AN ABSTRACT OF THE DISSERTATION OF

Alison L. Reeve for the degree of Doctor of Philosophy in Horticulture presented on March 1, 2018.

Title: Using Vineyard Floor Management to Manipulate Vine Vigor: Impacts on 'Pinot noir' Yield Productivity and Fruit Composition.

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Winegrapes are an important crop for Oregon agriculture, ranking amongst the top ten agricultural commodities based on farmgate value. The most widely planted winegrape cultivar in the state is 'Pinot noir' (*Vitis vinifera* L.), and the majority of acreage is produced in the Willamette Valley. Production of quality 'Pinot noir' is expensive due to small vineyard size, dependence on manual labor, and low yield targets that are believed to enhance fruit quality. These industry production standards have traditionally been rooted in practices adopted from other wine regions and on higher-yielding cultivars. 'Pinot noir' has low physiological yields compared to other winegrape cultivars, which may not warrant such extensive crop removal. Additionally, the Willamette Valley has high rainfall and deep soils, resulting in vegetatively vigorous vines that cannot be managed through deficit irrigation practices to reduce vine vigor as in other winegrape production regions of Oregon and the West Coast. Vineyard floor management has been shown to reduce vine growth through competition for water or nutrient

resources in other high-rainfall regions and was evaluated as a means to alter vine balance in Oregon ‘Pinot noir’.

Vine balance is the optimum ratio between canopy size and fruit yield (vegetative versus reproductive tissue) required to fully ripen the crop. However, the optimum ratio in the current literature does not apply to ‘Pinot noir’ produced in Oregon’s Willamette Valley, as vine balance ratios fall below the range considered optimum. To understand how canopy size relative to fruit yield affects ‘Pinot noir’ productivity and fruit quality, a three-year trial was conducted to determine the impacts of vineyard floor management and cluster thinning on vine balance. To alter canopy growth, three vineyard floor management practices were used, including soil tillage and competitive perennial grass cover crop in the vineyard alleyways. Two crop levels were compared, including vines with a full crop maintained and removing nearly half of the clusters per vine. The perennial grass cover crop was successful at reducing véraison shoot leaf area by as much as 44% and dormant pruning weights by 52%, but the cover crop did not negatively affect vine water status, as determined by midday stem water potential. Vines with smaller canopies had lower tissue nitrogen (N) status compared to vines with larger canopies that resulted from complete tillage. Results suggest that vine N, rather than water limitation, was responsible for altering vine vegetative growth. Interestingly, as perennial grass cover crop reduced canopy size, yields were also reduced resulting in similar canopy size to yield ratios as higher vigor vines grown with different levels of tillage. While floor management primarily affected vine vegetative growth, crop level mainly affected fruit composition such as total soluble solids, pH, total anthocyanins, and total tannins in multiple years. There was no universal vine balance metric that could be used to predict fruit composition amongst the years.

As vine yield differed due to floor management treatments in the first trial, a subsequent two-year trial was conducted on the same vines, maintaining only the floor management treatments. Focus of this second trial was to understand how vine nutrient status may influence yield through floral primordia development in the first season and fruitfulness of the following season. Seasonal dynamic of carbohydrate and nitrogen status were monitored in various vine tissues over the course of the two years to understand the impact of these nutrients on fruitfulness in the bud, observed fruitfulness following bud break, and yield at harvest. Root, trunk, internode, and bud tissues were analyzed for total non-structural carbohydrate (TNC) and N concentrations, two main reserves involved in primordia development. The number and size of inflorescence primordia, also known as bud fruitfulness (FFL) and integrated fruitfulness index (IFI), was determined in each of the buds that composed of the latent, compound bud. High vigor vines had more and/or larger inflorescence primordia than low vigor vines. Low vigor vines had lower N concentrations in root and trunk tissues. Few correlations were found for bud FFL or IFI and internode, root, or trunk TNC concentrations measured throughout the growing season as results were inconsistent between years. In addition to higher bud FFL, high vigor vines showed a greater decline in root TNC concentration from bud break to bloom and a larger canopy and higher leaf blade N concentration by vérasion than low vigor vines in the first season. In the second season, however, there was a similar decrease in root TNC concentrations between the two vigor levels and no difference in bud FFL or IFI, likely suggesting the ability to supply TNC to canopy establishment directly or indirectly, through photoassimilation, influences inflorescence primordia development and/or growth. This finding is in opposition to many studies that suggest solar radiation is a prime driver of inflorescence primordia initiation and

growth as bud FFL and IFI decreased as the amount of light infiltrating the canopy increased in this study.

In addition to vine size and growth, cane vigor was also evaluated for relationships with bud fruitfulness and inflorescence primordia size. Unlike several studies, high vigor vines and canes with greater weight and diameter, were associated with higher bud FFL and IFI averaged along the cane. The presence of a woody lateral at a node, which was more common in the high vigor vines, increased bud FFL and IFI at that node. Additionally, buds at each node position along a dormant cane were evaluated to determine the role of node position on inflorescence primordia number and size. Both bud FFL and IFI increased from a low at the base of the shoot (node position one) to node position four. Node position had greater influence on FFL and IFI than the vineyard floor management practices. Overall, the two basal nodes had the lowest FFL and IFI and are not likely to be increased by cultural practices that increase cane or vine vigor.

The results of this work indicate that a perennial grass cover crop can be an effective long-term management strategy for overly-vigorous vineyards of Oregon's Willamette Valley. In our study, this practice reduced canopy size and yield, which maintained vine balance and hence sufficient canopy leaf area to adequately ripen fruit. Vines were not subject to water stress under the deep soil conditions of the vineyard in this study. The cover crop likely restricted soil N availability leading to lower yields, which needs to be monitored to ensure production standards are met. Although growers may choose to reduce yields, maintaining minimum base yields is still critical and of concern due to the high yield variability experienced in this region. Therefore, understanding the conditions under which yield is affected can aid growers in management decisions. Cane selection at pruning, may be a potential strategy to affect yield under those conditions. Growers choosing to maximize potential yield, may opt to promote vegetative vigor,

or retain more vigorous canes at pruning. Seasonal events that reduce vine reserves, such as canopy loss due to frost, pests, or disease, will likely reduce fruitfulness through lowering carbohydrate reserves.

Using Vineyard Floor Management to Manipulate Vine Vigor: Impacts on ‘Pinot noir’ Yield Productivity and Fruit Composition.

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Alison L. Reeve

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APPROVED:

Major Professor, representing Horticulture

Head of the Department of Horticulture

Dean of the Graduate School

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

Alison L. Reeve, Author

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Dr. Patricia A. Skinkis contributed to funding, data collection, interpretation, writing, and guidance throughout all experiments in this dissertation.

Amanda J. Vance was responsible for the implementation of treatments in Chapters 2 and 3, as well as data collection during the first year of that trial. She also assisted in editing the two chapters.

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Dr. R. Paul Schreiner contributed to the research idea and experimental planning (particularly Chapter 4), input in methodology, laboratory space and equipment, data analysis, interpretation, and editing of the work involved in Chapter 4.

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USING VINEYARD FLOOR MANAGEMENT TO MANIPULATE VINE VIGOR: IMPACTS ON 'PINOT NOIR' YIELD PRODUCTIVITY AND FRUIT COMPOSITION

CHAPTER 1

INTRODUCTION

Wine grapes are one of the top ten agricultural commodities produced in Oregon with a farmgate value of over 140 million U.S. dollars (Oregon Department of Agriculture, 2017). Oregon's wine grapes are produced predominately in the Willamette Valley with *Vitis vinifera* L. 'Pinot noir' the most commonly planted cultivar (SOURCE, 2017). The Willamette Valley is considered a cool climate viticultural region and is described as a Mediterranean climate, but with cooler summers (AESOSU, 1993). Rainfall in this region occurs primarily in the winter months, but also in spring and fall, with little rainfall in the summer (AESOSU, 1993). These growing conditions lead to vigorous vine growth, with nearly a third of total management costs allocated to canopy management (Julian et al., 2008). Oregon 'Pinot noir' producers remove clusters (cluster thin) from the vine to improve fruit quality (Uzes and Skinkis, 2016). Oregon growers often target a certain ton per acre; however, this tonnage has remained the same over the past few decades despite the density of vines per acre increasing (Uzes and Skinkis, 2016). Therefore, it is unknown if the tonnage growers aim for can be increased given the climatic limitations, although it is believed that higher vigor vines have the capacity to ripen more fruit.

Vine balance is a concept used to describe the amount of leaf area required to ripen crop (Howell, 2001). Ravaz (1903) was the first to introduce vine balance ratios including leaf area to fruit production and vine pruning weight to yield. Literature suggests that a vine with a Ravaz Index between five and ten or a leaf area to yield ratio of 0.5 to 1.2 m^2 of leaf area per kg in warm climates is balanced and will produce high-quality fruit (Kliewer and Dokoozlian, 2005). However, it has been noted that a more appropriate range for cool climate cultivars such as

‘Pinot noir’ may be between three and six (Kliewer and Dokoozlian, 2005). The lower Ravaz Index range suggests a larger canopy size is required or crop yield needs to be reduced, compared to vines grown in warmer climates. This is suggested as photosynthesis is temperature dependent, there needs to be a greater leaf area to adjust for lower photosynthetic rates in cooler temperatures (Greer and Weedon, 2012).

Cluster thinning reduces vine yield, which typically decreases the Ravaz Index or increases the leaf area to yield ratio (Bravdo et al., 1984; Dami et al., 2006; Kliewer et al., 1983; Naor et al., 2002). However, pruning weights have been reported to increase as the result of cluster thinning (Bravdo et al., 1984, 1985; Dami et al., 2006; Weaver and Pool, 1968). Fruit competes with the vine for photoassimilates especially at véraison; therefore, it is believed that by reducing the sink strength of the fruit, the remaining fruit can accumulate higher concentrations of sugar than if all fruit remained on the vine (Mansfield and Howell, 1981). Cluster thinning has been used in cool climates to hasten fruit ripening (Frioni et al., 2017). However, reducing the number of clusters per vine, reduces the sink strength of the crop and has been shown to reduce the photosynthetic rate consequentially (Edson et al., 1995; Kaps and Cahoon, 1989; Naor et al., 1997; Petrie et al., 2000). The effects of cluster thinning therefore are dependent upon cultivar, vine capacity, vigor level, climate, weather as these factors influence source-sink relationships (Bowen et al., 2011; Bravdo et al., 1984, 1985; Frioni et al., 2017; King et al., 2015).

Regulated deficit irrigation has been used to reduce vegetative vigor in regions that require irrigation for vine growth (Chaves et al., 2007). This method cannot be used in dry-farmed situations as vines are not supplied with irrigation, such as on deep soils in the Willamette Valley. However, certain types of cover crops in alleyways of vine rows or under

vine rows have been shown to reduce leaf area and pruning weight (Hatch et al., 2011; Hickey et al., 2016; Ingels et al., 2005; Tesic et al., 2007). In some cases, reduced vine vigor in the presence of a cover crop is due to water competition between the vine and the cover crop (Hatch et al., 2011; Hickey et al., 2016), while in other situations, it is due to nitrogen deprivation (Celette et al., 2009). Use of competitive cover crops to reduce vine vegetative vigor has been reported to reduce yield as well (Hickey et al., 2016; Tesic et al., 2007).

Yield is influenced by several factors including those that can be controlled, such as cultural practices as well as uncontrollable factors like weather and climate (May, 2004). There are also genetic differences between cultivars and clones that are inherent and cannot be controlled beyond certain limitations (Castagnoli and Vasconcelos, 2006; Mercado-Martín et al., 2006). Likewise, climate cannot be controlled; however, there are management practices that can shift vine development to avoid certain climatic conditions. For instance, delayed pruning has been shown to shift ripening into a cooler part of the season in Australia as hot temperatures, combined with gradual warming of the climate, has led to problems in fruit quality related to temperatures under these conditions (Petrie et al., 2017). Yield is determined by the number of clusters per vine and cluster weight, but it is the number of clusters per vine that is often reported as the main source of variability year to year in yield (Li-Mallet et al., 2016; Mercado-Martín et al., 2006). Shoot number per vine influences clusters per vine, but this is readily adjustable by viticulturists. Therefore, understanding what determines the number of inflorescences per shoot is of interest for vineyard productivity and economics.

Inflorescences arise from floral primordia that develop within the bud the season before it becomes fruit (May, 2004; Srinivasan and Mullins, 1981; Vasconcelos et al., 2009). Inflorescence primordia initiate acropetally within the bud and along the shoot (Buttrose, 1969a;

Goffinet, 2004; Lavee et al., 1981; Morrison, 1991; Vasconcelos et al., 2009; Winkler and Shemsettin, 1937). Light exposure and temperature are two factors that are most cited to influence whether a bud initiates an inflorescence primordium or not (Baldwin, 1964; Buttrose, 1969a, b; May, 1965; Palma and Jackson, 1981; Perez and Kliewer, 1990). However, more recent studies have suggested that the link between light and temperature to inflorescence primordia initiation is through their influence on carbon assimilation (Eltom et al., 2014; Li-Mallet et al., 2016; Sánchez, 2003; Sánchez and Dokoozlian, 2005). This theory helps explain why reports of more inflorescences per shoot have been found in vines or canes that have been described as more vigorous (Christensen, 1986; Eltom et al., 2014; Jones et al., 2013; Sánchez and Dokoozlian, 2005). However, there have also been reports of reduced numbers of inflorescences on shoots of very vigorous vines, which has been associated with primary bud necrosis, as death of the primary bud results in less fruitful secondary buds (Dry and Coombe, 1994; Morrison and Iodi, 1990; Noyce et al., 2016). Primary bud necrosis is believed to be associated with vigorous shoots that often create dense, shaded canopies (Perez and Kliewer, 1990).

A whole systems approach was utilized to examine the effect of vegetative vigor on vine health, yield, and fruit quality. The data presented herein are a part of a three-phase set of experiments that were conducted sequentially over ten years. The first phase was implemented in 2007 and utilized three floor management treatments to determine if perennial red fescue (*Festuca rubra* L.) planted in the alleyways adjacent to the vine row could reduce vine vegetative vigor. The red fescue stand was planted in 2004 and was not reseeded throughout the entirety of the project. The first treatment had red fescue established in both alleyways adjacent to the vine row. This treatment was compared against tillage of both adjacent alleyways and a third

treatment which had red fescue established in one adjacent alleyway while the other was tilled. In 2010, treatments created differences in vegetative vigor, determined by pruning weight and leaf area, between the treatments that had grass in both alleyways or were tilled in both alleyways (Vance, 2012). Chapters 2 (Reeve et al., 2016) and 3 (Reeve et al., 2018) describe the next phase of that work where the three floor management treatments were retained and two different crop thinning treatments were imposed as sub-plots, resulting in a split-plot design. The third phase of this research focused on how the same vineyard floor managements impact grapevine inflorescence primordia development, as lower yields were found in lower vigor vines in the second phase of research. The research presented herein evaluated the impact vineyard floor management and cluster thinning have on vegetative vigor, yield productivity, and fruit composition while providing physiological evidence to support the effects of these cultural practices on 'Pinot noir' grown in the Willamette Valley of Oregon.

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CHAPTER 2

VINEYARD FLOOR MANAGEMENT INFLUENCES ‘PINOT NOIR’ VINE GROWTH AND PRODUCTIVITY MORE THAN CLUSTER THINNING

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Abstract

Vigor and crop level management are important practices for premium wine grape production. The implications of crop thinning ‘Pinot noir’ (*Vitis vinifera* L.) vines of varying vigor were investigated in the Willamette Valley of Oregon in 2011 to 2013 to better understand the relationship between canopy size and yield within the framework of a cool-climate, premium production wine grape vineyard. To manipulate vigor, a competitive grass cover crop (*Festuca rubra* L.) was grown in both (Grass), alternating (Alternate), or neither side of the flanking alleyways (Tilled). Vines within each vineyard floor treatment had two crop levels applied, including cluster thinning to one cluster per shoot (Half Crop) or no crop thinning (Full Crop). Grass treatment had reduced leaf area and leaf N concentrations during all years compared to Tilled treatments. Leaf photosynthesis was also lower in Grass treatments despite more light in the canopy interior. Grass treatments had lower yield than Tilled treatments in two of three years and lower yeast assimilable nitrogen (YAN) concentrations in fruit every year. There was limited impact of floor treatments on total soluble solids (TSS) and pH. Reduced yields through cluster thinning had limited impact on vegetative growth but increased TSS and pH, in two of three years. There were few floor management by crop level interactions in any year. Grass effectively reduced vegetative growth to moderate vigor levels with cane weights between 20 and 40 g. Utilizing a competitive grass cover crop may be an effective strategy to reduce excessive vine growth and require less labor in canopy management and crop thinning without compromising basic fruit ripeness, although YAN levels need to be monitored.

Introduction

'Pinot noir' is the most important grape cultivar produced in the state of Oregon based on production and value. Vineyards within Oregon's Willamette Valley, contain 82% of the state's 'Pinot noir' acreage (SOURCE, 2015), are characterized by excessive vine vigor as a result of high annual rainfall on sites with high water-holding capacity soils. These conditions allow for substantial vegetative growth throughout most of the season despite a relatively dry summer period (1981-2010 average rainfall from July to September in McMinnville, OR was 57 mm, Western Regional Climate Center, 2010).

'Pinot noir' is a small-clustered variety and has relatively low yields in Oregon. Clonal trials conducted in the Willamette Valley report yields ranging from 2.4 to 5.8 $t \cdot ha^{-1}$ with a mean of 4.3 $t \cdot ha^{-1}$ (Castagnoli and Vasconcelos, 2006). Anderson et al. (2008) reported nearly four-fold higher yields for the same 'Pinot noir' clones evaluated in Sonoma, CA. Despite low yields for Oregon 'Pinot noir,' cluster thinning is a standard practice used to ensure yield targets are met in the range of 4.5 to 6.2 $t \cdot ha^{-1}$ to hasten ripening and achieve quality in a cool climate (Uzes and Skinkis, 2016). While there are numerous studies that validate yield reduction to enhance fruit quality in wine grapes in both warm and cool climates (Bravdo et al., 1984; Chapman et al., 2004; Edson et al., 1995a; Guidoni et al., 2002; Reynolds et al., 1994), others show little to no effect (Bowen et al., 2011; King et al., 2015) or an opposite effect (Bravdo et al., 1985). Several studies with *V. vinifera* wine grapes show increases in canopy size with cluster thinning at bloom and fruit set, as measured by dormant pruning weights (Bravdo et al., 1985; Weaver and Pool, 1968), thus yield management practices used in Oregon may be exacerbating already high vegetative growth (vigor).

High vegetative vigor can have negative physiological impacts on the vine. Without adequate canopy management, such as hedging, lateral shoot removal, and cluster-zone leaf removal, high canopy density and intra-canopy shading can create short- and longer-term issues with fruit quality or yield the following year. Studies with 'Pinot noir' have shown cluster shading influences fruit composition, including reduced norisoprenoids (Feng et al., 2015) and lower anthocyanin concentrations (Lee and Skinkis, 2013; Price et al., 1995). Canopy shading has been found to reduce inflorescence primordia number and/or size in buds (Sánchez and Dokoozlian, 2005), elicit inflorescence necrosis (Gu et al., 1996), and cause poor fruit set (Ferree et al., 2001). Additionally, high vegetative vigor has been associated with primary bud necrosis (Cox et al., 2012; Dry and Coombe, 1994), all which can lead to reduced yield. In cool climates where short seasons and low heat units limit yield (without thinning) and fruit ripening, focus is placed on canopy and yield management practices to increase sunlight exposure and reduce crop levels (Jackson and Lombard, 1993). As a result, canopy and crop level adjustment by Oregon 'Pinot noir' growers requires nearly 30% of the cash costs in vineyard management each year (Julian et al., 2008).

Better understanding of source-sink relationships is needed for the improvement of vineyard management practices. There are many studies that have investigated source-sink relationships using various cultural techniques, including those that alter canopy architecture and light environment through leaf removal (Bennett et al., 2005) and hedging (Petrie et al., 2003), and those that alter leaf area physiologically through regulated deficit irrigation (Romero et al., 2010; Tarara et al., 2011) and fertilization (Schreiner et al., 2013). Understanding source-sink management is particularly challenging in vineyards that are naturally out of balance due to high vegetative vigor.

Research in vineyards within cool climate and high rainfall regions has shown floor management to be an effective tool in vigor management. Perennial grasses grown on the vineyard floor within and between vine rows have been used to reduce canopy size without creating vine water stress (Celette et al., 2005; Giese et al., 2014). Some studies found that grasses effectively competed for nitrogen (N), resulting in vines with smaller canopies and reduced vegetative N concentration or content (Celette et al., 2009; Celette and Gary, 2013; Tan and Crabtree, 1990). In many of these studies, canopy size was reduced without reducing yield (Giese et al., 2014; Monteiro and Lopes, 2007; Pérez-Álvarez, et al., 2015) or affecting fruit ripening (Giese et al., 2015; Monteiro and Lopes, 2007; Pérez-Álvarez, et al., 2015).

While there are many competitive cover crop studies, few report impacts on fruit N concentration. Sufficient fruit N is required for healthy fermentations, and must/juice nutrient supplementation at the winery is common to avoid off flavors in the wine (Bell and Henschke, 2005). Skinkis (2009) and Pérez-Álvarez et al. (2015) have shown reduced yeast assimilable nitrogen (YAN) concentrations in the presence of a competitive cover crop, similar to low YANs found in fruit from vines with low tissue N (Neilsen et al., 2010; Schreiner et al., 2013).

A 3-year study was conducted to alter vine source-sink ratios using vineyard floor management and cluster thinning, and to investigate their effects on vine growth and fruit composition. The objectives of the research were to 1) understand impacts of vigor reduction on canopy light environment, vine water status, and fruit ripeness at harvest; 2) determine whether cluster thinning impacts vine vigor and/or fruit composition; and 3) determine if the interaction of vigor and crop level impact vine physiology or fruit composition. We hypothesized that vegetative vigor management would be more effective than yield management in achieving long-term vine productivity without negatively impacting fruit ripening.

Materials and Methods

Research was conducted from 2011 to 2013 (years 5-7) in a long-term cover crop study initiated in 2007 (Skinkis, 2009) in a commercial vineyard in Dayton, OR (45°14’42”N, 123°04’11”W; elevation 104 m). The vineyard was planted in 1998 to ‘Pinot noir’ (*V. vinifera* L.; Dijon clone 115 on 101-14 Mgt rootstock) in Jory silty clay loam with a slope between 12% and 20%. Vines were planted in north-south oriented rows and spaced 1.5 m between vines and 2.1 m between rows, for a plant density of 3076 vines·ha^{-1}. Vines were cane pruned to a bilateral Guyot system with a head height of 0.61 m and positioned just below the fruiting wire. Two sets of movable catch wires were raised as the canopy grew, maintaining a vertical canopy with a hedge height of 2.21 m from the soil surface. Phenology was determined using the BBCH scale (Lorenz et al., 1995). Vines were grown without irrigation and were managed with commercially accepted disease and canopy management practices with the exception of cluster thinning. Foliar fertilizers were applied annually, including split applications of boron at a total application rate of 1.12 kg·ha^{-1} per year between April and August (Solubor®; Borax, Greenwood Village, CO) and magnesium at a total application rate of 2.2 to 5.1 kg·ha^{-1} per year split across May to August (various products with Mg concentration 9% to 12%).

A split-plot experimental design was implemented with three vineyard floor treatments as main plots and two crop levels as sub-plots. Main plots consisted of 16 vines and were organized in a completely randomized design with crop levels assigned randomly to eight-vine sub-plots. Each treatment plot was replicated five times. One buffer row separated each main plot on either side and four buffer vines separated plots within row. Perennial red fescue (*Festuca rubra* L.) had been planted in 2004, and floor treatments were implemented shortly after bud break in 2007. A 4-year study occurred from 2007-2010 utilizing only the main plots (Skinkis, in

preparation). At the onset of this study, there was still a good stand of cover crop, but had encroachment of broad leaf and grass species, but were not identified or quantified. A rototiller (Rotavator HR36; Kongskilde Industries, Sorø, Denmark) was used to cultivate both alleyways flanking the vine row for vines in the Tilled treatment. One alleyway flanking the vine row was tilled and the other maintained as grass for the Alternate treatment, and grass was maintained in the alleyways for the Grass treatment. A 0.6-m strip within the vine row was kept free of weeds in 2011 by herbicide application (glyphosate; Gly Star®, Albaugh, Inc., Ankeny, IA) at a rate of 4.7 $L \cdot ha^{-1}$ during dormancy. During 2012 and 2013, the weed-free strip was maintained by the use of a grape hoe (Braun Maschinenbau GmbH, Burrweiler, Germany). Crop level treatments were applied in sub-plots at lag phase (BBCH stage 74 to 75, ~50-55 days post 50% bloom) by either leaving all clusters on the vines (Full Crop) or by retaining only the basal cluster on each shoot, or about half of the clusters per vine (Half Crop). The percentage of clusters removed ranged from 38% to 45% over three seasons. Branched sections of the cluster near the peduncle (wings) were removed in both Full Crop and Half Crop treatments at the time of thinning to mimic standard industry practice. Because of cluster development on lateral shoots during 2012 and 2013, these secondary clusters were removed at the time of thinning. Temperature and precipitation data were obtained from an on-site weather station, and growing degree days were calculated using the daily mean with a threshold temperature of 10 °C and no upper threshold.

Growth. At least five mid-cane shoots per plot were randomly selected and tagged post-bud break each year for measurements of shoot length, leaf area, and percent fruit set. Shoot lengths were measured to the nearest cm with a cloth tape every 1-2 weeks until early to mid-July when hedging commenced post-fruit set. Tagged shoots were measured again at bloom and véraison for length and leaf area. Leaf areas were determined with a non-destructive template

(Navarrete, 2015). Every leaf on the shoot was measured against the template and all leaf size classes were summed by shoot. Dormant pruning weights were measured January 2013 and December 2013; no data were collected in 2011 due to early commercial pruning. The number of shoots per vine was counted, and all 1-year-old wood was pruned and weighed per plot and expressed in weight per unit vine row.

Mineral nutrient analysis. Tissue samples were collected for nutrient analysis at bloom (50% capfall, BBCH stage 65) and véraison (50% color change, BBCH stage 85). Leaf blades and petioles (n=20) were collected at each stage except during bloom of 2011, when only petioles were collected. At bloom, all leaves were collected from opposite the basal cluster, whereas at véraison, 10 leaves were collected from opposite the basal cluster and 10 from the fifth to seventh apical node (or the top 1/3 of the canopy if it had been hedged) as recommended for Oregon growers (Schreiner and Skinkis, 2014). Samples were kept cool and transported to the laboratory, washed, and dried at 65 °C until constant weight was reached (~48 hours). Dried tissues were then ground to pass through a 425-µm screen and submitted to the Central Analytical Lab at Oregon State University (Corvallis, OR). Tissues were analyzed for total carbon and N using CNS-2000 Macro Analyzer (Leco, St. Joseph, MI), and other macro- and micronutrients using inductively coupled plasma optical emission spectrometry (Optima 3000DV; PerkinElmer, Waltham, MA).

Fruitfulness and fruit set. Number of inflorescences per vine was counted on all vines in each plot once inflorescences were visible (BBCH stage 53), and fruitfulness was defined as the number of inflorescences per shoot. The number of florets per inflorescence was determined using a similar method as the one described by Poni et al. (2006). The basal cluster of tagged shoots was digitally photographed pre-bloom during 2011 and 2012 (florets separating, BBCH

stage 57). Photographs were taken at the beginning stages of flowering (BBCH stage 63) during 2013 as the BBCH stage 57 was missed. An additional set of photographs were taken post-berry drop (groat- to pea-size berries, BBCH stage 73-75) using the same tagged clusters. At each sampling time, a minimum of 20 basal clusters was photographed from buffer row vines, but were removed from the vine to hand-count the number of florets per inflorescence or berries per cluster. A standard curve was developed using regression analysis to relate the number of florets or berries in the photograph to the number counted by hand. This equation was used to estimate the number of florets per inflorescence or berries per cluster, and used to determine fruit set.

Canopy light environment. To determine differences in incident light intensity that resulted from changes in canopy size, Photosynthetic Photon Flux (*PPF*) was measured above and within canopies using a ceptometer (AccuPAR LP-80; Decagon Devices, Pullman, WA) on one clear day during ripening in 2013. Measurements were recorded hourly in three of five plots when ambient *PPF* exceeded 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Treatments included Grass-Full Crop, Grass-Half Crop, Tilled-Full Crop, and Tilled-Half Crop. The ceptometer was placed parallel to the vine row centrally within the canopy just above the fruiting cane, mid-canopy, and upper canopy (0.6 m, 1.2 m, and 2.0 m above the soil surface, respectively) and these locations were flagged for return measurements. Above-canopy readings were taken at the same time as below-canopy readings but were averaged across the hour to address temporal variability.

Soil moisture and stem water potential. Volumetric soil water content (θ_v) was measured using a capacitance probe (AP-204; AquaPro Sensors, Ducor, CA) at least 12 times per season, starting before bloom and continuing until 4 weeks prior to harvest. One access tube per plot was installed at the onset of the long-term experiment (2007) and was replaced as needed. Access tubes were positioned under the trellis, 0.3 m from a mid-plot vine. Measurements were recorded

at depths of 15, 22.5, 30, 45, 60, and 75 cm. Values obtained using the capacitance probe were converted to θ_v using an equation based on readings and known volumetric water content developed for the soil previously. Data were analyzed at each depth but averaged over the first four depths due to similarities in this portion of the profile.

Mid-day stem water potential (Ψ_s) was measured within one hour of solar noon on cloudless days starting after bloom and continuing until post-véraison. Healthy, fully expanded primary leaves located mid-canopy were sealed in Mylar zip-close bags. Leaves were removed from the vine after at least one hour, cut with a razor blade at the petiole end, and immediately measured in a pressure chamber (Model 600; PMS Instruments, Albany, OR). One leaf per plot was measured in 2011 and three leaves per plot were measured in 2012 and 2013.

Leaf gas exchange. A fully expanded primary leaf in the mid-canopy was selected from each plot in Grass and Tilled treatments on the exposed side of the canopy (east in the morning and west for solar noon and afternoon measurements). Gas exchange was measured (LiCor 6400-XT; LiCor Inc., Lincoln, NE) between 1100 and 1245 HR Pacific Daylight Time (PDT), between 1310 and 1450 HR PDT at solar noon, and between 1430 and 1535 HR PDT in the afternoon on clear, sunny days during bloom, pea-size, véraison, and ripening in 2012 and 2013. The flow meter was set to 400 $\mu mol \cdot s^{-1}$, the CO_2 mixer to 400 ppm, and the temperature and relative humidity to the ambient conditions. Measurements across all plots were completed within 60 minutes to avoid variable readings resulting from major shifts in environmental conditions. Photoassimilation rate (P_n) and stomatal conductance (g_s) were calculated from gas exchange measures.

Yield components. A five-cluster sample was harvested from four vines in each plot approximately weekly, starting three weeks prior to harvest to track ripening. Fruit was harvested

from the other four vines in the plot the same day or up to two days prior to commercial harvest each year. Clusters were counted and weighed by plot. Yield was expressed per unit row length. Average cluster weight was back-calculated. A seven-cluster sample was randomly selected per plot. In the laboratory, only five clusters and their rachises were weighed and berries counted for efficiency. Rachis weight was subtracted from cluster weight when berry weight was calculated. Berries were removed from all seven clusters and stored at 4 °C until next day for juicing.

Juice analysis. Fruit was pressed to juice within 24 hours of harvest. In 2011, this was done by placing fruit in a gallon-sized zippered plastic bag and pressing with a rolling pin, and juice was filtered through two layers of cheesecloth. In 2012 and 2013, fruit was juiced using a Welles Juice Press (Samson Life Inc., Danbury, CT) with the sample enclosed in a muslin bag. A 50 mL aliquot was frozen at -20 °C for analysis of yeast assimilable nitrogen (YAN). The remaining juice was measured for total soluble solids (TSS), pH, and titratable acidity (TA). Total soluble solids were measured in °Brix using a digital temperature-compensating refractometer (Digital Refractometer 300024; Sper Scientific Ltd., Scottsdale, AZ). The pH of the juice sample was measured with a temperature-compensating pH meter (Accumet AB15; Fisher Scientific, Pittsburgh, PA). Titratable acidity (TA) was determined by using a 5 mL juice sample diluted in 45 mL of distilled water and titrated to a pH end point of 8.2 with 0.1 N sodium hydroxide and is expressed in $g \cdot L^{-1}$ of tartaric acid equivalents.

Yeast assimilable N content was determined by measuring N from primary amino acids (excluding proline and hydroxyproline) and ammonia using separate assays. Nitrogen from primary amino acids was determined spectrophotometrically following the protocol from Dukes and Butzke (1998) with a few modifications. Juice samples were defrosted, shaken, centrifuged (Sorvall ™Legend™ XTR; Fisher Scientific, Langenselbold, Germany) for 5 min at 10,000 g_n,

and a 0.5-mL aliquot was diluted 1:1 v/v with distilled water. A juice sample and a juice blank, containing no *ortho*-phthalaldehyde (Sigma-Aldrich, St. Louis, MO) were run and measured against a blank containing distilled water in substitution of juice, and the reagent with or without the OPA, depending on whether juice samples or juice blanks were being measured. After 10 min, samples were measured by spectrophotometer (Genesys 10S UV-VIS; ThermoFisher Scientific, Madison, WI) at 335 nm and compared against an L-isoleucine (Sigma-Aldrich, St. Louis, MO) standard curve. Ammonia N was determined from juice samples spectrophotometrically using an enzymatic assay kit (R-Biopharm AG, Darmstadt, Germany). Total YAN was calculated by the sum of N from both assays (expressed as mg $N \cdot L^{-1}$).

