used to compare treatment means (n=5) at 95% confidence. Effects were considered significant at 95% confidence ($P<0.05$).

Results and Discussion

Climate.

The climatic information from the research vineyard for the 2009 and 2010 growing seasons was monitored from budbreak to leaf abscission (20 Apr. through 20 Nov. 2009; 2 Apr. through 16 Nov. 2010). The 2009 season had 2341 °F Growing Degree Days (GDD), 388 mm precipitation, and a relatively cool spring and moderate summer (Table 2.2). The 2010 growing season was the coolest year in 20 years (U.S. Department of the Interior Bureau of Reclamation) with 2198 °F GDD and 499 mm precipitation (Table 2.2). Seasonal soil temperatures were moderated by mulching treatments (data not shown). Soil temperatures in-row were buffered in mulched treatments at 15 and 30 cm with daily fluctuations of 0.5-1.0 °C where non-mulched treatments fluctuated 3.0-5.0 °C per day. Mean soil temperatures in mulched treatments were generally 3.0-5.0 °C lower than non-mulched treatments during the growing season.

Observed weed species.

A general shift in weed species composition and density (abundance) over the entire site was visually observed between 2009 and 2010. Weed species recorded in 2009 were lambsquarters (*Chenopodium album*), pigweed (*Amaranthus retroflexus*) sow thistle (*Sonchus arvensis*), fescues (*Festuca* spp.), perennial ryegrass (*Lolium perene*), black nightshade (*Solanum nigrum*), willow herb (*Epilobium* spp.), wild carrot (*Daucus carota*), buckhorn plantain (*Plantago lanceolata*), common knotweed (*Polygonum erectum*), and common groundsel (*Senecio vulgaris*). Weed species observed in 2010 included the species listed for 2009, with the exception of buckhorn plantain, and included prickly lettuce (*Lactuca serriola*), and two species of willowherb.

Weed biomass in alleyway cover crop.

Total dry weights of alleyway weeds in 0.25-m^{-2} quadrat samples, taken just prior to imposing treatments in 2009 and 2010, did not differ between treatments. Percent weed biomass of the total sampled alleyway biomass also did not differ between treatments (data not shown). This was expected in 2009, as all cover cropped alleyways had been treated similarly prior to planting. It was hypothesized that reduced weed biomass would occur due to decreased seed to soil contact in treatments where residue was incorporated into alleyways (Liebman and Mohler, 2001). The lowest mean weed dry matter was found in the incorporate treatment (4.6

g·m^{-2}) where biomass was tilled into the alleyway. Other treatments in the study had 6.2-7.6 g·m^{-2}dry matter. Total cover crop biomass grown in alleyways did not differ across treatments in either year of the study (Fredrikson, 2011). Cumulative effects of mulched residues from 2009 on in-row weeds in 2010 may have occurred. Based on visual observation, the mulch layer completely degraded in the mulch1 treatment and degraded by approximately 90% in the mulch3 treatment over the Winter 2009-10.

In-row weed coverage and densities.

Mulched treatments had lower weed coverage and densities in-row than non-mulched treatments (Figs. 2.1-2.3) when analyzed across the 2009 season. The mulch1 and mulch3 treatments had mulch dry matter rates of 1.0 and 3.0 kg·m^{-2}, respectively, which is in excess of the 0.6 kg·m^{-2} proposed by Teasdale and Mohler (1993) to be the minimum biomass required to suppress weed seed germination through light interception. The same effect was observed at the 2010 sampling date (Figs. 2.1-2.3) despite the mulch biomass applications being 50% lower in 2010 due to reduced total cover crop biomass accumulation by Spring 2010. The cooler seasonal temperatures in 2010 may have reduced weed emergence compared to 2009 (Forcella et al., 2000). Weed emergence may have also been reduced by the more buffered soil temperatures in mulched vine rows compared to non-mulched vine rows (Forcella et al., 2000). Allelopathic chemicals from the cereal rye and crimson clover residues also may have inhibited weed development (Liebman and Mohler, 2001; Weston, 1996) though allelopathy was not measured directly in this study.

Cumulative weed coverage in-row includes the summation of coverage from each sampling date across a season, and it was 19% to 23% in non-mulched treatments and 1% to 3% in mulched treatments during 2009 (Fig. 2.1). At each 2009 evaluation date, mulched treatments had lower weed coverage than non-mulched treatments (Fig. 2.1). A similar trend in weed coverage was observed in 2010 (Fig. 2.1). In both years, mulch3 plots were nearly weed-free compared to the other treatments (Figs. 2.1-2.3). Similarly, mulch3 had mean broadleaf and grass densities <1.0 weed·m^{-2} at each sampling date in 2009 and 2010 (Figs. 2.2-3). Based on this information, residue fresh weight applications in mulch3 vine rows of 15.0 kg·m^{-2} in the first year and 7.5 kg·m^{-2} in the second year of this study attained nearly complete weed control. Mulch densities of 5.0 kg·m^{-2} in the first year and 2.5 kg·m^{-2} in the second year for the mulch1 treatment still suppressed weeds as indicated by the five to ten-fold reduction in coverage and densities compared to non-mulched treatments (Figs. 2.1-2.3). These results are consistent with a similar study conducted in an apple orchard in which three different organic mulch treatments at 10-cm thickness suppressed broadleaf and grass weed species better than non-mulched treatments (Granatstein and Mullinix, 2008). Hostetler et al. (2007) applied composted bark mulch to vine rows at a similar thickness as mulch3 and observed reduced weed growth compared to an non-mulched control, although various perennial broadleaf and grass species persisted in bark mulch treatments with coverage as high as 35%.

Two methods of in-row weed assessment may have influenced results. During assessment of weeds in the mulched treatments, the mulch was temporarily removed by hand and it is possible that existing weeds were severed at the soil surface and not accounted for in the assessment. However, severing of weeds was never observed during mulch removal. Even though the mulch layer may have acted as a barrier to glyphosate contact to weeds, the data indicate that weed growth and densities were reduced in mulched treatments as compared to non-mulched treatments (Fig. 2.1).

Grass weed species accounted for greater density than broadleaf species in 2009 and 2010 (Figs. 2.2-2.3); however, percent coverage data was correlated more closely with broadleaf density (r^2=0.81, P<0.0001) than grass density (r^2=0.60, P<0.0001). These correlations suggest that coverage data was more reflective of broadleaf weed coverage than grass coverage, which was consistent with Neeser et al. (2000). Mulched treatments had lower broadleaf densities in-row than non-mulched treatments at each sampling date in 2009 and 2010 (Fig. 2.2). In 2010, mulch3 had lower densities of broadleaf species than mulch1 with 0.8 broadleaf weeds$\cdot m^{-2}$ and 6.5 broadleaf weeds$\cdot m^{-2}$, respectively (Fig. 2.2). As expected, in-row broadleaf densities were not different between non-mulched treatments (unplanted, remove, incoporate) at any sampling date in 2009 or 2010 (Fig. 2.2) because the in-row area was treated similarly between these treatments except for an additional application of glyphosate in the unplanted treatment in winter.

In-row grass densities averaged between 0-1 grass weeds$\cdot$m^{-2} in mulched treatments and 29-30 grass weeds$\cdot$m^{-2} in non-mulched treatments on 26 May 2009 (Fig. 2.3). These results indicate that mulched treatments suppressed emergence of early-season grass weeds almost completely compared to non-mulched treatments. No differences were seen at the latter sampling dates in 2009 due to glyphosate that killed emerging weeds; mean grass densities were <1 grass weeds$\cdot$m^{-2} in all treatments on those dates (Fig. 2.3). However, across-season analysis for 2009 indicated that mulched treatments had lower grass densities in-row than non-mulched treatments (Fig. 2.3). A similar trend in grass density was observed in 2010 with mean densities of 0-1 grass weeds$\cdot$m^{-2} in mulched treatments and 11-20 grass weeds$\cdot$m^{-2} in non-mulched treatments (Fig. 2.3). These results corroborate the findings of Monks et al. (1997). However, residue mulch has been observed to decrease broadleaf density without a concurrent decrease in grass weed density (Hoy et al., 2002; Shilling et al., 1986). The treatment where residues were incorporated had a density of 11 grass weeds$\cdot$m^{-2} which was less than the treatment where residues were removed which had a density of 20 grass weeds$\cdot$m^{-2} in 2010 (Fig. 2.3), suggesting an effect of alleyway residue incorporation on grass weed density in-row.

In-row soil moisture did not differ between non-mulched treatments where the residue was incorporated or removed from the alleyway in either year (Fredrikson, 2011), although weed seed dispersal may have been different between the two treatments.

Alleyway weed coverage and densities.

Alleyway weed coverage compared across three sampling dates in 2009 indicate a treatment effect (Table 2.3). The treatment where residues were incorporated had a lower mean coverage than all other treatments when analyzed across 2009; there was no interaction between treatment and sampling date. This followed the hypothesis that growing and incorporating cover crop biomass (mowed residue, stubble, and roots) would reduce weed growth, as is well documented in several studies (Brennan and Smith, 2005; Dyck and Liebman, 1994; Lehman and Blum, 1997; Liebman and Mohler, 2001). Sweet and Schreiner (2010) found that alleyway weeds were reduced in a winter annual cover crop treatment as compared to perennial grass cover and resident vegetation treatments. At the 13 July 2009 sampling date when alleyway weed coverage was greatest, the unplanted treatment had the greatest percent coverage, followed by treatments remove, mulch1 and mulch3, with the incorporate treatment having the lowest coverage (Fig. 2.1). It was also hypothesized that remove, mulch1, and mulch3 would have similar values for alleyway weed coverage and densities as they were managed similarly in the alleyway (Table 2.1). The differences between the treatments remove, mulch1, and mulch3, compared to incorporate and unplanted treatments, may be attributed to differences in alleyway management (Table 2.1). The unplanted treatment was treated with glyphosate in winter, and the soil surface was subject to compaction by winter rains. Also, the treatments remove, mulch1, and mulch3 had cover crop root biomass remaining during incorporation, and this may have suppressed weed emergence. The additional cover crop residue disked into the incorporate treatment may have further suppressed weeds compared to the other treatments. Hoffman et al. (1996) found that cereal rye root residues delayed weed emergence while shoot residues had little effects on weed emergence.

The differences in alleyway weed coverage found on 13 July 2009 were not observed at other sampling dates in 2009 or 2010 (Fig. 2.1). At the 30 June assessment in 2009, incorporate had the lowest coverage and differed from the other treatments except mulch1 (Fig. 2.1). This may be attributed to the relatively low growth of weeds at that first sampling date. Interestingly, the unplanted treatment had greater alleyway broadleaf density than other treatments on 30 June 2009, while percent coverage in the unplanted treatment did not differ from other treatments except incorporate (Figs. 2.1-2.2). This suggests that weeds in the unplanted treatment were smaller in size than other treatments based on the correlation between broadleaf density and weed coverage. In 2010, the lowest coverage (5.3%) was in the treatment where residue was incorporated whereas there was 20.0% and 23.3% coverage in treatments that were unplanted or where residues were removed, respectively (Fig. 2.1). Results indicate that mulch1 coverage was 6.0%, which was less than unplanted and remove (Fig. 2.1), and mulch3 did not differ in weed coverage from any treatment in 2010 (Fig. 2.1). The variation between sampling dates may be ascribed to the relatively low coverage and high variation between field replicates.