Statistical analysis. Statistical analyses were performed using SAS Statistical Software 9.3 (SAS Institute, Cary, NC) using PROC MIXED for analyses of variance (ANOVA). When significant differences were found (α=0.05), separation of means were determined by Tukey's Honestly Significant Differences (HSD). The data were analyzed separately by year due to seasonal differences. Percent ambient *PPF* data were log-transformed. PROC REG was used for fruit set standards. Simple linear regression was used for regressing tissue N against YAN.

Results

Climate. Year one (2011) was the coolest of the three years and one of the coolest seasons on record for Oregon. Heat unit accumulation from bud break to harvest was 301 and 133 GDD_{10} lower in 2011 than in 2012 and 2013, respectively (Table 2.1). Therefore, the 2011 season spanned approximately 70 more days from bud break to harvest than the other two seasons. The 2012 season was warmer from bloom to harvest than the other two seasons. The 2012 season was also the driest from bloom to harvest, with five to six times less precipitation than 2011 or 2013. Rainfall between bud break and véraison was fairly similar in 2012 and 2013,

140 and 149 mm respectively, however, rainfall between véraison and harvest was much higher in 2013 (55 mm) than 2012 (1 mm, data not shown). The 2011 season had intermediate precipitation during bud break to harvest compared to the other two seasons.

Vine growth. Early season (bud break to bloom) shoot growth was affected by vineyard floor treatment but not by crop level. Shoots from Grass treatments generally elongated more slowly than those from either the Tilled or Alternate treatments. Consequently, shoots were 25% (2013) to 38% (2012) shorter in the Grass treatment than the Tilled treatments by bloom (Fig. 2.1A). Grass treatments had smaller canopies than Alternate and Tilled, with 19% to 39% lower leaf area per shoot at bloom (Fig. 2.1B) and 21% to 45% lower leaf area per shoot at véraison in all years (Fig. 2.1C). At bloom and véraison, Alternate and Tilled had similar leaf area. Cluster thinning resulted in 21% higher leaf area per vine at véraison than in Full Crop in 2011 (P = 0.032, data not shown). In 2012, Grass-Half Crop had longer shoots by the time hedging began (P = 0.039) and higher leaf area at véraison than Grass-Full Crop (P = 0.030), but there were not any crop level effects on growth in the other floor management treatments. There were no differences in 2013 due to crop level.

Vine nutrition. In both petioles and leaf blades, percent N was lower in Grass than Tilled in all instances and generally lower than Alternate at bloom (Table 2.2). Alternate had intermediate petiole N at bloom compared to Tilled and Grass. There were no crop level effects on tissue N except in one instance.

Other than N, there were few consistent differences in nutrient status. Consistent differences across years in tissue nutrient concentrations were apparent in both petiole and leaf blade tissues at bloom for manganese (Mn) and boron (B), and for potassium (K) and zinc (Zn) at véraison. Potassium and Zn tended to be lowest in Grass petioles, by 0.58% to 0.97% (K, $P \leq$

0.023) and by 13 to 23 ppm (Zn, $P \leq 0.028$). By contrast, there were higher Mn ($P \leq 0.011$) and B ($P \leq 0.002$) concentrations in Grass leaf blades than Tilled in 2012 and 2013. Some other macro- and micronutrients differed among treatments but inconsistently, i.e., petiole vs. leaf blade, or across years (Appendices A-D). Crop level did not produce any consistent differences in macro- or micronutrient concentrations over the three years.

Canopy light environment. One date during ripening 2013 (Fig. 2.2), the percent of ambient *PPF* in the cluster zone differed only between Grass and Tilled treatments and only in the afternoon. Lower *PPF* was seen in the fruit zone at the earliest and latest daily time points measured, as shading from adjacent vine rows occurred. More *PPF* tended to infiltrate the mid- and upper canopy of Grass than Tilled. Full Crop had more *PPF* infiltrating the mid-canopy in the morning, but crop level did not affect radiation penetration in the upper canopy (data not shown).

Volumetric soil water content (θ_v*) and stem water potential (*ψ_s*).* The only season-long impact of floor management on θ_v occurred in the upper 45 cm of the soil profile from early June to September 2011, where Grass had lower θ_v than Tilled (Fig. 2.3). In 2012, θ_v was lower in Grass than in Tilled in August, but only at 15 cm (data not shown). There were no differences in θ_v with vineyard floor management at any depth or time in 2013.

Crop level did not influence θ_v, except at one time point in 2012 (29 Aug.) at 60 cm depth and three in 2013 (7 Aug., 13 Aug., and 11 Sept.) at 45 cm depth (data not shown). However, between August and September in 2012, θ_v was 7 to 8% higher in Grass-Half Crop than in Grass-Full Crop at 45 cm ($P \leq 0.045$).

Despite lower θ_v in Grass treatments during 2011, there were no differences among treatments in ψ_s measured on the same dates (Appendix B). In 2012, Grass ψ_s was -0.66 MPa in

late Aug. while Tilled was -0.76 MPa ($P = 0.011$) and Grass ψ_s was -0.77 MPa in mid-Sept. while Tilled was -0.89 MPa ($P = 0.047$). The Alternate treatments had intermediate stem water potentials at these time points. Crop level had little effect on ψ_s in all years. Overall, the lowest ψ_s values occurred in mid- to late September at -0.78 (2011), -0.89 (2012), and -0.64 MPa (2013).

Leaf gas exchange. Mid-canopy P_n increased from the bloom to pea-size then decreased during the remainder of the season in 2012 and 2013. Both years showed similar patterns, but only 2012 data are presented for brevity (Fig. 2.4). There was lower P_n in Grass than in Tilled at some phenological stages and times of day, but patterns were inconsistent. For example, in the morning during bloom, véraison, and ripening, P_n in Grass was 20%, 23%, and 19% lower than Tilled. However, there was only a difference at bloom (Grass < Tilled) in 2013. Results were mixed for the noon and afternoon readings. Where differences were found, P_n was lower in Grass than Tilled. Crop level had no influence on P_n except for a single measurement at véraison in 2011 where Full Crop had a P_n of 18.5 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$ and Half Crop had a P_n of 21.2 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$ ($P = 0.008$).

Consistent with P_n, there were few differences in g_s in any year. Only during solar noon at bloom of 2012 was g_s in Grass different from Tilled (Grass 0.25 mol $H_20 \cdot m^{-2} \cdot s^{-1}$, Tilled 0.38 mol $H_20 \cdot m^{-2} \cdot s^{-1}$; $P = 0.006$). Results were also mixed with respect to crop level and few differences were found. The highest g_s measured was at pea-size in Tilled (0.73 $mol \cdot m^{-2} \cdot s^{-1}$; 2012) and the lowest was at ripening in Half Crop (0.15 mol $H_20 \cdot m^{-2} \cdot s^{-1}$; 2012).

Yield components. Differences in inflorescences per shoot were found in 2012 and 2013, with Grass having fewer inflorescences per shoot than Tilled (Table 2.3). Grass also had fewer florets per inflorescence relative to Tilled in all years and greater fruit set than Tilled in 2011 and

2012. Alternate treatments generally had intermediate values compared to Grass and Tilled treatments. There were no differences in inflorescences per shoot, florets per inflorescence, or fruit set found by crop level. In 2012, inflorescence necrosis was observed in Tilled and to a lesser extent, Alternate treatments, which may have led to the similar yields among floor treatments.

The number of berries per cluster early in the season (determined just after fruit set) was lower in Grass than Alternate and Tilled only in 2013 (Table 2.3). At harvest in 2011, Grass had fewer berries per cluster than Tilled or Alternate, but in 2012 and 2013 there were similar numbers of berries per cluster among floor treatments. In 2012, post-fruit set berry counts were later than the other years, as berries continued to drop after the original assessment, making the number of berries per cluster post-fruit set and the number at harvest more similar than in 2011 or 2013. Crop level did not impact berries per cluster.

Vineyard floor treatments impacted yield in 2011 and 2013, with Grass having lower yields than Tilled both years (Table 2.4). The difference in 2011 may be accounted for by lower cluster weights from fewer berries per cluster. By contrast, the yield difference in 2013 could be attributed to fewer clusters per vine, partially driven by fewer shoots per vine. There were no differences in yield among floor management treatments in 2012, as clusters per vine and cluster weights were inconsistent. As expected, Half Crop treatments had 35% to 42% lower yields than Full Crop treatments, which resulted from fewer clusters per vine. Crop level influenced cluster weights in one year (2012; Half Crop > Full Crop), but did not influence berry weights in any year.

Vineyard floor treatments affected dormant pruning weights. Grass had lower pruning weights compared to Tilled, while Alternate was intermediate (Table 2.4). Cane weights were

55, 96, and 109 g for Grass, Alternate, and Tilled treatments, respectively in 2012 ($P < 0.0001$) and treatment averages were 3-12 g lighter in 2013. Crop level did not affect total pruning or individual cane weights in either 2012 or 2013.

Juice analysis. Total soluble solids (TSS) and pH were more affected by crop level than by floor management (Table 2.5). However, in 2012, TSS from Grass was lower than Tilled. Juice pH was not affected by vineyard floor treatment in any year. Titratable acidity was lower in Grass compared to Tilled and Alternate in 2011 and 2012. Half Crop had higher TSS than Full Crop at harvest in all years. Differences in TSS by crop level were detected earlier in 2011 and 2012 than in 2013 (data not shown). Half Crop had higher pH than Full Crop in 2 years and lower TA in 1 year.

Juice from Grass had the lowest YAN at harvest in all years (Table 2.6). The lower YAN in Grass was due to lower concentrations of N from both primary amino acids and ammonia. In 2012, Half Crop had 24.1% higher YAN concentrations compared to Full Crop, which was also due to higher N concentrations from both primary amino acids and ammonia.

Leaf tissue N at bloom and véraison had a strong linear relationship with juice YAN at harvest (Fig. 2.5). YAN generally increased with increasing tissue N at all times measured in all years, but bloom petiole tissues responded non-linearly depending on year (data not shown). There was no tissue type or timing that was best related with YANs consistently over the three years. Tissue N concentrations that predicted the target minimum YAN of 140 mg $N \cdot L^{-1}$ were determined separately from each equation, resulting in an average of 2.70% in bloom leaf blades, 0.38% in véraison petioles, and 2.11% in véraison leaf blades over the three years.

Discussion

This experiment was designed with vineyard floor treatments to alter vine vigor and cluster thinning to alter crop level to achieve a range of crop loads by which to investigate biological outcomes of varying the source-sink relationship. However, few interactions between vineyard floor treatments and crop level were found. The vineyard floor treatments effectively altered vine vigor as measured by early season shoot growth, whole vine leaf area, and pruning weight while crop level mainly impacted yield, TSS, and pH. However, lower yields in Grass resulted in a truncated range of Ravaz Indices (yield to pruning weight ratio, 0.5 to 3.7). Suggested Ravaz Indices for sustainable production are between 3 and 10 (Bravdo et al., 1984, 1985), but are likely to be lower in cool climates, or small clustered varieties such as 'Pinot noir' (Kliewer and Casteel, 2003; KIiewer and Dokoozlian, 2005).

Across years, N was the most consistently reduced vine nutrient in the presence of a cover crop, despite some differences in other macro- and micronutrients. Results indicate that the perennial grass had an impact on reducing canopy size in Grass through competition for N early season or reduced N reserves in woody tissues from prior years under the Grass treatment, particularly as water was not limiting at this time (Celette et al., 2009). Grass treatments had reduced shoot growth in spring, less leaf area, and reduced tissue N at bloom, as compared to other vineyard floor treatments, similar to other studies that used competitive cover crops like Gramineae species, as opposed to studies using leguminous cover crops (Celette et al., 2009; Giese et al., 2015; Hatch et al., 2011; Monteiro and Lopes, 2007; Perez-Álvarez et al., 2015; Volaire and Lelièvre, 2010). In addition, N fertilization studies (Cheng et al., 2004; Schreiner et al., 2013) show similar reductions in vine growth when N was restricted, supporting the role of grasses in reducing N available to the vine. Reductions in canopy size were found at véraison in

the Grass treatment and included leaf area, reduced N and pruning weights at dormancy. Growth effects may have been carried over from the limited growth early in the season. By the end of each season, Grass treatments had the lowest pruning weights and were considered closest to optimal (0.3-0.6 $kg \cdot m^{-1}$), as suggested for Oregon vineyards (Kliewer and Casteel, 2003).

Leaf blades from Grass and Alternate treatments at bloom were deficient in N based on thresholds of 2.2% to 2.5% for 'Pinot noir' in this region (Schreiner and Skinkis, 2014). All treatments in 2011 and 2012 and Grass and Alternate treatments in 2013, were also considered to be N-deficient (Schreiner and Skinkis, 2014), as véraison petiole levels were ≤ 0.4%. Despite reduced leaf area and yield in Grass, all three treatments were considered to be of reasonable production standards and did not require additional N fertilization. This may suggest a lower critical tissue value can be maintained without detrimental effects on vine productivity.

Stem water potential did not differ by floor management, which supports the notion of N limitation as the driving factor behind reduced vegetative growth in the presence of the grass cover crop. Stem water potential never fell below –0.9 MPa and g_s was above 0.15 mol $H_2O \cdot m^{-2} \cdot s^{-1}$, suggesting that none of the treatments were experiencing water stress, according to published data (Cifre et al., 2005; Williams and Araujo, 2002; Williams and Baeza, 2007). Water stress is thought to be occurring at leaf water potentials (ψ_l) of less than -1.2 MPa (Williams and Baeza, 2007), which is approximately -0.91 MPa for stem water potential determined from the relationship between ψ_l and ψ_s (Williams and Araujo, 2002).

The temporal and spatial uptake of water by the grass in the alleyway compared to vines may account for differences in θ_v but not differences in vine water status (Celette et al., 2005, 2008). Cool-season grasses are active under cool temperatures, likely causing competition with the vine early season for water and nutrients (Celette et al., 2009) but may be less competitive

later in summer when they become quiescent under warmer and dry conditions. Lower θ_v was found in the upper soil profile of Grass plots mainly in 2011 but did not impact ψ_s. In August and September of 2012, the Grass treatment likely had reduced θ_v in the upper soil depths due to much less precipitation between bloom and harvest that year. The grass likely used the water in this section of the soil profile while it was active earlier in the season as grass transpiration is higher than evaporation from bare soil surface (Celette et al., 2008; Centinari et al., 2013). However, ψ_s was less negative in Grass than Tilled at the latest time point in the 2012 season, similar to Hickey et al. (2016) findings in two of three years. Other studies that compared grass cover to bare ground found reduced θ_v in grass treatments but little to no impact on ψ_s (Giese et al., 2015; Hatch et al., 2011; Sweet and Schreiner, 2010). Grass vine water status may have been less affected by the lower soil moisture in the depths we measured due to potentially greater and deeper root growth, as increased root growth has been found in N-limited or grass-intercropped vineyards (Celette et al., 2008; Keller and Koblet, 1995). Grass vines may also have had increased root growth under the vine row, reducing soil moisture where measurements were taken, as there is some evidence that suggests a horizontal shift in root growth in the presence of alleyway cover crops (Celette et al., 2005, 2008). Additionally, Grass had reduced leaf area and g_s was lower compared to Tilled, which likely reduced vine transpiration, as has been seen when comparing small canopy vines with those of larger canopy sizes (Myburgh et al., 1996; Williams and Ayars, 2005).

There were few differences in g_s due to floor management and inconsistent differences due to crop level, similar to other studies that have compared g_s in vines grown with or without a competitive cover crop (Celette et al., 2005; Hatch et al., 2011). In an N-restriction study in ‘Pinot noir’, there were no differences in g_s (Schreiner et al., 2013). There was no clear impact of

crop level on g_s, which is similar to the mixed results seen in the literature (Naor et al., 1997; Petrie et al., 2000b). Similar to the current study, lower P_n has been found in vines grown in the presence of grass compared to herbicide-treated soil (Krohn and Ferree, 2005). Work with vines grown with restricted N also showed reduced P_n (Cheng et al., 2004; Schreiner et al., 2013). Grass likely had reduced P_n due to the reduced leaf blade N which is an important factor in photoassimilation (Boussadia et al., 2011).

In the present study, differences in incident *PPF* at locations in the vine canopy were expected as leaf area varied among floor management treatments. The diurnal *PPF* curves showed specific times when Grass had higher incident light than Tilled in the mid- and upper-canopy. The magnitude of differences in *PPF* between Grass and Tilled reflects variations in attributes such as the horizontal distribution and density of shoots positioned in the trellis catch wires. Nonetheless, there was a clear trend of higher *PPF* in Grass canopies. Combined with the reduced leaf area in Grass, whole vine assimilation may be lower compared to Tilled. Alternatively, because of the higher leaf area of Tilled, *PPF* reaching the interior canopy was <350 $\mu mol \cdot m^{-2} \cdot s^{\cdot -1}$, which is less than light saturation for optimal P_n (1036 $\mu mol \cdot m^{-2} \cdot s^{\cdot -1}$; Cartechini and Palliotti, 1995). In most research on crop-thinned vines, there is lower P_n associated with crop thinning (Edson et al., 1995a; Naor et al., 1997; Petrie et al., 2000b). However, we found no impact of crop thinning on P_n, consistent with Chaumont et al. (1994).

Several studies have shown leaf area and shoot growth to be reduced by higher crop levels (Edson et al., 1995b; Keller et al., 2005; Petrie et al., 2000a). However, other crop thinning studies did not find any influence of yield on vegetative growth (Naor et al., 1997; Vance, 2012). The influence of crop thinning on vegetative growth may depend on physiological yields. The 2012 and 2013 seasons had lower than average yields in this study, and no effect on canopy size,

whereas crop thinning in 2011 increased leaf area at véraison in this higher yielding year. For years in which both leaf area and pruning weight data were collected, there were no differences in either due to crop level, contrary to many others (Bravdo et al., 1984; Bravdo et al., 1985; Dami et al., 2006; Kliewer et al., 1983; Weaver and Pool, 1968), but these were the low yielding years of our trial.

Floor treatments affected yield in 2 years of the study. Grass had fewer berries per cluster in 2011 and fewer clusters per vine in 2013. Some studies have found decreased yields in the presence of a competitive cover crop (Celette et al., 2005; Hatch et al., 2011; Volaire and Lelièvre, 2010). Other cover cropping studies did not report differences in yield when cover crops were compared to bare ground, likely due to the short durations of cover crop establishment (Steenwerth et al., 2013; Sweet and Schreiner, 2010) or due to N fertilization (Giese et al., 2015; Monteiro and Lopes, 2007). Vines with low N reserves have reduced yields (Cheng et al., 2004; Schreiner et al., 2013); supporting our contention that lower tissue N through grass competition reduces yields.

In the current study, TSS differed by floor management when yields were comparable. In 2012, yields were similar among floor treatments but fruit from Grass treatments had significantly lower TSS than Tilled or Alternate. Grass, although lower vigor, achieved similar ripeness to Tilled in 2011 and 2013 as yields were reduced. Yield reduction in Grass treatments may have been associated with reduced $P_{n,}$ resulting in no difference in TSS between Grass and Tilled treatments. However, some studies have not found differences in TSS when comparing cover crops to bare ground even when yields were not altered (Giese et al., 2015; Monteiro and Lopes, 2007; Sweet and Schreiner, 2010). Alternatively, Schreiner et al. (2013) found higher TSS in N-restricted vines as yields were reduced compared to higher N treatments. As in our

study, no differences in juice pH were found in vines grown with cover crops or bare soil (Monteiro and Lopes, 2007; Perez-Álvarez et al., 2015; Sweet and Schreiner, 2010). Giese et al. (2015) and Sweet and Schreiner (2010) did not find any differences in TA when comparing cover crops to tilled vineyard floor treatments, but Monteiro and Lopes (2007) found higher TA in their tilled versus vegetated treatment, as was found for two years in our study.

Regardless of the vigor level imposed by the floor management treatments, cluster thinning to one cluster per shoot increased TSS. Cluster thinning studies of high-yielding cultivars have shown delays in TSS accumulation when vines were not cluster-thinned (Bravdo et al., 1984; Edson et al., 1995b; Naor et al., 2002). Although 'Pinot noir' grown in the Willamette Valley generally have low yields, a 3- to 6-day delay in TSS accumulation was generally observed in the Full Crop, which persisted until harvest during all years. Cluster thinning 'Pinot noir' in British Columbia, Canada resulted in higher TSS in 2 of 4 years, pH in 1 year, but no differences in TA (Reynolds et al., 1994). The amount of yield reduction that may be needed is dependent upon the cultivar, canopy size, training system, yield, season, and climate.

Grass and Alternate treatments in 2011 and 2012, had YAN levels lower than the recommended 140 mg $N \cdot L^{-1}$ (Bell and Henschke, 2005). Reduced YAN, amino acid N, and/or ammonia concentrations have been found in studies under reduced N fertilization (Schreiner et al., 2013) or competitive cover crop (Giese et al., 2015; Gouthu et al., 2012). Both primary amino acid N and ammonia N were decreased in the Grass treatment. Year influenced the slope of the relationship between tissue N and YAN. Bloom leaf blade N may be the best indicator for using current-season N fertilization to affect YAN at harvest. However, there is little work on predictive recommendations. Based on our 3-year study, bloom leaf blade N concentrations of

2.7% would be suggested to achieve 140 mg $N \cdot L^{-1}$ YAN at harvest, similar to Schreiner et al. (2013), who used potted vines. Neilsen et al. (2010) recommended 0.5% N concentration in petioles at véraison to achieve 140 mg $N \cdot L^{-1}$ in lower yielding years; they did not find relationships between bloom N and harvest YAN. Trying to achieve YAN concentrations of 140 mg $N \cdot L^{-1}$ though vine or tissue N, may result in higher vigor vines however. Clearly, more work is needed to determine recommendations for tissue N levels to achieve certain YAN concentrations, particularly in high vigor vineyards where increased vine vigor is not desired.

Reducing crop level through thinning was not an effective strategy to increase YAN at harvest; an effect was only found in one year and the increase in YAN was too small to be of practical value in the winery (24.1 mg $N \cdot L^{-1}$). Other studies conducted on 'Pinot noir' in the Willamette Valley did not show increased YANs when vines were crop thinned (Navarrete, 2015; Vance, 2012). However, when Neilsen et al. (2010) compared véraison petiole N to YAN concentrations, YANs were lower at a given petiole concentration in the highest yielding year.

Practical advantages of using Grass treatments to control vigorous vines in the Willamette Valley may include reducing canopy size, controlling yields, and ecological and practical benefits of perennial cover crops. Labor savings on canopy management practices may be possible if growers change from current standards (Alternate) to the use of perennial grass cover in all alleyways. Both Alternate and Tilled treatments grew to fill the trellis and required multiple hedging passes to reduce overgrowth, while Grass treatments had not fully filled the trellis. In the Grass treatment fruit zone, *PPF* was increased in the afternoon due to less leaf area, suggesting that less labor may be required for leaf pulling or that pulling may not be required, as it is an expensive practice when done manually. Despite lower yields in the Grass treatment, production was still within the 4.5 to 6.2 $t \cdot ha^{-1}$ range typically required of premium 'Pinot noir'

producers (Uzes and Skinkis, 2016), suggesting less crop thinning would be required, or may not be needed in some years. Cluster thinning is a more expensive practice than leaf pulling, as it cannot be reasonably mechanized at this time and requires twice as many labor hours than manual leaf pulling (Julian et al., 2008). However, seasonal differences can result in varying effects of the cover crop as fruit set in this region is highly variable by year, so utilization of cover crops for the sole purpose of adjusting yield is not warranted and could prove risky. Grass treatments were able to reach similar ripening levels as Alternate treatments and additionally had reduced TA, even in the cool 2011 season. Levels of YAN were reduced in Grass but did not result in problems with the wine completing fermentation (R. Schultz, personal communication). Local growers who farm without irrigation are reluctant to grow grasses in the alleyways during the growing season as they are concerned about conserving soil water and avoiding competition. This study shows no additional vine water stress with grassed alleyways. There may be ecological advantages of using perennial grass in alternate alleyways, although there were few differences in vine growth and productivity compared to Tilled. The ecological benefits of using perennial grass cover crop in-season may be of interest to growers who are a part of environmentally-focused farming certification programs. Reducing the tilled surface area by using grass can prevent loss of soil organic matter (Merwin et al., 1994) and may prevent erosion late in the season, before a winter cover crop is established (Novara et al., 2011). Both mowing and tilling only required a single tractor pass in this climate. The devigorating effect of grass on vines may also reduce the number of times vines are hedged which would limit CO_2 emissions from fuel combustion and reduce soil compaction. A perennial grass cover crop can also provide practical benefits such as promoting traction for equipment and workers, or decreasing canopy density.

Conclusion

Vineyard floor management altered vegetative growth, yield and fruit N concentrations while cluster thinning primarily affected berry composition. Using perennial grass cover in high-vigor vineyards may be an effective management strategy to reduce canopy size while maintaining sufficient canopy to ripen fruit. The reduced canopy size and fruit N concentration found with growing a long-term perennial grass cover suggests the impact of N limitation, not water limitation, which may lead to lower yields over time. While no supplemental irrigation was required at this site, producers may need to consider impacts of growing perennial grass in vineyards of different soil depth and soil type. Producers who choose to use perennial grass cover in vineyards will need to monitor vine N status and fruit YAN at harvest and consider supplementation of N in the winery or in the vineyard when levels become too low and result in reduced fruit quality or yield.

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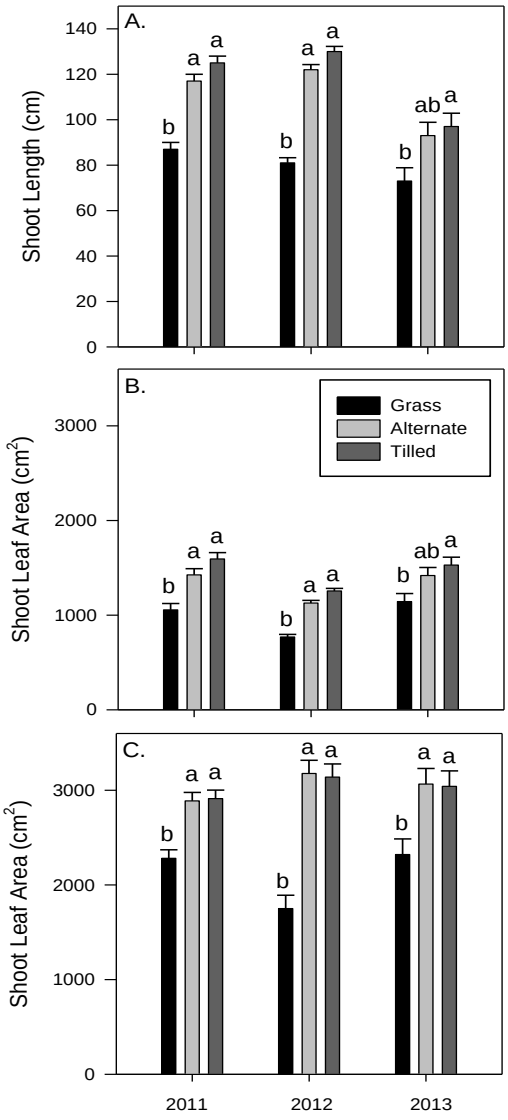

Figure 2.1. Mean (± SE) shoot length at bloom (A), leaf area at bloom (B), and leaf area at véraison (C) from 2011 to 2013 by vineyard floor management treatments. Floor treatments include Grass (black) - red fescue established in both alleyways flanking the vine row; Alternate (light grey) - red fescue in one flanking alleyway while the other was tilled; and Tilled (dark grey) - the two flanking alleyways were kept free of vegetation by tilling. Different letters each year represent means separation by Tukey's HSD at α=0.05.

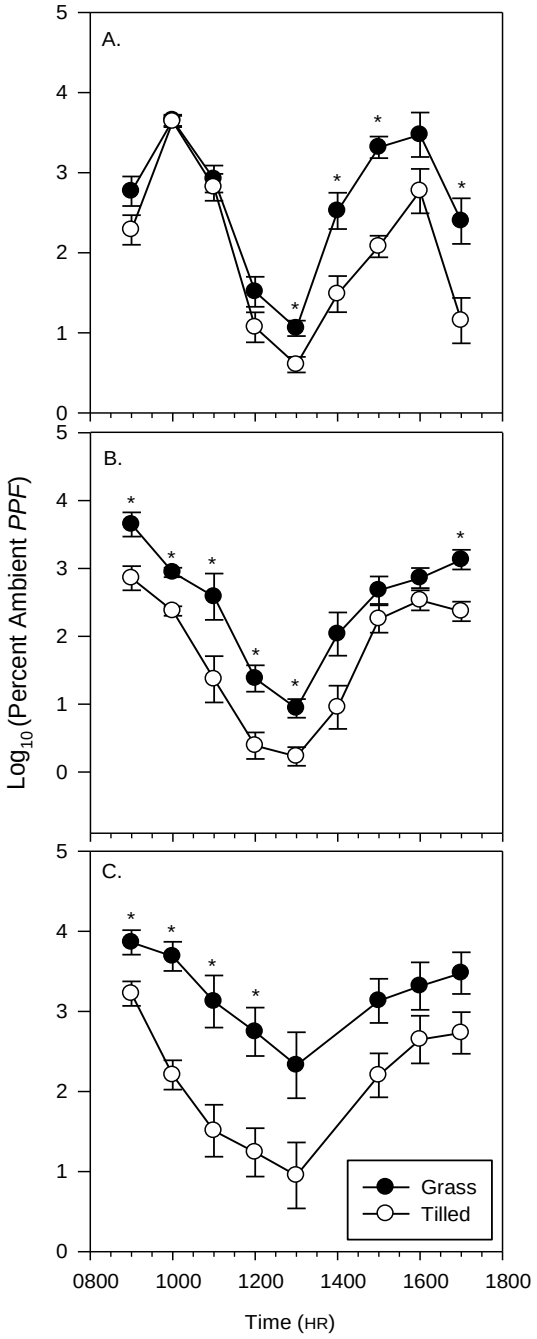

Figure 2.2. Mean (± SE) percent of ambient *PPF* (Log_{10} transformed) during ripening on 12 Sept. 2013 in the fruit zone (A), mid canopy (B), and the upper canopy (C). Vineyard floor management treatments include Grass (●) - red fescue established in both alleyways flanking the vine row, and Tilled (○) - the two flanking alleyways were kept free of vegetation by tilling. The ceptometer was placed centrally amongst shoots and clusters within the canopy, parallel to the vine row. *Significant at $P \leq 0.05$ by Tukey's HSD.

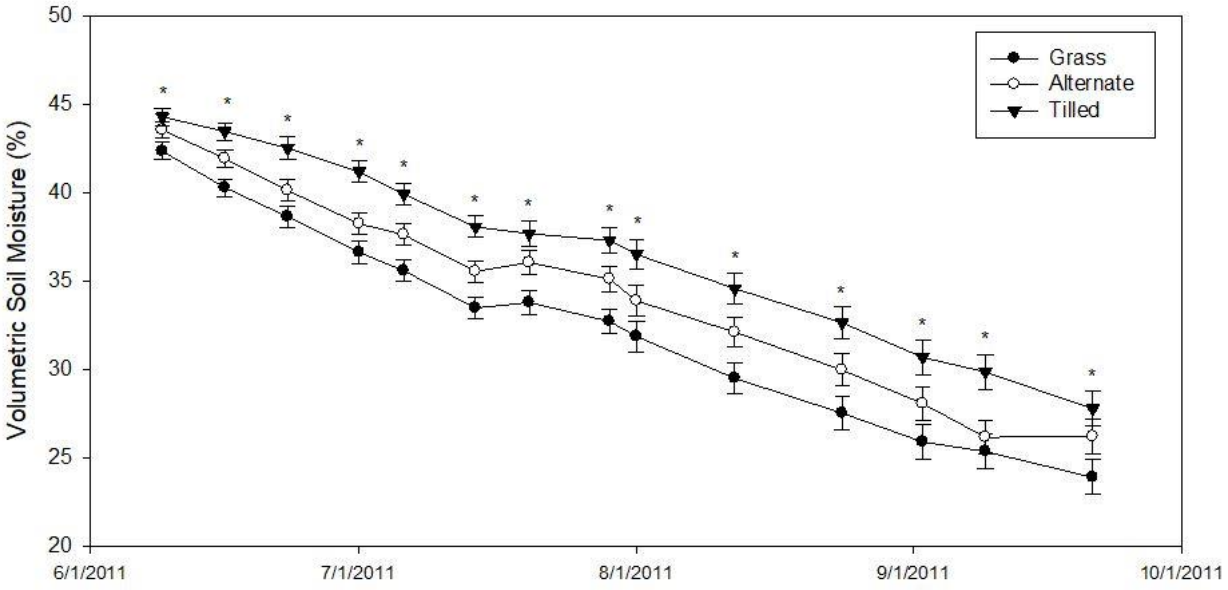

Figure 2.3. Mean (± SE) volumetric soil water content (θ_v) averaged from 15 to 45 cm during 2011 by vineyard floor management treatments. Floor treatments include Grass (●) - red fescue established in both alleyways flanking the vine row; Alternate (○) - red fescue in one flanking alleyway while the other was tilled; and Tilled (▼) - the two flanking alleyways were kept free of vegetation by tilling. *Significant at $P \leq 0.05$ by Tukey's HSD.