Alleyway broadleaf densities followed a similar trend as percent coverage in 2010 but not in 2009 (Figs. 2.1-2.2). Across-season analyses in 2009 indicate that the unplanted treatment had greater broadleaf weed density than all other treatments (Table 2.3), which further suggests that the differential treatment of the alleyway in winter and lack of cover crop biomass may have allowed for greater proliferation of broadleaf weeds relative to the other treatments. In 2010, broadleaf density in the unplanted treatment was greater than all treatments except whre residues were removed (Fig. 2.2). Similarly, Monteiro and Lopes (2007) found that annual broadleaf species in a vineyard were more abundant in unplanted alleyways than cover cropped alleyways, whereas grass species were more abundant in cover cropped alleyways.

When analyzed across the 2009 season, alleyway grass densities were lower in unplanted and incorporate treatments compared to remove, mulch1 and mulch3 treatments (Table 2.3). However, no differences were observed at individual sampling dates in either year (Fig. 2.3). Grass weed density may have been lower in the incorporate treatment as there was greater alleyway residue incorporated than in remove, mulch1, and mulch3 to potentially reduce weed seed-to-soil contact. Still, differences in grass weed density were marginal (Fig. 2.3) and only seen when analyzed across the 2009 season.

Studies using similar floor management treatments reached variable conclusions regarding cover crop effects on weed densities (Baumgartner et al., 2008; Mennan et al., 2006; Reddy, 2001; Vasilakoglou et al., 2006). Vineyard floor cultivation has been found to be a more important factor in weed recruitment than cover crop management (Ingels et al., 2005) though a less effective weed management strategy than herbicide (Baumgartner et al., 2007). Although we did not measure the effect of cultivation on alleyway weeds, we found that a sown winter annual cover crop reduced weed coverage and broadleaf density compared to the unplanted alleyway at some sampling dates. Incorporation of mowed residue further reduced alleyway weed coverage and broadleaf density.

Conclusion

Using mowed cover crop residue as a mulch in vine rows provided nearly complete weed control when compared to non-mulched vine rows in a growing season with minimal summer precipitation. Supplemental mulch in the mulch3 treatment provided similar in-row weed control as the mulch1 treatment which reflects the "mow and throw" technique, indicating that mulching can provide effective weed control when cover crop residue levels are greater than 2.5 $kg \cdot m^{-2}$ fresh weight in the vine row. Incorporating cover crop biomass into vineyard alleyways suppressed weed growth as compared to an unplanted treatment or removing mowed residue, whether or not it was mulched into vine rows. Alleyway broadleaf weed growth was reduced in cover-cropped alleyways as compared to unplanted, herbicide-treated alleyways. Few differences in alleyway grass weed densities were found between these floor management treatments. The results of this study suggest that cover crops may be effectively managed to control in-row and alleyway weeds simultaneously in vineyards located in areas of limited summer rainfall.

Table 2.1. Floor management treatments imposed in May 2009 and 2010 at a commercial vineyard site near Independence, OR.

Dates[z] of management treatment imposition: 13-15 May 2009; 5 May 2010

Treatment ID and description	Alleyway management (each year)	In-row management (each year)
Unplanted	Not seeded to cover crop in fall. Sprayed with herbicide once in winter to control weeds. Rototilled twice in summer to control weeds.	Sprayed once with glyphosate in winter concurrent with alleyway spray. Glyphosate used to control weeds in summer.
Remove	Planted to cover crop in fall. Mowed in spring and residue removed from the alleyway. Rototilled twice in summer to control weeds.	Glyphosate used to control weeds in summer.
Incorporate	Planted to cover crop in fall. Mowed in spring and residue left in alleyway to be incorporated. Rototilled twice in summer to control weeds.	Glyphosate used to control weeds in summer.
Mulch1	Planted to cover crop in fall. Mowed in spring and residue transferred into vine row as a mulch. Rototilled twice in summer to control weeds.	Mowed alleyway residue transferred in-row as a mulch at 5 kg m-2 fresh weight in 2009 and 2.5 kg m-2 fresh weight in 2010. Glyphosate used to control weeds in summer.
Mulch3	Planted to cover crop in fall. Mowed in spring and residue transferred into vine row as a mulch. Rototilled twice in summer to control weeds.	Mowed alleyway residue transferred in-row as a mulch at 15 kg m-2 fresh weight in 2009 and 7.5 kg m-2 fresh weight in 2010. Glyphosate used to control weeds in summer.

[z]Dates of treatment imposition were determined by phenology of *T. incarnatum* (90% flowering) and *V. vinifera* L. 'Chardonnay' grapevines (EL 11-15, 1-5 leaves unfolded)

Table 2.2. Weather parameters and phenology of young vines at a research site near Independence, OR.

	Mean monthly temperature (°C)		GDD[z] (>10 °C)		ET_0 (mm)[y]		Accumulated Precipitation (mm)		Phenology dates	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
April	9.2	9.0	28	68	84	87	31	102	Budbreak 20 Apr.	Budbreak 2 Apr.
May	13.1	11.4	158	103	152	114	89	78		
June	16.4	14.6	200	157	162	140	15	66	Bloom 15 June	
July	20.3	18.5	317	270	227	226	19	2		Bloom 7 July
August	18.6	18.2	268	259	173	183	6	13	Véraison 24 Aug.	
September	16.7	16.2	221	215	128	94	28	64		Véraison 10 Sept.
October	10.9	11.5	99	113	52	53	73	119		
November	7.8	7.3	22	35	20	19	142	144	Leaf fall 20 Nov.	Leaf fall 16 Nov.
Cumulative[x]			1301	1221	943	920	388	499		

[z]Growing Degree Days (base 10 °C) accumulated each month

[y]Evapotranspiration (Kimberly-Penman) accumulated each month, collected from a Corvallis, OR weather station (http://www.usbr.gov/pn/agrimet)

[x]Cumulative GDD, ET, precipitation from Budbreak to Leaf fall for each year

Table 2.3. ANOVA F-values (and associated *p*- values) at α=0.05 for experimentwise variation between means of weed coverage and density, in-row and alleyway, at each sampling date.

Sampling location	In-row					Alleyway				
Sampling date	5/26/2009	7/13/2009	8/31/2009	Across 2009[z]	6/16/2010	6/30/2009	7/13/2009	8/31/2009	Across 2009	8/6/2010
Percent coverage	3.9 (0.016)	3.7 (0.021)	5.1 (0.006)	19.6 (<0.001)	19.4 (<0.001)	4.8 (0.007)	5.1 (0.005)	2.1 (0.123)	6.6 (<0.001)	4.3 (0.011)
Broadleaf density	6.8 (0.001)	7.0 (0.001)	5.5 (0.004)	12.7 (<0.001)	11.1 (<0.001)	4.0 (0.015)	--[y]	3.4 (0.029)	9.5 (<0.001)	5.1 (0.006)
Grass density	13.3 (<0.001)	1.1 (0.393)	1.0 (0.431)	13.5 (<0.001)	11.8 (<0.001)	2.5 (0.074)	--	0.9 (0.488)	4.3 (0.004)	2.1 (0.124)

[z]Values represent analysis across three sampling dates in 2009 (two sampling dates for alleyway broadleaf- and grass density).

[y]Broadleaf and grass densities were not assessed on 7/13/2009.

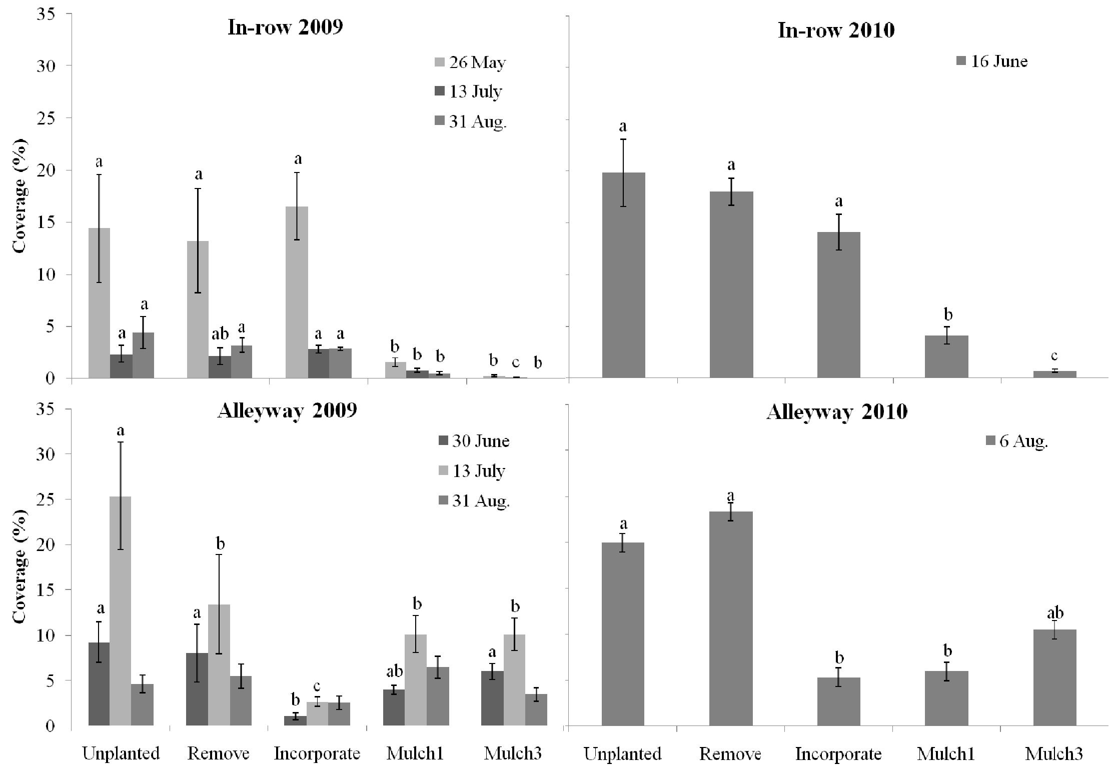

Figure 2.1. Mean (±SE) weed percent coverage at three sampling dates in 2009 and one sampling date in 2010 with different vineyard floor and cover crop management treatments in the vine rows and alleyways of a young 'Chardonnay' vineyard. Unplanted, Remove, Incorporate, Mulch1, and Mulch3 represent vineyard floor management treatments (Table 2.1). Percent weed coverage of vineyard floors is expressed as Coverage (%). Means followed by the same letter within a given sampling date do not differ by Fisher's protected least significant difference test at α=0.05.

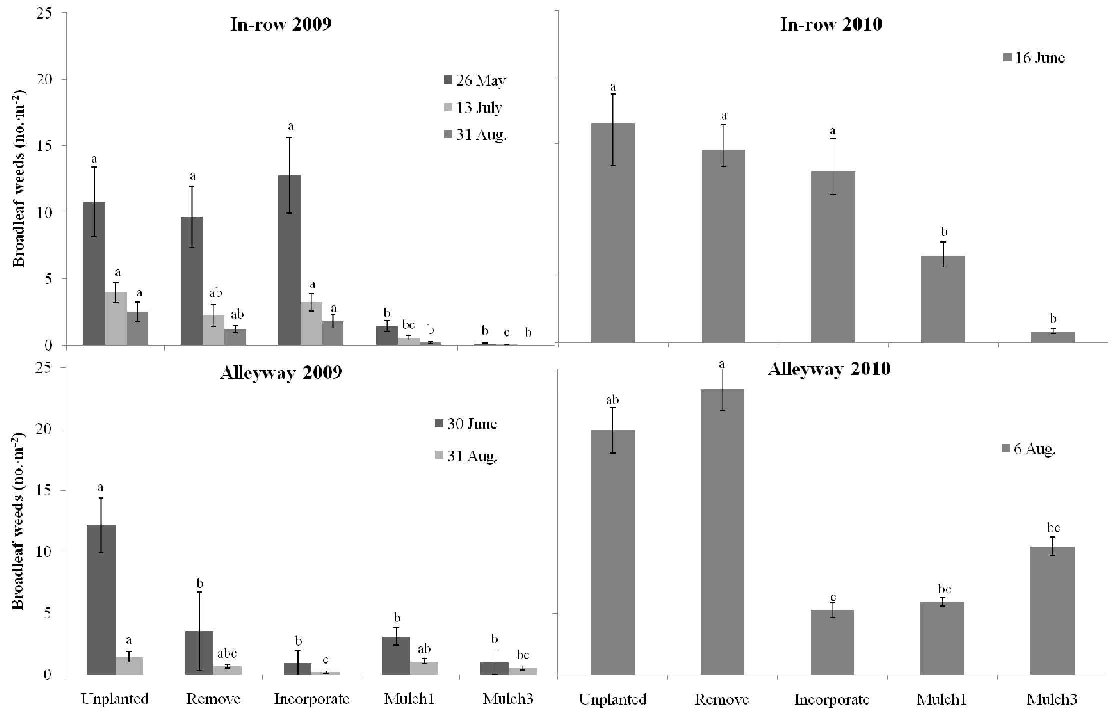

Figure 2.2. Mean (±SE) broadleaf weed density at multiple sampling dates in 2009 and one sampling date in 2010 with different vineyard floor and cover crop management treatments in the vine rows and alleyways of a young 'Chardonnay' vineyard. Unplanted, Remove, Incorporate, Mulch1, and Mulch3 represent vineyard floor management treatments (Table 2.1). Means followed by the same letter within a given sampling date do not differ by Fisher's protected least significant difference test at α=0.05. The broadleaf weeds were measured as no.$\cdot$m^{-2}, which is defined as 1 weeds$\cdot$m^{-2} =0.0929 weed/ft^2.

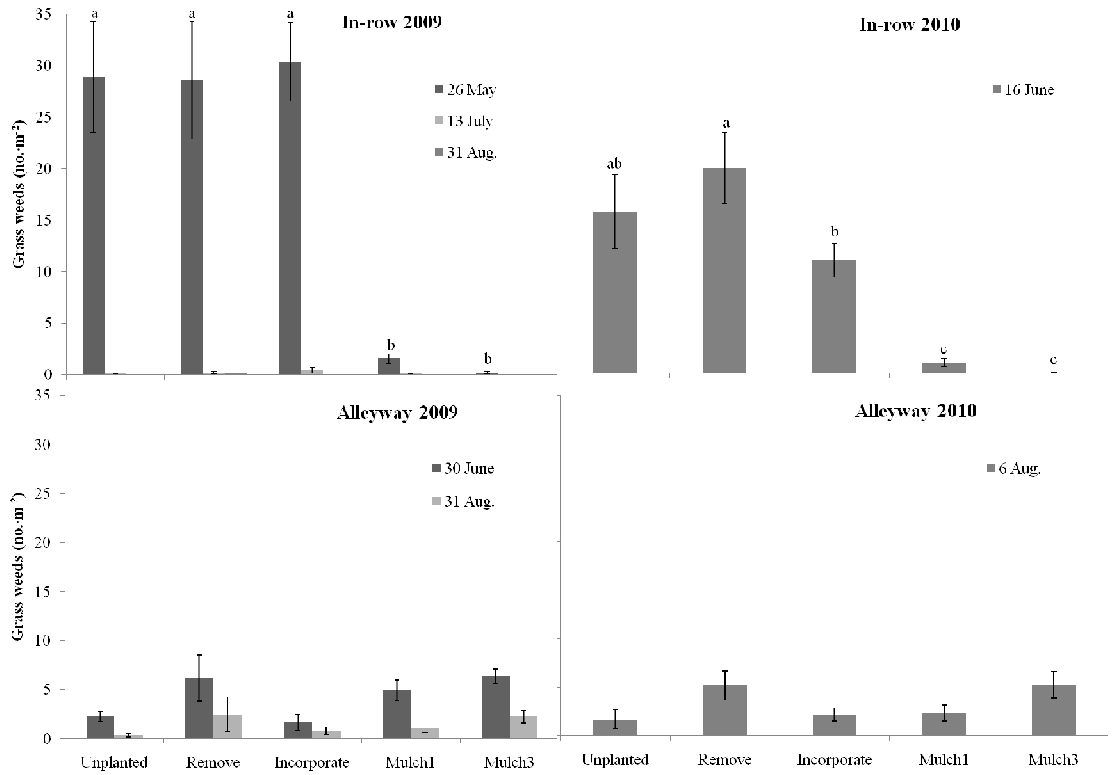

Figure 2.3. Mean (±SE) grass weed density at multiple sampling dates in 2009 and one sampling date in 2010 with different vineyard floor and cover crop management treatments in the vine rows and alleyways of a young 'Chardonnay' vineyard. Unplanted, Remove, Incorporate, Mulch1, and Mulch3 represent vineyard floor management treatments (Table 2.1). Means followed by the same letter within a given sampling date do not differ by Fisher's protected least significant difference test at α=0.05. The grass weeds were measured as no.·m^{-2}, which is defined as 1 weeds·m^{-2} =0.0929 weed/ft^2.

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CHAPTER 3

Management of cover crops to enhance establishment of young *Vitis vinifera* vines in western Oregon

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Abstract

The impact of five vineyard floor practices using cover crops and placement of cover crop residues on grapevine performance was evaluated in a new vineyard in western Oregon. Treatments used included a clean cultivated control (no cover crop) and four treatments with the same winter annual cover crop managed in the following manner; two different levels of mowed cover crop residue transferred in-row as a mulch, incorporation of residue into alleyways, and removal of residue. Young vine canopy growth, root density, and nutritional status were assessed over two growing seasons, as was soil moisture from 0-76cm depth. Volumetric soil moisture averaged across 15-30 cm depth was greater in mulched than non-mulched treatments each year, while the higher-level mulch treatment had greater soil moisture than the lower-level mulch in 2010. In-row soil compaction was lower in mulched treatments than non-mulched treatments each year. Mulched treatments apparently altered vine rooting patterns and had greater root densities in vine rows than in alleyways. SPAD readings (indicating leaf chlorophyll content) were higher in mulched treatments than non-mulched treatments. Vine leaf size was greater in the higher-level mulch treatment in 2010. Mulched residue treatments had greater shoot lengths than non-mulched treatments in 2010. Mulched treatments had higher pruning weights by 43% in 2010 than a non-mulched treatment. Vines in the higher-level of mulch treatment in 2010 had more clusters per shoot than vines in all other treatments. Leaf and wood

biomass in one-year old destructively harvested grapevines were greater in mulched treatments than non-mulched treatments each year. These results indicate that cover crops may be effectively managed to conserve soil moisture and increase growth of one- to three-year old *V. vinifera* 'Chardonnay' vines in a non-irrigated vineyard in a Mediterranean climate.

Introduction

Cover crops have been used to fulfill an array of management goals in vineyards, though most of the research on cover crop use has been conducted in mature vineyards of at least five years of age. Some cover crops are thought to compete too aggressively with young vines, thus newly planted vineyards are often kept vegetation-free by cultivation or herbicide application for the first three years after establishment. Cultivation can increase soil erosion, run-off, dust, and decrease water infiltration into the soil due to compaction (Paningbatan et al. 1995). Herbicides can damage young grapevines if not applied correctly and may be prohibited for some growers due to restrictions within farming certifications.

Optimal establishment of young vines contributes to a more productive vineyard in later years and may allow earlier vine training, production and economic return on investment. During the establishment of a vineyard, adequate soil moisture and nutrients must be provided to support healthy root and canopy development. An important goal for vineyard managers in the first three years after planting is to develop a healthy root system for adequate nutrition and water uptake. Over time, vine roots may avoid growing into cover-cropped alleyways which can result in deeper rooting and greater in-row root densities (Morlat and Jacquet, 2003). Water and nutrient competition between vines and cover crops is dependent on soil moisture (Morlat and Jacquet, 2003; Tesic et al. 2007). Competition between cover crops and vines for water may be reduced by killing the cover crop with herbicide or mowing at strategic times (Monteiro and Lopes, 2007).

In western Oregon, a cover may be maintained during the dormant period to prevent erosion without competing with vines. In two Willamette Valley (Oregon) vineyards, Sweet and Schreiner (2010) observed no measurable competition between mature vines and six different alleyway cover crop treatments that were mowed in spring and summer. Strategically timed mowing or incorporation of cover crops when vines break bud can reduce early season competition (Monteiro and Lopes, 2007). However, maintaining a cover crop through the growing season has been shown to reduce shoot growth, Nitrogen (N) status, and fruit quality of mature winegrape vines as compared to vines in alleyways where the cover crop was killed early season (Rodriguez-Lovelle, 2000).

Another cover crop management technique known as “mow and throw” is the transfer of mown cover crop biomass into the vine row through side-discharge mowers. This technique has been shown to suppress weeds, increase winegrape yield, and generate higher capital returns when compared to herbicide applications or cultivation in California vineyards (Steinmaus et al. 2008). Using cover crop residues as a mulch may conserve soil moisture (Elmore et al. 1998) and this method can conserve more moisture in summer than what cover crops deplete while growing in spring (Clark et al. 1997).

Much of the research on mulches in vineyards has focused on synthetic materials such as colored plastic (Hegazi 2000; Hostetler et al. 2007; Reynolds et al. 2008). While these materials differ substantially from organic mulches in terms of decomposition, reflection, and heat absorption, some of the fundamental effects of conserving soil water may be similar with organic mulches. Organic mulches appear to increase grape root branching, length, and overall biomass by conserving soil moisture and buffering temperature fluctuations near the soil surface (Eastham et al. 1996; Van Huysteen, 1988). Pinamonti (1998) demonstrated that mulch municipal waste compost conserved soil moisture and improved nutrient uptake of grapevines. Though irrigation can meet vine water needs during establishment, some vineyard sites may have limited or no access to irrigation water.

The timing of cover crop residue management (i.e. mowing or incorporation) influences the dynamics of residue breakdown, competition with vines, and weed suppression. An adaptive nitrogen (N) management strategy seeks to synchronize mineralization of cover crop-derived N with peak vine N requirements which occurs from budbreak to bloom (Schreiner et al. 2006). In order to maximize N uptake, residues should be placed near the highest root densities, such as in the vine row (Cheng et al. 2008).

There is potential to enhance young vine establishment through management of cover crop residues, which can provide weed control, conservation of soil moisture and improvement of soil structure and nutrition to young vines. The purpose of this study was to determine how various vineyard floor management regimes impacted soil moisture, young vine canopy growth, nutritional status, and root system development. It was expected that using the cover crop residue as a mulch in vine rows would conserve soil moisture and increase nutrient availability to vines resulting in greater vine growth. Further, it was hypothesized that a winter annual cover crop grown in vineyard alleyways could be managed to minimize competition with young vines.