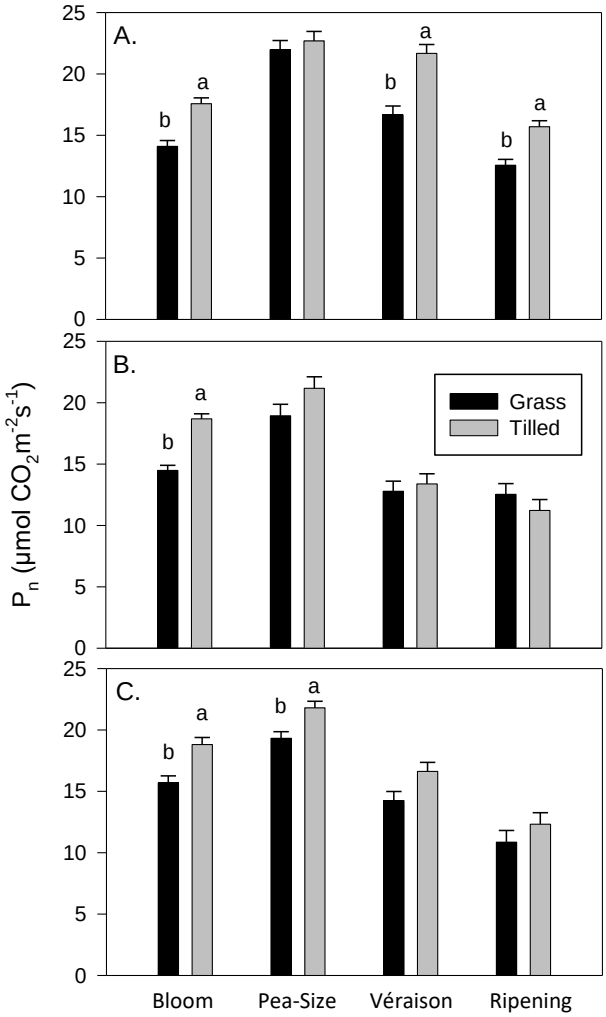

Figure 2.4. Mean (± SE) leaf photoassimilation rates (P_n) during four phenological stages in 2012 assessed at 1100 HR PDT (A), 1310 HR PDT (B), and 1430 HR PDT (C). Vineyard floor management treatments include Grass (black) - red fescue established in both alleyways flanking the vine row, and Tilled (grey) – both alleyways flanking the vine row were kept free of vegetation by tilling. Different letters in a given time point represent a difference in means for each phenology by Tukey's HSD at α=0.05.

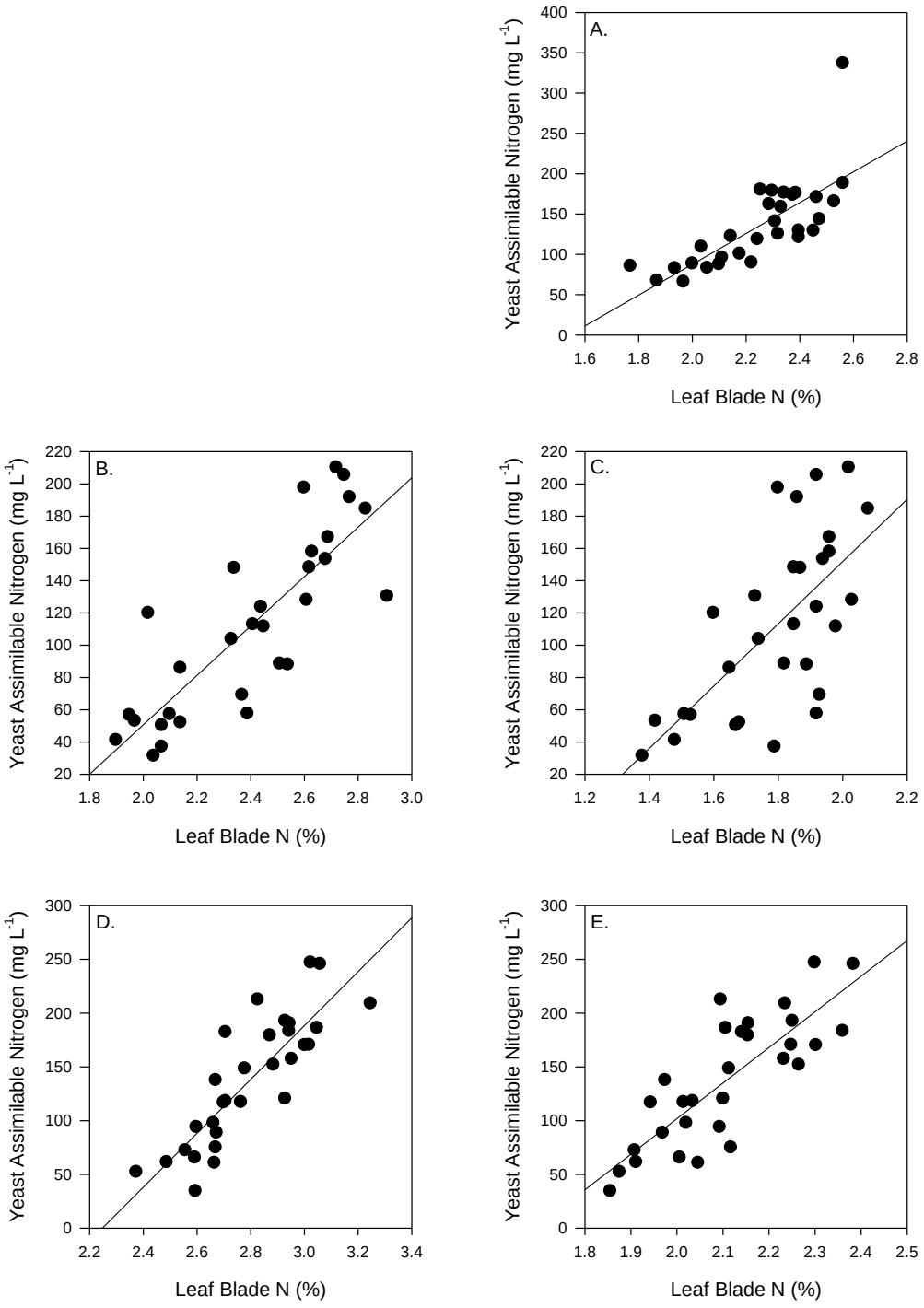

Figure 2.5. Linear regressions of leaf blade N (%) and juice yeast assimilable nitrogen (YAN) at bloom (B and D) and véraison (A, C, and E) in 2011 (A), 2012 (B-C), and 2013 (D-E). A. r^2=0.5538, B. r^2=0

Table 2.1. Seasonal climate summary by phenology of the grapevine at the experimental site located in Dayton, OR for 2011 to 2013.

Phenology	Dates			GDD_{10}[z]			Mean Daily Temperature (°C)			Precipitation (mm)		
	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
Bud break to bloom[y]	May 6 - Jul 4	Apr 24 - Jun 21	Apr 18 - Jun 8	241	303	245	13.55	14.32	14.19	81	123	101
Bloom to véraison	Jul 4 - Sept 6	Jun 21 - Aug 30	Jun 8 - Aug 14	616	803	655	19.05	21.11	18.87	26	16	47
Bloom to harvest	Jul 4 - Oct 20	Jun 21 - Oct 2	Jun 8 - Sept 18	906	1147	1036	17.69	21.05	19.20	84	17	103
Bud break to harvest	May 6 - Oct 20	Apr 24 - Oct 2	Apr 18 - Sept 18	1139	1440	1272	16.22	18.63	17.52	165	141	204
Full season	Apr 1 - Nov 1	Apr 1 - Nov 1	Apr 1 - Nov 1	1168	1665	1413	14.60	17.38	15.79	268	356	386

[z] Growing degree days (GDD_{10}) calculated by Σ ((daily maximum temperature (°C) + daily minimum temperature (°C))/2-10).
[y] Bud break is date at which approximately 50% of the buds reached BBCH stage 07, bloom is BBCH stage 65, véraison is date at which approximately 50% of the berries reached BBCH stage 83.

Table 2.2. Petiole and leaf blade nitrogen concentrations (%) at bloom and véraison from 2011 to 2013 by vineyard floor management treatments.

Treatments	2011		2012		2013	
	Blade	Petiole	Blade	Petiole	Blade	Petiole
			Bloom[z]			
Floor mgt. (F)[y]						
Grass	n.d.[x]	0.6 c[w]	2.0 c	0.4 c	2.6 c	0.7 b
Alternate	n.d.	0.9 b	2.4 b	0.5 b	2.8 b	0.8 ab
Tilled	n.d.	1.0 a	2.7 a	0.8 a	3.0 a	0.9 a
P-value						
F	n.d.	<0.001	<0.001	<0.001	<0.001	0.039
C	n.d.	n.d.	NS[u]	NS	NS	0.017
F x C	n.d.	n.d.	NS	NS	NS	NS
			Véraison[v]			
Floor mgt. (F)						
Grass	2.0 b	0.3 c	1.6 b	0.3 b	2.0 b	0.4 b
Alternate	2.3 a	0.4 b	1.9 a	0.3 b	2.1 b	0.4 ab
Tilled	2.4 a	0.4 a	1.9 a	0.4 a	2.3 a	0.5 a
P-value						
F	0.001	<0.001	<0.001	0.003	<0.001	0.013
C	NS	NS	NS	NS	NS	NS
F x C	NS	NS	NS	NS	NS	NS

[z] Samples collected at bloom consisted of 20 fully expanded leaves taken from the same node as the basal cluster, and separated into petiole and leaf blades for analysis.
[y] Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.
[x] n.d.- not determined. Leaf blades were not analyzed at bloom in 2011 and crop level effects were not determined because crop level treatments were not yet implemented.
[w] Different letters following means within a column represent differences by Tukey's HSD at α=0.05.
[v] Samples collected at véraison consisted of 10 pairs of fully expanded leaves; each pair consisted of one leaf from the same node as the basal cluster and one from the apical third of the canopy. Petiole and leaf blades were separated for analysis.
[u] NS – not significant at $P > 0.05$.

Table 2.3. Yield components measured in vineyard floor management and crop level treatments during 2011 to 2013.

	Inflorescences per shoot			Florets per inflorescence			Fruit set (%)			Early berries per cluster[z]			Harvest berries per cluster		
Treatments	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
Floor mgt. (F)[y]															
Grass	1.4	1.5 b[x]	1.4 b	253 b	254 b	234 b	77 a	44 a	73	194	107	166 b	106 b	108	88
Alternate	1.5	1.6 ab	1.6 a	310 b	265 ab	275 a	69 ab	46 a	69	205	105	189 a	146 a	102	85
Tilled	1.4	1.7 a	1.8 a	380 a	283 a	294 a	63 b	37 b	68	225	99	196 a	150 a	98	89
Crop level (C)[w]															
Full crop	n.d.[v]	1.6	1.6	n.d.	263	262	n.d.	43	68	n.d.	104	177	130	105	87
Half crop	n.d.	1.6	1.6	n.d.	272	273	n.d.	42	71	n.d.	103	190	139	100	88
P-value															
F	NS[u]	0.021	<0.001	0.001	0.026	<0.001	0.021	0.013	NS	NS	NS	0.010	<0.001	NS	NS
C	n.d.	NS	NS	n.d.	NS	NS	n.d.	NS	NS	n.d.	NS	NS	NS	NS	NS
F x C	n.d.	NS	NS	n.d.	NS	NS	n.d.	NS	0.049	n.d.	NS	NS	NS	NS	NS

[z] Berries per cluster measured post-fruit set (BBCH 71).
[y] Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.
[x] Different letters following means within a treatment column represent differences by Tukey's HSD at α=0.05.
[w] 000000
[v] n.d.- not determined; crop level treatment not implemented by time of measurement in 2011.
[u] NS - not significant at $P > 0.05$.

Table 2.4. Vine growth and yield variables from vineyard floor management and crop level treatments in 2011 to 2013.

	Shoots per vine[z]			Clusters per vine			Cluster wt. (g)			Yield (kg·m row^{-1})			Pruning wt. (kg·m row^{-1})		
Treatments	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013	2011	2012	2013
Floor mgt. (F)[y]															
Grass	19 b[x]	20 b	17 b	26	26 b	22 b	101.7 b	95.9 ab	75.1	1.76 b	1.62	1.10 b	n.d.[w]	0.6 c	0.6 c
Alternate	22 a	19 b	18 a	30	27 ab	27 a	142.5 a	102.1 a	75.1	2.76 a	1.79	1.31 ab	n.d.	1.1 b	1.0 b
Tilled	22 a	21 a	19 a	30	29 a	29 a	159.1 a	88.8 b	71.3	3.11 a	1.62	1.35 a	n.d.	1.3 a	1.2 a
Crop level (C)[v]															
Full Crop	21	20 a	18	35 a	35 a	33 a	131.1	89.3 b	73.7	3.09 a	2.06 a	1.59 a	n.d.	1.0	0.9
Half Crop	21	19 b	18	22 b	19 b	19 b	137.8	101.9 a	74.0	2.00 b	1.30 b	0.93 b	n.d.	1.1	1.0
P-value															
F	0.002	0.034	0.001	NS	0.021	0.002	<0.001	0.033	NS	0.002	NS	0.023	n.d.	<0.001	<0.001
C	NS[u]	0.035	NS	<0.001	<0.001	<0.001	NS	0.031	NS	<0.001	<0.001	<0.001	n.d.	NS	NS
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	n.d.	NS	NS

[z] Measured at dormancy when collecting pruning weight.

[y] Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.

[x] Different letters following means within a treatment column represent differences by Tukey's HSD at α=0.05.

[w] n.d.- not determined.

[v] Crop Level treatments included Full Crop- no clusters removed, and Half Crop – fruit was thinned to one cluster per shoot (~ 42% clusters removed).

[u] NS - not significant at $P > 0.05$.

Table 2.5. Basic ripening variables measured at harvest during 2011 to 2013 from vineyard floor management and crop level treatments.

	Total soluble solids (°Brix)			pH			Titratable acidity ($g \cdot L^{-1}$)		
Treatments	2011	2012	2013	2011	2012	2013	2011	2012	2013
Floor mgt. (F)[z]									
Grass	20.1	22.7 b[y]	21.1	3.20	3.26	3.19	8.4 b	8.6 b	7.6
Alternate	19.9	23.3 ab	21.5	3.17	3.26	3.19	9.3 a	9.4 a	8.2
Tilled	19.5	23.6 a	22.5	3.16	3.31	3.23	9.8 a	9.6 a	8.3
Crop level (C)[x]									
Full crop	19.5 b	22.6 b	21.4 b	3.16	3.24 b	3.18 b	9.2	9.4 a	8.0
Half crop	20.2 a	23.7 a	22.0 a	3.19	3.32 a	3.23 a	9.1	9.1 b	8.1
P-value									
F	NS[v]	0.019	NS	NS	NS	NS	0.001	0.009	NS
C	0.002	<0.001	0.022	NS	<0.001	0.018	NS	0.036	NS
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.

[y] Different letters following means within a treatment column represent differences by Tukey's HSD at $\alpha=0.05$.

[x] Crop Level treatments included Full Crop- no clusters removed and Half Crop – fruit was thinned to one cluster per shoot (~ 42% clusters removed).

[v] NS - not significant at $P > 0.05$.

Table 2.6. Juice yeast assimilable nitrogen (YAN) and YAN components at harvest from vineyard floor management and crop level treatments from 2011 to 2013.

	Primary amino acid N ($mg \cdot L^{-1}$)			Ammonia N ($mg \cdot L^{-1}$)			YAN ($mg \cdot L^{-1}$)		
Treatments	2011	2012	2013	2011	2012	2013	2011	2012	2013
Floor mgt. (F)[z]									
Grass	74.7 b[y]	45.7 c	53.3 c	9.7 b	12.5 c	21.8 c	84.4 b	58.2 c	75.1 c
Alternate	112.5 a	75.6 b	89.7 b	25.6 b	29.3 b	52.2 b	138.1 a	104.9 b	141.9 b
Tilled	135.0 a	109.7 a	121.4 a	46.8 a	62.6 a	74.5 a	181.8 a	172.4 a	195.8 a
Crop level (C)[x]									
Full crop	99.6	68.1 b	81.6 b	26.4	31.7 b	46.3	126.1	99.8 b	128.0
Half crop	115.1	85.9 a	94.6 a	28.3	38.0 a	52.6	143.4	123.9 a	147.2
P-value									
F	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001	<0.001	<0.001
C	NS[w]	<0.001	0.037	NS	0.001	NS	NS	0.002	NS
F x C	NS	NS	NS	NS	0.015	NS	NS	NS	NS

[z] Floor management treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.
[y] Different letters following means within a treatment column represent differences by Tukey's HSD at $\alpha=0.05$.
[x] Crop Level treatments included Full Crop- no clusters removed, and Half Crop – fruit was thinned to one cluster per shoot (~ 42% clusters removed).
[w] NS - not significant at $P > 0.05$.

CHAPTER 3

VINEYARD FLOOR MANAGEMENT AND CLUSTER THINNING INCONSISTENTLY AFFECT 'PINOT NOIR' CROP LOAD, BERRY COMPOSITION, AND WINE QUALITY

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Abstract

Growers of high-end ‘Pinot noir’ winegrapes (*Vitis vinifera* L.) commonly reduce yield by cluster thinning with the goal of increasing fruit quality; however, there are no objectively defined yield targets to achieve optimum fruit composition. Canopy leaf area relative to fruit yield can affect total soluble solids (TSS), and recommendations have been established for warm winegrape production regions. However, the relationship between leaf area and photoassimilation differs among climates and training systems. Leaf area to yield ratios developed in warm, arid regions may not be suitable for cool, wet regions such as western Oregon. A 3-year field study was conducted to elucidate relationships between canopy to yield ratios and berry composition for ‘Pinot noir’. Vegetative growth and fruit yield were manipulated through competitive cover cropping and cluster thinning. Growth was manipulated in three ways: perennial red fescue (*Festuca rubra* L.) was grown in 1) both (Grass), 2) one (Alternate), or 3) neither (Tilled) of the alleyways flanking the vine row. Within each vineyard floor treatment, fruit clusters were thinned to one per shoot (Half Crop) or vines were left unthinned (Full Crop). Floor management influenced both canopy size and yield due to altered vine nitrogen (N) status. Effects of crop load on berry components were not always consistent between the crop load metrics used (yield to pruning weight ratio (Y:PW) or leaf area to yield ratio (LA:Y)). In 2 years, TSS reached a maximum at similar LA:Y; however, this did not necessarily produce optimum TSS. In the highest yielding coolest year, yield had the greatest influence on pH and total anthocyanins. Crop load metrics were not reliable predictors of TSS because of the dominant effect of seasonal variation. Relationships between canopy to yield metrics and other berry components were partially explained by tissue N, photosynthetic photon flux through the cluster zone, and/or yield. Cluster thinning to adjust yields may not alter source to sink relationships or

canopy to yield ratios enough to overcome ripening limitations in cool climates. Only one vintage of wines had sensory differences with wines from Alternate-Half Crop and Alternate-Full Crop ranked high quality and wines from Tilled-Half Crop and Tilled-Full Crop ranked low quality by both consumer and winemaker panels. Therefore, cluster thinning may have limited impact on wine sensory properties.

Introduction

Viticultural literature describes crop load as a measure of canopy size relative to fruit yield and is used to assess source-sink interactions as related to vine health and berry sugar accumulation. Crop load is expressed as either yield to pruning weight (Y:PW) or leaf area to yield (LA:Y) because leaf area is generally correlated with pruning weight. In practice, the objective is to optimize the source to sink ratio with vineyard management practices to sustain vine productivity and achieve ripeness within climatic constraints. Some studies suggest that crop load, rather than yield, may be a better indicator of wine quality (Bravdo et al., 1985; Naor et al., 2002). Crop load metrics cannot be applied universally because source strength depends upon regional and viticultural factors such as global irradiance, temperature, canopy training, cultivar, rootstock and inherent vine yield. Therefore, it is important to conduct research to define appropriate crop load metrics for specific regions and cultivars (Bravdo et al., 1984; Howell, 2001; Jackson and Lombard, 1993; Kliewer and Dokoozlian, 2005; Kliewer and Weaver, 1971).

Many studies have defined winegrape crop load metrics related to basic ripeness, including sugar accumulation, under greenhouse conditions (Jackson, 1986) and primarily in warm, arid regions (Geller and Kurtural, 2013; Jackson and Lombard, 1993; Keller et al., 2005; Kliewer and Weaver, 1971; Uriarte et al., 2016). However, studies that investigated relationships

between crop load and wine quality have been inconclusive due to climate, cultural, and cultivar differences (Bravdo et al., 1984, 1985; King et al., 2015; Reynolds et al., 1994, 1996; Zhuang et al., 2014). Previously defined crop load metrics have not been useful for cool climate 'Pinot noir' production, in part due to limited applicability to the climatic or cultivar constraints.

According to what has become common viticulture theory (Howell, 2001; Jackson and Lombard, 1993; Kliewer and Dokoozlian, 2005), grapes grown in cool-climates require higher LA:Y than warmer regions. This is based on the premise that lower daytime temperatures in cool climates restrict carbon assimilation and phenological development.

Vine size and canopy architecture affect light attenuation (Dokoozlian and Kliewer, 1995) and ultimately source-sink physiology (Reynolds and Vanden Heuvel, 2009). However, the majority of vineyards in Oregon are trained to single canopy vertically shoot positioned (VSP) systems, which are one of the most light-restricted training systems. Given high soil moisture and a cool climate, vines in this region are rarely water stressed and produce excess vegetative growth that requires repeated hedging to maintain the VSP canopy architecture. Repeated hedging may hinder fruit ripening which is a negative consequence in cool climates with short growing seasons and late season rainfall that negatively impact fruit quality. This, coupled with the inherent lower yields of 'Pinot noir', may help explain why established crop load metrics are inappropriate in the current conditions (Kliewer and Dokoozlian, 2005).

To our knowledge, there is little research that shows applicability of crop load metrics for vines grown on VSP canopies under cool climate conditions. This may explain, in part, why Oregon 'Pinot noir' growers cluster-thin vineyards to a narrow range of yields across vineyards that vary in vigor and yield potential rather than strategizing yield targets relative to canopy size. Furthermore, many producers cluster thin under the presumptive cause-effect relationship

between low yields and premium wine quality (Uzes and Skinkis, 2016). To develop crop load guidelines that enhance ‘Pinot noir’ ripeness and fruit/wine quality in a cool climate, a 3-year study was conducted by manipulating vegetative growth and fruit yields to influence crop load. The first results of this study were published by Reeve et al. (2016). The results herein address relationships between traditional viticulture measures (yield, pruning weight, and yield to canopy metrics) and fruit composition and wine sensory perception. We hypothesized that higher LA:Y was required for Oregon ‘Pinot noir’ production than published elsewhere to achieve optimum ripeness, with a point of diminishing return on TSS. We also hypothesized that there would be a relationship between berry components and vine physiology or climatic factors that may explain the impacts of crop load or yield on fruit composition and wine sensory perception.

Materials and Methods

Experimental Site and Design. A split plot vineyard floor management and crop level experiment was conducted from 2011 to 2013 in a commercial vineyard near Dayton, OR, USA. The vineyard was planted in 1998 to ‘Pinot noir’ (*Vitis vinifera* L. Dijon clone 115) grafted on 101-14 rootstock at a spacing of 2.1 m between rows and 1.5 m between vines in N-S oriented rows. Three floor management treatments served as main plots with two crop levels as sub-plots. Plots consisted of 16 vines in main plots and eight vines per sub-plot. All treatments were replicated in a completely randomized design across five field replicates. Alleyways of the entire vineyard block were seeded to Red Fescue (*Festuca rubra* L.) in 2004 by the vineyard manager, and three different floor management practices applied in 2007 as part of an earlier study and maintained annually according to the following treatments: Grass – both alleyways flanking the vine row were not tilled and allowed to maintain growth of the perennial grass, Alternate - one alleyway was maintained with grass growth while the other alleyway was tilled, and Tilled – had

both alleyways flanking the vine row tilled to keep free of vegetation during the entire growing season. Cultivation of alleyways was conducted with a rototiller (Rotavator HR36; Kongskilde Industries, Sorø, Denmark) in May and at least once again during mid-summer to maintain alleyways free of vegetation. Crop level was adjusted through cluster thinning at the lag phase stage of berry development, ≈ 50 to 55 days post 50% bloom. Half of the vines in each plot were thinned to one cluster per shoot, retaining basal clusters only and were referred to as Half Crop. The remaining vines had no clusters removed and were referred to as Full Crop. However, in both Half Crop and Full Crop treatments, the top branched section of clusters, known as "wings", were removed during the thinning pass to follow commercial standard practice. Half Crop treatments had on average 42% fewer clusters than Full Crop.

Field methods. Whole vine leaf area at véraison and yield at harvest were used to calculate leaf area to yield ratio (LA:Y). Vine yield at harvest and dormant pruning weight post-harvest were used to determine the yield to pruning weight ratio (Y:PW). Whole vine leaf area, yield, and pruning weight methods and treatment means are stated in Reeve et al. (2016). No data were available for pruning weight in the 2011 season because commercial pruning occurred before field data were collected. Percent leaf blade N was determined at véraison, using the method described in Reeve et al. (2016) and data are reported therein. Leaf blade N was chosen for regression analysis with berry composition data, as leaf blades have been shown to correlate better with vine measures than petioles (Schreiner and Scagel, 2017; Schreiner et al., 2013).

The percent of ambient photosynthetic photon flux (abbreviated as *PPF* for brevity) that infiltrated through the fruit zone was measured using a ceptometer (AccuPAR LP-80, Decagon Devices, Pullman, WA) positioned on the shaded side of the canopy, including the west side for morning readings and the east side for solar noon and afternoon readings. Measurements were

made in the morning (1000 HR to 1050 HR), at solar noon (1250 HR to 1350 HR), and in the afternoon (1450 HR to 1600 HR) on one day during three berry development time points: pea-size, véraison, and ripening, except in 2011 when data were only collected in the morning and solar noon at véraison. To determine *PPF* infiltrating the fruit zone, was positioned. The sensor bar was held parallel to the vine row, at the height of the fruiting wire and as close to the shoots as possible, and held level in 2011 and 2013, but angled toward the sun in 2012. Above canopy *PPF* readings were simultaneously taken with below canopy readings, but above canopy readings were averaged over the hour-long measurement period for consistency across the sampling period.

Fruit composition. Basic ripeness, including total soluble solids (TSS), pH, titratable acidity (TA), and yeast assimilable nitrogen (YAN) were measured using juice pressed from clusters at harvest as described in Reeve et al. (2016).

Whole-berry extracts were prepared from seven randomly selected clusters per plot that were stored at -80°C after harvest. The extraction process is described in Iland et al. (1996) with the following modifications. Fifty berries were collected at random from frozen destemmed berries, had their pedicel removed while the berries were still frozen, the berries were weighed and left to defrost at room temperature (~1 h). Berries were then pulverized using a homogenizer (IKA Ultra-Turrax T 25 digital; IKA Works Inc., Wilmington, NC) for 45 s at 5,806 g_n then homogenized for another 30 s. Homogenate (2 g) was weighed into 50 mL centrifuge tubes and 15 mL of acidified aqueous ethanol (0.1% HCl, 50% v/v EtOH) was added. The mixtures were agitated on a shaker table for 1 h in the dark and then centrifuged for 10 min at 1,800 g_n. Supernatants were then decanted into 50 mL volumetric flasks and brought to 50 mL with

deionized water. Aliquots (2 ml) of the extracts were stored at -20°C until analysis for total anthocyanin (ACY), phenolic (PHE), and tannin (TAN) concentrations.

Total anthocyanin concentrations were spectrophotometrically determined by the pH-differential method (Genesys 10S Vis, Thermo Fisher Scientific, Madison, WI) as described in Lee et al. (2005). Results are presented in malvidin-3-glucoside equivalents (molar extinction coefficient 28,000 $L \cdot cm^{-1} \cdot mol^{-1}$ and molecular weight 493.3 $g \cdot mol^{-1}$). The Folin-Ciocalteu spectrophotometric assay (Waterhouse, 2002) was used to quantify PHE, was compared against gallic acid (Sigma-Aldrich, St. Louis, MO), and expressed in gallic acid equivalents. The spectrophotometric methyl cellulose precipitation assay (Sarneckis et al., 2006) was used to determine TAN, and results are reported in epicatechin equivalents using a standard curve.

Wine production. Wines were made by the collaborating commercial winery. All fruit from the field replicates of each treatment was combined, meaning that one wine lot was made per treatment in each year so that wines could undergo sensory evaluation. All wines were fermented using equal amounts of fruit to yield the same fermentation size across all treatments. For fermentation, fruit was destemmed, placed into 45 L plastic vessels (Main Brew, Hillsboro, OR), 50 $mg \cdot L^{-1}$ potassium metabisulfite ($K_2 S_2O_5$) was added, and then innoculated with *Saccharomyces cerevisiae* P1Y2 (Phyterra, Napa, CA) at the manufacturer's rate. Punch downs occurred one to two times daily until yeast fermentation was complete. Wines were basket pressed once dry, settled for 24 h, then racked off gross lees. Thereafter, wines were inoculated for malolactic fermentation with *Oenococcus oeni* MT01 (Scott Labs, Petaluma, CA) at the manufacturer's rate. Sulfur dioxide (50 $mg \cdot L^{-1}$) was added to malolactic-fermented wines using $K_2S_2O_5$. The wines were left to settle until they were racked off prior to bottling late winter-early

spring into green, 750 mL glass bottles with natural cork closures. Finished wines were stored at 13°C.

Wine sensory evaluation. After bottle-aging for 2 years, wines were evaluated by consumer and commercial winemaker panels. The consumer panelists participated in two sorting tests and one overall liking test, while the winemaker panelists were additionally subjected to descriptive analysis. Consumer panelists had to be non-smokers, free of oral diseases and piercings, drink red wine at least once a week, and over the age of 21 years. In 2013, 2014, and 2015, 16 (38% male, 62% female), 18 (33% male, 67% female), and 20 unique consumer panelists (35% male, 65% female) participated in analysis of 2011, 2012, and 2013 wines, respectively. Panelist ages ranged from 34 to 44 across all years. Winemakers had to meet the above criteria and worked with commercial 'Pinot noir' production for at least five years. In 2013, 2014, and 2015, 16 (56% male, 44% female), 13 (62% male, 38% female), and 15 professional winemakers (73% male, 27% female) participated in sensory analysis of 2011, 2012, and 2013 wines, respectively.

All facilities had a mix of natural and artificial lighting, an air purifier (WAC5500, Winix Inc., East Dundee, IL), the temperature maintained at 26°C (±3°C), and portable cardboard booths (Flipside Products, Inc.; Cincinnati, OH) to separate panelists. All bottles were opened 1 h before tasting and ~30 mL was poured 30 min before serving. Glasses were coded with random 3-digit numbers and covered with watch glasses. Wines were presented in random order following a balanced incomplete block design (Masuoka et al., 1995) for each test/panelist combination. To avoid fatigue, panelists cleansed their palates with saltless saltine crackers and water after each wine and had a 5 min break between tests.

Each tasting session began with two sorting tests, one in clear glasses and one in black INAO (Institut National d'Appellation d'Origine) standard tasting glasses (ISO, 1977) presented randomly. Each sorting test was composed of a flight of six wines, one from each of the vineyard treatments. Panelists were asked to smell, taste, then expectorate the wines. Based on their personal definition of quality, wines were sorted into three quality categories (low, medium, and high); however, there was no medium category in 2013. There were no restrictions on the number of wines that a panelist could assign to a category. For the last test, panelists were asked to mark on a scale how much they liked each wine. In 2013 and 2014, a 100 mm visual analog scale with word anchors "strongly dislike" and "strongly like" were used, while in 2015, panelists were given a scale between -5 (strongly dislike) and 5 (strongly like) with 0 representing neutral.

The professional winemaker panel session followed the same format as the consumer panel but included descriptive analysis. Panelists were given a 100 mm visual analog scale with the word anchors "none" and "extreme" at the two ends for each aroma attribute and taste/mouthfeel characteristic listed. The aroma attributes included green, red fruit, floral, jam, spice, dark fruit, butter, and earthy, while the taste/mouthfeel attributes included bitter, sour, and astringency. Attributes were chosen based on previous work with 'Pinot noir' wines from Oregon's Willamette Valley.

Statistical analyses. Statistical analyses were performed on vine and berry composition data using PROC MIXED in SAS Statistical Software 9.3 (SAS Institute, Cary, NC) for analyses of variance (ANOVA), simple linear regression, and multiple regression. Tukey's Honestly Significant Differences (HSD) at the $\alpha = 0.05$ level was used for mean separation when using ANOVAs. For relationships between crop load and berry components, linear, power, and

quadratic functions were tested, and the lowest *P*-value and/or highest R^2 was used to describe the relationship. Percent ambient *PPF*, YAN, and TAN were log-transformed as necessary to normalize residual plots and are presented as log values. The data were analyzed separately by year due to seasonal differences, with one exception described below. Using PROC GLM, ANOVA was used when considering floor management treatments as predictors, while simple linear or multiple regression was used when evaluating an observed characteristic or characteristics, respectively. Multiple regression analysis was performed with berry chemistry components as the dependent variable, and year, whole vine leaf area, yield, leaf blade N, and *PPF* as independent variables. With the exception of year, all single interactions were included. Multicollinearity was assessed through correlation plots and Variance Inflation Factors (VIF). Using backward elimination, variables with *P*-values > 0.05 and VIFs > 3.3 were removed from the full model, starting with interactions. Main effects were left in the model if they were included in a significant interaction. Because these analyses were exploratory, individual variable *P*-values ≤ 0.05 were considered significant despite multiple comparisons using the same set independent variables with potentially correlated dependent variables. Many model *P*-values were still significant using the conservative Bonferroni adjustment.

Sensory data analysis was conducted using XLStat version 2014.6.01 (Addinsoft™, New York, NY USA), using panelists as replicates. Liking and sorting data were analyzed using ANOVA and Tukey's multiple comparison. Sorting results were analyzed by coding each grouping with 0, 1, or 2 (or only 0 and 1 for 2011 wine) with 0 being the highest quality. Panelist likeness for a wine was determined by the distance from the "highly dislike" anchor. Aroma and mouthfeel attributes were rated for intensity using the distance from the "none" anchor.