Materials and Methods

Site description

The study was conducted at a 4-hectare commercial vineyard (lat. 44.77'N, long. -123.18'W, elevation 90 m) 10 km south of Independence, OR. The vineyard was planted in July 2008 with *Vitis vinifera* 'Chardonnay' grapevines (Dijon clone 96 on rootstock 3309-C). Vines were spaced 2.1 m between-row and 1.5 m in-row and planted in north-south oriented rows. The soil in this vineyard is an Amity series (fine-silty, mixed, superactive, mesic Argiaquic Xeric Argialboll) silt loam with a 0% to 3% slope across the experimental site. Soil bulk density in the experimental site was 1.37 $g \cdot cm^{-3}$ at 10 cm, 1.38 $g \cdot cm^{-3}$ at 20 cm, 1.45 $g \cdot cm^{-3}$ at 40 cm, and 1.48 $g \cdot cm^{-3}$ at 60 cm of soil depth. The site was not irrigated or fertilized for the duration of the study.

Experimental design and cover crop management

There were five treatments in the study, including four that used cover crop residues and one that was left unplanted (Table 3-1). A winter annual cover crop mix of cereal rye (*Secale cereale*) and crimson clover (*Trifolium incarnatum* L. 'Dixie') was planted on 16 Sept. 2008. The cover crop was seeded at a rate of 34 $kg \cdot ha^{-1}$ cereal rye and 22 $kg \cdot ha^{-1}$ crimson clover. The crimson clover seed had been pre-inoculated with rhizobium (*Rhizobium trifolii)* to ensure nodulation. A double-roller drop-seeder (Brillion® Sure-Stand™ SSP-5; Brillion Farm Equipment, Brillion, WI) was used to plant the cover crop seed into a 1.2-m-wide prepared seedbed. For year two of the trial, a fall planting of the same cover crop blend was seeded on 10 Sept. 2009 at a rate of 46 $kg \cdot ha^{-1}$ cereal rye, and 26 $kg \cdot ha^{-1}$ crimson clover. The higher rate of seeding in Sept. 2009 was due to differences in performance by the drop-seeder. Plots were mown when crimson clover reached 90% flowering in May each year, when it was at the highest potential N contribution based on total biomass and percent N (Ranells and Wagger, 1992). The cover crop plots were mown using a modified flail mower with a catchment bin to collect mown residue (Thatch-n-Catch™; KR Mfg, Salem, OR). After treatments were imposed, alleyways in all experimental plots were disked within one week to incorporate remaining vegetation and terminate cover crop growth. Alleyways were disked again in summer, as needed, to control weeds each year. The unplanted treatment plots were not seeded to cover crop and were kept at minimal vegetative coverage using glyphosate applied at a rate of 1.1 kg/ha (acid equivalent) to vine rows and alleyways in Jan. each year.

One week prior to cover crop mowing each year, weeds in the vine rows were killed using glyphosate (Bronco®; Monsanto Company, St. Louis, MO) applied at a concentration of 1.1 kg/ha (acid equivalent) with a tractor-mounted sprayer. Glyphosate was applied in-row as needed to control summer weeds. Alleyway weeds were controlled by disking as needed during summer. Weed coverage and densities were assessed as part of a concurrent study (Chapter 2).

In 2009, mowed alleyway residue was applied in-row as mulch in the mulch1 treatment in the quantity of 5 $kg \cdot m^{-2}$ fresh weight to an approximate thickness of 10 cm and width of 1 m. The mulch3 treatment received residue density at three-fold that of mulch1 with 15 $kg \cdot m^{-2}$ fresh weight at an approximate thickness of 30 cm and width of 1 m. Residue was applied by hand to ensure even distribution across a treatment replicate. Mowed residue was managed in the same manner in 2010. However, residue applied in-row and incorporated between-row in 2010 was lower due to reduced growth of the cover crop. The mulch1 and mulch3 treatments received 2.5 $kg \cdot m^{-2}$ and 7.5 $kg \cdot m^{-2}$ fresh weight residue in-row, respectively in 2010.

Alleyway cover crop biomass was sampled in May of each year, 1 d prior to mowing plots. Biomass was sampled by randomly placing a 0.25 m^2 meter quadrat into the alleyway and harvesting all aboveground biomass 10 cm above the soil surface to simulate mowing. Sampling was performed twice per plot, once on each side of the experimental vine row. Samples of biomass were separated by hand into three classifications: cereal rye, crimson clover, or weeds. Fresh weights were taken separately for each classification. To determine levels of mulch used in treatments mulch1 and mulch3, mean total biomass of cover-cropped alleyways (1.5 m x 30.5 m) was estimated using fresh weights of the corresponding 0.25 m^2 quadrat sample.

Total mowed residues were measured at the time of mowing to assess total growth, N-status, and biomass of residue removed from the alleyway from each plot. The cover crop was mowed to a height of 10 cm above the soil surface. Fresh weights of mowed residue were measured using 20 L plastic pails and a hanging scale (Pelouze, Huntersville, NC). Ten 100 mL aliquots were taken from the total mowed residue, combined, weighed immediately, and oven -dried at 70 ºC for 72 h. The dried residue was then cut and ground using a Wiley® Mill (Thomas Scientific, Swedesboro, NJ) with a 400-µm screen for total C and N analyses.

The five treatments were replicated five times across the site in a completely randomized design. Each plot included 20 vines and measured 3.4 m wide. Each plot included the 0.9-m-wide grape row and the 1.2-m-wide alleyways on either side of the vine row. A buffer vine row separated each replicate plot from other plots. During Winter 2008-09 preceding year one of the study, vines were pruned to two 2-bud spurs. Shoots were summer-pruned during the 2009 growing season. During Winter 2009-10), vines were pruned to a single trunk and trained to the fruiting wire.

Vine growth assessment

Vine phenology was recorded weekly based on the EL-BBCH scale (Lorenz et al. 1994) (Table 3.2). All inflorescences were removed at bloom during 2009. Shoot length and leaf area were measured to assess vine growth. In 2009, shoot lengths were measured by randomly selecting 10 vines per treatment replicate and measuring lengths of the two most-apical shoots. In 2010, lengths of the two most-apical shoots were measured on 18 vines per treatment replicate. Different shoots were measured at each time point as vines were being trained during the study. Leaf area was measured at bloom and véraison each year using a non-destructive method where leaves were assigned to size classes from 1-5. To determine the five leaf area size classes, five leaves of varying sizes were collected from buffer vines at the trial site and measured using a leaf area meter (LI-COR 3100; LI-COR Biosciences, Lincoln, NE). Outlines of each leaf were drawn on a grid to develop a key for the in-field assessment, and a number assigned to each leaf size 1-5 was linked to the actual leaf area measured. This grid was used in the field to measure each leaf on shoots that were randomly selected on each of three vines per treatment replicate. Shoots per vine were recorded and used to estimate total vine leaf area.

To determine treatment impacts on vine size, trunk diameters and pruning weights were collected during dormancy following each experimental year. Trunk diameters were measured using a digital caliper (EC6, Kurt, Minneapolis, MN). Ten vines per treatment replicate were measured by taking one north-south measurement and one east-west measurement at 10 cm above the graft union. The same ten vines were assessed on 24 Nov. 2009 and again on 16 Nov. 2010 (Table 3.4). Dormant pruning weights were collected at the end of 2009 and 2010 growing seasons by weighing all one-year-old wood from all vines within a treatment replicate.

Evaluation of Destructively Harvested Grapevines

To determine treatment effects on above-ground vine growth, grapevines were interplanted between commercial vines in 2009 and 2010 for destructive harvest. In May 2009, four self-rooted 'Chardonnay' vines were planted between existing commercial vines in each treatment replicate. During May 2010, vines were planted in areas where commercial vines had died and been removed to avoid competition with the growing vines. The interplanted vines were destructively harvested in mid-October prior to leaf senescence each year. Leaf and wood tissue were collected separately, rinsed of soil and debris with water, dried at 70 ºC for 72 h in a forced-air dryer until a constant dry weight was obtained, and dry weights of leaf and wood tissue were measured.

Root sampling

Grapevine roots were sampled from vine rows and alleyways of unplanted, incorporate, mulch1, and mulch3 at véraison 2010. Samples were collected from separate depth intervals of 0-20 cm, 20-40 cm, and 40-60 cm and were comprised of five soil cores (5.7 cm diameter) from each depth interval in each replicate plot. Root densities were not taken below 60 cm due to sampling limitations and due to the findings of Schreiner (2005) that 90% of fine roots and 66% of woody roots occurred in the top 50 cm of soil as compared to 50-100 cm depth in herbicide-treated vine rows. Samples were stored at 4 °C and processed within two weeks. Woody and fine roots were collected from the entire sample using the wet-sieving method described by Sweet and Schreiner (2010). Woody roots were handpicked from samples and the soil was then stirred with water to suspend root material and strained through a 1-mm sieve to collect the remaining woody and fine roots. A stereomicroscope was used to identify fine and woody roots; each group was weighed separately to obtain fresh weights. Dry soil weights were determined by measuring gravimetric water content of each sample.

Vine water and nutrient status

Midday stem water potential (ψ_{stem}) was monitored every two weeks from mid-June to Sept. according to the methods of Williams and Araujo (2002). Aluminum foil-covered bags were secured over leaves of three vines per treatment replicate and removed after 2 hr and measured using a pressure chamber (PMS Instruments, Corvallis, OR).

Leaf chlorophyll concentrations were estimated using a SPAD meter (SPAD 502; Minolta Corp., Ramsey, NJ) as SPAD measurements have been correlated with leaf N concentrations (Chapman and Baretto, 1997). SPAD measurements were taken on five vines per treatment replicate at bloom and véraison each year by selecting a single leaf from the fifth to seventh most recently expanded leaves of a shoot. Tissue samples were collected at bloom and véraison 2010 to assess macro- and micronutrient concentrations in vine leaves and petioles. At bloom in 2010, 20 leaves located opposite a basal cluster were collected. At véraison 2010, 20 leaves located opposite a basal cluster and 20 leaves collected from within the fifth to seventh most recently expanded leaves of a shoot. Leaf blades and petioles were rinsed in distilled water, separated, dried at 65 °C for 48 h, and tissue was ground in a Wiley mill to pass through a 425-µm screen. Tissue sampled from basal nodes and apical nodes was analyzed separately. Total tissue N and C was determined by combustion analysis using a CN analyzer (TruSpec; LECO Corp., St. Joseph, MI). Concentrations of P, K, S, Ca, Mg, Mn, Cu, B, Zn, and Fe were measured by inductively coupled plasma-optical emission spectrometry (Optima 3000DV; PerkinElmer, Wellesley, MA) after nitric acid digestion (Zarcinas et al. 1987).