Descriptive analysis data were analyzed using discriminant analysis with treatments or year as the grouping factor.

Results

Treatment effects on crop load. Floor management treatments had an inconsistent effect on LA:Y over the 3 years (Table 3.1). Grass had the lowest LA:Y in 2012, but there were no differences in LA:Y in other years. In all years, Y:PW was highest in Grass and lowest in Tilled. The Full Crop and Half Crop vines of all floor management treatments differed in LA:Y and Y:PW – the direct consequence of cluster thinning. There was a significant floor management by crop level interaction in 2012 where all floor management treatments had lower Y:PW when cluster thinned. In 2012, the largest difference in Y:PW was between Grass-Half Crop (1.9) and Grass-Full Crop (3.4).

Treatment effects on berry composition. There were no differences in berry weight (1.1 to 1.3 g) among treatment combinations and years, so data are presented as concentrations in $mg \cdot g^{-1}$ berries (Table 3.2). The only consistent treatment effect on phenolic composition in all years was 15% to 20% higher TAN concentrations in Grass than Tilled. Grass had higher concentrations of ACY than Tilled in 2011, and higher concentrations of PHE in 2012. In 2011 and 2012, Half Crop had 12% to 13% higher ACY than Full Crop. Conversely, Full Crop had 7% to 8% higher concentrations of TAN in 2 years (2011 and 2013).

Crop load impacts on berry composition. Due to variability by year, regressions between crop load metrics and berry composition were run within years. Basic fruit maturity parameters (TSS, pH, and TA) were significantly related to LA:Y in 2011 and 2012 (Table 3.3). The relationships between LA:Y and TSS in 2011 and 2012 were curvilinear, with TSS plateauing between 1.25 and 1.75 $m^2 \cdot kg^{-1}$ (Fig. 3.1). The highest TSS measured in 2011 was less than the

lowest measured in 2012. The pH was slightly lower in 2011 than 2012. In both years, there was a positive relationship between pH and LA:Y. Titratable acidity was related to LA:Y differently in all years (Table 3.3, Fig. 3.1). In 2011, TA was negatively related to LA:Y in curvilinear fashion, approaching an asymptote of 2 $m^2 \cdot kg^{-1}$. In 2012, TA was linearly (positively) related to LA:Y. There was no relationship between TA and LA:Y in 2013. Yeast assimilable N was positively correlated with LA:Y in both 2012 and 2013 (2012: $\log_{10}(y) = 0.46x + 3.57$ and 2013: $y = 19.56x + 79.48$), although the 2013 relationship was weak. There were no significant relationships between PHE and LA:Y in any year and no consistent trends between ACY and LA:Y or TAN and LA:Y.

Crop load-berry component relationships using Y:PW were best described by linear functions. In both 2012 and 2013, Y:PW was related to TA, YAN, and TAN (Table 3.3). TA was lower at higher Y:PW, although 2013 had slightly lower TA (2012: $y = - 0.35x + 9.86$ and 2013 $y = - 0.55x + 8.85$). YAN was also lower at higher Y:PW in 2012 and 2013 ($\log_{10}(y) = - 0.21x + 2.39$; $y = - 62.42x + 229.8$, respectively). Unlike TA and YAN, TAN was higher at higher Y:PW values in 2012 ($\log_{10}(y) = 0.02x + 0.72$) and 2013 ($y = 0.70x + 3.89$). No relationships were found for Y:PW and pH or ACY.

There were few consistent relationships between yield and berry components across all years (Table 3.3). In 2011, yield had a relationship with the all components except TAN and PHE. However, the only two components that yield had a relationship with in more than one year were TSS and pH. Higher yield resulted in lower TSS in 2011 and 2012 (2011: $y = - 0.36x + 21.24$; 2012: $y = - 0.57x + 24.64$), but the 2012 relationship was weak. Higher yields also had lower pH in 2011 and 2012 ($y = 3.30x^{-0.030}$ and $y = - 0.046x + 3.40$, respectively). Higher yields in 2011 led to both higher TA and YAN, with only a slight upward curvature as yields increased

($y = 7.47x^{0.16}$and $y = 74.3x^{0.45}$, respectively). Higher yields resulted in lower ACY but had less of a decrease in ACY at yields of ≈3.5 kg/vine or higher ($y = 0.0051x^2 - 0.090x + 0.72$).

To determine if one of the two crop load components was heavily influencing relationships between crop load and berry composition, each crop load metric (LA:Y and Y:PW) was broken down into its measured components and interactions and analyzed against each berry component through multiple regression analyses. All berry components were related to either leaf area or yield in at least 1 year (Table 3.4). The most relationships were found between berry composition and crop load components in 2011 and very few were found in 2013. Only TSS, TA, and YAN were related to both leaf area and yield, although inconsistently so each year. The remaining berry components were related to only leaf area or yield in a given year. Tannin was the only phenolic group that showed a consistent relationship with leaf area for more than 1 year. Although YAN showed a consistent relationship with leaf area, the relationship was different each year. In 2011, YAN was related to all variables and their interaction, and YAN was influenced by leaf area and yield independently in 2012 and only leaf area in 2013. Similarly, even though TSS was related to both crop load components for LA:Y in 2012, TSS was related to only yield in 2011 and only leaf area in 2013.

There were no interactive effects between pruning weight and yield on berry composition (Table 3.5). Only TSS and TAN were related to both pruning weight and yield in 1 year. YAN was consistently influenced by only pruning weight, as higher pruning weights were related to higher YAN. In both years, there was a weak association between PHE and pruning weight. Tannin concentration was related to pruning weight in both years but was also related to yield in 2013. Pruning weight and yield were not related to pH, TA, or ACY (Table 3.5).

Leaf blade N impacts on berry composition. Since vineyard floor management influenced vine growth and tissue N status, it was expected that N effects on the canopy (pruning weight and leaf area) would influence berry N composition. Total soluble solids and YAN had relationships with leaf blade N each year (data not shown). There was a negative linear relationship with leaf blade N and TSS in 2011 ($P = 0.031$, $r^2 = 0.16$), whereas TSS was higher at higher leaf blade N in 2012 and 2013 ($P = 0.049$ and 0.001, and $r^2 = 0.13$ and 0.31, respectively). However, the 2011 and 2012 relationships were weak. With increasing leaf blade N, TA was higher in 2011 and 2012 but lower in 2013 ($P < 0.001$, $r^2 = 0.49$; $P = 0.002$, $r^2 = 0.29$; and $P = 0.011$, $r^2 = 0.21$, respectively). As expected, the strongest relationships were between YAN and leaf blade N, with higher YAN associated with higher leaf blade N ($P < 0.001$ all years; $r^2 = 0.69$, $r^2 = 0.44$, and $r^2 = 0.66$ in 2011, 2012, and 2013, respectively). Generally TAN and PHE were lower with higher leaf blade N, except there was no relationship with PHE in 2012.

Light environment effects. The relationships between berry composition and vegetative measures may be related to N effects on canopy growth and microclimate, particularly light infiltration through the fruit zone. Vegetative measures and leaf blade N influenced *PPF*, as higher pruning weight, leaf area, and leaf blade N resulted in lower *PPF* (Fig. 3.2). There were no consistent relationships between berry components and *PPF* in the morning or at solar noon in any year (data not shown), and afternoon measurements were only taken in 2012 and 2013. There were no relationships between ACY and *PPF* during any phenological time point measured (data not shown). However, PHE and TAN were higher with higher *PPF* at véraison in 2012 and 2013 (Fig. 3.3). Additionally, TA was lower at higher *PPF* at the véraison and ripening time points in both years ($P \leq 0.042$).

Since leaf area, yield, leaf blade N, and *PPF* are physiologically linked, multiple regressions with these measures and their interactions were assessed against each berry component controlling for the effect of year. All berry components, except ACY, were influenced by year, and no significant interactions were found (Table 3.6). With the exception of ACY, whenever yield was related to a berry component, year was also a factor, which was anticipated given the high yields in 2011 compared to the other two years. With the exception of PHE, whenever leaf blade N was significant, leaf area or *PPF* were also significant, although no interactions were found for any berry components. Total soluble solids were related to yield and leaf area but were affected by year as well. This supports our previous findings where TSS was related to leaf area in some years whereas it was related to yield or both leaf area and yield in other years. TA was related to all factors analyzed except leaf area. Although it was expected that YAN would be influenced by leaf blade N, YAN was related to year and leaf area. Only TAN and TA were influenced by *PPF*.

Wine sensory analysis. Wines produced from 2011 and 2012 did not differ by descriptive analyses, sorting, or liking by either consumer or winemaker panels, while both panels found differences among 2013 wines. Wines from the 2013 vintage were differentiated through descriptive analysis by winemakers with Grass-Half Crop statistically separating from all other treatments (Fig. 3.4). Grass-Half Crop wine was described as having more intense floral and jam aromas and sour taste. There was some statistical separation between other wines, but overall they were described as more green, earthy, buttery, and had an astringent mouthfeel.

Quality differences were found by both consumer and winemaker panels when sorting 2013 wines into high, medium, and low quality categories. Consumers, when presented wines in clear glasses, considered Alternate-Full Crop and Grass-Half Crop to be the highest quality and

Tilled-Half Crop to be the lowest quality (P = 0.021). However, when the wines were presented in black glasses, consumers did not find differences in quality among the wines (P = 0.754). Conversely, winemakers were not able to separate 2013 wines into different quality categories when presented in clear glasses (P = 0.655), but they could discern differences when wines were served in black glasses (P = 0.004). Like consumers, winemakers thought Alternate-Full Crop was one of the highest quality, but unlike consumers, they thought Alternate-Half Crop was also high quality and Tilled-Full Crop to be of low quality. Despite the ability to sort wines into different quality groups, the winemaker and consumer panels did not have a preference for any wine based on liking scores (P = 0.802 and 0.120, respectively).

Discussion

Treatment effects on crop load. Both crop load metrics, Y:PW and LA:Y, were strongly affected by crop level treatments. However, the effects of floor management treatments were less clear, as differences among floor management treatments were generally found for Y:PW but not LA:Y. Unlike studies that involve the deliberate removal of leaf area or fruit to alter crop load, the floor management treatments in this study affected both yield and canopy size naturally in a field setting. As previously reported for this study (Reeve et al., 2016), there were clear differences in canopy size among floor management treatments, with mean véraison leaf area of 4.6 m^2 per vine for Grass vines and 6.8 m^2 per vine for Alternate and Tilled vines over all years. Similarly, the 2-year mean pruning weights were 0.9, 1.6, 1.9 kg per vine for Grass, Alternate, and Tilled vines, respectively. Yields were also impacted by floor management treatments, as Grass, Alternate, and Tilled vines averaged 2.3, 3.0, and 3.1 kg per vine over all years. The reduced canopy size and yields of Grass vines were attributed to lower vine N. Similarly, others

have noted physiological reduction in yield and leaf area in response to lower vine N status (Christensen et al., 1994; Schreiner and Scagel, 2017; Schreiner et al., 2013).

Due to the concurrent reductions in yield and leaf area in Grass vines, the effect of floor management treatments on crop load depended on which crop load metric was used. Grass vines had less source (canopy size) and thus were considered to have a greater sink demand when estimating crop load by Y:PW. Despite clearly different canopy sizes and yield in Grass and Tilled vines, both had similar LA:Y in 2 of the 3 years. In 2012, yields were similar across treatments, but LA:Y differed by floor management treatment. Interestingly, this was also the only year that TSS differed by floor management treatments, as Grass vines had the lowest TSS and Tilled vines had the highest (Reeve et al., 2016). This suggests that Tilled vines had a larger source to sink ratio compared to Grass vines. The lack of differences in TSS among floor management treatments in the other 2 years suggests that Grass and Tilled vines had comparable source to sink ratios, as shown by similar LA:Y, despite contrasting canopy sizes and fruit yields. These results exemplify the concept of vine capacity under different conditions, as both treatments were able to physiologically adjust yields and canopy size without the use of manual canopy or crop management (Keller et al., 2005; Koblet et al., 1994).

It is likely that the lack of consistency between crop load metrics in this study was influenced by commercial canopy management practices. The single curtain VSP system was hedged mechanically with multiple passes to avoid overgrowth and shading beyond the confines of the trellis system. Leaf area measurements were conducted based on phenology each year to estimate vine size differences between treatments, and similar amounts of leaf area were measured between Alternate and Tilled vines in all years. This suggests that the amount of leaf area measured at véraison was the amount that filled the volume created by the hedger and the

maximum leaf area attainable in this study (Reeve et al., 2016). However, differences in pruning weight were found between Alternate and Tilled vines (Reeve et al., 2016), indicating differences in vine size, namely cane girth, which was not captured by leaf area assessments.

Leaf area to yield. There have been many reports of relationships between LA:Y and TSS cited in the literature, although limited studies have examined the relationship between LA:Y and other berry components (Kliewer and Dokoozlian, 2005; Kliewer and Weaver, 1971; Naor et al., 2002; Reynolds et al., 1994). In this study, LA:Y ranged from 0.7 $m^2 \cdot kg^{-1}$ to 6.3 $m^2 \cdot kg^{-1}$ with an average of 2.3 $m^2 \cdot kg^{-1}$ over all years. The relationships between TSS and LA:Y in 2011 and 2012 were curvilinear, similar to many other studies (Kaps and Cahoon, 1992; Kliewer, 1970; Kliewer and Antcliff, 1970; May et al., 1969; Naor et al., 2002), although not all (Keller et al., 2005). The LA:Y range where TSS plateaued was similar in 2 of 3 years, at approximately 1.25 to 1.75 $m^2 \cdot kg^{-1}$, and represents the crop load at which further increases in leaf area or decreases in yield had little influence on TSS. This is higher than the 0.8 to 1.2 $m^2 \cdot kg^{-1}$ suggested by Kliewer and Dokoozlian (2005); however, those guidelines were for single canopy winegrapes in a warm region. Although the crop load plateau was similar in 2 years of our study, it cannot be interpreted as the amount of leaf area needed to ripen ‘Pinot noir’ under the cool climate of western Oregon. Climatic conditions varied significantly between 2011 (cool year) and 2012 (warm year), thereby resulting in 2011 having much lower TSS than 2012 at all LA:Y values achieved (Reeve et al., 2016). The crop level treatments in this study decreased yield by about 40%; however, further decreases in yield (and thus increases in LA:Y) would have had little effect, as LA:Y greater than 1.5 $m^2 \cdot kg^{-1}$ were not able to reach commercially accepted maturity in 2011. These results suggest that climate and variable seasonal weather serve as greater limitations to consistently ripening fruit, and that crop load adjustments can only impact TSS to a

certain extent and may not be able to compensate for seasonal or climatic limitations of a given region (Frioni et al., 2017). For example, similar LA:Y values were achieved in 2013 compared to the prior 2 years, yet there was no relationship between LA:Y and TSS. The 2013 season had intermediate heat units from budbreak to harvest and lower yields, and this suggests that the climatic conditions that season did not limit TSS accumulation given the yields observed in that year (Reeve et al., 2016).

Likewise, utilization of crop load metrics may be better suited for regions and climates where canopies are under less manipulation and where a given cultivar can be ripened consistently.

Similar to the findings for TSS, LA:Y was also related to pH and TA in 2011 and 2012. Crop load (LA:Y) influenced pH in 2011 and 2012, but yield explained this relationship in 2011 since it was the highest yielding and coolest year. Unlike pH, both leaf area and yield likely influenced TA, but this relationship was only apparent in 2011. In 2012 and 2013, LA:Y was also related to YAN.

Yield to pruning weight. Grass vines had a higher Y:PW ratio than Tilled vines due to a greater reduction in pruning weight (50-54%) than yield (0-19%) (Reeve et al., 2016). The Y:PW in this study ranged from 0.5 to 3.7, which is considerably lower than the suggested 3 to 6 for Oregon ‘Pinot noir’ (Kliewer and Casteel, 2003) or the more commonly used metric of 5 to 10 suggested by Kliewer and Dokoozlian (2005). ‘Pinot noir’ in British Columbia had four-year averages ranging from 8 to 13 without reported detrimental effects on TSS, TA, pH, and color (Reynolds et al., 1994). Although, their greater crop loads were achieved using a divided canopy training system, allowing for better canopy light attenuation and greater yields. Additionally, the yields in that study were reported to be higher than a study concurrently conducted in the

Willamette Valley (Reynolds et al., 1996). In our study, a higher Y:PW range was observed in 2011 due to the high yields that year, but unfortunately pruning weight data were not available to make these comparisons.

The Y:PW ratio was shown to be an important indicator of berry composition as more relationships were found than with LA:Y in 2012 and 2013. Given this research was conducted in the field, low R^2 values were expected, especially due to the low yields exhibited in these years with 'Pinot noir', resulting in a narrow range of Y:PW and LA:Y. Similar to LA:Y, TSS was influenced by Y:PW in 2012, with both yield and pruning weight contributing to this relationship. Despite TA, YAN, and TAN also having relationships with Y:PW, none of them were related to both yield and pruning weight, suggesting that these components are also influenced by factors other than carbohydrate partitioning.

Yield. Cluster thinning is a common practice used by 'Pinot noir' producers in Oregon's Willamette Valley since it is believed to maintain a premium standard and promote ripening. However, most of those producers target a specific yield (4.5 to 6.2 $t \cdot ha^{-1}$) across diverse vineyards rather than using canopy to yield metrics to ensure quality (Uzes and Skinkis, 2016). Yield was generally not a better predictor of berry composition than crop load metrics, and Y:PW related to berry composition more often than yield alone. Relationships between yield and berry composition were primarily limited to 2011, the highest yielding and coolest season where delayed ripening led to more differences at harvest than is typical for the region or the 3-year period of this study. However, yield was the main factor determining pH in this study, but this was best observed when yield was high. For example, LA:Y influenced pH in 2011 and 2012, but yield could explain this relationship in 2011. This was supported through multiple regression

with all factors as only yield and year were contributors. This suggests that the relationship between pH and yield may only be evident in higher yielding years.

Although increases in ‘Pinot noir’ anthocyanins have been associated with light exposure in several studies (Feng et al., 2015; Lee and Skinkis, 2013), there was no relationship between ACY and *PPF* in this study despite differences in canopy size. Yield was the factor that influenced ACY most across the 3-year study with lower yields leading to higher ACY, with the strongest relationship in the highest yielding year (2011). However, higher yield with more clusters in the fruit zone would have reduced light infiltration due to cluster occlusion in 2011. Studies have shown anthocyanins to increase with decreasing yield in ‘Nebbiolo’ (Guidoni et al., 2002) and ‘Pinot noir’ (Reynolds et al., 1994, 1996; Vance, 2012), but these studies do not address the potential light effects. Interestingly, Kliewer and Weaver (1971) found a curvilinear relationship between LA:Y and coloration of fruit with coloration of ‘Tokay’ grapes reaching a plateau at higher LA:Y.

Light environment & leaf blade N. Although vine N status and *PPF* are often related due to the canopy growth effects of high or low N status, they cannot be separated within the bounds of this study. Nitrogen had few relationships with berry components that were not also explained by canopy size, *PPF*, or yield. This was not surprising because N is one of the most important mineral nutrients for grapevine growth. It can have a strong effect on yield, leaf area, and pruning weight in ‘Pinot noir’ (Schreiner and Scagel, 2017).

However, there were instances where N alone may have influenced berry components, most notably YAN, or in association with *PPF*, TAN and PHE. Both TAN and PHE were linearly related to leaf blade N and *PPF*, although no relationship existed between PHE and leaf blade N in 2012. However, when both *PPF* and leaf blade N were considered together, PHE was

not related to *PPF*. There have been mixed results between N and PHE from other studies. Lower PHE have been found with high N vines for 'Tempranillo' (Delgado et al., 2004) and 'Pinot noir' (Schreiner et al., 2014) which was independent of *PPF* in the latter study. Keller and Hrazdina (1998) also found higher total PHE concentrations in 'Cabernet sauvignon' berry skins of lower N vines under the same *PPF* at some points during ripening but not at harvest. However, there were higher concentrations of PHE found in more-exposed fruit in several other studies (Dokoozlian and Kliewer, 1996; Morrison and Noble, 1990; Price et al., 1995; Spayd et al., 2002).

In this study, both N and *PPF* can be related to TAN independently of each other. In a number of cultivars, Ough et al. (1968) did not find differences in TAN concentrations in juice between N-fertilized and unfertilized vines. Delgado et al. (2004) found lower total TAN in berry skins from N-fertilized vines at véraison but not at harvest. Downey et al. (2004) did not find a relationship between cluster shading and concentrations of TAN in 'Shiraz' skins or seeds. However, Price et al. (1995) found that wine from more exposed 'Pinot noir' clusters had higher berry quercetin glycosides but lower catechin and epicatechin concentrations.

In our study, there was no consistent factor that influenced TA. Yield, leaf blade N, and *PPF* were related to TA based on multiple regression analyses, but yield was only related to TA in the highest yielding year (higher yields, higher TA). Furthermore, TA had inconsistent relationships with leaf blade N each year, similar to other research with 'Pinot noir' (Schreiner et al., 2013). However, higher *PPF* in our study was associated with lower TA. The relationship between leaf blade N and yield may be indirect and possibly the consequence of the more direct effects that N has on vine growth and intercepted *PPF*. Additionally, yield may affect light infiltration of the fruit zone, particularly in high-yielding years when clusters overlap or when

cluster thinning removes light-occluding clusters. Lower TA has been associated with higher temperature and cluster exposure (Reynolds et al., 1986; Spayd et al., 2002). However, only light was measured in this study; temperature may have been a confounding effect.

There was a positive linear relationship between leaf blade N at véraison and YAN. Many studies have shown positive relationships between tissue N and nitrogenous compounds in juice of 'Riesling' (Spayd et al., 1994), 'Merlot' (Hannam et al., 2013; Neilsen et al., 2010), and 'Pinot noir' (Lee and Schreiner, 2010; Reeve et al., 2016; Schreiner and Scagel, 2017; Schreiner et al., 2013). Ough et al. (1968) also found juice N increased linearly with Y:PW when tested across five white and five red cultivars. We found a similar linear relationship with higher YAN associated with larger canopy size relative to yield. However, these relationships were only found in the lowest yielding years. Further statistical analyses indicated that pruning weight had greater impact and was influenced by leaf blade N, suggesting that the relationships found in other studies (Kliewer and Weaver, 1971; Ough et al., 1968) may have been due to vine N status rather than crop load.

Wine sensory evaluation. Only 2013 wines differed between treatments, and differences were apparent to both consumers and winemakers. However, relating wine quality rankings to measures of crop load proved challenging. Wines that were considered higher quality had LA:Y ratios between 3.2 and 5.1 $m^2 \cdot kg^{-1}$ whereas the wines from the lower quality group had LA:Y ratios that encompassed that range (2.7 and 6.1 $m^2 \cdot kg^{-1}$). Similar results were found when using Y:PW as the crop load metric, as one of the treatments (Tilled-Full Crop, 1.5 Y:PW) considered to be of low quality had a Y:PW between two treatments (Alternate-Half Crop, 1.0 and Alternate-Full Crop, 1.7) that were considered to be of high quality. Additionally, both the highest and lowest yielding treatments were grouped in the high quality category (Alternate-Full

Crop and Grass-Half Crop, respectively). Bravdo et al. (1984) could attribute the highest 'Carignane' wine quality scores to the lowest Y:PW ratios in 2 of 6 years. Using the combined rankings of sensory attributes, including appearance, aroma, taste, and harmony, Naor et al. (2002) found higher rated 'Sauvignon blanc' wine sensory scores when Y:PW decreased and LA:Y increased above 1.8 $m^2 \cdot kg^{-1}$.

The influence of yields on sensory perception of wine quality was of less importance than floor management treatments. Both consumers and winemakers considered wine from a Tilled treatment to be in the lowest quality group. Both panels ranked wine from Alternate vines with no cluster thinning to be of higher quality. This is dissimilar to the finding by Filippetti et al. (2013) studying 'Sangiovese' in Tuscany, Italy where high vigor vines were considered to be of lesser quality than low vigor vines, as both Tilled and Alternate vines in our study were considered high vigor.

Winemakers were able to distinguish Grass-Half Crop wines apart from all other treatments. Although neither panel liked this treatment more than others (in liking test), consumers gave it a higher quality rating (preference test). Reynolds et al. (1996) found greater cherry, berry, and currant aromas in cluster thinned 'Pinot noir' grown in Oregon, which may be similar to the jammy aroma that was associated with the Grass-Half Crop in our study. These wine sensory differences were found in only 1 year, and no differences in any wine sensory tests were found in the other 2 years, including 2011, the year with the greatest range of yields and most consistent berry component impacts between treatments. This may suggest that sensory perception differences in 2013 were related to other factors than the field treatments employed in that year, such as variation in panelists, small panel size, growing season, etc.

Conclusion

The floor management and cluster thinning treatments employed in this study resulted in a range of crop loads that helped explore relationships between vine productivity and berry composition at harvest. The relationships were evaluated to understand which factors may be altered by vineyard canopy management practices to reach desired fruit composition and to estimate wine quality. Given the relationships between tissue N and vine growth measures, N was likely a physiological driver of source-sink relationships affecting berry composition. Total soluble solids were best explained by crop load, while other berry components were better explained by leaf blade N, yield, *PPF*, or a combination of these factors. Winemakers were not able to distinguish between wines of different yields in any year, suggesting that yield management does not ensure wines that can be perceived as having higher sensory quality, despite the strong industry adherence to this paradigm. Furthermore, viticultural practices other than yield management and annual climate conditions likely had greater impact on vine growth and fruit composition in this study. In regards to sensory perception, individual panelist taste preferences, and experimental wine lacking flavors from wood aging may have influenced wine quality perceptions. These factors combined make the use of crop load metrics to achieve even the most basic ripening parameter such as TSS unreliable under the cool climate conditions studied herein. These findings suggest there is an intricate relationship between season and yield which affects berry composition and wine perception, and neither canopy to yield or yield metrics can be universally applied each season.

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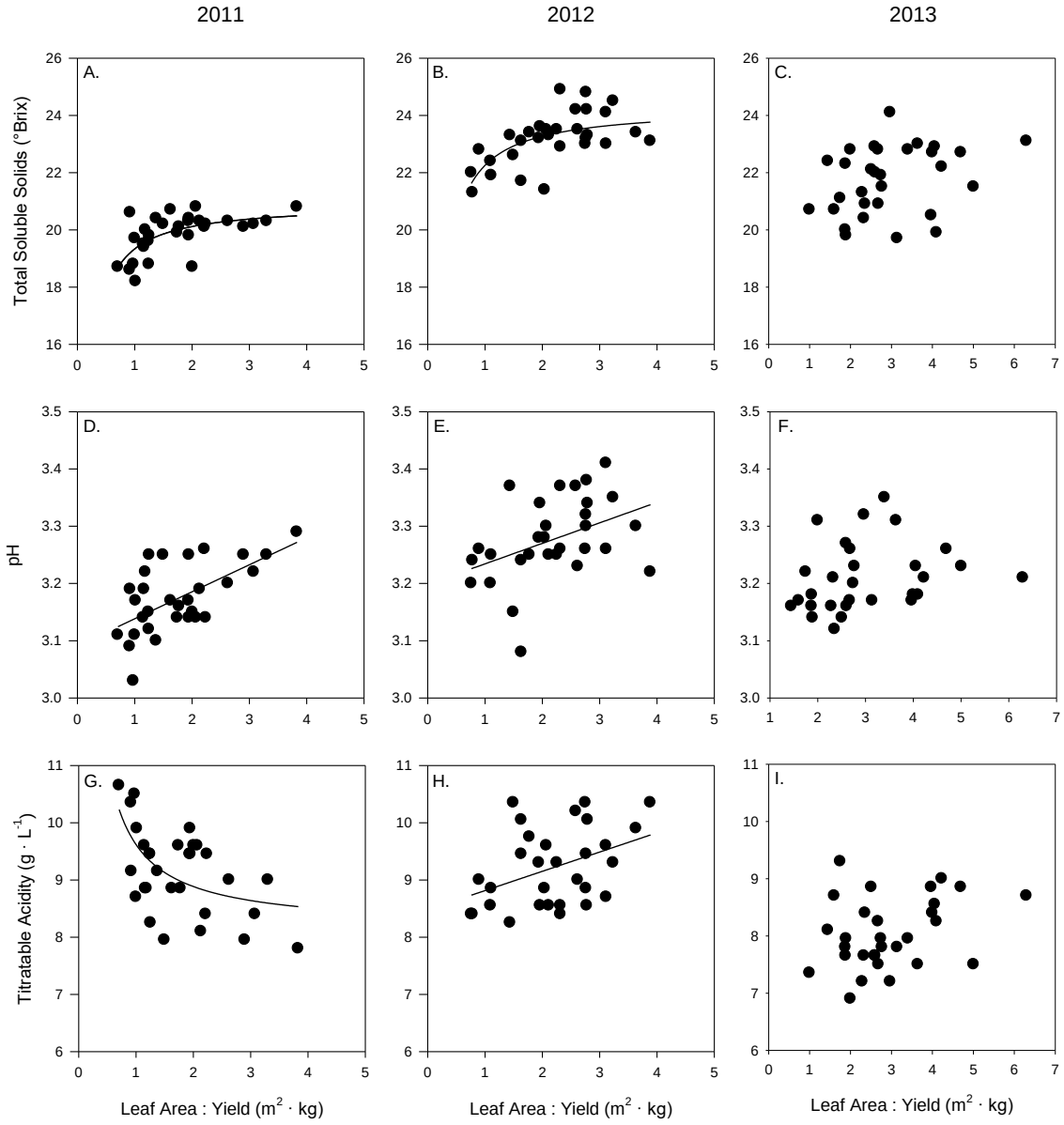

Fig. 3.1. Influence of the leaf area to yield ratio of Oregon 'Pinot noir' on total soluble solids (A, B, C), pH (D, E, F), and titratable acidity (G, H, I) in 2011 (A, D, G), 2012 (B, E, H), and 2013 (C, F, I). A. $y = 19.37x^{0.050}$, $P < 0.001$; B. $y = 22.26x^{0.057}$, $P < 0.001$; D. $y = 0.047\ x + 3.09$, $P < 0.001$; E. $y = 0.036\ x + 3.20$, $P = 0.024$; G. $y = 9.60\ x^{-0.10}$, $P < 0.001$; H. $y = 0.34\ x + 8.48$, $P = 0.024$.

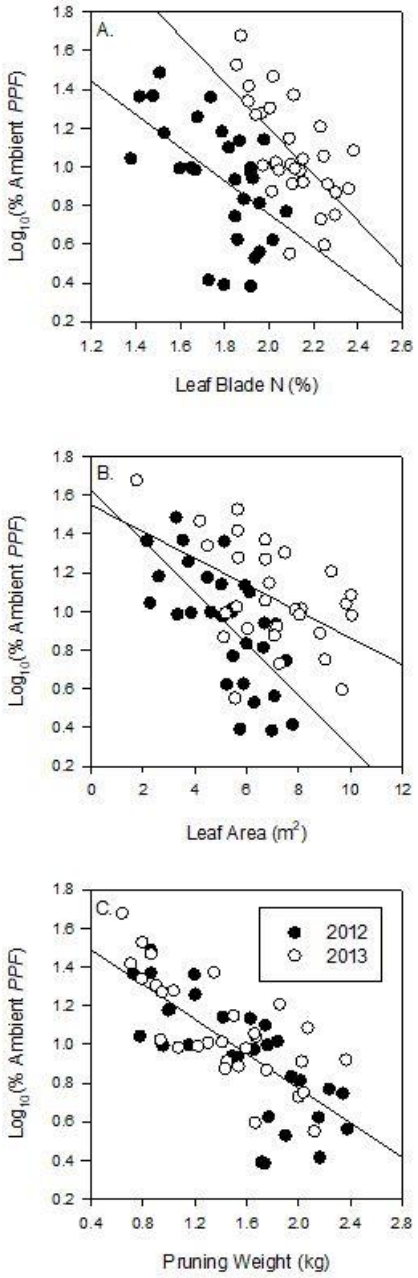

Fig. 3.2. Influence of leaf blade N (A), leaf area (B), and pruning weight (C) on the percent of ambient *PPF* infiltrated through the fruit zone of Oregon 'Pinot noir' during an afternoon at véraison. Leaf blade and leaf area data were collected at véraison, while pruning weight data were collected the winter following the growing season. A. Leaf blade N $P < 0.001$, year $P < 0.001$, model $P < 0.001$, $R^2 = 0.37$ (2012: y = - 0.98x + 2.70, 2013: y = - 0.98x + 3.14). B. Leaf area $P < 0.001$, year $P < 0.001$, model $P < 0.001$, $R^2 = 0.37$ (2012: y = - 0.09x + 1.46, 2013: y = - 0.09x + 1.73). C. Pruning weight $P < 0.001$, year and interaction not significant, $R^2 = 0.56$ (y = - 0.45x + 1.67).

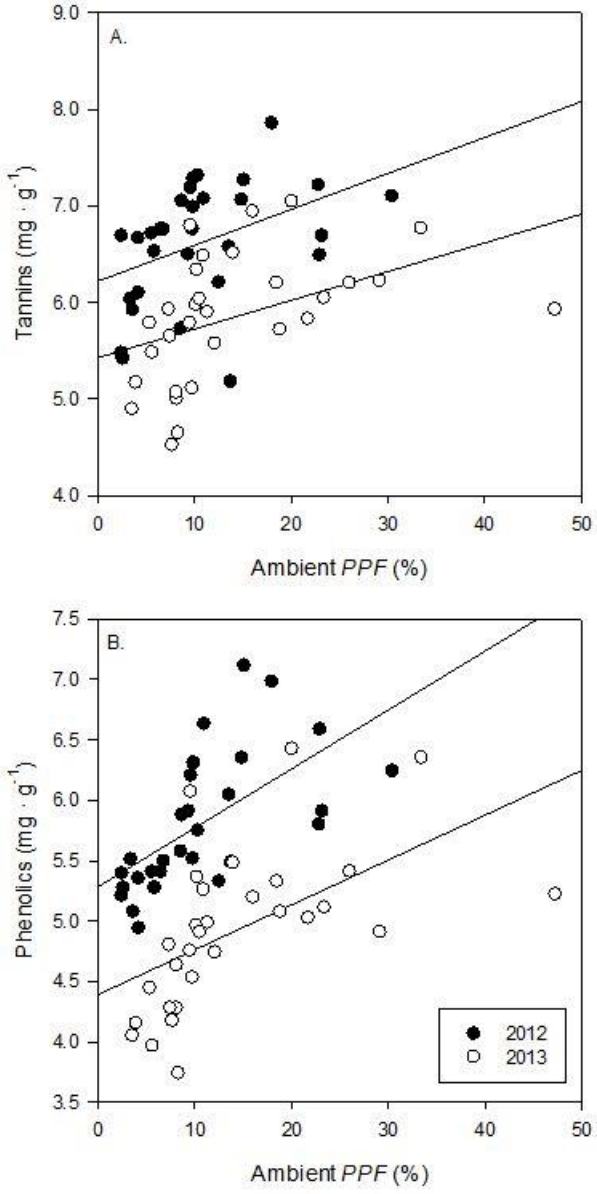

Fig. 3.3. Effect of fruit zone light infiltration (percent ambient *PPF*) of Oregon 'Pinot noir' in the afternoon during véraison on (A) total tannin and (B) total phenolic concentration of 'Pinot noir' berries. Tannins: Year $P < 0.001$, ambient *PPF* $P < 0.001$, interaction not significant, model $P < 0.001$, $r^2 = 0.57$ (2012: $y = 0.041x + 5.37$; 2013: $y = 0.041x + 4.34$). Phenolics: Year $P = <0.001$, ambient *PPF* $P < 0.001$, interaction not significant, model $P < 0.001$, $r^2 = 0.40$ (2012: $y = 0.032x + 6.27$, 2013: $y = 0.032x + 5.39$).

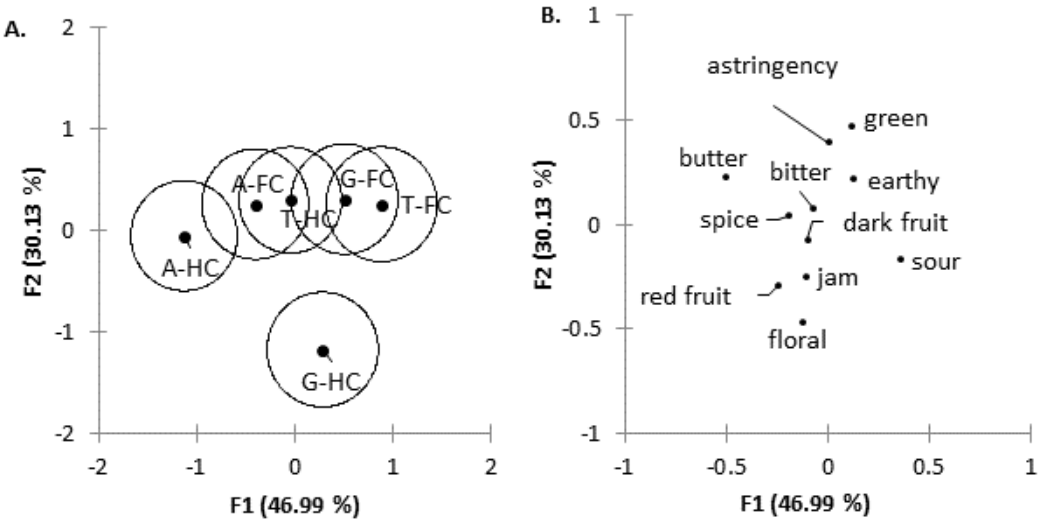

Fig. 3.4. Separation of 2013 ‘Pinot noir’ wines based on canonical variate analysis by treatment scores (A) and sensory loadings (B) obtained from a winemaker sensory panel. Treatments are positioned using centroids with circles representing 95% confidence intervals surrounding the treatment means. Abbreviations: Grass (G), Alternate (A), Tilled (T), Half crop (HC), and Full crop (FC).

Table 3.1. Canopy and fruit ratio metrics of Oregon 'Pinot noir' vines under different vineyard floor management and crop level treatments from 2011 to 2013.

Treatments	Leaf area:yield ($m^2 \cdot kg^{-1}$)[z]			Yield:pruning weight ($kg \cdot kg^{-1}$)[y]		
	2011	2012	2013	2011	2012	2013
Floor mgt. (F)[x]						
Grass	2.1	1.6 b[w]	2.7	ND[v]	2.6 a	2.0 a
Alternate	1.7	2.4 a	3.0	ND	1.7 b	1.4 b
Tilled	1.5	2.6 a	3.2	ND	1.3 c	1.1 b
Crop level (C)[u]						
Full crop	1.3 b	1.7 b	2.1 b	ND	2.4 a	1.9 a
Half crop	2.3 a	2.7 a	3.8 a	ND	1.4 b	1.1 b
P-value						
F	NS[t]	<0.001	NS	ND	<0.001	<0.001
C	<0.001	<0.001	<0.001	ND	<0.001	<0.001
F x C	NS	NS	NS	ND	0.046	NS

[z]Ratio determined from vine leaf area at véraison and yield at harvest.
[y]Calculated using vine yield divided by vine pruning weight measured during the dormant period after harvest.
[x]Floor management treatments include Grass - red fescue established in both alleyways flanking the vine row; Alternate - red fescue in one flanking alleyway while the other was tilled; and Tilled - the two flanking alleyways were kept free of vegetation by tilling.
[w]Different letters within columns represent differences by Tukey's HSD at α=0.05.
[v]n.d. – not determined, as pruning weight data not available.
[u]Crop level treatments included Full Crop - no clusters removed, and Half Crop - fruit was thinned to one cluster per shoot (≈42% clusters removed per vine).
[t]NS = not significant at $P > 0.05$.

Table 3.2. Oregon 'Pinot noir' composition at harvest from vineyard floor management and crop level treatments 2011 to 2013.

Treatments	Anthocyanins (mg·g^{-1})[z]			Tannins (mg·g^{-1})[y]			Phenolics (mg·g^{-1})[x]		
	2011	2012	2013	2011	2012	2013	2011	2012	2013
Floor mgt. (F)[w]									
Grass	0.47 a[v]	0.45	0.50	6.96 a	6.38 a	5.42 a	6.52	7.05 a	6.21
Alternate	0.38 ab	0.43	0.45	6.39 ab	5.72 b	4.82 ab	6.14	6.52 ab	5.86
Tilled	0.35 b	0.43	0.49	6.03 b	5.32 b	4.52 b	6.06	6.29 b	5.48
Crop level (C)[u]									
Full crop	0.38 b	0.41 b	0.46	6.67 a	5.81	5.10 a	6.34	6.38 b	5.98
Half crop	0.43 a	0.46 a	0.50	6.24 b	5.81	4.74 b	6.13	6.86 a	5.73
P-value									
F	0.028	NS[t]	NS	0.023	<0.001	0.043	NS	0.025	NS
C	0.021	0.040	NS	0.003	NS	0.007	NS	0.022	NS
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Total anthocyanin concentration reported as mg malvidin-3-glucoside equivalents per gram of berries.
[y]Total tannin concentration reported as mg epicatechin equivalents per gram of berries.
[x]Total phenolic concentration reported as mg gallic acid equivalents per gram of berries.
[w]Floor management treatments include Grass - red fescue established in both alleyways flanking the vine row; Alternate - red fescue in one flanking alleyway while the other was tilled; and Tilled - the two flanking alleyways were kept free of vegetation by tilling.
[v]Different letters following means represent differences by Tukey's HSD at α=0.05.
[u]Crop level treatments included Full Crop - no clusters removed, and Half Crop - fruit was thinned to one cluster per shoot (~ 42% clusters removed per vine).
[t]NS = not significant at $P > 0.05$.

Table 3.3. Crop load and yield relationships to Oregon 'Pinot noir' berry components in 2011 to 2013 using floor management and cluster thinning.

		Leaf area:yield		Yield:pruning weight		Yield (kg/vine)	
		Function Type	r^2	Function Type	r^2	Function Type	r^2
TSS (˚Brix)[z]	2011	P[y]***[x]	0.360	n.d.[w]	n.d.	L***	0.563
	2012	P***	0.401	L***	0.404	L*	0.209
	2013	-[v]	-	-	-	-	-
pH	2011	L***	0.367	n.d.	n.d.	P***	0.433
	2012	L*	0.169	-	-	L**	0.216
	2013	-	-	-	-	-	-
TA ($g \cdot L^{-1}$)[u]	2011	P***	0.288	n.d.	n.d.	P***	0.607
	2012	L*	0.169	L*	0.198	-	-
	2013	-	-	L**	0.320	-	-
YAN ($mg \cdot L^{-1}$)[t]	2011	-	-	n.d.	n.d.	P***	0.318
	2012	L***	0.461	L***	0.582	-	-
	2013	L*	0.154	L***	0.451	-	-
ACY ($mg \cdot g^{-1}$)[s]	2011	P***	0.276	n.d.	n.d.	Q***	0.552
	2012	-	-	-	-	-	-
	2013	-	-	-	-	-	-
TAN ($mg \cdot g^{-1}$)[r]	2011	-	-	n.d.	n.d.	-	-
	2012	P***	0.303	L**	0.277	-	-
	2013	-	-	L***	0.455	-	-
PHE ($mg \cdot g^{-1}$)[q]	2011	-	-	n.d.	n.d.	-	-
	2012	-	-	-	-	-	-
	2013	-	-	L**	0.287	-	-

[z]TSS = total soluble solids.
[y]Function type: L = linear, P = power, and Q = quadratic.
[x]*$P \leq 0.05$,** $P \leq 0.01$, and *** $P \leq 0.001$.
[w]n.d. = not determined.
[v]- no significant relationship.
[u]TA = titratable acidity.
[t]YAN = yeast assimilable nitrogen; the sum of primary amino acids and ammonia assays.
[s]ACY = total anthocyanin concentration reported as mg malvidin-3-glucoside equivalents per gram of berries.
[r]TAN = total tannin concentration reported as mg epicatechin equivalents per gram of berries.
[q]PHE = total phenolic concentration reported as mg gallic acid equivalents per gram of berries.

Table 3.4. Effects of véraison leaf area and yield on Oregon ‘Pinot noir’ berry composition under different floor management and crop levels.

[z]NS = not significant at $P > 0.05$, so variable removed from model.
[y]*P*-value for predictor variable in model.
[x]TSS = total soluble solids.
[w]TA = titratable acidity.
[v]YAN = yeast assimilable nitrogen; the sum of primary amino acids and ammonia assays and was log-transformed in 2011 and 2012.
[u]ACY = total anthocyanin concentration reported as mg malvidin-3-glucoside equivalents per gram of berries.
[t]TAN = total tannin concentration reported as mg epicatechin equivalents per gram of berries.
[s]PHE = total phenolic concentration reported as mg gallic acid equivalents per gram of berries.

Table 3.4. Effects of véraison leaf area and yield on Oregon 'Pinot noir' berry composition under different floor management and crop levels.

Berry component	Leaf area (m^2)	Yield (kg)	Interaction	Model *P*-value	R^2	Equation
				2011		
TSS (˚Brix)[x]	NS[z]	<0.001[y]	NS	<0.001	0.51	TSS = - 0.35 x yield + 21.18
pH	NS	<0.001	NS	<0.001	0.40	pH = - 0.03 x yield + 3.28
TA ($g \cdot L^{-1}$)[w]	0.002	<0.001	0.010	<0.001	0.72	TA = - 0.13 x LA x yield + 1.11 x yield + 0.60 x LA+ 4.21
YAN ($mg \cdot L^{-1}$)[v]	0.003	0.003	0.020	<0.001	0.61	$\log_{10}$(YAN) = - 0.26 x yield x LA + 0.20 x yield + 0.13 x LA + 1.10
ACY ($mg \cdot g^{-1}$)[u]	NS	<0.001	NS	<0.001	0.57	ACY = - 0.043 x yield + 0.57
TAN ($mg \cdot g^{-1}$)[t]	0.008	NS	NS	0.008	0.23	TAN = - 0.22 x LA + 7.78
PHE ($mg \cdot g^{-1}$)[s]	NS	NS	NS	NS		
				2012		
TSS (˚Brix)	0.004	0.014	NS	0.002	0.37	TSS = 0.24 x LA - 0.61 x yield + 23.51
pH	NS	NS	NS	NS		
TA ($g \cdot L^{-1}$)	NS	NS	NS	NS		
YAN ($mg \cdot L^{-1}$)	<0.001	0.027	NS	<0.001	0.63	$\log_{10}$(YAN)= 0.12 x LA - 0.09 x yield + 1.60
ACY ($mg \cdot g^{-1}$)	NS	NS	NS	NS		
TAN ($mg \cdot g^{-1}$)	<0.001	NS	NS	<0.001	0.58	TAN = - 0.27 x LA + 7.24
PHE ($mg \cdot g^{-1}$)	0.003	NS	NS	0.003	0.28	PHE = - 0.21 x LA + 7.74

Table 3.4. Effects of véraison leaf area and yield on Oregon 'Pinot noir' berry composition under different floor management and crop levels (Continued).

Berry component	Leaf area (m^2)	Yield (kg)	Interaction	Model *P*-value	R^2	Equation
				2013		
TSS (˚Brix)	0.005	NS	NS	0.005	0.25	TSS = 0.30 x LA + 19.61
pH	NS	NS	NS	NS		
TA ($g \cdot L^{-1}$)	NS	NS	NS	NS		
YAN ($mg \cdot L^{-1}$)	0.001	NS	NS	0.001	0.35	YAN = 17.94 x LA + 11.98
ACY ($mg \cdot g^{-1}$)	NS	NS	NS	NS		
TAN ($mg \cdot g^{-1}$)	NS	NS	NS	NS		
PHE ($mg \cdot g^{-1}$)	NS	NS	NS	NS		

Table 3.5. Multiple regression analyses of dormant vine pruning weight and yield with Oregon 'Pinot noir' berry composition under varying floor management and crop levels in 2012 and 2013.

Berry component	Pruning wt. (PW, kg)	Yield (Y, kg)	Interaction	Model *P*-value	R^2	Equation
				2012		
TSS (˚Brix)[z]	0.028[y]	0.010	NS[x]	0.004	0.34	TSS = - 0.55 x Y + 0.67 x PW + 23.54
pH	NS	NS	NS	NS		
TA ($g \cdot L^{-1}$)[w]	NS	NS	NS	NS		
YAN ($mg \cdot L^{-1}$)[v]	<0.001	NS	NS	<0.001	0.61	$\log_{10}$(YAN) = 0.38 x PW + 1.40
ACY ($mg \cdot g^{-1}$)[u]	NS	NS	NS	NS	NS	
TAN ($mg \cdot g^{-1}$)[t]	<0.001	NS	NS	<0.001	0.54	$\log_{10}$(TAN)= - 0.06 x PW + 0.86
PHE ($mg \cdot g^{-1}$)[s]	0.029	NS	NS	0.029	0.16	PHE = - 0.51 x PW + 7.40
				2013		
TSS (˚Brix)	NS	NS	NS	NS		
pH	NS	NS	NS	NS		
TA ($g \cdot L^{-1}$)	NS	NS	NS	NS		
YAN ($mg \cdot L^{-1}$)	<0.001	NS	NS	<0.001	0.75	YAN = 106.1 x PW – 14.29
ACY ($mg \cdot g^{-1}$)	NS	NS	NS	NS		
TAN ($mg \cdot g^{-1}$)	<0.001	0.031	NS	<0.001	0.51	TAN = 0.33 x Y - 0.95 x PW + 5.65
PHE ($mg \cdot g^{-1}$)	0.006	NS	NS	0.006	0.24	PHE = - 0.67 x PW + 6.81

[z]TSS = total soluble solids.
[y]*P*-value for predictor variable in model.
[x]NS = not significant at $P > 0.05$, so variable removed from model.
[w]TA = titratable acidity.
[v]YAN = yeast assimilable nitrogen; the sum of primary amino acids and ammonia assays and was log-transformed in 2011 and 2012.
[u]ACY = total anthocyanin concentration reported as mg malvidin-3-glucoside equivalents per gram of berries.
[t]TAN = total tannin concentration reported as mg epicatechin equivalents per gram of berries.
[s]PHE = total phenolic concentration reported as mg gallic acid equivalents per gram of berries.

Table 3.6. Multiple regression analyses of viticulture measures for Oregon ‘Pinot noir’ berry components under different floor management and crop levels for three years.

[z]Vine yield measured at harvest (kg).
[y]Leaf area measured at véraison (m^2).
[x]Nitrogen concentration in leaf blades at véraison (%).
[w]*PPF* infiltration through cluster zone at solar noon during one day during véraison.
[v]TSS = total soluble solids.
[u]NS = not significant at $P > 0.05$.
[t]TA = titratable acidity.
[s]YAN = yeast assimilable nitrogen; the sum of primary amino acids and ammonia assays.
[r]ACY = total anthocyanin concentration reported as mg malvidin-3-glucoside equivalents per gram of berries.
[q]TAN = total tannin concentration reported as mg epicatechin equivalents per gram of berries.
[p]PHE = total phenolic concentration reported as mg gallic acid equivalents per gram of berries.

Table 3.6. Multiple regression analyses of viticulture measures for Oregon 'Pinot noir' berry components under different floor management and crop levels for three years.

Berry component	Year (R)	Yield (Y)[z]	Leaf area (LA)[y]	Leaf Blade Nitrogen (N)[x]	*PPF* (P)[w]	Model	R^2	CV	Equation
TSS (˚Brix)[v]	<0.001	<0.001	<0.001	NS[U]	NS	<0.001	0.77	3.8	TSS = 23.03 - 2.97 x (R=2011) - 2.08 x (R=2013) - 0.39 x Y + 0.22 x LA
pH	<0.001	<0.001	NS	NS	NS	<0.001	0.46	1.8	pH = 3.35 - 0.06 x (R=2011) - 0.09 x (R=2013) - 0.03 x Y
TA ($g \cdot L^{-1}$)[t]	<0.001	0.009	NS	0.001	0.001	<0.001	0.68	5.7	TA = 6.91 - 0.39 x (R=2011) - 1.42 x (R=2013) + 0.15 x Y - 0.08 x P + 1.21 x N
YAN ($mg \cdot L^{-1}$)[s]	<0.001	NS	0.002	<0.001	NS	<0.001	0.59	29.0	YAN = - 250.53 - 63.38 x (R=2011) - 45.45 x (R=2013) + 175.50 x N + 9.13 x LA
ACY ($mg \cdot g^{-1}$)[r]	NS	<0.001	NS	NS	NS	<0.001	0.31	15.9	ACY = 0.61 - 0.04 x Y
TAN ($mg \cdot g^{-1}$)[q]	<0.001	NS	NS	<0.001	0.004	<0.001	0.70	8.7	TAN = 7.93 + 0.86 x (R=2011) - 0.51 x (R=2013) + 0.07 x P - 1.31 x N
PHE ($mg \cdot g^{-1}$)[p]	<0.001	NS	NS	<0.001	NS	<0.001	0.33	8.8	PHE = 8.71 + 0.15 x (R=2011) - 0.40 x (R=2013) - 1.17 x N

CHAPTER 4

ASSOCIATIONS OF ‘PINOT NOIR’ BUD FRUITFULNESS WITH VINE NITROGEN AND TOTAL NON-STRUCTURAL CARBOHYDRATE STATUS

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Abstract

Yields are restricted in commercial ‘Pinot noir’ vineyards of Oregon’s Willamette Valley to maintain high-quality wine production standards. However, high inter-annual yield variability is challenging for producers in this cool climate region. While genotype and climate determine yield; it is important to recognize that vineyard management also has a role. Vineyard floor, nutrient, and irrigation management practices may alter yields; however, understanding how these practices influence vine physiology is key to applying them effectively. The quantity and size of clusters can vary annually and becomes a challenge for winegrape producers. A long-term competitive cover cropping trial was studied to understand the influence of seasonal root and trunk nitrogen (N) and total non-structural carbohydrate (TNC) status on inflorescence primordia presence and size in vines of varying vigor levels. The floor management treatments included Grass, which had resident vegetation in the alleyways flanking the vine row; Tilled, which was kept vegetation-free through cultivation; and Alternate, which had one alleyway as resident vegetation and the other vegetation-free. Grass vines had the lowest N concentrations in perennial and annual tissues, and had the fewest and/or smallest inflorescence primordia within primary buds, which resulted in fewer inflorescences per shoot post-bud break and the lowest yield in two of three years. Grass vines had the highest root tissue TNC concentrations at harvest and the lowest N concentrations in roots at all phenological stages compared to Tilled vines. Tissue N concentrations had greater relationships to fruitfulness than TNC. Lower N status and vine vigor in Grass vines led to greater solar exposure of shoots, but shoots that were under higher solar exposure had lower fruitfulness. This study suggests that N limitation, rather than low TNC or light exposure, led to the reduced number of inflorescence primordia initiated in primary buds, consequently lowering fruitfulness.

Introduction

Inter-annual yield variability is a concern for cool climate winegrape producers. Yield variability in winegrapes is thought to be more prevalent in cool climates, and it has been reported to be as significant as 150% for *Vitis vinifera* cv. Pinot noir (Heazlewood, 2005). 'Pinot noir' is a small clustered cultivar, and although fruit set can alter yields in other cultivars quite substantially, it only has a limited affect in 'Pinot noir' (Mercado-Martín et al., 2006). Therefore, the number of clusters per shoot is the more important variable in yield variation among years (Li-Mallet et al., 2016). Since the number of shoots per vine can easily be manipulated through pruning or thinning shoots early in the season, the primary uncertainty in yield is fruitfulness-the number of inflorescences borne per shoot (Vasconcelos and Castagnoli, 2000).

Grape inflorescences arise from floral primordia that are developed within a compound bud that remains latent one season prior to the season in which it is borne on a growing fruitful shoot (Morrison, 1991; Noyce et al., 2016; Watt et al., 2008). *Vitis vinifera* buds contain three single buds within a single compound bud at each node, consisting of one primary bud and two secondary buds (Morrison, 1991). Bud fruitfulness (bud FFL) refers to the number of inflorescence primordia within a latent bud, while FFL refers to the number of inflorescences per shoot post-bud break (Dry, 2000; Li-Mallet et al., 2016). Research in Tasmania shows 'Pinot noir' inflorescence primordia initiate three weeks prior to bloom (Jones, 2009), and it is unclear how consistent the timing of floral primordia initiation is between different climates.

Floral initiation and growth of inflorescence primordia in the bud are affected by temperature and solar radiation (Baldwin, 1964; Buttrose, 1969a, 1969b; May, 1965; Perez and Kliewer, 1990; Sánchez and Dokoozlian, 2005). Although it is often thought that temperature and light directly influence floral initiation, it is also possible these variables may indirectly

affect FFL through their impact on carbon assimilation (Baldwin, 1964; Bennett et al., 2005; Buttrose, 1969a, 1969b; Eltom et al., 2014; Li-Mallet et al., 2016; Perez and Kliewer, 1990; Sánchez and Dokoozlian, 2005). Many of these studies did not address other coexisting factors that may affect FFL. For example, studies that focused on light effects on bud FFL used whole vine shading or light exposure to affect photosynthetic photon flux (*PPF*) or temperatures. Since past temperature studies did not isolate the bud, increased whole vine carbon assimilation may have influenced FFL through altering vine carbohydrate reserves. High temperature may inhibit photosynthesis and FFL in 'Muscat of Alexandria' (Buttrose, 1969b; Luo et al., 2011). Sánchez (2003) found that lengthening the day from 10 to 16 hours resulted in a 4.7-fold increase in the number of fruitful buds, likely because photosynthesis occured for longer periods of time.

Leaf removal studies have been used to alter carbohydrate status of vines, but these studies rarely address the effect of N loss by preventing resorption from leaves (Acimovic et al., 2016; Bennett et al., 2005; Candolfi-Vasconcelos and Koblet, 1990; Holzapfel and Smith, 2012). Defoliation may result in a considerable loss of N, as up to 50% of stored N is remobilized for next year's spring growth (Cheng et al., 2004; Schreiner et al., 2006; Zapata et al., 2004). Additionally, canopy defoliation studies may alter current season photoassimilation and may cause a higher proportion of reserve TNC to be utilized for fruit ripening than under normal conditions, limiting our interpretation of the effect of tissue N reserves on FFL.

Relationships between the number of inflorescences per shoot and internode starch concentrations have been shown in the literature (Jones, 2009; Thomas and Barnard, 1937). Duchene et al. (2003) reported a reduction in 'Pinot noir' FFL when (TNC) were reduced in pruning wood tissue. Lower starch concentrations in root and trunks at bud break have also been associated with lower FFL of 'Chardonnay' (Bennett et al., 2005).

The relationship between vine N status and FFL are of limited mention in the literature, and rarely has vine N status been related to bud FFL or inflorescence primordia initiation and growth. However, Srinivasan et al. (1972) reported an increase in inflorescence primordia size when vines were supplied with N, and Duchene et al. (2003) found higher FFL in vines with higher concentrations of free amino acids in pruning wood.

It is well established that increasing N status leads to increases in vine vegetative growth. Persistent woody laterals are associated with higher vigor and when nodes with and without laterals were compared, nodes with persistent woody laterals had higher FFL in 'Thompson Seedless' (Christensen and Smith, 1989). Eltom et al. (2014) found higher FFL on larger diameter canes of 'Sauvignon blanc', suggesting higher vigor vines are more fruitful. Conversely, high-vigor vines have been associated with primary bud necrosis (PBN), which reduces FFL, as the primary bud dies (Dry and Coombe, 1994; Morrison and Iodi, 1990), leaving the less fruitful secondary buds (Noyce et al., 2016; Sánchez and Dokoozlian, 2005) to emerge at bud break. Although PBN is often associated with vigorous shoot growth and buds with low starch concentrations (Morrison and Iodi, 1990; Vasudevan et al., 1998). Primary bud necrosis was the cause of reduced FFL in a trial where vines were defoliated immediately after harvest, presumably limiting N resorption or carbohydrate reserve replenishment post-harvest (Holzapfel and Smith, 2012).

Previous work in 'Pinot noir' indicates lower FFL in vines with lower leaf blade N concentrations and higher shoot light exposure (Reeve et al., 2016, 2018). To investigate whether reduced FFL was due to fewer inflorescence primordia being initiated or retained within the bud, a study was conducted to determine the role of N, TNC, and ambient solar radiation on inflorescence primordia presence and retention across two growing seasons. Our objectives were

to 1) determine if PBN played a role in FFL, 2) determine if there were relationships between bud FFL and *PPF*, and 3) determine if relationships were present between bud FFL and vine N and TNC status. It was hypothesized that vine N status would influence inflorescence primordia initiation more than shoot light microclimate or carbohydrate reserves.

Materials and Methods

Experimental site and design. A trial was established in a commercial vineyard in Dayton, OR, USA to monitor fruitfulness from February 2014 (dormancy) to August 2016 (harvest) within the confines of an experiment that altered vine vegetative vigor using competitive cover cropping over the prior seven years (Reeve et al., 2016). Briefly, three floor management treatments were arranged in a completely randomized design using 'Pinot noir' Dijon clone 115 on 101-14 rootstock, and cane-pruned to a bilateral Guyot training system with vertical shoot positioning. The three floor management treatments were replicated five times with eight vines per plot and consisted of the following: Grass, resident vegetation in the alleyways adjoining the vine row; Alternate, one of the alleyways contained resident vegetation and the other was free of vegetation; and Tilled, both alleyways were kept vegetation-free through soil tillage.

Field measurements. Vine vigor was assessed through leaf area measurements taken at bloom and véraison and dormant pruning weights measured after each growing season. Whole vine leaf area and pruning weights were measured using previously reported methods (Reeve et al., 2016) at BBCH stages 83 (50% véraison) and 0 (dormancy; Lorenz et al., 1995).

Single leaf photosynthesis (P_n) was measured on sun-exposed primary leaf blades using an infra-red gas analyzer (Li-Cor 6400-XT, Lincoln, NE), with the temperature and relative humidity set to ambient conditions, a flow rate set to 400 $\mu mol \cdot s^{-1}$, and the CO_2 mixer set at 400

ppm. Morning measurements occurred between 1030 HR and 1130 HR on the east side of the canopy. Solar noon and afternoon measures (between 1430 HR and 1530 HR) were taken on the west side of the canopy. Photosynthetic rate was measured in both years at bloom, fruit set, bunch closure, and véraison (BBCH – 65, 71, 77, and 83), with additional measurements at the pea-size and ripening stages (BBCH – 75 and 88) in 2014.

The canopy light environment was quantified using a ceptometer (LP-80, Decagon Devices, Pullman, WA) and reported as the percent ambient *PPF*. Measurements were taken on the west side of the canopy from 1030 HR to 1130 HR, and on the east side at solar noon (1230 HR to 1330 HR) and 1430 HR to 1530 HR. Measurements were averaged over the three ceptometer readings during the day. The ceptometer was held level with the sensor surface facing upward, parallel to the 150-cm tall canopy at the base of three canopy zones, including proximal (cluster zone), middle, and distal at 0 cm, 50 cm, and 100 cm above the trellis fruiting wire, respectively. Measurements were taken at pre-bloom, pea-size, bunch closure, and 50% véraison (BBCH 52-59, 75, 77, and 83) and additionally at the BB-sized berries and ripening stages in 2014 (BBCH 73 and 88). Measurements were only obtained in the fruit zone for early phenological stages (pre-bloom, BB, and pea-size) in 2014 and pre-bloom in 2015, as there was insufficient canopy growth to measure separate zones. For later phenological stages, readings over the three zones were averaged and termed canopy zone *PPF*.

Fruitfulness was evaluated when inflorescences were clearly visible (BBCH 53), about five weeks post-bud break, by counting the number of inflorescences on each shoot per vine and recording node position. A day prior to commercial harvest, the number of clusters per vine were counted, removed from the vine and weighed for whole vine yields. Mean cluster weight was

determined from the whole vine yield and number of clusters per vine. The trial was harvested on 12 Sept. 2015, 16 Sept. 2015, and 26 Aug. 2016.

Dormant canes were collected from all treatment plots for bud dissections in Feb. of 2014, 2015, and 2016. In 2014, one cane per vine (n = 8) in each plot was harvested, whereas two canes per vine were collected in the later years (n = 16). Each year, an additional cane per vine was collected to determine total non-structural carbohydrate ([TNC]) and nitrogen concentrations ([N]) in internode and bud tissue. Canes that were average size for each vine were selected, avoiding fruiting canes and canes from renewal spur positions at the head of the trunk. All canes were placed into large plastic bags with damp paper towels, taped closed after removing as much air as possible, and transported back to the laboratory. Canes used for TNC and N analyses were processed immediately upon return to the laboratory as described later. Canes used for bud dissections were kept in storage (6°C) until processed, which was within one week in 2015 and 2016 but within seven weeks in 2014.

Bud fruitfulness dissections. Buds on dormant canes were dissected from node positions one to ten, with node one being the most proximal node to the vine trunk. In 2014, the second most-proximal bud was considered the first node position, as the proximal-most bud is usually considered a non-count bud. The non-count bud was not included in 2015 and 2016, and assessment began with the bud located at the node with 0.5 to 1.0 cm of internode below it. Buds were dissected by hand using single-edge razor blades under a stereoscope (Olympus SZ651, Olympus America Inc., Center Valley, PA) and were assessed for necrosis presence or absence and bud FFL, the number of inflorescence primordia in the primary bud of the compound latent bud. In 2014, sequential longitudinal slices were made parallel to cane, exposing all three buds within the compound latent bud. When the first inflorescence primordium was visible, the bud

scales and trichomes at the top of the bud were gently pushed back to expose the primary bud axis. This method likely underestimated bud fruitfulness (Sánchez, personal communication), so in 2015 and 2016, transverse, sequential slices were made perpendicular to the bud axis. Additionally, the widest diameter of the inflorescence primordia going through the main axis of the inflorescence primordium, closest to the bud axis was measured to the nearest 0.1 mm with a 10 mm micro-ruler with 0.1 mm increments (Ted Pella Inc., Redding, CA). The sum of the lengths of the inflorescence primordia within a bud made up the integrated fruitfulness index (IFI; Sánchez and Dokoozlian, 2005).

Trunk and root samples were collected at six phenological time points in the Grass and Tilled treatments during the 2014 and 2015 seasons, starting at dormancy (Feb. 2014), bud break, 50% capfall, 50% véraison, harvest, and 100% leaf fall corresponding to the BBCH 0, 7, 65, 85, 89, and 97 stages, respectively. Both treatments were sampled on the same day for each phenological stage except leaf fall in 2014 when Grass and Tilled differed for 100% leaf fall. To avoid damaging the vine during sampling, the vine and surrounding soil surface was split into four quadrants, including northeast, southeast, northwest, and southwest. At each sampling, two vines per plot were sampled for root and trunk tissue using different quadrants within the same vine, ensuring that no quadrant was repeatedly harvested. The sampling included two trunk cores collected per vine at 30 cm above the soil level using a 20-cm increment borer with a 3-thread, 0.20 mm diameter bit (Haglöf, Långsele, Sweden). The corer was bored just past the center of the vine, and upon extraction, the sample was cut to the length of the trunk radius, which retained the periderm. The second core was taken in the same quadrant within 5 cm below the first and slightly offset. Root samples were obtained by digging into the soil within 30 cm from the trunk. One large woody root sample (1.5 to 3.0 cm diameter) was collected per vine by bisecting the

root along its axis with a serrated pocket knife (Gerber, Portland, OR) and making two perpendicular cuts using a folding jaw saw (Milwaukee, Brookfield, WI) with a 10 cm Hackzall blade (Milwaukee). Roots were cut carefully to retain the periderm. All samples were transported on ice, washed with deionized water, and stored at -80°C. Exposed trunk and root tissues were immediately sealed (Morrison's Tree Seal, Lilly Miller Brands, Clackamas, OR) once samples were obtained.