Soil moisture and compaction assessment

Volumetric soil moisture (VSM) was measured bimonthly from May to Sept. each year with a capacitance soil moisture probe (AquaPro, Ducor, CA). Three polycarbonate access tubes were installed per replicate plot to a depth of 1 m in May 2009. Measurements of soil moisture were taken at depths of 15, 23, 30, 46, 61, and 76 cm. Gravimetric Soil Moisture (GSM) was measured in-row to assess whether cover crop had an effect on early season soil moisture. Measurements were taken 1 d prior to mowing the cover crop treatments each season. Three soil cores per plot were sampled at a distance of 30 cm from vine trunks using an auger to a depth of 30 cm, combined, and oven-dried at 105 ºC until constant weight was attained. Soil compaction was assessed in-row with a hydraulic penetrometer (Hypen1; Pike Agri-Lab Supplies, Livermore Falls, ME). The probe was inserted to soil depths of 7.5, 12.5, 23, and 30.5 cm and resistance measured as kPa (kilopascals). Three penetrometer insertions were made per replicate plot on 16 June and 13 July 2009 and on 29 July 2010. Climatic data was collected using an on-site weather station (Vantage Pro2™, Davis Instruments, Hayward, CA) except for evapotranspiration (ET_0) data which was collected from a regional weather station for Corvallis, OR (U.S. Department of the Interior Bureau of Reclamation).

Statistical analysis

Data analysis was performed using SAS 9.2 (SAS Institute, Cary NC) General Linear Models (GLM) and Mixed (MIXED) procedures where appropriate. Sub-sample data taken within treatment replicates were averaged to generate a summary measure for each replicate at each sampling date. Levene's test was used to check for homogeneity of variance in the data, and residuals were examined for skew or lack of normality. Data violating assumptions of Analysis of Variance (ANOVA) were transformed prior to analysis using the log, square root, or arcsine transformations with addition of a constant to meet the assumptions, and the data were re-checked to ensure assumptions were met post-transformation. ANOVA type III sums of squares were used to assess effects of treatment, sampling date, and interactions between treatment and sampling date. Years were analyzed independently because cumulative effects of treatments from 2009-10 could have violated the assumption of independence between years. Tukey's Honestly Significant Difference (HSD) test was used to compare treatments (n=5) at 95% confidence. Effects were considered significant at 95% confidence ($P<0.05$).

Results

Environment and vine phenology

Vineyard site weather data for 2009 and 2010 growing seasons were recorded from bud-break to leaf abscission (Table 3.2). The 2009 season was characterized as a relatively cool spring and moderate summer. The 2010 growing season was one of the coolest for the region in 20 years (U.S. Department of the Interior Bureau of Reclamation). A relatively early bud break in 2010 was attributed to higher-than-average temperatures for the region in March (U.S. Department of the Interior Bureau of Reclamation). Low heat accumulation from May to July 2010 resulted in relatively late bloom and véraison.

Cover crop biomass

Alleyway biomass collected after mowing averaged 3.15 $kg \cdot m^{-2}$ fresh weight in 2009 and 1.88 $kg \cdot m^{-2}$ fresh weight in 2010. The lower total biomass produced in 2010 was due to poor growth of cereal rye as compared to 2009 (Appendix 1). There were no differences between treatments in cover crop fresh weight, moisture content, percent N, percent C, or plant composition (cereal rye, crimson clover and weeds) of sampled biomass in either year (Appendix 1). The composition of total cover crop dry matter averaged 63.1% cereal rye, 20.8% crimson clover, and 5.3% weeds in 2009 and 15.7% cereal rye, 77.9% crimson clover, and 6.4% weeds in 2010. Estimated crimson clover fresh weight$\cdot m^{-2}$ was 70% higher in 2010 than in 2009, whereas cereal rye was 89% lower in 2010 than in 2009. This suggests that cereal rye did not have as favorable growing conditions during 2010 as compared to 2009. Weed composition of mowed residues in both years consisted of predominantly annual ryegrass (*Lolium multiflorum*).

Soil moisture

In-row GSM measured 1 d prior to cover crop mowing in May did not differ by treatment in either year. Gravimetric soil moisture averaged 24.9% on 12 May 2009 and 19.7% on 14 July 2009. Gravimetric soil moisture averaged 27.3% on 4 May 2010 and 13.3% on 29 July 2010 (Table 3.3). Similarly, in-row VSM from 15 to 30 cm depleted faster across 2010 than 2009 (Fig. 3.1). VSM declined steadily across 2009 from 80% on 10 June to 71% on 2 Sept. (Fig. 3.1). In 2010, VSM declined from 85% on 10 June to 61% on 14 Sept. (Fig. 3.1). An unusual rain event on 8 Aug. 2010 recharged soil moisture which remained fairly constant for the remainder of Aug.-Sept. Mulched treatments had greater in-row GSM than all other treatments in July 2009 (Table 3.3). A similar trend was observed in July 2010, though gravimetric soil moisture was higher with greater mulch rates (Table 3.3). In-row VSM was greater in mulch3 than all other treatments at most sampling dates in 2009 (Fig. 3.1). However, in 2010, both mulch1 and mulch3 had greater VSM than non-mulched treatments at most sampling dates (Fig. 3.1).

Soil compaction

In-row soil compaction measured in 2009 and 2010 was greater in non-mulched treatments than mulched treatments at each sampling depth (Appendix 2). Soil compaction values across 0 to 30 cm were lower in 2009 than 2010 as they were taken earlier in the season when there was higher soil moisture (Table 3.3). Soil compaction was correlated with gravimetric soil moisture in 2009 (r^2=0.797, *P*<0.001) and in 2010 (r^2=0.631, *P*<0.001) which is consistent with Smith et al. (1997).

Root density of grapevines

Root density across 0-60 cm depth in vine rows was 88% greater than alleyway root density across all treatments. Sampling location and treatment interactions affected total root density (Table 3.5). Mulch1 and mulch3 had greater root densities in-row than in alleyways, while unplanted and remove had similar root densities in-row and in alleyways (Fig. 3.2). Location and depth interactions also affected total root density (Table 3.5). In-row root densities were greater than alleyway root densities at 0-20 cm and 20-40 cm depth intervals.

Vine water status

No differences were observed between treatments in midday Ψ_{stem} at any sampling dates in 2009 or 2010, though sampling date was significant each year (*P*<0.001). During 2009, Ψ_{stem} ranged from -0.59 to -0.32 MPa across all sampling dates. During 2010, Ψ_{stem} ranged from -1.03 to -0.39 MPa across all sampling dates. The lowest Ψ_{stem} was recorded at bloom 2010, as maximum daily temperature reached 35 °C. Rain events on 12 July 2009 and 8 Aug. 2010 were suspected to increase Ψ_{stem} at subsequent sampling dates.

Vine Nutrition

Leaf chlorophyll concentration, as estimated by SPAD, differed by treatment in both years. Vine leaf SPAD readings in 2009 were greater in mulch3 than in unplanted (Table 3.4). When analyzed across all sampling dates in 2009, SPAD was different by treatment; however, there were no differences found at individual sampling dates. Vine leaf SPAD readings analyzed across 2010 were greater in mulched treatments than non-mulched treatments (Table 3.4). At bloom and véraison 2010, leaf SPAD readings were greater in mulch3 than non-mulched treatments (Table 3.6). During 2010, SPAD readings across-season were lower than 2009 (Table 3.4) due to an extra sampling date in July 2009 which increased the mean.

Differences in petiole nutrient concentrations were inconsistent between bloom and véraison in 2010 (Table 3.6). Only Mn differed between treatments at both bloom and véraison, though no obvious trends were observed (Table 3.6). Similarly, treatment differences observed in leaf blade or petiole tissue taken at véraison were inconsistent. The only consistent trend observed between petiole and leaf tissues at véraison was in Mg and Mn, in which the remove treatment had the highest concentrations while unplanted and mulch3 had the lowest concentrations (Table 3.6).

Vine growth

Shoot lengths did not differ between treatments when compared at individual dates or across-season in 2009 (Table 3.4). Shoot lengths were not measured after 15

July 2009 as vines were summer-pruned on 15 July 2009 according to standard management practices. There were no differences in trunk diameters after vines entered dormancy in 2009 (Table 3.4). Vine leaf area was not different in 2009, but a trend of leaf areas was observed across-season where mulch3 had the greatest leaf area (0.87 m^2) and unplanted had the smallest leaf area (0.61 m^2). Vine leaf area differed by treatment at véraison 2009 (P=0.0368) with mulched treatments having greater leaf areas than non-mulched treatments.

Although 2009 did not yield differences in vine growth measures by treatment, there were differences observed in 2010. During 2010, mulch1 and mulch3 (327 and 324 $g \cdot vine^{-1}$, respectively) had 43% higher pruning weights than remove (228 $g \cdot vine^{-1}$) (Table 3.4). Shoot lengths were greater in mulched treatments than non-mulched treatments (Table 3.4). Specifically, at individual sampling dates in 2010, shoot lengths were greater in mulched treatments than non-mulched treatments at pre-bloom (3 June, P=0.002) and bloom (7 July, P=0.002). However, there were no differences in shoot lengths between treatments at 1 wk after mowing (13 May) or at véraison (10 Sept.). Trunk diameters were not different at the end of the 2010 season nor was the rate of change in diameters from 2009-10 (Table 3.4). Leaf area per vine did not differ between treatments in either year, though leaf size was greater in mulch3 (47 cm^2) at véraison 2010 than the incorporate and remove treatments (each 40 cm^2) (P=0.018). In addition to differences in shoot length and leaf size, there were observable differences with potential yield. Clusters per shoot were 58-94% greater in mulch3 than all other treatments in 2010 (Table 3.4).

Destructively harvested one-year old vines

In 2009, interplanted grapevines had greater total dry weights in mulch3 by 113% to 263% compared to all other treatments (Table 3.4). Total growth was greater in both the leaf and wood (shoot) biomass of mulch3. Vines planted and harvested in 2010 had lower total dry weights than 2009. Mulch1 and mulch3 had 59% to197% greater total dry weights than incorporate, remove, and unplanted treatments in 2010. Leaf and shoot biomass in 2010 were each greater in mulch1 and mulch3 than incorporate, remove, and unplanted treatments.

Discussion

The primary objectives of this study were to assess competition between young vines and cover crops as well as effects of in-row residue mulch on vine growth and nutrient status. Total cover crop biomass and the species composition varied by year which was potentially due to differences in climatic conditions of the season as well as slight differences in seeding rates. The differences in cover crop growth resulted in a 50% reduction of residue mulch biomass applied in 2010 compared to 2009. Differences by treatment in soil moisture and vine growth were observed in both years of the study despite the lower mulch density in 2010.

The winter annual cover crop did not compete with the vines for in-row soil moisture in either year of the study, as in-row gravimetric soil moisture measured in May did not differ between treatments. In-row VSM depleted at a faster rate in 2010 than 2009 when comparing similar vine phenology stages (Fig. 3.1) despite lower ET_0 and higher precipitation in 2010 (Table 3.1). The faster rate of depletion was likely due to a larger vine canopy in 2010 than 2009 (Table 3.4). Soil water loss in this vineyard may have occurred through transpiration of vines, transpiration of weeds, evaporation from the soil surface, and percolation. Soil water loss due to weeds was probably minimal as in-row weeds were controlled by herbicides and covered less than 5% of in-row surface area from bloom to véraison each year (Chapter 2). Water loss to percolation was highly unlikely during the growing season after June as precipitation was minimal. Therefore, differences in GSM and VSM between treatments (Fig. 3.1; Table 3.3) were primarily attributed to evaporative losses or vine transpiration, although these were not measured directly in this study.