Total non-structural carbohydrate and nitrogen analyses. Dormant canes used for nutrient analyses were processed in the laboratory before freezing at -80˚C. Bud samples were taken from node positions one to 15 by undercutting the latent bud at each node while internode samples were obtained from the middle 1 cm of internode between each node. The bud cushion, tissue between the bud and the cane, was later cut from the compound bud to avoid variability in bud size and how deeply the bud was undercut from affecting starch concentration. To minimize the impact of root diameter on periderm to vascular tissue obtained in a sample, roots were cut following the root axis to a width of 40 to 80 mm, centered perpendicularly to the cut surface made from the field bisection. Any part of the root sample that was in contact with a knife during sampling, was shaved off to remove soil residue. Root, bud, and internode samples were cut into smaller pieces to facilitate drying. Trunk and root samples were lyophilized at -20°C (Lyph-Lock 6, Labconco, Kansas City, MO) for 5 d until reaching a constant weight, and then stored in paper coin envelopes placed within a vacuum desiccator (Scienceware, Wayne, NJ) with Drierite (Drierite, Xenia, OH). All samples were later ground with a Wiley Mill (Thomas Scientific, Swedesboro, NJ) to pass through 1.0 and 0.5 mm screens, successively. A 2 g aliquot of 0.5 mm ground sample was placed in a ball mill (Kleco 4200, Garcia Manufacturing, Visalia, CA) for 2 min and stored in a vacuum desiccator in coin envelopes until analyzed for [N] and [TNC].

To determine [TNC], simple sugars (referred to as sugar for brevity) were extracted and starch hydrolyzed similarly to Chow and Landhäusser (2004). Briefly, from 50 mg finely ground samples, sugars were extracted using ~ 5 mL 80% ethanol at 85˚C for 10 min, and reextracted two additional times, centrifuged, supernatants collected, and brought up to a final volume of 15 mL. The pellet was saved for starch analysis described below. Sugar concentrations were determined using the phenol-sulfuric acid assay using a 1:1:1 glucose: fructose: galactose solution for the standard curve. Starch was hydrolyzed from the pellet by resuspending it in 0.1 N sodium hydroxide, incubation at 50˚C for 30 min, and neutralization with 0.1 N acetic acid. A buffered solution containing α-amlyase and amyloglucosidase, in excess, was added to the mixture with the pellet before incubation at 50˚C with intermittent mixing. After 20 h, the solution was cooled, vortexed, diluted to 10 mL, and centrifuged. This supernatant was used for determination of glucose using a commercial enzymatic assay kit (K-GLUC, Megazyme International, Bray, Ireland), and estimated as starch. A spectrophotometer (Genesys 10S UV-VIS; ThermoFisher Scientific, Madison, WI) was used for both analyses. Sugar and starch concentrations were combined for TNC. An aliquot of the finely ground sample was used to determine percent N by combustion with a LECO TruSpec CN Analyzer (LECO Corp., St. Joseph, MI).

Total N was analyzed from leaf blades (n=20) and petioles (n=20) collected at bloom and véraison each year, using established methods (Schreiner et al., 2013) with modifications previously described in Reeve et al. (2016). Collected tissues were cleaned in distilled water, wiped dry, oven-dried at 60°C for 48 h, ground and analyzed for N (%) through Central Analytical Laboratory at Oregon State University using methods described in Reeve et al. (2016).

Statistics. Floor management treatment differences were determined by analysis of variance with means separation using Tukey's Honest Significant Difference (HSD) in the SAS Proc Mixed package of SAS 9.4 (SAS Institute, Cary, NC). Simple linear and multiple regressions were analyzed using Proc GLM for relationships between percent ambient *PPF* and bud dissections. Homogeneity of variance was assessed using residuals plots.

Results

Climate. The 2015 growing season began earlier than in 2014 but reached bloom around the same calendar date (Table 4.1). Although the bud break to bloom period was ~1.0˚C warmer in 2014 than 2015, the period from bloom to véraison was ~1.5˚C warmer in 2015, resulting in similar GDD_{10} between bud break and véraison both years. Precipitation was ~70 mm greater in 2014 than the 2015 season from bud break to véraison. The post-harvest period had ~90 more GDD_{10} in 2014 than in 2015. Both seasons had between 1728 and 1771 GDD_{10}, but 2014 had more than 100 mm more precipitation over the growing season than 2015.

Vine vigor. Floor management treatments influenced vine growth, including leaf area and dormant pruning weight. Tilled had greater leaf area than Grass at bloom in 2014, but not 2015 ($P = 0.003$ and $P = 0.340$, respectively). Tilled had greater vine leaf area than Grass at véraison in 2014 and 2015 ($P = 0.002$ and $P = 0.022$, respectively). The 3-year mean leaf area at véraison measured 2.96, 4.43, and 4.66 m^2 per vine for Grass, Alternate, and Tilled respectively. Vine pruning weights over the three years averaged 0.78, 1.27, and 1.49 kg per vine for Grass, Alternate, and Tilled, respectively. Grass consistently had lower pruning weights than Tilled in all three years ($P \leq 0.002$).

Fruitfulness. Grass had the lowest bud FFL in 2014 and 2015 and fewer inflorescences per shoot post-bud break in both years (Table 4.2). In 2016, there were no differences in either

Bud FFL or FFL among floor management treatments. Tilled consistently had 0.2 more inflorescence primordia than Grass in 2014 and 2015 and 0.1 more inflorescences per shoot (FFL) following bud break in those years. Interestingly, despite Alternate having lower or equal number of inflorescence primordia to Grass in 2014 and 2015, Alternate had 0.1 more inflorescences per shoot than Tilled in those years. When including the size of inflorescence primordia, IFI was lowest in Grass and highest in Tilled during 2015. During 2016, there was no difference in IFI among floor management treatments.

Primary bud necrosis. The percentage of buds showing some necrotic tissue in the primary bud differed by floor management treatment in only one year (2014). This was the year the most necrosis was found (Table 4.2). The percentage of buds showing any necrosis ranged from 0% to 21% in all years; however, only 0% to 3% of the buds showed complete necrosis of the primary bud (PBN). Alternate had the highest occurrence of PBN (2.1%), and Grass and Tilled had the lowest occurrences at 0.6% and 0.8%, respectively in 2014 ($P = 0.020$). There were very few incidences of PBN found in 2015 and 2016 (data not shown).

Yield components. Grass had the fewest cluster numbers per vine at harvest for all three years (Table 4.3). Grass had the lowest cluster weights in 2014 and the lowest yields in 2014 and 2015. Tilled and Alternate had similar numbers of clusters per vine, cluster weights, and yields at harvest for all three years. Although bud FFL and FFL were not different by treatment in 2016, the number of clusters per vine at harvest differed, but there were no differences in cluster weight or whole vine yields that year (Table 4.3).

Seasonal [TNC] and [N] reserves. Starch was the predominant component of root [TNC], ranging between 64% and 86% of [TNC] across phenological stages, treatments, and years. Seasonal change in root [TNC] was similar for 2014 and 2015, with minor differences between

some phenological stages (Table 4.4 and Fig. 4.1). For example, [TNC] decreased from dormancy to bud break in 2014 but increased during this period in 2015. Despite differences up to bud break, the response post-bud break was similar for both years. Root [TNC] dropped from bud break to bloom, reaching the lowest concentrations at bloom with a 2-year mean of 132 ± 22 $\mu g \cdot mg^{-1}$. Root [TNC] increased by véraison (167 $\mu g \cdot mg^{-1}$) and remained stable until leaf fall. Grass had higher root [TNC] at harvest than Tilled in 2014 and 2015 (P = 0.006 and 0.035, respectively). Grass root [TNC] increased between véraison and harvest in 2015. With the prior exception, root [TNC] remained steady from véraison to leaf fall in both years. Across treatments and years, root [TNC] pre- and post-bloom were similar with 2-year means of 162 ± 23 $\mu g \cdot mg^{-1}$ and 167 ± 27 $\mu g \cdot mg^{-1}$, respectively. Despite changes in root [TNC] over the seasons, concentrations were similar between leaf fall and dormancy.

There was no difference in root [N] between the years; however, root [N] differed among phenological stages (Table 4.4 and Fig. 4.1). Root [N] were similar between dormancy and bud break then increased to the highest concentrations at bloom. Root [N] decreased from bloom to véraison. By leaf fall in 2014, root [N] was higher than at harvest. However, in both years, root [N] by leaf fall was at the same level as at dormancy. Root [N] differed between treatments at each sampling except at véraison in 2015. There was a significant year x treatment interaction, as root [N] increased 0.03% from 2014 to 2015 in Grass while Tilled root [N] was 0.07% lower from 2014 to 2015. Grass had 39 to 72% lower root [N] compared to Tilled.

Trunks had lower [TNC] than roots and ranged from 21 to 76 $\mu g \cdot mg^{-1}$, while root [TNC] ranged from 106 to 198 $\mu g \cdot mg^{-1}$ over both years (Fig. 4.2). The 2014 season had higher trunk [TNC] than 2015. At each phenological stage, there was no difference in trunk [TNC] between the two years (Table 4.4). The seasonal trunk [TNC] dynamic was similar to root [TNC]. Trunk

[TNC] was highest at dormancy (62 μg·mg^{-1}) and lowest at BB, bloom, and véraison (39, 36, 35 μg·mg^{-1}, respectively) then increased from véraison to harvest. There was no change in trunk [TNC] between harvest and leaf fall in either year. By leaf fall, trunk [TNC] were similar to dormancy. There were no treatment differences in trunk [TNC] except one time point during 2014 (véraison).

Nitrogen concentration was lower in trunk than in root tissue over the course of two years, ranging from 0.11 to 0.18% while root [N] ranged from 0.18% to 1.18% (Figs. 4.1 and 4.2). Trunk [N] was highest at dormancy (0.16%) and steadily decreased until reaching 0.12% at véraison. Like root [N], trunk [N] increased from harvest to leaf fall in 2014 and reached [N] similar to dormancy levels. However, there was no difference between véraison, harvest, and leaf fall trunk [N] in 2015, and trunk [N] at leaf fall was equal to or lower than dormancy levels in Grass and Tilled, respectively. Unlike root tissue, higher trunk [N] were not found at bloom; however, the seasonal dynamic was similar for the remaining phenological stages over the two years. There was a year x phenology interaction, as trunk [N] was higher at leaf fall in 2014 compared to 2015 but was similar at other phenological stages (Table 4.4). Grass had lower mean trunk [N] than Tilled over the two years. However, it was only during bud break of 2014 and 2015 that Grass had lower trunk [N] compared to Tilled (P = 0.004 and 0.044, respectively).

Regression analyses were run between tissue [N] and [TNC] and FFL at bud break and bloom, as significant relationships between these components have been observed in other studies. Few relationships were found between FFL and [starch], [TNC], and [N] in root and trunk tissue at bud break and bloom, and none of these relationships were present in both years. Root and trunk [N] at bud break and bloom during 2014 were positively related to 2015 dormant bud FFL and IFI ($P \leq 0.038$; $0.43 \leq r^2 \leq 0.71$). The FFL in 2015 was positively related to root

and trunk [starch] at bud break and bloom in 2014 ($P \leq 0.020$; $0.51 \leq r^2 \leq 0.75$). There was no relationship between bud break root [starch] and FFL within the same year (2014: $P = 0.173$; 2015: $P = 0.639$).

Dormant tissue [TNC] and [N]. There were few consistent relationships between trunk and root [sugar], [starch], [TNC], and [N] across the two years (Table 4.5). Treatment differences were found for buds in 2015 and internodes in 2016 (Table 4.4). Grass had lower bud [starch] and [N] than Tilled in 2015. However, Grass and Tilled had similar internode [sugar] and [N] in 2016, and Alternate had the lowest concentrations of both.

There were no significant statistical relationships between bud FFL, bud IFI, or FFL and internode [starch], [TNC], or [N] in 2015 or 2016 ($P \geq 0.086$). There were also no relationships between bud [starch], [TNC], or [N] and bud FFL in either year ($P \geq 0.092$). Bud IFI was higher when bud [N] was higher in the same year (2015, $P = 0.033$; $r^2 = 0.31$, $y = 19.228x - 8.392$). Fruitfulness in 2015 was positively related to both bud [starch] and [N] measured at dormancy several months earlier ($P = 0.044$, $r^2 = 0.28$, $y = 0.005x + 1.100$ and $P = 0.024$, $r^2 = 0.33$, $y = 2.260x - 0.189$, respectively).

Leaf blade and petiole [N]. At most time points, Grass had lower leaf blade and petiole [N] than Tilled while Alternate had intermediate [N] (Table 4.6). The exception was during bloom 2015, as Grass and Tilled had lower petiole [N] than Alternate. However, there were no treatment differences for leaf blade tissue that year. Leaf blade [N] at bloom was positively correlated with bud FFL the following season (2014/2015: $P = 0.018$, $r^2 = 0.53$; 2015/2016: $P = 0.030$, $r^2 = 0.46$). There was a significant relationship between bloom leaf blade [N] and bud IFI measured at dormancy in 2014/2015 ($P = 0.009$, $r^2 = 0.59$, $y = 3.027x - 1.633$). Regressions

between bloom leaf blade [N] and FFL the following season were significant for 2014/2015 (P = 0.005, r^2 = 0.64, y = 0.314x + 0.667) but not 2015/2016 (P = 0.154).

Photosynthetic rate. Generally, there were few differences in P_n between Grass and Tilled. However, Grass had lower P_n in the morning than Tilled during the pea-size stage of berry development in 2014 (17.0 and 21.6 μmol $CO_2 \cdot m^{-2} \cdot s^{-1}$, respectively; P = 0.040). Grass also had lower P_n than Tilled in the morning and afternoon at fruit set in 2015 (P = 0.004 and P = 0.032, respectively).

Light environment and bud primordia. Grass was shown to have higher canopy zone *PPF* at nearly all times of day and phenological stages measured in 2014 and 2015 (data not shown). Grass also had lower bud FFL and IFI. Therefore, the influence of floor management treatments was investigated in addition to *PPF*. Floor management was not a significant covariate with canopy zone or cluster zone *PPF* at any phenological stage in any year to relate to bud FFL or IFI. However, when bloom or véraison leaf blade [N] were included in a model with véraison cluster zone *PPF*, 2014/2015 data show *PPF* was the better predictor of bud FFL, regardless of [N]. Bud FFL in 2016 was better related to bloom 2015 leaf blade [N] rather than 2015 véraison cluster zone *PPF*, but neither *PPF* or leaf blade [N] at véraison were good predictors of 2016 bud FFL.

Regression analyses show that canopy *PPF* was related to FFL and IFI the following season more consistently than cluster zone *PPF* in both years. In 2014, canopy zone *PPF* measured at bunch closure, véraison, and ripening were negatively related to bud FFL measured at dormancy of 2015 (P = 0.001, 0.003, and 0.003, r^2 = 0.57, 0.50, and 0.50, respectively), whereas only the bunch closure and véraison phenological stages were related to cluster zone *PPF* (P = 0.032 and 0.039, r^2 = 0.31 and 0.29, respectively). Similar results were found between

IFI and *PPF* in the canopy and cluster zone; however, these relationships were stronger than those with bud FFL. Bud IFI was lower at higher canopy zone *PPF* at bunch closure, ripening, and véraison ($P < 0.001$, $r^2 = 0.66$; $P < 0.001$, $r^2 = 0.64$; and $P < 0.001$, $r^2 = 0.63$, respectively). Similar results were also found in the second season (2015/2016), as bud FFL and IFI were more strongly (negatively) related to canopy *PPF* rather than cluster zone *PPF*. However, unlike 2014/2015, canopy zone *PPF* did not consistently relate better to IFI compared to bud FFL ($P = 0.026$ and 0.015, $r^2 = 0.37$ and 0.43, respectively) in 2015/2016. In general, relationships between ambient *PPF* and bud dissections were stronger in 2014/2015 than 2015/2016.

Number and/or size of inflorescence primordia within the bud were higher in 2014/2015 compared to 2015/2016 (Fig. 4.3). There were no significant interactions between *PPF* and year at any of the phenological stages measured in those years (data not shown). However, FFL only differed by year when using cluster zone *PPF* (model $P < 0.001$, $R^2 = 0.53$). The strongest negative relationships with IFI were found when averaging *PPF* over all canopy zones measured, regardless of the influence of year ($R^2 = 0.72 – 0.76$ and $R^2 = 0.62 – 0.69$, respectively).

Discussion

The long-term growth of resident vegetation in vineyard alleyways reduced grapevine vegetative growth, including canopy leaf area and dormant pruning mass. This response is attributed to reduced tissue N, as Grass had lower leaf blade and petiole [N] at véraison in 2014 and 2015, similar to prior years of the study (Reeve et al., 2016). Much like the prior years of this research (Reeve et al., 2016), the years reported herein showcase the impacts of vineyard floor management on reproductive biomass. Grass had lower FFL, bud FFL, and IFI compared to Tilled in 2014 and 2015, but treatment differences were no longer distinguishable by 2016. The

IFI was a more sensitive measure than FFL, as it could more easily distinguish treatment differences.

Bud FFL was higher in 2015 compared to 2014, but actual FFL was higher in 2015 compared to 2014, suggesting bud FFL was underestimated by the 2014 dissection method as no other study has reported higher bud FFL compared to FFL (Jones, 2009; Sánchez and Dokoozlian, 2005). Therefore, it could not be determined if there were treatment differences in inflorescence primordia survival. Treatment differences in bud FFL resulted in similar differences in FFL, number of clusters per vine, and ultimately yield in two of three years. Cluster weights only contributed to yield differences in one of the two years that yield was altered by floor management treatments, while the number of clusters per vine differed in both years. These results are similar to Mercado-Martín et al. (2006) who suggested number of clusters per vine likely influences 'Pinot noir' yield more than cluster weight. This may be due to the small size of 'Pinot noir' clusters compared to other cultivars. Bud number per vine is set at pruning, but this is later altered by many 'Pinot noir' producers by shoot thinning post-bud break, making the number of inflorescences per shoot (FFL) an important factor in yield determination. Interestingly, both 2014 and 2015 had a 0.2 difference in bud FFL between Grass and Tilled vines, which resulted in an increase of 1.96 kg per vine at harvest, suggesting that a 0.2 increase in bud FFL can result in a 43% to 44% increase in yield. While differences in FFL may seem small, they are important for commercial production, and we evaluated various aspects of the vine to determine how they may influence yield development, including PBN, solar radiation interception, TNC and N status. Studies have shown FFL to be altered by nutrient status (Bennett et al., 2005) and light (May, 1965; Morrison and Iodi, 1990; Perez and Kliewer, 1990; Sánchez and Dokoozlian, 2005).

The 2015 growing season followed by 2016 bud dissections showed fewer treatment differences than prior years. The floor management effects on vine vegetative and reproductive growth were dissipating from 2015 and 2016, nearly a decade after the trial was established. There were smaller differences between treatments as véraison canopy leaf area was 48% lower in Grass than Tilled in 2014 and 39% lower in 2015, and dormant pruning mass was 49% lower in Grass compared to Tilled in 2015 but only 38% lower in 2016. At bloom of 2015, there were no differences in leaf blade [N], unlike the prior four years (Reeve et al., 2016). This was likely when 2016 inflorescence primordia were initiating, as 'Pinot noir' inflorescence primordia initiate at the fourth most proximal node position seven weeks after bud break or three weeks prior to bloom in Tasmania (Jones, 2009). Therefore, it is reasonable to expect the lack of differences in bud FFL, IFI, and FFL during 2016, as there were fewer differences in vegetative growth and vine N status.

Primary bud necrosis. Few cases of PBN were found in this study. Lower FFL in Grass compared to Alternate and Tilled was not caused by PBN and were the result of fewer inflorescence primordia being developed. Lower bud starch has been observed in cases of PBN (Morrison and Iodi, 1990; Vasudevan et al., 1998), but Grass did not consistently have lower bud [starch] nor higher PBN. Some studies associate high vegetative vigor with PBN (Dry and Coombe, 1994; Wolf and Warren, 1995), but the vines with the highest vegetative vigor (Tilled) did not have more PBN than other treatments. The low incidence of PBN may be due to the commercial canopy management practices that were employed in this study, including hedging and cluster zone leaf removal. Alternatively, 'Pinot noir' may have lower incidence than other cultivars, as PBN incidence differs by cultivar and region (Lavee et al., 1981; Morrison and Iodi, 1990; Vasudevan et al., 1998; Wolf and Warren, 1995).

Light environment. Results of lower bud FFL at higher shoot ambient light exposure were somewhat expected in this trial but contradictory to other studies. Many have reported the importance of solar radiation for developing inflorescence primordia or increased FFL with higher light intensities (Buttrose 1969a, 1969b; May, 1965; Perez and Kliewer, 1990; Sánchez and Dokoozlian, 2005). We suspect *PPF* may play a role in determining FFL, but *PPF* may not be as important if other components are limiting such as N or if source strength is low. For example, the higher *PPF* measured in Grass did not compensate for the smaller canopy or potentially lower whole vine carbon assimilation which likely influenced bud floral development.

Contrary to our findings, Sánchez and Dokoozlian (2005) found a positive relationship between light exposure of the compound bud and primary bud IFI in several wine and table grape cultivars in the San Joaquin Valley of California; however, they did not have differences in vine vigor creating the altered light environment. In our study, higher solar exposure was resultant of lower vegetative vigor, whereas given vines of similar vigor, light may have influenced FFL.

Vigor has been suggested to be important in determining FFL, as nodes with persistent woody lateral shoots, had higher fruitfulness than nodes on the same shoot without the presence of laterals (Christensen and Smith, 1989). Since nodes were compared on the same shoots, it is unlikely that the solar radiative environment differed greatly among nodes, suggesting vigor may play an important role in determining FFL. In a similar study that resulted in more dense canopies and more clusters per vine due to the absence of ground cover compared to vines grown with ground cover, FFL was not reduced in the higher-vigor, more dense canopies, although there was likely lower solar radiation infiltration (Tesic et al., 2007).

Previous studies that show relationships between solar radiation and FFL overlooked the effect solar radiation has on carbon assimilation. Higher *PPF* within the canopy infers lower attenuation by the canopy and thus lower carbon assimilation on a whole vine basis. However, single leaf P_n was measured in this study using only fully exposed leaves, which represent a small fraction of the whole canopy and cannot be used to extrapolate to a whole vine level (Edson et al., 1993). It is likely that Grass vines had similar or lower carbon assimilation than Tilled, as P_n was lower due to Grass vines having significantly lower whole vine leaf area.

Cluster zone *PPF* was not a good predictor of FFL or IFI compared to canopy zone *PPF*. Since the proximal ten node positions were averaged together for bud FFL and IFI, cluster zone *PPF* from the prior year likely better represented the zone of buds that were evaluated. Sánchez and Dokoozlian (2005) found lower FFL at the four most proximal node positions where lower quantum solar irradiance was observed mid-day using a quantum sensor. The better associations between canopy zone *PPF* and FFL rather than cluster zone *PPF* and FFL also supports our hypothesis that carbon assimilation rather than solar exposure to the bud, is more important for inflorescence primordia initiation and growth.

There are additional possible explanations to our opposing finding of higher FFL in vines with lower canopy *PPF*. The solar radiative environment is difficult to measure and characterize, and there has been little consistency in methodology in the field of viticulture. A ceptometer was used approximately two hours before, during, and after solar noon integrating 80 points, 1 cm apart along the length of the canopy. Alternatively, by Sánchez and Dokoozlian (2005), used a point sensor located at individual buds during midday. Other studies that compare light and FFL used small plants in growth chambers, where the canopy was exposed to a more controlled radiative environment (Buttrose, 1969b; Keller and Koblet, 1995; Sánchez and Dokoozlian,

2005). Results from growth chamber studies are complicated, as both buds and leaves are exposed to similar radiative environments and therefore also influence carbon assimilation.

Correlative relationships with [TNC] and [N]. Few relationships were found between FFL and nutritive composition of dormant bud and internode tissues. Internode reserve concentrations were not indicative of or related to bud FFL, IFI, or actual FFL contrary to Duchene et al. (2003), who found positive relationships between FFL and internode [TNC] and free amino acid concentrations in 'Pinot noir'. Jones (2009) reported a positive relationship between internode [starch] and FFL in 'Pinot noir' vineyards with the lowest [starch], which ranged from 4.7% to 8.8% starch among the sites, greater than was found in our study. Similar to the majority of the sites in the Jones (2009) study, no relationship was found between internode [starch] and FFL similar to our study.

Among floor management treatments, differences in bud reserve concentrations were only found in the year (2015) bud FFL differed. Tilled buds had both higher [starch] and bud FFL. Starch accumulates in the bud throughout the season, primarily in prophylls (Vasudevan et al., 1998), but also in inflorescence primordia. Leaf blades export carbon to the subtending bud at the leaf axil (Hale and Weaver, 1962). Higher bud [N] was associated with higher IFI and FFL and higher bud [starch] with FFL in 2015. Dormancy reserve concentrations were not collected in 2014, the other year bud FFL differed among floor management treatments. However, since bud [N] were similar in both years, it is unlikely that a certain [N] threshold needs to be met in the bud to affect primordia development. While internode and bud tissues are easier to collect and analyse for nutrient reserves than roots and trunks, they do not provide the physiological evidence to describe the relationship between vine N and carbohydtrate status as it pertains to inflorescence primordia development. At best, dormant tissues may serve as a proxy to vine

nutritive status, but in our study these data did not support the status observed in trunk and roots during key development stages the prior season.

Some studies show positive correlative trends between FFL and TNC in vine storage tissues sampled at bud break and bloom (Bennett et al., 2005; Duchene et al., 2003). Candolfi-Vasconcelos and Koblet (1990) reported a reduction in FFL of 'Pinot noir' when [starch] decreased from ~12% to 10% in trunk tissue and ~8% to 5% in internode tissue at dormancy. Although root [starch] was not below 7% in the current study, there was no relationship found between root [starch] at bud break and FFL (data not shown), unlike Bennett et al. (2005) who found FFL in 'Chardonnay' increased over a range of root [starch] from 2% to 18% sampled at bud break. Holzapfel and Smith (2012) also did not find relationships between reproductive measures and [TNC] in storage organs such as cordons, trunks, and root tissues when studying 'Shiraz'. Relationships between FFL and tissue reserves measured throughout the growing season from trunk and roots were limited in this study, and no consistent relationships could be found in both years. Interestingly, bud FFL and bud IFI were never associated with [starch] or [TNC] in trunk or root tissue. Our results suggest that associations between tissue reserve concentrations and FFL are artifacts, indicating a difference in physiological responses to treatments which result in altered reserve concentrations as well as FFL, rather than reserve concentration determining bud FFL. Correlative trends between tissue reserves and FFL, especially those made at dormancy, may be of limited use, whereas source sink dynamics may provide better insight by looking at the reserve dynamics between source and sink throughout the season (Smith and Holzapfel, 2009).

Seasonal [TNC] and [N] dynamics. Root tissues contained higher [N] and [TNC] than trunks. Starch comprised the majority of tissue [TNC], similar to many other grapevine

carbohydrate reserve studies (Bates et al., 2002; Bennett et al., 2005; Scholefield et al., 1978; Smith and Holzapfel, 2009; Zapata et al., 2004). Like other studies, root [N] and [TNC] were more responsive to vineyard treatments than trunk tissues (Bennett et al., 2005; Smith and Holzapfel, 2009), likely because roots are the main storage organ during dormancy, containing 84% to 90% of vine starch, whereas trunks contain only ~3% (Bates et al., 2002; Zapata et al., 2004).

Organ biomass is important to consider when evaluating nutrient concentrations of plant tissues. However, this was not possible in the current study located within a commercial vineyard. Although the nutritive measurements are not indicative of whole vine content, the seasonal dynamic of [TNC] and [N] followed trends similar to studies where both tissue concentration and content were measured, although some were potted or younger vine studies (Bates et al., 2002; Pradubsuk and Davenport, 2010; Zapata et al., 2004). Additionally, similar patterns of concentration and content were found between our concentration data and studies with content data. For example, Pradubsuk and Davenport (2010) found the lowest root N content of ‘Concord’ between véraison and harvest, which was the time frame roots had the lowest [N] in our study. Zapata et al. (2004) found [starch] in perennial grapevine tissues were similar to content, with the exception of root starch from dormancy to bud break.

Early season shoot growth and inflorescence development relies on N and TNC reserves (Bates et al., 2002; Cheng et al., 2004; Schreiner et al., 2006; Zapata et al., 2004), as photosynthates are not exported out of leaf tissue until they reach about 80% of their final leaf area (Yang and Hori, 1980). Root [N] has been found to decrease around bloom in many grapevine studies (Bates et al., 2002; Pradubsuk and Davenport, 2010; Schreiner et al., 2006; Zapata et al., 2004), reaching the lowest root [N] between véraison and leaf fall (Schreiner et al.,

2006). From bud break to bloom, the period with the highest rate of canopy growth and development, there was greater decline in root [TNC] for Tilled compared to Grass in 2014, suggesting that more TNC was utilized by vine growth in Tilled vines. Tilled vines had higher root [N], higher leaf blade [N], and a greater leaf area at bloom in 2014 compared to Grass vines. Cheng et al. (2004) found 'Concord' vines with lower N content at dormancy remobilized a lower percentage of N to new canopy development than vines with higher N content. Therefore, the higher root [TNC] found in Grass during the 2014 growing season may have been from insufficient root N to support a large canopy, subsequently conserving root [TNC]. Although Tilled had a lower root [N] than reported values of 0.7% N from 'Concord' (Bates et al., 2002) and 0.6% N from 'Pinot noir' (Schreiner, personal communication), Grass had much lower minimum root concentrations of 0.2% N. Cheng et al. (2004) found 'Concord' vines with high N and low TNC content had greater leaf area and yields compared to vines with low N and high TNC content. The results found by Cheng et al. (2004) are congruent to the Tilled treatment in the current study having lower [N], higher [TNC], and subsequently greater leaf area and higher yields compared to Grass.

Grass had lower root [N] than Tilled in both years, but only one year showed differences in bud FFL and FFL between the two treatments. Unlike the period from bud break to bloom in 2014, there was not a large decrease in Tilled root [TNC] in 2015. In fact, Grass and Tilled had similar root [TNC] from bud break to bloom in 2015, a period that likely overlapped with the initiation of inflorescence primordia. Therefore, in 2014, Tilled may have partitioned more TNC to the canopy and thus a greater amount was available for bud and inflorescence primordia development. Unfortunately, N uptake from the soil cannot be distinguished from reserve N utilization in this study. However, leaf blade [N] and leaf area were similar between Grass and

Tilled at bloom in 2015, potentially indicating similar amounts of N reached above ground organs, despite differences in storage [N]. From bud break to bloom, vines translocate N from roots to shoots while also beginning root N uptake from soil (Bates et al., 2002; Schreiner et al., 2006; Zapata et al., 2004), complicating our interpretation of N mobilization as these data were not collected.

Both whole vine photoassimilation and storage reserves likely play a role in inflorescence development (Li-Mallet et al., 2016). Assimilated sugars are transported acropetally to the shoot tip, inflorescence, and leaves until six to nine leaves have unfolded on the main shoot, after which translocation can also occur basipetally (Yang and Hori, 1980). Furthermore, bloom coincides with the largest canopy N demand during the season (Schreiner et al., 2006), possibly limiting the amount of N available to developing buds as inflorescences are a competing sink. Pellegrino et al. (2014) attributed reduced yields in partially deficit irrigated 'Cabernet Sauvignon' vines to the reduced net photosynthesis, and consequently lower trunk [TNC] at harvest the prior season.

Higher root [TNC] in Grass during the 2014 growing season (bloom to harvest) may have been due to the use of photoassimilates to grow more fine root mass (Grechi et al., 2007; Keller and Koblet, 1995), allowing [TNC] in large woody roots to remain elevated. Lower leaf area in Grass may have influenced the amount of photosynthates available to support above ground tissues, as bloom-time canopy size differed from Tilled but P_n was the same. By fruit set and pea-size stage of berry development, Grass had lower P_n. Fine roots require N for development; however, Bates et al. (2002) found they were responsible for 84% of vine N use prior to bloom. Keller and Koblet (1995) found vines under high light and low N conditions allocated more

carbohydrates into trunks and roots, compared to those under low light and high N conditions, which would be representative of the results of Grass and Tilled treatments, respectively.

Yield differences between Grass and Tilled may explain why higher [TNC] was found in Grass at harvest in both years. By harvest, Tilled vines had 37% to 44% higher yield than Grass and may have required a larger proportion of TNC to be allocated to support fruit ripening. When canopy leaf area and thus photoassimilates are limited, TNC reserves may be used to supply sugar to the fruit; however, photoassimilates may also be used to ripen fruit (Candolfi-Vasconcelos et al., 1994). Holzapfel and Smith (2012) saw a higher rate of [TNC] accumulation in trunk and cordons between véraison and harvest when fruit was removed from vines compared to those that retained fruit. In our study, there was an increase in trunk [TNC] from véraison to harvest in 2014 in the lower-yielding Grass treatment, while the higher-yielding Tilled trunk [TNC] did not change over this period.

The post-harvest period has been suggested as a critical time for reserve replenishment, particularly in high-yielding cultivars or warm climate regions (Bates et al., 2002; Holzapfel et al., 2006; Smith and Holzapfel, 2009), although it is likely also important in cool climates (Bennett et al., 2005; Greven et al., 2016). In the current study, there was no increase in root or trunk [TNC] from harvest to leaf fall, suggesting that this time period was not the most important for TNC replenishment compared to other studies. However, [N] increased from harvest to leaf fall in 2014, but this did not differ by floor management treatment. In 2014, leaf abscission occurred two weeks later in Tilled, the impact of which did not seem to affect [TNC] or [N] during the post-harvest period. Although Greven et al. (2016) found this timeframe to be important in a cool climate, they were evaluating high-yielding ‘Sauvignon blanc’. The generally low yields of ‘Pinot noir’ may not deplete TNC in vines as much as higher yielding cultivars,

similar to findings by Holzapfel et al. (2006). Additionally, late harvests that occur during cooler weather make for a short, cool post-harvest period leading to low amounts of carbon assimilation (Poni et al., 2006). However, Holzapfel et al. (2006) suggested that reduced FFL in vines partially defoliated at harvest may have been due to reduced N and TNC reserves.

Conclusion

‘Pinot noir’ fruitfulness was more affected by vine N status, as determined by leaf blade, root, and trunk [N] than by [TNC] of these tissues. Lower [N] resulted in lower bud FFL and FFL due to a reduction in the number of inflorescence primordia initiated in primary buds. Primary bud necrosis was not responsible for the lower fruitfulness in Grass vines. The number and size of inflorescence primordia decreased as the amount of shoot light exposure increased; however, this was likely related to a canopy size and sunlight infiltration interaction, and likely was more affected by vine vigor status than incident light. It is unclear to what extent stored reserves or current season uptake and/or assimilation contribute to inflorescence primordia initiation, development, and growth in the following year. It is likely that N limitation was the primary cause of reduced fruitfulness in this study, although the mechanisms into which this occurs are still unknown. This study provided basic information into the seasonal dynamics of TNC and N and influences on yield potential that may allow future research into source-sink relationships on grapevine bud development.

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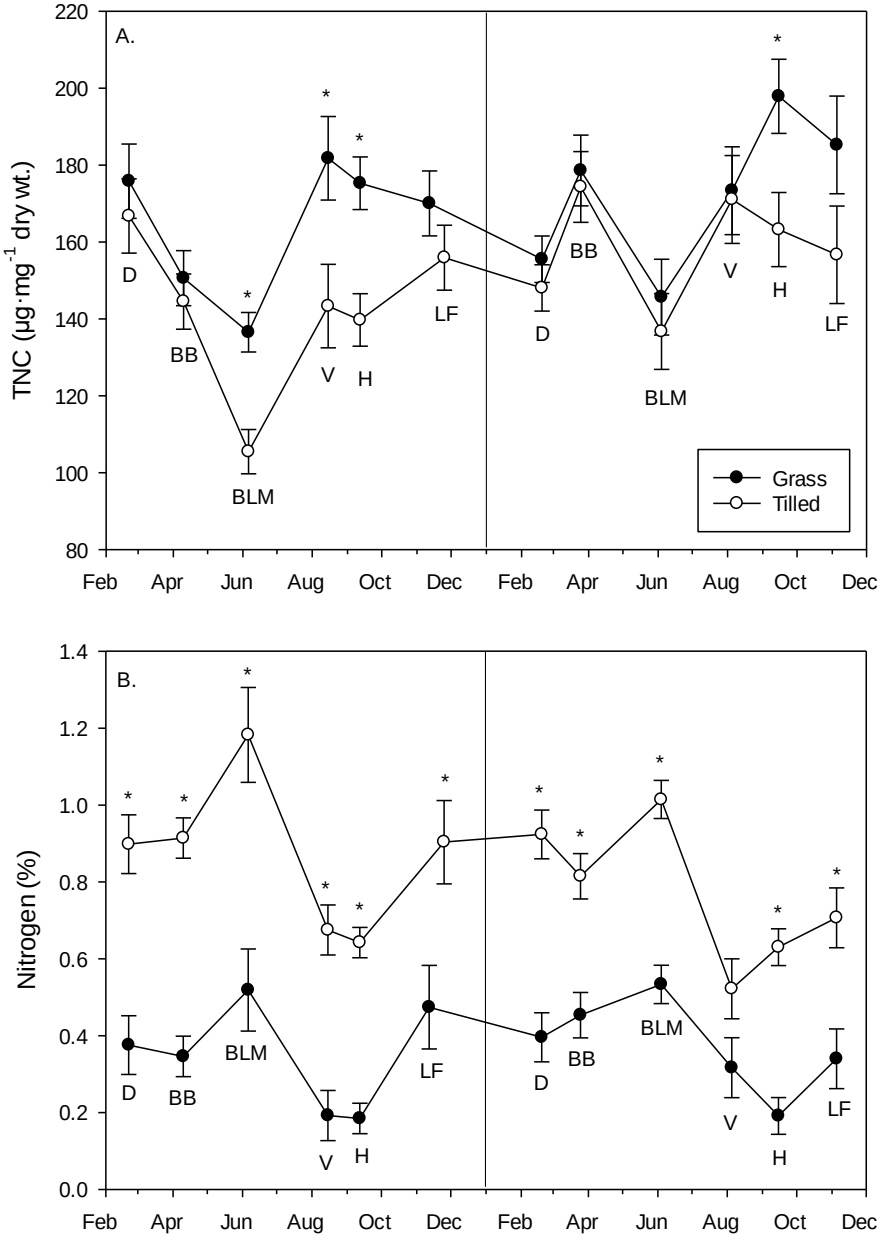

Fig. 4.1. Mean (± SE) total non-structural carbohydrate (TNC) (A) and nitrogen (B) concentrations of 'Pinot noir' root tissues through a two-year period for vines that had grass (Grass - closed circles) or were tilled (Tilled - open circles) in adjacent alleyways. Phenology stages include D=dormancy, BB=bud break, BLM=bloom, V=véraison, H=harvest, LF=leaf fall. *Means significantly different at $\alpha = 0.05$.

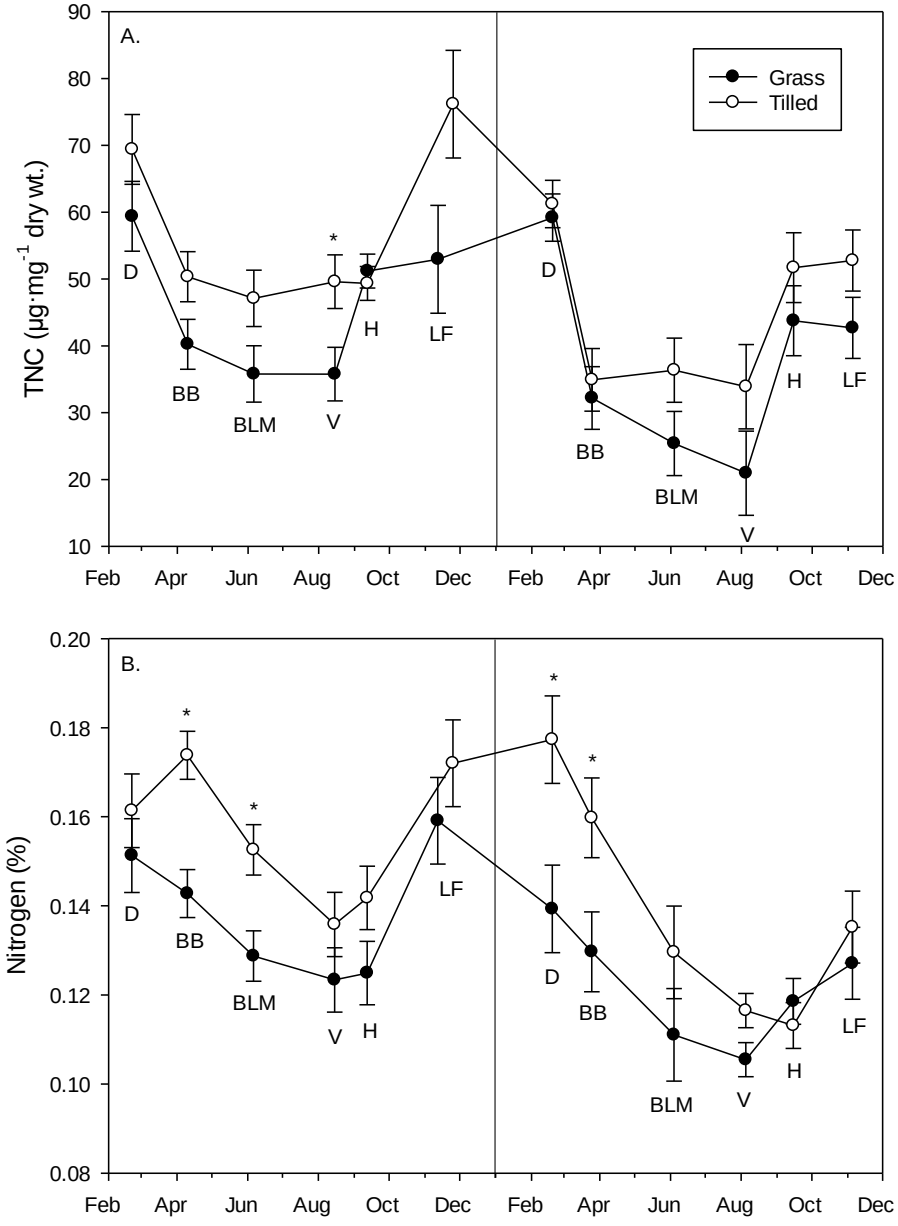

Fig. 4.2. Mean (± SE) total non-structural carbohydrate (TNC) (A) and nitrogen (B) concentrations of 'Pinot noir' trunk tissues through a two-year period between vines that had grass (Grass- closed circles) or were tilled (Tilled- open circles) in adjacent alleyways. Phenology stages include D=dormancy, BB=bud break, BLM=bloom, V=véraison, H=harvest, LF=leaf fall. *Means significantly different at $\alpha = 0.05$.

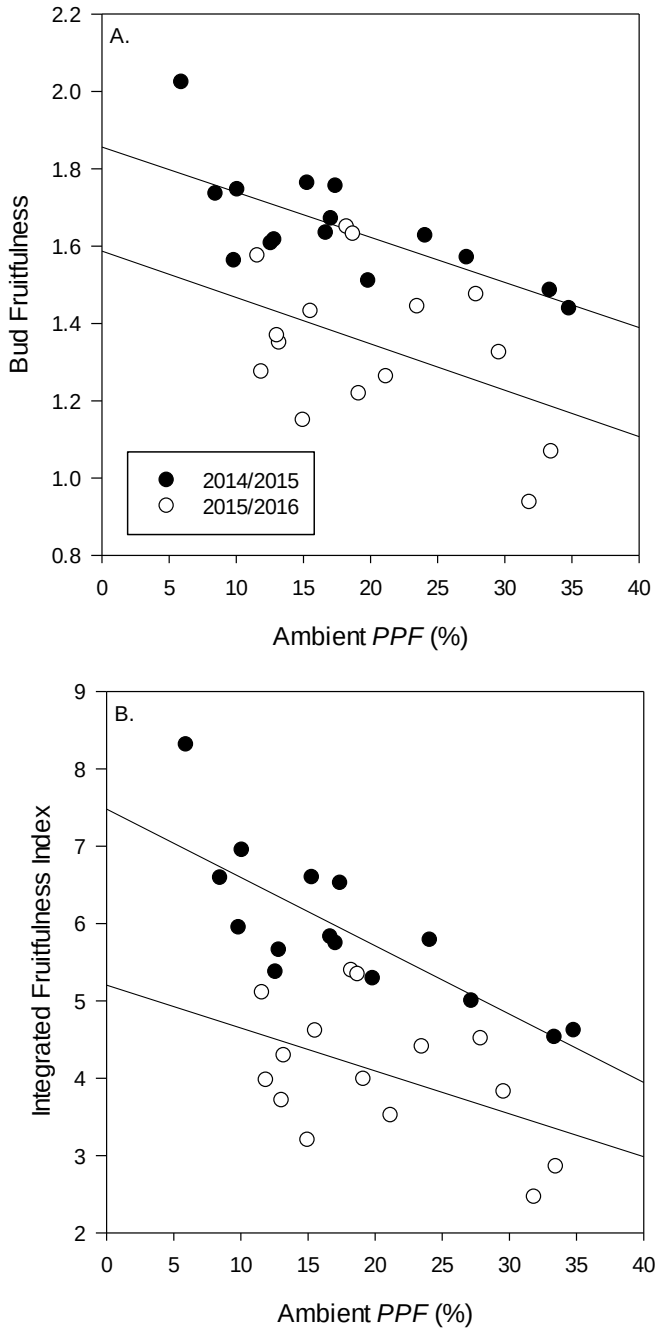

Fig. 4.3. Relationship between canopy zone ambient *PPF* (%) at véraison and bud fruitfulness (A) and the integrated fruitfulness index (B) the following dormancy for years 1 (2014/2015 – closed circles) and 2 (2015/2016 - open circles) in a 'Pinot noir' vineyard floor management trial in the Willamette Valley of Oregon. (A) Canopy *PPF* $P = 0.002$, year $P < 0.001$, model $P < 0.001$, $R^2 = 0.61$. (B) Canopy *PPF* $P < 0.001$, year $P < 0.001$, model $P < 0.001$, $R^2 = 0.73$.

Table 4.1. Seasonal climate data of 'Pinot noir' development in the Willamette Valley of Oregon during 2014 and 2015.

	Dates		GDD_{10}[z]		Mean daily temperature (˚C)		Precipitation (mm)	
Phenology	2014	2015	2014	2015	2014	2015	2014	2015
Bud break[y] to bloom	10 Apr. - 7 Jun.	25 Mar. - 4 Jun.	326	339	14.3	13.1	128	108
Bloom to véraison	7 Jun. - 14 Aug.	4 Jun. - 5 Aug.	705	736	20.2	21.8	52	4
Véraison to harvest	14 Aug. - 12 Sept.	5 Aug. - 16 Sept.	318	406	20.9	19.7	1	24
Harvest to leaf fall[x]	12 Sept. - 12, 25 Nov.	16 Sept. - 5 Nov.	375 - 382	290	15.2 - 13.4	14.4	214 - 252	169

[z]Growing degree days (GDD_{10}) summed between phenological stages calculated by Σ {[daily maximum temperature (˚C) + daily minimum temperature (˚C)]/2-10}. Data obtained from the U.S. Bureau of Reclamation AgriMet service in Aurora, OR.
[y]Bud break date was when ~50% of buds reached BBCH stage 7, bloom was BBCH stage 65, véraison was when ~50% of berries reached BBCH stage 83, leaf fall was when ~50% of vines had all leaves abscise.
[x]Post-harvest period for Grass treatments in 2014 as leaf fall dates varied between Grass and Tilled treatments in 2014.

Table 4.2. Components of 'Pinot noir' fruitfulness from dormant tissue collected over three winters in a vineyard floor management trial in the Willamette Valley of Oregon.

	Bud fruitfulness[z]			Integrated fruitfulness index[y]			Fruitfulness[x]			% Bud necrosis[w]		
Floor Mgt.[v]	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
Grass	1.4 b[u]	1.6 b	1.2	n.d.[t]	5.2 b	3.6	1.6 b	1.4 b	1.3	6 c	2	3
Alternate	1.2 b	1.6 ab	1.4	n.d.	5.7 b	4.4	1.8 a	1.6 a	1.3	19 a	2	2
Tilled	1.6 a	1.8 a	1.4	n.d.	6.9 a	4.3	1.7 b	1.5 a	1.4	11 b	2	2
P-value	0.005	0.043	NS[s]	n.d.	0.006	NS	0.018	0.002	NS	<0.001	NS	NS
SE[r]	0.05	0.05	0.09	n.d.	0.3	0.4	0.05	0.03	0.06	1.3	0.7	1.5

[z]Mean number of inflorescence primordia within the primary bud of the ten most proximal latent buds measured at dormancy (February). Counts in 2014 were made by slicing the bud parallel to the bud axis, while counts in 2015 and 2016 were made slicing perpendicular to the bud axis.

[y]Integrated fruitfulness index (IFI) is the sum of all inflorescence primordia diameters (in tenths of a millimeter) within the primary bud of the compound latent bud measured at dormancy by visual dissection. The mean IFI values are shown for node positions one to ten.

[x]Number of inflorescences per shoot averaged over node positions one to ten approximately five weeks post-bud break.

[w]The percentage of buds that showed any sign of necrosis in the compound latent bud.

[v]Floor management treatments: Grass – alleyways flanking vine row composed of resident vegetation, Alternate – one alleyway composed of resident vegetation while the other kept free of vegetation by tilling, and Tilled – both alleyways kept free of vegetation by tilling.

[u]Means separation by Tukey's HSD at $\alpha = 0.05$; different letters following means within a column are not significantly different.

[t]n.d. – Not determined.

[s]NS – Non-significant at $P > 0.05$.

[r]SE – Standard error of the mean.

Table 4.3. Yield components for 'Pinot noir' from a vineyard floor management trial in the Willamette Valley of Oregon.

	Clusters number[z]			Cluster weight (g)			Vine yield (kg)		
Floor mgt.[y]	2014	2015	2016	2014	2015	2016	2014	2015	2016
Grass	35 b[x]	35 b	32 b	126.7 b	129.6	89.2	4.49 b	5.23 b	2.98
Alternate	41 a	40 a	35 ab	150.3 a	144.5	96.6	6.28 a	6.47 a	3.42
Tilled	42 a	42 a	38 a	153.8 a	153.5	92.7	6.45 a	7.19 a	3.57
P-value	0.025	0.005	0.047	<0.001	NS[w]	NS	<0.001	0.005	NS
SE[v]	1.7	1.3	1.5	2.5	6.6	3.1	0.28	0.34	0.20

[z]Number of clusters per vine at harvest.
[y]Floor management treatments: Grass – alleyways flanking vine row composed of resident vegetation, Alternate – one alleyway composed of resident vegetation while the other kept free of vegetation by tilling, and Tilled – both alleyways kept free of vegetation by tilling.
[x]Means separation by Tukey's HSD at $\alpha = 0.05$; different letters following means within a column are not significantly different.
[w]NS – Non-significant at $P > 0.05$.
[v]SE – Standard error of the mean.

Table 4.4. Three-way analysis of variance results for year, floor management treatment, and phenological stage on 'Pinot noir' total non-structural carbohydrate (TNC) and nitrogen (N) concentrations in root and trunk tissues from a vineyard floor management trial conducted across two seasons in the Willamette Valley of Oregon.

	TNC (µg·mg dw^{-1})							
	Root				Trunk			
	SS[z]	MS[y]	F-value	*P*-value[x]	SS	MS	F-value	*P*-value
Year (Y)[w]	4075	4074	9.6	0.003	3114	3114	25.6	<0.001
Floor mgt. (F)[v]	10020	10020	23.6	<0.001	2676	2676	22.0	<0.001
Phenology (P)[u]	19540	3908	9.2	<0.001	12737	2547	20.9	<0.001
Y x F	478	478	1.1	0.291	83	83	0.7	0.412
Y x P	7424	1485	3.5	0.006	835	167	1.4	0.242
F x P	2854	571	1.4	0.251	660	132	1.1	0.374
Y x F x P	2019	404	1.0	0.451	402	80	0.7	0.655
Residual	40262	424			11689	122		
	N (%)							
	Root				Trunk			
	SS	MS	F-value	*P*-value	SS	MS	F-value	*P*-value
Year	0.043	0.043	1.8	0.184	0.009	0.009	29.1	<0.001
Floor mgt. (F)	6.079	6.079	251.0	<0.001	0.009	0.009	29.7	<0.001
Phenology (P)	2.073	0.415	17.1	<0.001	0.024	0.005	16.1	<0.001
Y x F	0.110	0.110	4.6	0.035	0.000	0.000	0.0	0.870
Y x P	0.123	0.025	1.0	0.411	0.004	0.001	2.3	0.049
F x P	0.159	0.032	1.3	0.264	0.002	0.001	1.5	0.191
Y x F x P	0.081	0.016	0.7	0.649	0.002	0.000	1.1	0.368
Residual	2.253	0.024			0.029	0.001		

[z]Sum of squares; numerator degrees of freedom: year = 1, floor management = 1, phenology = 5, year x floor management = 1, year x phenology = 5, floor management x phenology = 5, and year x floor management x phenology = 5.
[y]MS = Mean square.
[x]Error degrees of freedom are 96 for trunk tissues, 95 for root TNC, and 93 for root N.
[w]Y = Year.
[v]F = Floor management.
[u]P = Phenology.

Table 4.5. Mean total non-structural carbohydrate (TNC) and nitrogen (N) concentrations in dormant bud and internode tissues of 'Pinot noir' from a vineyard floor management trial in the Willamette Valley of Oregon.

	Bud							
	Sugar (µg·mg dw^{-1})		Starch (µg·mg dw^{-1})		TNC (µg·mg dw^{-1})		N (%)	
Floor mgt.[z]	2015	2016	2015	2016	2015	2016	2015	2016
Grass	114	67	68 b[y]	32	182	99	0.72 b	0.76
Alternate	111	70	84 a	35	195	105	0.74 ab	0.77
Tilled	111	65	83 a	40	194	104	0.77 a	0.78
P-value	NS[x]	NS	0.046	NS	NS	NS	0.024	NS
SE[w]	2.0	1.7	4.4	2.8	5.1	3.7	0.01	0.01

	Internode							
	Sugar (µg·mg dw^{-1})		Starch (µg·mg dw^{-1})		TNC (µg·mg dw^{-1})		N (%)	
Floor mgt.	2015	2016	2015	2016	2015	2016	2015	2016
Grass	112	85 a	95	68	207	153	0.68	0.37 ab
Alternate	111	75 b	95	66	206	141	0.79	0.34 b
Tilled	118	79 ab	97	65	215	143	0.79	0.39 a
P-value	NS	0.013	NS	NS	NS	NS	NS	0.023
SE	1.8	2.0	1.1	4.6	2.5	4.4	0.04	0.01

[z]Floor management treatments: Grass – alleyways flanking vine row composed of resident vegetation, Alternate – one alleyway composed of resident vegetation while the other kept free of vegetation by tilling, and Tilled – both alleyways kept free of vegetation by tilling.

[y]Means separation by Tukey's HSD at $\alpha = 0.05$; different letters following means within a column are not significantly different.

[x]NS – Non-significant at $P > 0.05$.

[w]SE – Standard error of the mean.

Table 4.6. Nitrogen (N) concentrations in 'Pinot noir' leaf blades and petioles sampled at 50% bloom and 50% véraison during two years of a vineyard floor management trial in the Willamette Valley of Oregon.

	Petiole (% N)				Leaf blade (% N)			
	Bloom		Véraison		Bloom		Véraison	
Floor mgt.[z]	2014	2015	2014	2015	2014	2015	2014	2015
Grass	0.68 b[y]	0.67 b	0.39 b	0.37 ab	2.30 b	2.30	2.02 b	1.96 b
Alternate	0.73 ab	0.74 a	0.42 ab	0.34 b	2.49 ab	2.57	2.11 ab	2.06 ab
Tilled	0.85 a	0.66 b	0.44 a	0.41 a	2.75 a	2.47	2.24 a	2.13 a
P-value	0.035	0.047	0.007	0.027	0.005	NS[x]	0.008	0.017
SE[w]	0.04	0.02	0.01	0.02	0.08	0.08	0.04	0.04

[z]Floor management treatments: Grass – alleyways flanking vine row composed of resident vegetation, Alternate – one alleyway composed of resident vegetation while the other kept free of vegetation by tilling, and Tilled – both alleyways kept free of vegetation by tilling.

[y]Means separation by Tukey's HSD at $\alpha = 0.05$; different letters following means within a column are not significantly different.

[x]NS – Non-significant at $P > 0.05$.

[w]SE – Standard error of the mean.

CHAPTER 5

INFLUENCE OF NODE POSITION AND CANE ORIGIN ON NUMBER AND SIZE OF INFLORESCENCE PRIMORDIA IN ‘PINOT NOIR’ BUDS

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Abstract

Yield potential of ‘Pinot noir’ in the Willamette Valley of Oregon is considered low by comparison to other cultivars, as growers often site inability to produce very high yields on a consistent basis, despite practicing cluster thinning. Yield variability can be significant and result in low yields one year and record yields the next. ‘Pinot noir’ producers struggle with managing high vine vigor, and we hypothesized that the high vigor may be contributing to low yields. To understand yield potential, inflorescence primordia and fruitfulness post-bud break were evaluated in vines of varying vegetative vigor in a long-term vineyard floor management trial. The floor management treatments included the growth of a perennial grass alleyway between vine rows, tilling soil between vine rows, or alternating tillage and perennial grassed alleyways. The vineyard floor treatments differentially affected canopy growth and yield to allow evaluation of vigor on yield potential. The role of node position, lateral presence, secondary bud fruitfulness, and cane origin were examined as these factors can influence fruitfulness and yield. Node position had a larger impact on inflorescence primordia number and size in primary buds than floor management. Fruitfulness of primary buds increased from nodes one (most basal) to three on canes arising from 2-year canes and from renewal spurs. Fruitfulness of secondary buds was low, with fewer than 22% of buds having at least one inflorescence primordium at dormancy, although node position and cane type affected fruitfulness. Greater vegetative vigor, defined as cane diameter or weight, increased the number and/or size of inflorescence primordia in primary buds. At the same node position, the presence of a lateral resulted in similar or greater numbers and/or sizes of inflorescence primordia than no persistent lateral at the node. The two most basal nodes had fewer and or smaller inflorescence primordia in both primary and

secondary buds, suggesting that the lower ‘Pinot noir’ yields found in this region are not due to cane-pruning or reduced fruitfulness due to high vigor.

Introduction

In the Willamette Valley of Oregon, ‘Pinot noir’ is carefully managed to attain a target yield range which is thought to produce premium-quality fruit (Uzes and Skinkis, 2016). Although much time and labor is devoted to crop thinning, some seasons have low yield potential, preventing growers from achieving yield targets. The variability in baseline yields is poorly understood, but is influenced by climate and genotype (Bindi et al., 1996). It is well established that differences in cultivar or clone productivity can be due to biological, cultural, and/or environmental factors (Jones et al., 2013; Li-Mallet et al., 2016). Although biological and environmental factors cannot be changed after vineyard establishment, cultural practices can be adapted to influence yield. Therefore, understanding factors that influence ‘Pinot noir’ yield is of interest to growers as they strive for more consistent annual production.

Grapevine yield is determined by the number and size of clusters carried per vine. Cluster number is physiologically determined, but can be easily manipulated by pruning or cluster thinning. Cluster size is determined by the number of fertilized florets and berry weight. Berry weight of ‘Pinot noir’ has not been found to change with cultural practices such as floor management or canopy management in this region (Reeve et al., 2016). Fruit set is thought to be impacted by both physiological and weather-related factors (May, 2004), making the number of inflorescences borne per shoot the factor in which viticulturists may have the most control. Cluster number per shoot has been found to account for a large portion of interannual yield variability (Li-Mallet et al., 2016; Mercado-Martín et al., 2006). Therefore, understanding what physiologically determines bud fruitfulness (the number of inflorescence primordia within the

bud), is important for yield management. Bud fruitfulness has been shown to be affected by cultivar, climate, rootstock, training system, pruning method, node position, nodes retained at pruning, lateral presence, and damage to the primary bud resulting in secondary bud growth (Christensen, 1986; Dry and Coombe, 1994; Eltom et al., 2014; Jones, 2009; Jones et al., 2013; Li-Mallet et al., 2016; May, 1966; Sánchez and Dokoozlian, 2005; Sommer et al., 2000; Watt et al., 2008; Winkler and Shemsettin, 1937).

The latent (dormant) grapevine bud is a compound bud that overwinters under normal conditions and begins growth the following season (Boss et al., 2003). Three single buds comprise the compound bud, including the primary bud and two secondary buds (Morrison, 1991), sometimes referred to as the secondary and tertiary bud. The compound bud is formed in the axil of the basal prophyll of the prompt bud (Morrison, 1991; Srinivasan and Mullins, 1981). The prompt bud may grow during the season it is initiated, forming the lateral shoot. When the compound bud begins growth, the primary bud emerges as the primary shoot. In the event of damage to the primary bud, the secondary buds grow to become the source of yield (Dry and Coombe, 1994).

Buds develop in sequence acropetally during shoot growth (Buttrose, 1969a; Morrison, 1991; Vasconcelos et al., 2009; Winkler and Shemsettin, 1937). Development within each bud also occurs acropetally (Goffinet, 2004; Lavee et al., 1981; Winkler and Shemsettin, 1937). During the progression of bud growth and development along the shoot, each bud is under different environmental and physiological conditions than other buds along the shoot, thereby allowing the potential for differences in fruitfulness along a cane. Regions with variable weather from bud break to véraison may have more pronounced variability in fruitfulness (Antcliff and

Webster, 1955; Buttrose, 1969a; Howell et al., 1994; Lavee et al., 1981; Sánchez and Dokoozlian, 2005; Smart et al., 1982; Winkler and Shemsettin, 1937).

Associations between vine vigor and bud fruitfulness have been reported for ‘Pinot noir’ with heavier canes having higher bud fruitfulness (Jones et al., 2013). Higher observed fruitfulness (the number of inflorescences per shoot) was found for canes with larger cross-sectional areas in ‘Sauvignon blanc’ (Eltom et al., 2014). Commonly, we observe greater vigor in canes arising from renewal spurs at the head of cane pruned vines than those arising from the base of the prior year’s cane (2-year cane). Lignification of lateral shoots is a common indicator of high vegetative vigor of which higher fruitfulness was observed at these nodes in ‘Thompson Seedless’ (Christensen, 1986).

Lower fruitfulness has been associated with high vigor growth. In some cases this has been attributed to primary bud necrosis (PBN), a condition where the primary bud becomes necrotic and fails to grow, leaving the less fruitful secondary buds (Dry and Coombe, 1994; Morrison and Iodi, 1990; Sánchez and Dokoozlian, 2005). Inflorescence primordia in secondary buds are also smaller than those in primary buds (Sánchez and Dokoozlian, 2005), and often lead to smaller clusters at harvest (Dry and Coombe, 1994). Higher incidences of PBN were found in larger diameter canes of ‘Riesling’ by Wolf and Warren (1995) and ‘Queen of Vineyard’ by Lavee et al. (1981). Higher vigor ‘Shiraz’ canes, by means of larger diameter and higher prevalence of lateral shoots, was associated with higher PBN incidence, which resulted in fewer clusters per shoot (Dry and Coombe, 1994).

Most literature pertaining to the initiation of inflorescence primordia and fruitfulness were obtained through research on table grapes that are known to have lower fruitfulness at basal nodes (Buttrose, 1969a, 1969b; Sánchez and Dokoozlian, 2005; Winkler and Shemsettin, 1937).

‘Pinot noir’ grown in the Willamette Valley has variable yields each year which are in part influenced by variability in fruitfulness. To better understand yield potential of ‘Pinot noir’ in a cool-climate, bud fruitfulness (bud FFL) and observed fruitfulness (FFL) were evaluated based on cane vigor and node position. The objectives of this study were to 1) determine the number and size of inflorescences in primary and secondary buds with regards to cane vigor; 2) determine the influence of node position on number and size of primordia in buds and in observed fruitfulness; 3) compare fruitfulness measurements between cane origins: those arising from renewal spurs or from 2-year old canes in cane-pruned vines; and 4) determine whether persistent laterals affect fruitfulness.

Materials and Methods

Experimental design. The experiment was conducted in a commercial vineyard located in Dayton, OR, and was managed per industry standards. The vineyard was planted in 1998 to ‘Pinot noir’ Dijon clone 115 grafted to 101-14 rootstock with vines spaced 1.5 m apart and rows oriented N-S with 2.1 m between rows. Vines were trained to a cane-pruned bilateral Guyot system with vertical shoot positioning. Beginning in 2007, vines were managed with three different vineyard floor management treatments as follows: tilled between rows (Tilled), red fescue (*Festuca rubra* L.) grown between rows (Grass), and alternating tillage and red fescue between rows (Alternate) (Chapter 4). The main plot consisted of five field replicates of each treatment, applied to paired eight-vine panels in a completely randomized design.

Fruitfulness measurements. Canes arising from different origins, one cane arising from a two-year old cane and one arising from a renewal spur were collected from every vine during dormancy from late January to early February of 2015 and 2016. Canes were wrapped in moist paper towels, placed in black plastic bags to maintain hydration during transport, and stored at

4°C. Individual cane weights were recorded in the laboratory, and the widest diameter was measured at the mid-point between every node from one to ten. Node one was assigned to the first node with at least 0.6 cm of internode tissue below. Bud fruitfulness was determined by hand-dissection under a stereoscope (Olympus SZ651, Olympus America Inc., Center Valley, PA) for the ten most proximal nodes along the cane as previously described (Chapter 4). Using a single-edged razor blade, thin slices were cut sequentially along the bud axis, parallel to the cane to observe the inflorescence primordia. The number of inflorescence primordia present in each of the three buds (one primary and two secondary) within the compound bud was counted and recorded separately. The size of the floral primordia, known as the integrated fruitfulness index (IFI), was determined by measuring the diameter at the widest point of each floral primordium using a micro-ruler (Ted Pella, Inc., Redding, CA) and summed per individual bud within the compound bud (Sánchez and Dokoozlian, 2005). Fruitfulness was assessed approximately five weeks after bud break by counting inflorescences at each node along the length of the fruiting cane and on the shoots arising from the two-bud renewal spurs of each vine.

Fruit set. Percent fruit set was quantified in 2015 to determine if bud fruitfulness would relate to yield, given the impact fruit set has on cluster size and yield. Fruit set was measured using a variation of the method described by Poni et al. (2006) with the modifications explained in Reeve et al. (2016). Briefly, one cluster per vine on each of the eight vines per plot, was randomly selected and tagged to count the number of florets per inflorescence pre-bloom (BBCH 55 - 61) and berries per cluster post-fruit set (BBCH 70 - 75) through visual inspection of digital images (Lorenz et al., 1995). Digital photographs were taken of each inflorescence/cluster and the number of florets/berries was counted from the images. The relationship between the number of florets/berries in the images and actual florets/berries was determined through regression

analysis. Additionally, 30 random inflorescences were photographed from buffer vines in the plot, individually bagged, and the number of florets was counted. The same process was repeated post-fruit set.