Treatment differences in gravimetric and volumetric soil moisture from bloom to véraison each year indicated greater soil moisture in-row from 0 to 30 cm in mulched treatments as compared to non-mulched treatments. Mulched residue may have reduced evaporative losses due to sunlight interception (Hostetler et al. 2007) and reduction of soil temperatures (Pinamonti, 1998). Shading of the soil surface by vine and tree canopies is known to decrease evaporative losses compared to unshaded soil (Wallace et al. 1999; Williams and Ayars, 2005); therefore, it is reasonable to conclude that in-row soil evaporative losses were reduced by mulched treatments.

The lower in-row soil compaction observed in mulched treatments compared to non-mulched may have been attributed to greater soil moisture in the mulched treatments. Lower soil compaction has also been found with increasing organic matter inputs from mulches (Balesdent et al. 2000; Soane, 1990). In the present study, mulched residues likely increased in-row soil organic matter compared to non-mulched treatments based on the substantial amount of mowed residue applied in-row to mulch treatments (Table 3.1). Further, residue mulch may have reduced in-row soil surface compaction compared to non-mulched vine rows through protecting soil from the impact of precipitation. Increased soil compaction has been shown to reduce 'Chambourcin' grapevine shoot growth, leaf size, and cluster development (Ferree and Streeter, 2004).

In the present study, approximately two-thirds of vine roots were found under the vegetation-free strip in-row and one-third of roots under alleyways. The higher root density in vine rows than alleyways from 0-60 cm was expected due to vine location and age but may have been influenced by treatments and cultivation of alleyways (Van Huyssteen and Weber, 1980). Conversely, Sweet and Schreiner (2010) found no differences between in-row and alleyway fine root length at a young vineyard in which alleyways had been cultivated. Though cultivation may have influenced alleyway root development, there were no differences in alleyway root densities between the unplanted treatment and treatments with seeded cover crop (Fig. 3.2). This indicated that a winter annual cover crop did not reduce root growth of vines from 0-60 cm as compared to unplanted, herbicide-treated alleyways.

Grapevine roots generally proliferate in conditions of increased soil moisture and reduced compaction (Morlat and Jacquet, 1993; Ferree and Streeter, 2004). Mulched treatments likely created a more favorable environment for vine root development compared to non-mulched treatments based on increased soil moisture and reduced compaction. Total root density was higher in vine rows under mulch as compared to non-mulched rows. These results correspond with the findings of Van Huyssteen and Weber (1980) that vine root density in the top 20 cm of soil increased with straw mulch or herbicide application as compared to tillage or permanent grass cover. Based on greater total root densities in vine rows than alleyways in mulched treatments, it was expected that young vine water- and nutrient status may have been affected by treatment as well.

Midday Ψ_{stem} has been shown to be correlated with VSM in 'Chardonnay' (Williams and Araujo, 2002), but findings on this correlation are conflicting (Intrigliolo and Castel; 2008) and are likely highly dependent on site and climatic conditions. The lack of observed differences in Ψ_{stem} may have been due to low water demand of young vines in this cool climate and adequate soil moisture to support growth throughout 2009 and 2010. Midday stem water potential is correlated with vine transpiration (Chone et al., 2001), and despite some trends in larger vine canopy size in mulched treatments compared to non-mulched treatments each year, soil moisture was apparently adequate in all treatments to support transpiration of the young vines without reaching vine water stress. Therefore, it was suspected that increases in aboveground growth in mulched compared to non-mulched treatments may be attributed to differences in vine nutrient status rather than differences in vine water status.

Ultimately, differences in nutrient concentrations between treatments were relatively small and nutrient concentrations fell within sufficiency ranges for *V. vinifera* (Robinson, 2005). Differences in nutrient concentrations between treatments were not consistent between sampling tissue nor sampling date. Inconsistencies in tissue nutrient concentrations between bloom and véraison have been observed in *V. vinifera* previously (Sweet and Schreiner, 2010), as have inconsistencies in nutrient concentrations between leaf blade and petiole tissue (Romero et al. 2010). Interestingly, vines from treatments that exhibited greater shoot growth generally had lower nutrient concentrations (Tables 3.4, 3.6). At véraison 2010, mulch3 vines had larger leaf size compared to vines from the remove and incorporate treatments, yet concentrations of Mg and Mn were lower in mulch3 which suggests a dilution effect of leaf growth on nutrient concentrations. Therefore, it was suspected that leaf and petiole nutrient concentrations were influenced by differences between treatments in vine vegetative growth. Indeed, greater shoot lengths, leaf size and pruning weights were observed in mulch3

As expected, vine leaf SPAD values were different by sampling date as SPAD changed with leaf age and chlorophyll concentration. The data from 2009 and 2010 demonstrate that mulch3, and to a lesser degree mulch1, increased leaf chlorophyll concentrations at bloom and véraison as compared to non-mulched treatments. However, the differences in leaf SPAD values were not observed in leaf blade tissue sampled at bloom and véraison 2010 (Table 3.6). Leaf chlorophyll content in *V. vinifera* has been shown to increase with increased vine N uptake (Keller et al. 2001). Increased vine N uptake has also been shown to increase vine leaf area and lateral shoot length (Keller et al. 2001).

Given that mulch treatments in this study exhibited greater in-row soil moisture, increased in-row vine root density, and greater leaf chlorophyll concentrations, it was suspected that aboveground vegetative vine growth would be increased in mulched compared to non-mulched treatments. Increased vegetative vine growth from organic (Pool et al. 1990) and plastic (Van der Westhuizen, 1980) mulches has been observed in non-irrigated vineyards. Few differences in vegetative vine growth were observed between treatments in 2009. Summer-pruning in 2009 likely altered dormant pruning weights which may partially explain the lack of differences in pruning weights at the end of the growing season (Table 3.4). Leaf area sampling at véraison 2009 occurred 40 d after shoots had been summer-pruned; therefore, leaf area measurements may have been skewed by summer pruning.

Differences by treatment in vegetative vine growth were more apparent in 2010 than 2009. Greater vine pruning weights in mulched treatments than the remove treatment suggests greater shoot growth when mulch was applied in-row. Similarly, greater shoot lengths were observed in mulched compared to non-mulched treatments across the 2010 season. Differences in shoot lengths early in the 2010 season may be due to cumulative effects of residue mulch on vine nutrition from 2009 such as increased C reserves (Bennett et al. 2005), N reserves (Bell and Robson, 1999) or due to specific effects of the 2010 season. N reserves are critical to shoot growth and canopy development from budbreak through harvest; Schreiner et al. (2006) observed that approximately 50% of vine canopy N was supplied from reserves throughout the season. Increased growth of storage organs such as roots and trunks in 2009 would have allowed for increased reserves of C and N which could impact early season shoot and canopy development in 2010. While there were no differences in trunk diameters at the end of 2009, the present study did not measure roots at the end of the 2009 season.

Clusters per shoot has been found to be linearly related to shoot length (Miller et al. 1996). However, if clusters per shoot was attributed only to the observed increases in vine shoot length in mulched vs. non-mulched treatments, vines in mulch1 would be expected to have similar clusters per shoot as mulch3. Bell and Robson (1999) observed that supplemental N increased vine shoot, leaf, and cluster growth up to a critical level of N; when the critical level of N was exceeded, cluster growth was reduced. Greater clusters per shoot in mulch3 then follows in part with the observed greater SPAD values, shoot lengths and leaf size in mulch3 than non-mulched treatments.

Finally, the most apparent effects of vineyard floor management treatments on vine growth were observed in the above-ground biomass of the destructively harvested vines. There was greater biomass of interplanted vines in 2010 compared to 2009, potentially due to cool growing conditions and reduced soil moisture as compared to 2009. Reduced in-row mulch densities in 2010 than 2009 may account for the lower biomass of interplanted vines in 2010. The effects of residue mulch on interplanted vine growth were ascribed primarily to increased water availability to vines in mulched treatments. Pinamonti (1998) found that one-year-old *V. vinifera* vines had approximately 150% greater pruning weights when 5 mm of compost was added as an in-row mulch as compared to a bare soil, and he attributed the enhanced growth to improved soil water stability and thermal conditions under mulch treatments. As the newly planted vines in this study were never irrigated after being planted in May, soil moisture availability in the root zone was likely a critical factor for growth.

Conclusions

Results of this study indicate that winter annual cover crop residues can be used to manage water and vine growth without competition for water or nutrients in a young 'Chardonnay' vineyard in western Oregon. We did not observe any vine growth or soil moisture effects by incorporating cover crop residues in the vineyard alleyways. However, transferring cover crop residue into vine rows as a mulch increased vine growth in the first and second year of the study. Impacts were most noticeable in increased growth of destructively-harvested vines in each year of the study. Supplementing mulch with additional residue enhanced these effects on vine growth in some cases. However, increases in vine growth were not likely sufficient to justify the increased costs associated with supplementing residue. Increases in vine growth were largely attributed to soil moisture conservation by the mulched residue, and to a lesser extent increases in N-status of vines within mulched vine rows.

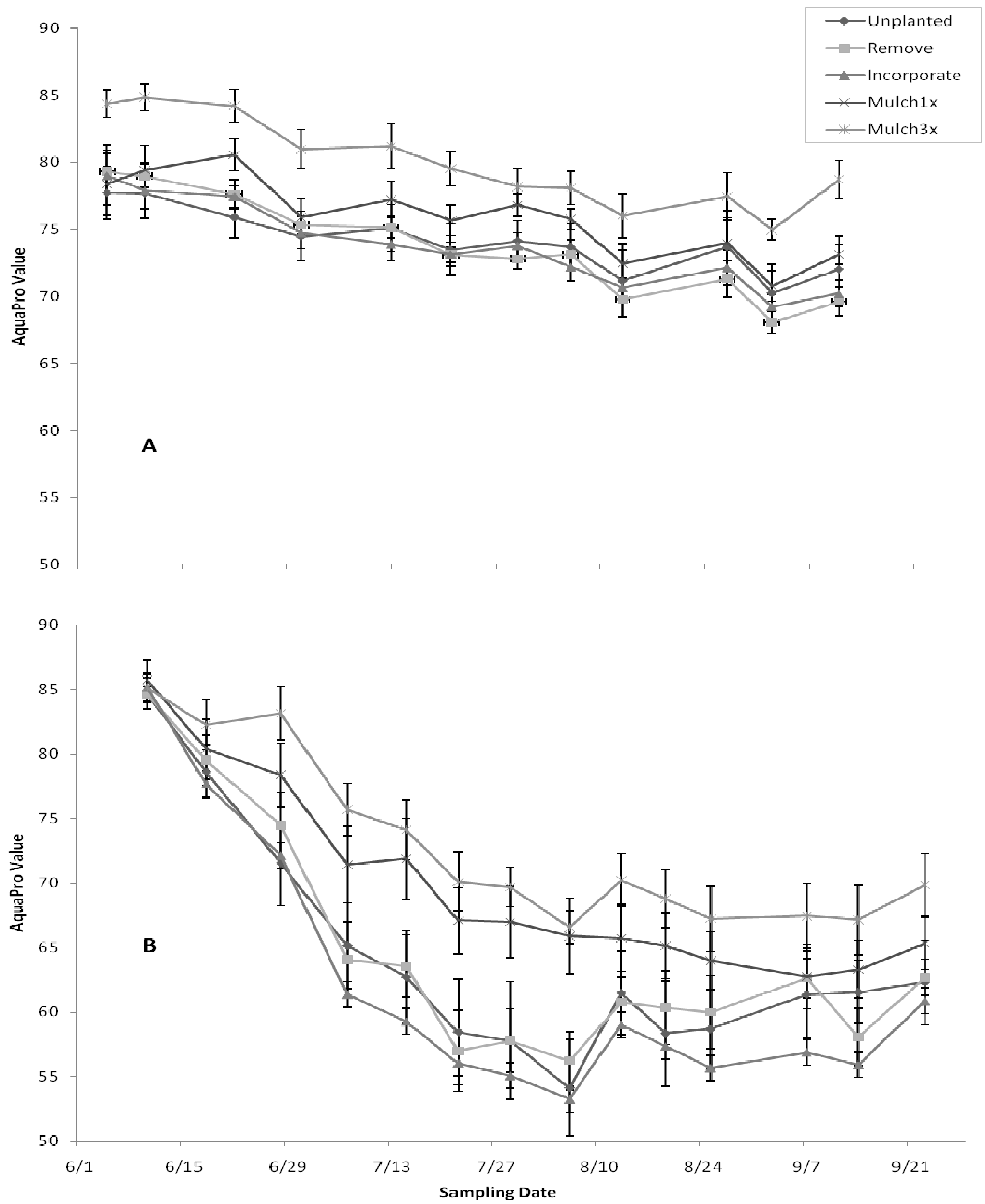

Fig. 3.1. Average soil moisture from 15-30 cm as measured by AquaPro in 2009 (**A**) and 2010 (**B**). Data points represent means with standard errors of measurements taken at 15, 23, and 30 cm soil depths at each sampling date (n=12, 2009; n=14, 2010).

Table 3.1. Floor management treatments imposed in May 2009 and 2010 at a commercial vineyard site near Independence, OR.

Dates[z] of management treatment imposition: 13-15 May 2009; 5 May 2010

Treatment ID and description	Alleyway management (each year)	In-row management (each year)
Unplanted	Not seeded to cover crop in fall. Sprayed with herbicide once in winter to control weeds. Rototilled twice in summer to control weeds.	Sprayed once with glyphosate in winter concurrent with alleyway spray. Glyphosate used to control weeds in summer.
Remove	Planted to cover crop in fall. Mowed in spring and residue removed from the alleyway. Rototilled twice in summer to control weeds.	Glyphosate used to control weeds in summer.
Incorporate	Planted to cover crop in fall. Mowed in spring and residue left in alleyway to be incorporated. Rototilled twice in summer to control weeds.	Glyphosate used to control weeds in summer.
Mulch1	Planted to cover crop in fall. Mowed in spring and residue transferred into vine row as a mulch. Rototilled twice in summer to control weeds.	Mowed alleyway residue transferred in-row as a mulch at 5 kg m-2 fresh weight in 2009 and 2.5 kg m-2 fresh weight in 2010. Glyphosate used to control weeds in summer.
Mulch3	Planted to cover crop in fall. Mowed in spring and residue transferred into vine row as a mulch. Rototilled twice in summer to control weeds.	Mowed alleyway residue transferred in-row as a mulch at 15 kg m-2 fresh weight in 2009 and 7.5 kg m-2 fresh weight in 2010. Glyphosate used to control weeds in summer.

[z]Dates of treatment imposition were determined by phenology of *T. incarnatum* (90% flowering) and *V. vinifera* L. 'Chardonnay' grapevines (EL 11-15, 1-5 leaves unfolded)

Table 3.2. Weather parameters and phenology of young vines at a research site near Independence, OR.

	Mean monthly temperature (°C)		GDD[z] (>10 °C)		ET_0 (mm)[y]		Accumulated Precipitation (mm)		Phenology dates	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
April	9.2	9.0	28	68	84	87	31	102	Budbreak 20 Apr.	Budbreak 2 Apr.
May	13.1	11.4	158	103	152	114	89	78		
June	16.4	14.6	200	157	162	140	15	66	Bloom 15 June	
July	20.3	18.5	317	270	227	226	19	2		Bloom 7 July
August	18.6	18.2	268	259	173	183	6	13	Véraison 24 Aug.	
September	16.7	16.2	221	215	128	94	28	64		Véraison 10 Sept.
October	10.9	11.5	99	113	52	53	73	119		
November	7.8	7.3	22	35	20	19	142	144	Leaf fall 20 Nov.	Leaf fall 16 Nov.
Cumulative[x]			1301	1221	943	920	388	499		

[z]Growing Degree Days (base 10 °C) accumulated each month

[y]Evapotranspiration (Kimberly-Penman) accumulated each month, collected from a Corvallis, OR weather station (http://www.usbr.gov/pn/agrimet)

[x]Cumulative GDD, ET, precipitation from Budbreak to Leaf fall for each year

Table 3.3. In-row soil moisture and compaction as assessed in a vineyard research site near Independence, OR

	Gravimetric Soil Moisture[z] (%)		Mean Soil Compaction[z] (Mpa)		VSM (AquaPro values)[y]		Total root density[x] (mg roots g^{-1} dry soil)	
Year	2009	2010	2009	2010	2009	2010	2010	2010
# sampling dates	1	1	2	1	12	14	in-row	alleyway
Treatment								
UN	18.3 (0.6) b[w]	12.2 (0.5) c	1.55 (0.12) a	3.20 (0.19) a	74 (1) c	64 (4) b	0.16 (0.05) bc[v]	0.10 (0.02) bcd
MR	18.1 (0.7) b	11.4 (0.6) c	1.54 (0.06) a	3.20 (0.22) a	74 (2) c	64 (4) b	--	--
M	17.4 (0.4) b	11.3 (0.7) c	1.58 (0.06) a	3.25 (0.14) a	74 (1) c	62 (4) b	0.16 (0.03) bcd	0.07 (0.02) cd
MS1	22.0 (0.5) a	14.2 (0.6) b	0.87 (0.04) b	1.92 (0.13) b	76 (1) b	70 (3) a	0.26 (0.04) ab	0.04 (0.03) cd
MS3	22.7 (0.6) a	17.5 (0.7) a	0.68 (0.02) c	1.38 (0.10) b	80 (1) a	73 (3) a	0.34 (0.06) a	0.05 (0.02) d
ANOVA *p-value*	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		

[z]Soil moisture and compaction averaged from 0-30 cm of soil.

[y]Total root density collected from 0-60 cm of soil at one sampling date (véraison).

[x]AquaPro values collected at three sampling depths from 15-30 cm.

[w]Mean separations within columns by Tukey's HSD test at p =0.05.

[v]Root density mean separations compared across columns for in-row and alleyway sampling.

Table 3.4. Growth and development parameters of three-year old (in 2010) commercial *V. vinifera* L. 'Chardonnay' grapevines and destructively harvested 'Chardonnay' vines

	Mean[z] shoot lengths (cm)		Leaf area per vine (m^2)		Leaf SPAD values		Clusters per shoot	Mean pruning weight ($g \cdot vine^{-1}$)		Mean trunk diameter (mm)		Interplanted[y] vine total aboveground biomass (g)	
Year	2009	2010	2009	2010	2009	2010	2010[x]	2009	2010	2009	2010	2009	2010
# of sampling dates	2	4	2	2	3	2	1	1	1	1	1	1	1
Treatment													
UN	111 (8)	68 (1) b[w]	0.61 (0.08)	1.27 (0.17)	34.9 (0.6) b	27.4 (0.3) b	0.62 (0.10) b	84 (6)	287 (18) ab	12.73 (0.08)	18.25 (0.31)	13.7 (0.9) b	5.6 (1.1) b
MR	112 (8)	73 (2) b	0.67 (0.04)	1.14 (0.10)	35.1 (0.7) ab	27.5 (0.7) b	0.76 (0.05) b	106 (12)	228 (24) b	13.02 (0.14)	18.75 (0.30)	12.0 (0.4) b	4.0 (1.2) b
M	121 (9)	73 (1) b	0.70 (0.06)	1.33 (0.09)	35.8 (0.5) ab	27.4 (0.3) b	0.69 (0.05) b	101 (19)	263 (24) ab	12.93 (0.02)	19.20 (0.32)	15.2 (0.7) b	3.4 (0.2) b
MS1	113 (10)	80 (3) a	0.80 (0.05)	1.38 (0.15)	36.7 (0.7) ab	29.8 (0.6) a	0.76 (0.09) b	116 (6)	327 (21) a	13.07 (0.15)	19.22 (0.32)	20.4 (0.5) b	9.0 (1.1) a
MS3	113 (7)	81 (1) a	0.87 (0.03)	1.61 (0.05)	36.9 (0.5) a	31.1 (0.3) a	1.20 (0.03) a	98 (4)	324 (20) a	12.97 (0.11)	19.34 (0.33)	43.5 (1.9) a	10.1 (1.5) a
ANOVA *p-value*	0.890	<0.001	0.058	0.089	0.011	<0.001	<0.001	0.354	0.019	0.618	0.207	<0.001	<0.001

[z]Means were taken across a season after analyzing sample dates individually.

[y]Self-rooted 'Chardonnay' cuttings planted in-row in spring of 2009 and 2010 and destructively harvested at the end of each year.

[x]Clusters were removed in July 2009 as vines had not reached commercial cropping age.

[w]Mean separations within columns by Tukey's HSD Test $p = 0.05$. Different letters signify different means.

Table 3.5. ANOVA for effect of treatment, sampling location, and sampling depth on total vine root density at véraison 2010.

Effect	F-statistic	*p*-value
Treatment[z] (UN, M, MS1, MS3)	1.1	0.364
Location (In-row, alleyway)	65.7	<0.001
Depth (0-20 cm, 20-40 cm, 40-60 cm)	2.2	0.116
Treatment x Location	5.8	0.001
Treatment x Depth	0.4	0.880
Location x Depth	7.4	0.001
Treatment x Location x Depth	0.9	0.485

[z]MR not included in root sampling

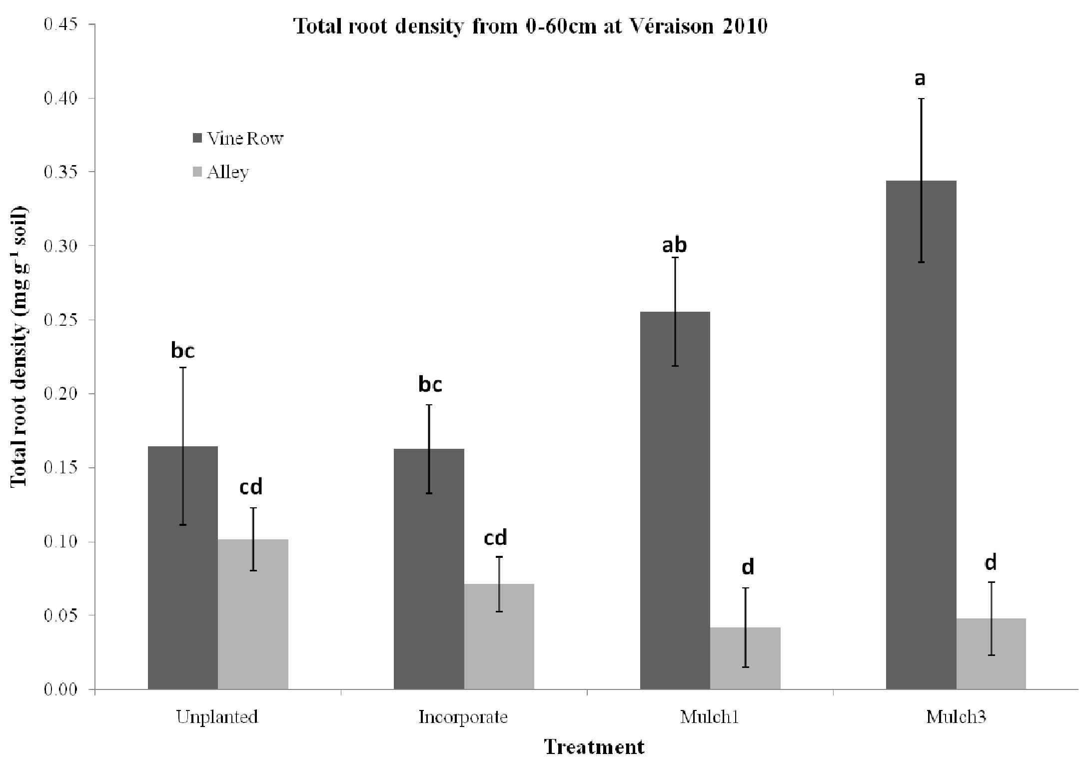

Fig. 3.2. Total vine root density sampled from 0-60cm at véraison 2010 in vine rows and alleyways. Columns represent backtransformed means (±SE) by treatment of total root density across 0-60cm expressed as mg fresh root weight g^{-1} dry soil.

Table 3.6. Leaf size and nutrient status of *V. vinifera* L. 'Chardonnay' leaf blades or petioles at bloom and véraison 2010. Values represent means (±SE).

Concentration	--	--	%	g kg-1	g kg-1	g kg-1	g kg-1	g kg-1	mg kg-1	mg kg-1	mg kg-1	mg kg-1	mg kg-1
Nutrient	Leaf size	Leaf SPAD	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Mn**	**Cu**	**B**	**Zn**	**Fe**
Bloom Petiole (7/7/2010)													
Unplanted	44.1 (3.7)	26.7 (1.2) b	1.29 (0.03)	0.188 (0.009) b[z]	4.29 (0.15)	0.269 (0.010)	1.29 (0.05)	0.32 (0.01)	208 (16) b	14.4 (0.4)	60.5 (1.3) b	36.8 (1.7)	35.3 (2.4) ab
Remove	41.7 (2.9)	26.1 (1.2) b	1.16 (0.10)	0.208 (0.013) ab	4.07 (0.32)	0.263 (0.024)	1.38 (0.04)	0.38 (0.05)	244 (6) ab	14.3 (1.0)	63.3 (1.0) ab	38.9 (2.4)	36.3 (2.7) ab
Incorporate	45.5 (2.3)	26.6 (1.0) b	1.20 (0.09)	0.231 (0.008) a	4.25 (0.19)	0.286 (0.011)	1.38 (0.02)	0.36 (0.02)	283 (12) a	15.2 (1.0)	65.3 (1.1) a	50.1 (5.0)	43.6 (4.0) a
Mulch1	43.6 (3.5)	28.1 (1.3) ab	1.14 (0.07)	0.195 (0.008) ab	4.21 (0.08)	0.270 (0.008)	1.38 (0.04)	0.37 (0.02)	220 (12) b	13.3 (0.4)	60.6 (1.2) ab	49.3 (6.0)	35.6 (0.5) ab
Mulch3	46.3 (3.7)	29.5 (1.1) a	1.14 (0.04)	0.192 (0.010) ab	4.65 (0.16)	0.253 (0.022)	1.34 (0.05)	0.29 (0.02)	212 (17) b	12.8 (0.5)	60.1 (1.0) b	40.7 (2.2)	32.4 (1.2) b
ANOVA *p-value*[y]	0.889	**0.004**	0.570	**0.039**	0.317	0.721	0.434	0.126	**0.004**	0.170	**0.016**	0.075	**0.050**
Véraison Petiole (9/10/2010)													
Unplanted	--	--	0.53 (0.04)	0.084 (0.004)	2.19 (0.25)	0.097 (0.005)	1.13 (0.04)	0.72 (0.03) ab	369 (20) c	5.3 (0.4)	26.9 (0.9)	69.0 (8.8)	24.8 (0.7)
Remove	--	--	0.49 (0.03)	0.093 (0.007)	1.70 (0.38)	0.103 (0.002)	1.33 (0.04)	0.98 (0.09) a	515 (21) a	5.0 (0.1)	28.8 (0.8)	58.1 (5.8)	26.8 (0.8)
Incorporate	--	--	0.52 (0.03)	0.099 (0.005)	1.99 (0.37)	0.094 (0.002)	1.17 (0.04)	0.85 (0.10) ab	481 (18) ab	5.0 (0.2)	28.7 (0.9)	49.7 (1.5)	25.1 (1.5)
Mulch1	--	--	0.50 (0.03)	0.101 (0.009)	1.89 (0.27)	0.096 (0.004)	1.32 (0.06)	0.84 (0.08) ab	469 (23) ab	4.7 (0.3)	27.4 (1.4)	59.5 (8.3)	24.5 (0.4)
Mulch3	--	--	0.51 (0.03)	0.103 (0.001)	2.78 (0.19)	0.099 (0.002)	1.19 (0.07)	0.64 (0.03) b	413 (28) bc	4.6 (0.2)	30.3 (1.1)	53.6 (2.0)	27.9 (0.2)
ANOVA *p-value*	--	--	0.935	0.173	0.157	0.450	**0.043**	**0.035**	**0.001**	0.449	0.211	0.316	0.765
Véraison Leaf Blade (9/10/2010)													
Unplanted	44.5 (1.6) ab	28.2 (1.7) b	2.70 (0.07)	0.210 (0.009) a	1.11 (0.03)	0.229 (0.008)	1.44 (0.04)	0.36 (0.01) ab	189 (5) c	7.8 (0.3)	22.2 (2.0)	14.4 (0.2) ab	111.7 (6.8)
Remove	39.7 (1.5) b	28.9 (1.3) b	2.74 (0.12)	0.185 (0.007) b	1.00 (0.06)	0.217 (0.006)	1.66 (0.06)	0.41 (0.03) a	239 (9) a	7.1 (0.4)	21.7 (1.1)	13.9 (0.3) b	112.3 (3.9)
Incorporate	40.0 (1.2) b	28.2 (1.3) b	2.74 (0.08)	0.188 (0.004) ab	1.08 (0.08)	0.214 (0.004)	1.55 (0.08)	0.36 (0.01) ab	237 (4) a	7.5 (0.4)	20.5 (1.3)	14.2 (0.5) ab	115.2 (9.1)
Mulch1	44.0 (0.6) ab	31.4 (1.4) ab	2.74 (0.06)	0.189 (0.002) ab	1.08 (0.04)	0.215 (0.005)	1.63 (0.09)	0.38 (0.02) ab	226 (8) ab	6.9 (0.6)	21.4 (1.0)	14.3 (0.2) ab	113.0 (5.4)
Mulch3	47.1 (1.6) a	32.6 (1.0) a	2.75 (0.09)	0.211 (0.005) a	1.19 (0.04)	0.219 (0.005)	1.42 (0.05)	0.31 (0.02) b	198 (8) bc	7.5 (0.4)	23.6 (1.2)	15.5 (0.4) a	117.8 (6.2)
ANOVA *p-value*	**0.018**	**0.001**	0.808	**0.006**	0.176	0.381	0.058	**0.010**	**<0.001**	0.592	0.613	**0.033**	0.961

[z]Mean separations within columns by Tukey's Honestly Significant Difference Test p=0.05.

[y]*p-values* calculated from ANOVA within column and sampling date. Different letters signify different means.

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Chapter 4

General Conclusion

Growth of young 'Chardonnay' vines was increased through transferring alleyway cover crop residues into vine rows as mulch. Supplementing residue in-row enhanced these effects in some cases, though increases in vine growth were not likely sufficient to justify the increased costs associated with supplementing residue. This increase in growth was largely attributed to conservation of in-row soil moisture in the upper 30 cm of soil by mulched treatments as compared to non-mulched treatments. No effects of competition between alleyway cover crops and young vines were observed. Incorporation of cover crop residues into alleyways was not observed to effect vine growth or soil moisture, though did reduce alleyway weed growth as compared to an unplanted treatment and treatments that removed residue from the alleyway. In-row weeds were greatly reduced by cover crop residues applied in-row at densities of at least 2.5 $kg \cdot m^{-2}$ fresh weight, though greater densities of residues corresponded with less weed coverage at some sampling dates. These results indicate that cover crops may be effectively managed to increase vegetative and root growth of one- to three-year old *V. vinifera* 'Chardonnay' vines, conserve soil moisture, and control weeds simultaneously in vineyards located in areas of limited summer rainfall.

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APPENDIX

Appendix 1. Cover crop biomass fresh weights, %moisture, %N, %C, and plant composition as sampled on 12 May 2009 and 4 May 2010.

	Cover Crop Fresh Weight ($kg \cdot m^{-2}$)		Cover Crop Moisture Content (%water)		Cover Crop N concentration (%)		Cover Crop C concentration (%)		Cover Crop Plant Composition (%)[z]					
Year	2009	2010	2009	2010	2009	2010	2009	2010	2009			2010		
Plant category									rye	clover	weeds	rye	clover	weeds
Treatment														
Remove	3.01	1.59	78.70	76.82	1.42	1.96	30.55	41.72	65.04	19.81	5.7172	16.38	78.80	4.82
Incorporate	3.05	1.80	78.90	76.97	1.47	1.62	29.73	41.29	56.64	24.63	7.3287	16.86	76.02	7.12
Mulch1	3.40	2.15	79.43	78.08	1.50	1.79	28.64	41.85	67.92	17.45	4.0766	15.62	76.76	7.62
Mulch3	3.14	2.01	79.32	76.44	1.61	1.74	26.94	41.24	62.86	21.46	3.9224	13.96	79.84	6.20

[z]Values expressed as percent of total fresh weight biomass.

Appendix 2. Soil compaction measured in-row by penetrometer at two sampling dates in 2009 and one sampling date in 2010 and expressed as PSI.

Sampling date	16 June 2009				13 July 2009				29 July 2009			
Depth interval	7.5cm	12.5cm	23cm	30.5cm	7.5cm	12.5cm	23cm	30.5cm	7.5cm	12.5cm	23cm	30.5cm
Treatment												
Unplanted	205 a	247 a	188 a	220 a	138 a	218 a	267 a	313 a	283 a	437 a	540 a	600 a
Remove	215 a	192 a	188 a	200 a	145 a	242 a	293 a	307 a	290 a	483 a	530 a	552 a
Incorporate	238 a	210 a	213 a	210 a	155 a	248 a	265 a	293 a	302 a	490 a	528 a	563 a
Mulch1	72 b	112 b	117 b	142 b	77 b	143 b	165 b	192 b	150 b	258 b	330 b	375 b
Mulch3	52 b	75 b	93 b	123 b	58 b	103 b	130 b	158 b	92 c	177 c	225 c	305 c
ANOVA *P*- value[z]	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

[z]Analyzed separately by depth interval.