Statistics. Statistical analyses were conducted using SAS 9.4 (SAS Institute, Cary, NC). Data were analyzed for main plot differences using the MIXED procedures for analysis of variance with treatment means being separated using Tukey's Honest Significant Difference (HSD) test. Multiple regression analyses were performed on relationships between cane vigor measures, cane origin, and year using the GLM procedure. Variables and their interactions were assessed in a full multiple regression model, then reduced by all interactions with $P > 0.05$, followed by single variables with $P > 0.05$ that were not included in a significant interaction, until no more terms could be removed from the model. Data were paired for t-tests comparing lateral presence/absence (TTEST procedure) at each node for canes originating from 2-year old canes and from renewal spurs. The REG procedure was used to develop regression equations to predict counts of florets/berries based on photographed standards for the fruit set methods described above.

Results

Cane fruitfulness. When integrating primary bud fruitfulness over node positions one to ten, year, floor management, and cane origin were significant factors in determining the number and size of inflorescence primordia in primary buds ($P < 0.001$, $P = 0.002$, and $P < 0.001$, respectively). Bud FFL in 2015 was higher by 0.3 inflorescence primordia per primary bud than 2016 (Table 5.1). In 2015, Tilled had 13% more inflorescence primordia in primary buds than Grass, and 31% greater IFI than Grass. In 2016, there were no differences in primary bud fruitfulness or IFI due to floor management. Year did not influence IFI ($P = 0.054$); however, the

impact of floor management on IFI differed by year ($P < 0.001$). Canes originating from renewal spurs had 9% to 14% more inflorescences per primary bud and 20% to 28% higher IFI compared to canes arising from 2-year canes over the two years.

Fewer than one percent of the smallest secondary buds (tertiary buds) had inflorescence primordia present in both years, and only Tilled had inflorescence primordia present in 2015. Therefore, the larger of the two secondary buds was analyzed further and is referred to herein as the secondary bud. Since fruitfulness of the larger secondary bud was less than one, it was quantified as either present or not. There was similar fruitfulness in secondary buds between the two years (Table 5.1). Secondary bud fruitfulness and IFI were influenced by floor management and cane origin in both years. Only 13% of nodes were fruitful in secondary buds of Grass compared to 23% in Tilled treatments. Secondary buds arising from 2-year canes had a 47% to 59% lower incidence of inflorescence primordia than those arising from renewal spurs. In secondary buds, IFI was double in canes from renewal spurs (0.05 mm) compared to those arising from 2-year canes (0.02 mm). There was also a significant floor management by cane origin interaction in 2016 for both fruitfulness and IFI. Canes from Grass and Alternate renewal spurs had lower fruitfulness and IFI than canes from Tilled 2-year canes.

Fruitfulness was higher by 0.18 inflorescences per shoot in 2015 compared to 2016 ($P < 0.001$). There was a floor management x year interaction ($P = 0.014$) due to a decrease in observed fruitfulness from 2015 to 2016 that was larger for Alternate than Grass or Tilled treatments.

Effect of node position. Analyzed by node, primary bud fruitfulness was found to differ by year, cane origin, node position, and floor management ($P < 0.001$, $P < 0.001$, $P < 0.001$, and $P = 0.044$, respectively). Since floor management treatment weakly affected bud fruitfulness,

those data were combined for further analysis. There was also a year by node position interaction ($P = 0.015$); however, node position trends were similar among the two years, so two-year averages are presented (Fig. 5.1).

Node position one had the lowest fruitfulness while node position two had the second lowest primary bud fruitfulness for both canes arising from 2-year canes and canes arising from renewal spurs (Fig. 5.1A and B). Nodes three and five had the highest primary bud fruitfulness in canes arising from 2-year canes, while node six had the highest fruitfulness of canes from renewal spurs. Nodes six to ten of canes from 2-year canes had similar fruitfulness to node two, while canes from renewal spurs had a more intermediate fruitfulness between that of nodes two and six. Canes from renewal spurs had higher bud fruitfulness than canes from 2-year canes at almost every node except at node four in 2015 and nodes three and five in 2016 (data not shown).

Similar to primary bud fruitfulness, nodes one and two had the lowest and second lowest IFI along the cane, respectively (Fig. 5.1C and D). In canes from 2-year canes, similar IFI was seen throughout the remaining node positions (three through ten). However, in canes from renewal spurs, there was nearly a steady increase in IFI from node position three to ten, with nodes nine and ten having the highest IFI. Primary bud IFI was higher at almost every node in canes from renewal spurs except at node five in 2016 (data not shown). The same trend was found for canes from 2-year canes and renewal spur from node positions one to four as IFI increased over these nodes. The largest difference in IFI between the two cane origins occurred over nodes five to ten in 2015.

Year, floor management treatments, node position, and year by floor management treatment affected secondary bud fruitfulness ($P = 0.029$, $P = 0.037$, $P < 0.001$, and $P < 0.001$,

respectively). The number of inflorescence primordia in secondary buds of canes from 2-year canes generally increased at distal positions (Fig. 5.2A and B). Less than 5% of the proximal two nodes contained inflorescence primordia. Node positions eight and nine had the highest fruitfulness, averaging 0.2 inflorescences per secondary bud over the two years. Similarly, higher secondary bud IFI was generally found at more distal node positions (Fig. 5.2C and D).

Fruitfulness differed by year and node position (Fig. 5.3, $P < 0.001$ and $P < 0.001$, respectively). The 2015 season had more inflorescences per shoot compared to 2016. Node four had the most inflorescences per shoot (1.5) compared to nodes two, eight, nine, and ten which had the fewest (1.3).

Effect of lateral shoot presence. Nodes with laterals present had similar or higher numbers of inflorescence primordia in primary buds than at nodes without laterals present (Fig. 5.4A and B). The presence of a lateral at a node resulted in higher bud fruitfulness at more distal node positions. Averaged along the cane, nodes with a lateral present had 0.3 and 0.4 more inflorescences per primary bud than nodes without a persistent lateral in 2015 and 2016, respectively. It should be noted that fruit zone leaf pulling (standard practice) included lateral removal, resulting in a lower frequency of laterals at node positions one to four (5% to 15%, data not shown). However, 20% to 40% of nodes at positions five to ten had laterals present.

Nodes with laterals present had both higher fruitfulness and IFI in both years (Fig. 5.4C and D). For nodes with laterals, node positions five through nine had greater IFI in both years, while the other node positions had similar or greater IFI in only one year. Averaged over node positions, nodes with a lateral present had 2.0 to 2.3 higher IFI in 2015 and 2016, respectively, compared to nodes without laterals.

Effect of cane size. Larger diameter canes had more inflorescence primordia in primary buds; however, 2015 had more inflorescence primordia present than in 2016 (Fig. 5.5A). Bud IFI increased as cane diameter increased, with 2015 having higher IFI than 2016 (Fig. 5.5C). There were no significant interactions between year and diameter for bud fruitfulness and IFI. Higher fruitfulness and IFI were associated with higher cane weights (Fig. 5.5B and D).

Fruit set. In 2015, Grass had fewer florets per cluster, but treatments were not statistically different ($P = 0.304$). There were also no differences in percent fruit set and berries per cluster in 2015 among floor management treatments ($P = 0.205$ and $P = 0.452$, respectively). There was no relationship found between IFI and number of florets per inflorescence ($P = 0.060$, $r^2 = 0.25$).

Discussion

Node position influenced bud FFL both years, with 2015 having higher bud FFL than 2016. Seasonal differences in bud fruitfulness suggest the may be an inherent effect of weather when inflorescence primordia are initiating, which was found to start approximately three weeks prior to bloom for 'Pinot noir' in Tasmania (Jones, 2009). There were 13 fewer GDD_{10} between bud break and bloom in 2014 compared to 2015 and 31 fewer GDD_{10} between bloom and véraison in 2014 versus 2015 (Chapter 4). The slightly fewer GDD_{10} in 2014 during the period of inflorescence primordia initiation likely does not explain the higher fruitfulness in 2015 compared to 2016. Differences in fruitfulness among years is common and is hypothesized to be influenced by weather conditions during inflorescence primordia initiation (Eltom et al., 2014; Li-Mallet et al., 2016; Mercado-Martín, 2006). Yield varied in our study an average of 73% from 2014 to 2016 (Chapter 4).

Numerous studies show that basal nodes are less productive than more distal nodes for 'Thompson Seedless' (Antcliff and Webster, 1955; Sánchez and Dokoozlian, 2005; Sommer et

al., 2000; Winkler and Shemsettin, 1937), ‘Pinot noir’ (Howell et al., 1994; Jones, 2009; Jones et al., 2013), ‘Muscat of Alexandria’ (Buttrose, 1969a, 1969b), ‘Sauvignon blanc’ (Eltom et al., 2014), and ‘Queen of Vineyard’ (Lavee et al., 1981). Cultivars with very low basal bud fruitfulness are often cane-pruned to retain nodes with greater fruitfulness to increase yield (Antcliff and Webster, 1955; Christensen, 1986; Eltom et al., 2014; Sánchez and Dokoozlian, 2005; Winkler and Shemsettin, 1937). Similarly, our study found lower fruitfulness at the proximal two nodes. Currently, Oregon ‘Pinot noir’ producers use cane-pruning as it is believed that spur-pruning will result in lower productivity, due to unfruitful basal buds (Skinkis and Gregory, 2017). While our study indicated lower fruitfulness, it did not show lack of fruitfulness of buds. However, spur-pruning was not evaluated in this study. Fruitfulness at the proximal two nodes was not lower than fruitfulness at other node positions, with the exception of node four, which had the highest fruitfulness.

Fruitfulness increased from node position one to node position three, similar to other reports (Eltom et al., 2014; Jones, 2009). The node position effect on bud fruitfulness was similar regardless of cane origin. Some studies have shown a continued increase in fruitfulness from node one to nodes five and nine in ‘Sultana’ (Antcliff and Webster, 1955; Christensen and Smith, 1989) or up to node 12 in ‘Sultanina’ and ‘Muscat of Alexandria’ (Buttrose, 1969a; Winkler and Shemsettin, 1937).

Like bud fruitfulness, IFI was influenced by node position and increased from node one to three. Antcliff and Webster (1955) found similar trends along ‘Sultana’ canes between inflorescence primordium size and percent fruitful buds. Like Sánchez and Dokoozlian (2005), using IFI allowed us to see larger treatments effects since it was a more robust measure than

number of inflorescence primordia. This was evident in floor management having a larger impact on IFI than bud fruitfulness.

Node position also affected fruitfulness. Node four had the highest fruitfulness, while nodes one and two were a few of the node positions showing the lowest fruitfulness values. This is contradictory to Jones (2009), who found low bud fruitfulness at proximal nodes but lower observed fruitfulness did not occur at basal node positions of 'Pinot noir' in Tasmania. However, Howell et al. (1994) found the proximal two nodes in 'Pinot noir' had reduced yields due to fewer clusters per shoot.

The effect of floor management was more pronounced in 2015 when there were larger differences in vigor among treatments (Chapter 4). Grass, which had the lowest pruning weights and canopy size, had lower IFI than Alternate and Tilled at most node positions in both years. Canes from renewal spurs had higher fruitfulness and IFI compared to those from 2-year canes.

Both cane origin and floor management impacted shoot size, therefore, the effect of cane size, or shoot vigor, was considered as a possible explanation for why higher fruitfulness was found in Tilled or in canes arising from renewal spurs (Chapter 4). Sánchez and Dokoozlian (2005) found internode diameter was the cane variable that was best related to bud fruitfulness in several cultivars. Higher fruitfulness was seen on canes with larger cross-sectional area for 'Sauvignon blanc' (Eltom et al., 2014). Heavier canes also were associated with increased fruitfulness in 'Sauvignon blanc' (Greven et al., 2016). Our data were similar with larger diameter or heavier canes having greater fruitfulness, similar to Jones et al. (2013). Canes with larger diameters were found to have a higher prevalence of PBN at all node positions in 'Shiraz' and consequently lower observed fruitfulness than canes with smaller diameters (Dry and Coombe, 1994). Interestingly, cane size did not show reduced fruitfulness at the highest

diameters or weights experienced, which may be because PBN was not prevalent in this study (Chapter 4). Due to the difference of bud fruitfulness, IFI, and observed fruitfulness between years, retaining a cane of a specific size will not ensure a specific fruitfulness.

Increased numbers of clusters were found by Christensen (1986) at nodes that had laterals the prior season. In a comparison of nodes near each other, nodes with a persistent woody lateral had higher observed fruitfulness the following season, but the authors noted that the presence of persistent woody laterals showed the same distribution as fruitfulness along a cane as others have found with fruitfulness (Christensen and Smith, 1989). Higher fruitfulness was found at all node positions that had a lateral present, with the exception of node positions that already had higher fruitfulness (Christensen, 1986). Our data were similar in 2015 as node four showed no difference in fruitfulness whether a lateral was present or not. Leaf and lateral pulling in the cluster zone (including ~nodes one to six) occurred in this trial per standard vineyard practice. Therefore, the data are heavily skewed to lateral absence at nodes one to three. Therefore, we cannot objectively say that lateral presence increases fruitfulness at nodes with inherently lower fruitfulness. However, more and/or larger inflorescence primordia were found in primary buds at node positions five through nine.

The presence of a lateral has been shown to be associated with a higher incidence of primary bud necrosis (Coombe and Dry, 1994). Cases of primary bud necrosis were uncommon in our evaluation of ‘Pinot noir’ and did not decrease fruitfulness at nodes with persistent laterals (Chapter 4). This likely also explains why continued increases in cane weight or diameter did not result in lower fruitfulness. However, Antcliff and Webster (1955) saw no differences in percent fruitful buds of ‘Sultana’ between canes that had laterals or did not have laterals, although the number and size of inflorescence primordia was not evaluated.

The effect of laterals on carbon partitioning is complicated: laterals require carbohydrates and nutrients to initiate growth, but then become autotrophic. Laterals break bud at various times during the season and this can be influenced by cultural practices such as hedging (Cartechini et al., 2000). Therefore, it is hard to estimate the physiological stage of a lateral when the primary shoot latent buds are forming inflorescence primordia. However, having a lateral at the same node as a latent bud may not have a direct influence on the subtending bud because lateral shoots do not have any vascular connections to the latent bud, despite the notion that the latent bud is developed in the axis of the first prophyll of the lateral bud (Morrison, 1991; Pratt, 1974).

Secondary buds had fewer inflorescence primordia than primary buds, consistent with other studies on 'Chardonnay', 'Cabernet Sauvignon', 'Flame Seedless', 'Shiraz', and 'Thompson Seedless' (Dry and Coombe, 1994; Sánchez and Dokoozlian, 2005). Similar to primary buds at proximal positions, secondary buds at these positions also had lower fruitfulness than more distal node positions. In our study, IFI in secondary buds was nearly ten times less than in primary buds. Damage to primary buds by biological or physiological means, would reduce yield with the largest potential reduction at proximal nodes, based on inflorescence primordia presence in secondary buds. This type of damage may be more detrimental in spur pruned systems if proximal bud damage occurs.

Fruit set can have a large influence on yield even if inflorescence primordia initiation and floret differentiation is optimal. Therefore, we evaluated whether fruitfulness or IFI was an indicator of yield potential, or if fruit set interfered with that relationship. Similar fruit set was observed among floor management treatments, resulting in yield differences in 2015, because bud fruitfulness and IFI differed by floor management treatment in that year(Chapter 4). The integrated fruitfulness index did not predict florets per inflorescence well, meaning higher IFI did

not necessarily relate to more florets per inflorescence. This finding suggests extrapolating IFI to yield is not warranted.

Conclusion

Overall, bud fruitfulness and IFI were shown to be affected by floor management, cane vigor, lateral presence, node position, and year. Results of this study confirm findings of reduced bud fruitfulness of the two most basal buds of canes. Lower fruitfulness at these node positions may be favorable to growers if they are thinning fruit. Lower bud fruitfulness at the basal two nodes seems to be inherent compared to the rest of the cane. Secondary buds generally had ten times fewer inflorescence primordia than primary buds and followed the same pattern of fruitfulness along the cane as primary buds. Canes arising from renewal spurs had more and/or larger inflorescence primordia present in primary buds at nearly all node positions as well as averaged along the cane. Larger canes, by weight or diameter, had higher bud fruitfulness. Nodes with laterals present had more and/or larger inflorescence primordia in primary buds. These results suggest higher vigor canes result in higher bud fruitfulness. By retaining larger diameter canes with more persistent laterals and/or a cane from the renewal spur, growers may be able to increase the number and/or size of inflorescence primordia at each node and result in more inflorescences per shoot and potentially increase yield.

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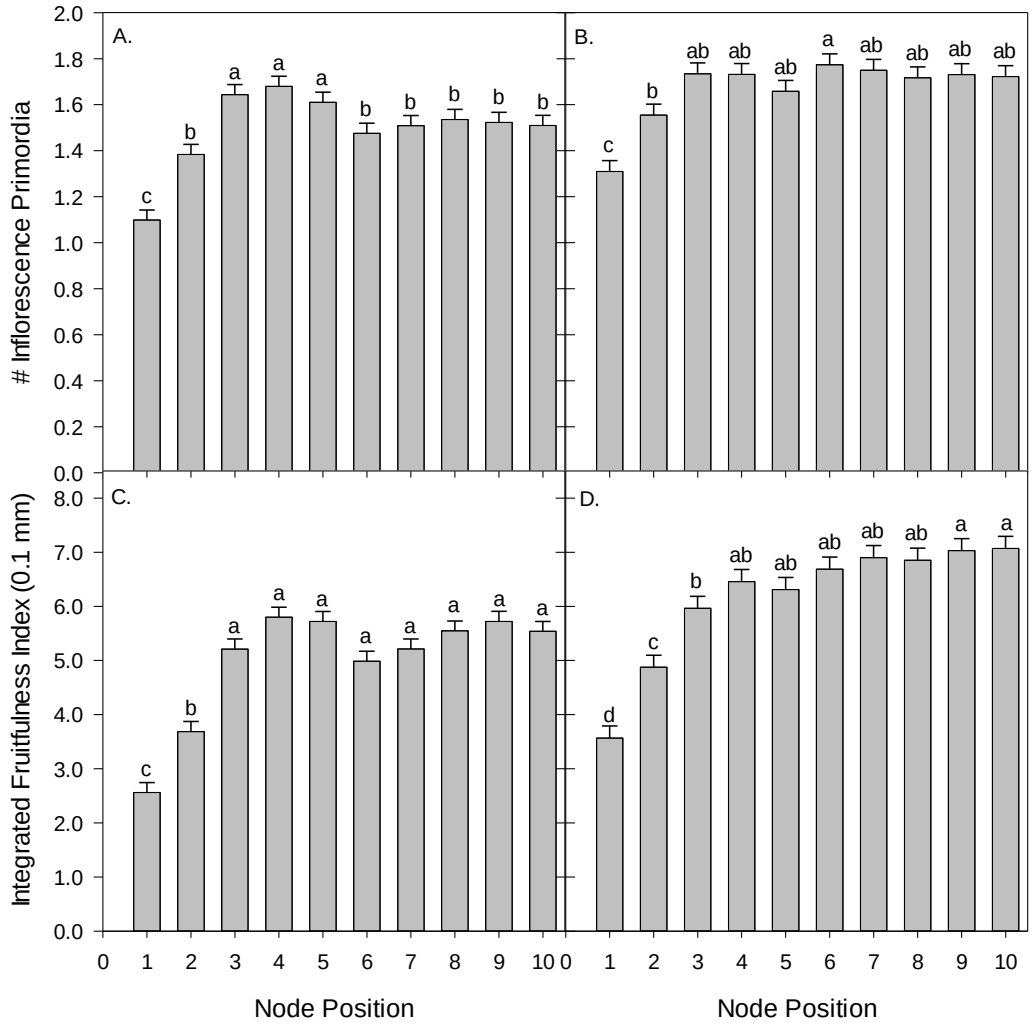

Fig. 5.1. Two-year mean (± SE) of primary bud fruitfulness (A and B) and the integrated fruitfulness index (IFI; C and D) at nodes positions one to ten collected from 1-year old canes originating from 2-year old canes (A and C) or from renewal spurs (B and D) of 'Pinot noir' in Oregon. IFI is the sum of the widest diameter of the inflorescence primordia within the bud. Different letters represent significantly different means by Tukey's HSD ($\alpha = 0.05$).

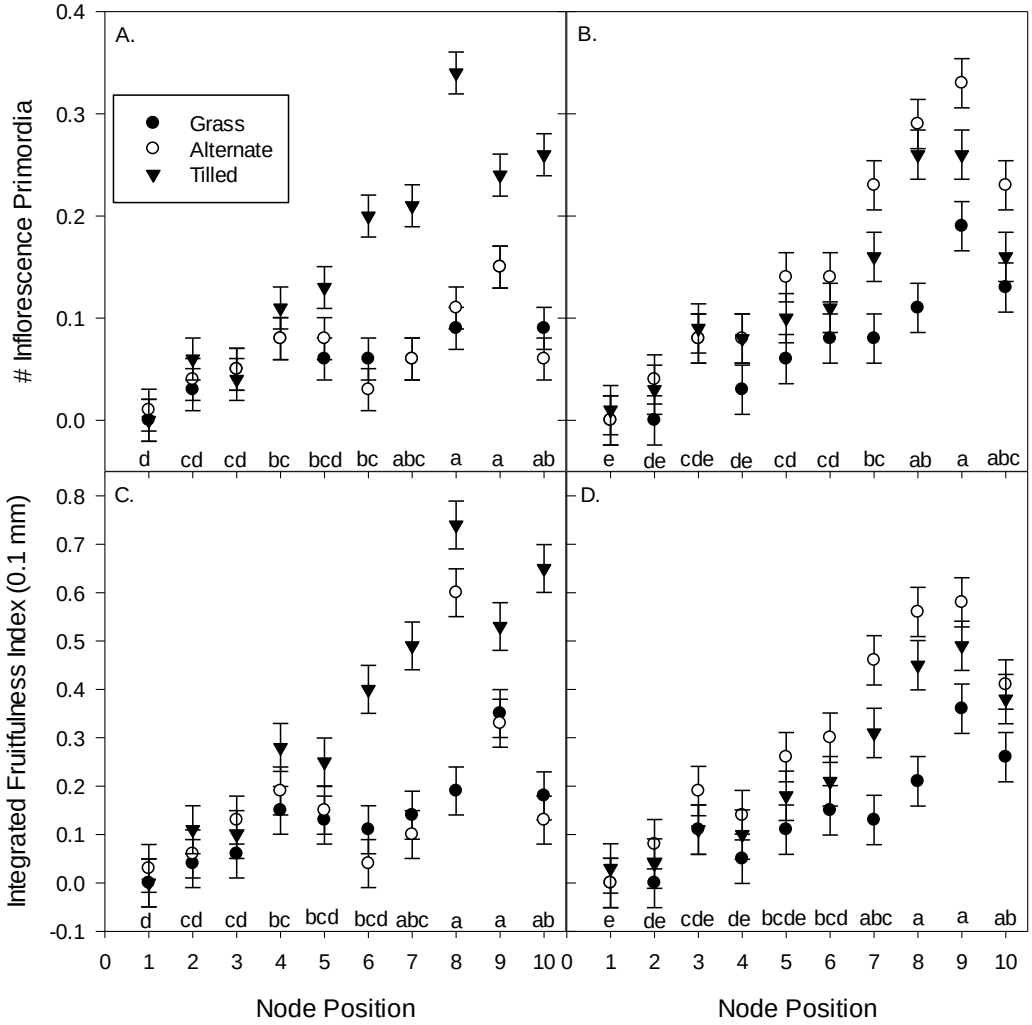

Fig. 5.2. Mean (± SE) secondary bud fruitfulness (FFL; A and B) and the integrated fruitfulness index (IFI; C and D) of vines under different floor management treatments at each node position along 1-year old canes arising from 2-year old canes in 2015 (A and C) and 2016 (B and D) for 'Pinot noir' in Oregon. IFI is the sum of the widest diameter of the inflorescence primordia within the bud. Different letters represent significantly different mean FFL and IFI between node positions determined by Tukey's HSD ($\alpha = 0.05$).

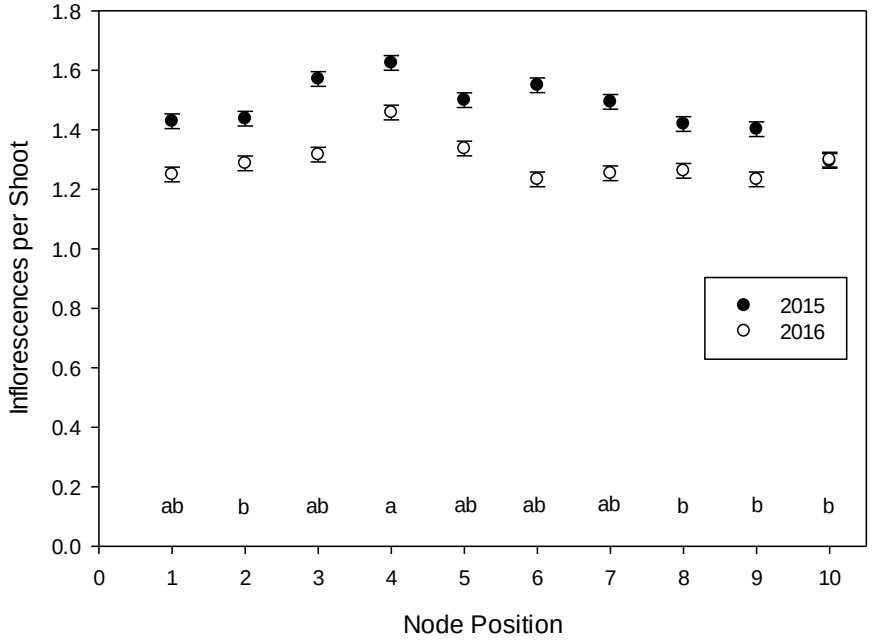

Fig. 5.3. Number of inflorescences per shoot (mean ± SE) for node positions one to ten after bud break in 2015 and 2016 in Oregon 'Pinot noir'. Different letters represent significantly different mean observed fruitfulness between node positions determined by Tukey's HSD ($\alpha = 0.05$).

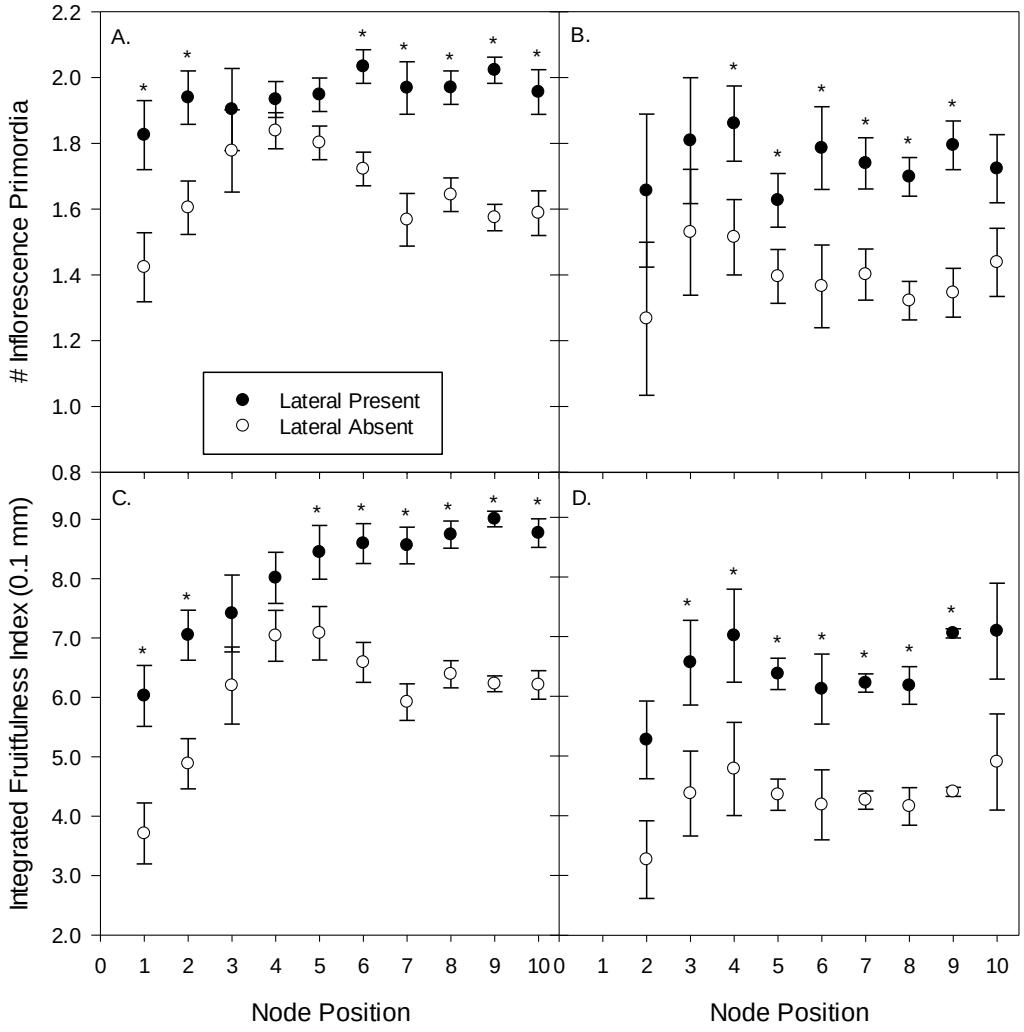

Fig. 5.4. Mean (± SE) fruitfulness (A and B) and the integrated fruitfulness index (IFI; C and D) in 2015 (A and C) and 2016 (B and D) at nodes with lateral shoots present or absent in Oregon 'Pinot noir'. Laterals were defined as shoots arising from the prompt bud at each node and was lignified at the time of sampling (dormancy). IFI is the sum of the widest diameter of the inflorescence primordia within the bud. *Means significantly different at $\alpha = 0.05$.

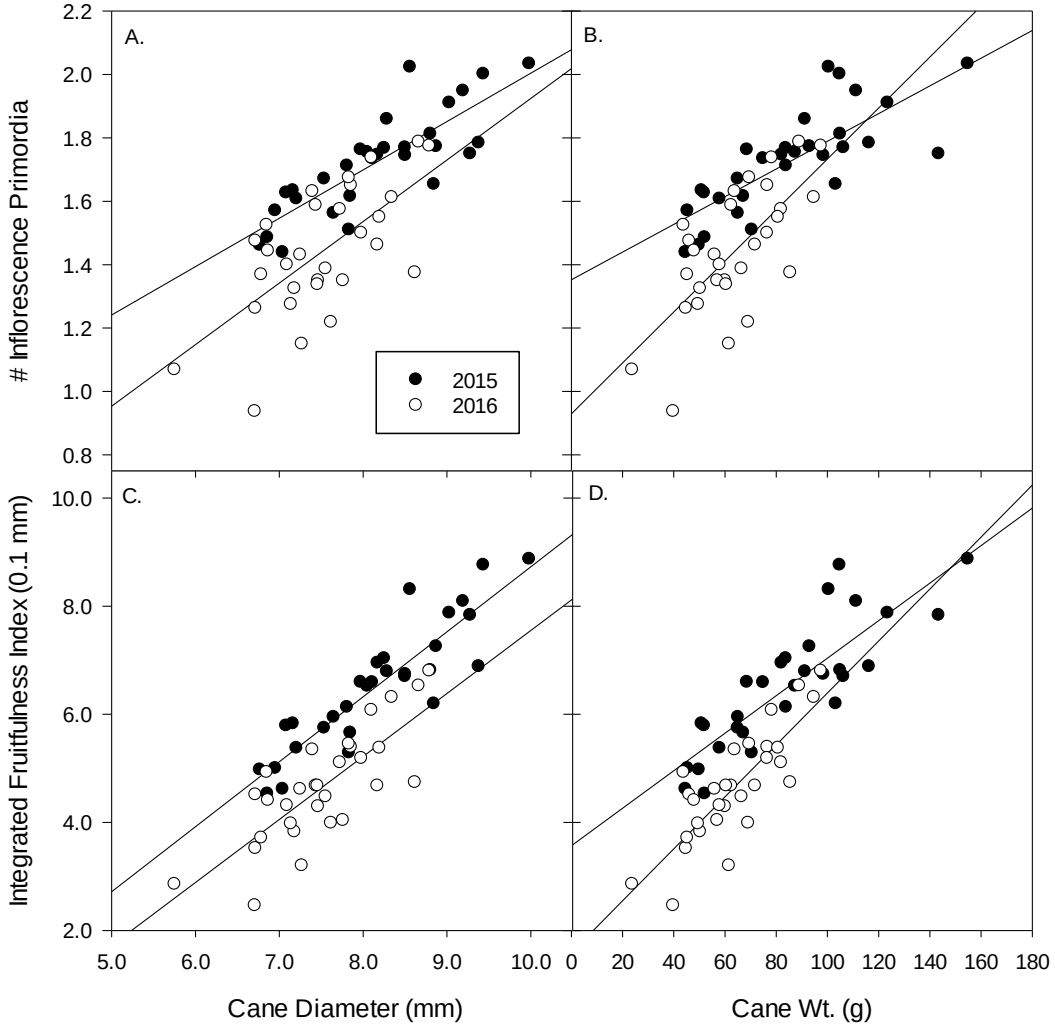

Fig. 5.5. Bud inflorescence primordia (A and B) and the integrated fruitfulness index (IFI; C and D) related to dormant cane diameter (A and C) and cane weight (B and D) in 2015 and 2016 averaged over node positions one to ten for 'Pinot noir' in Oregon. IFI is the sum of the widest diameter of the inflorescence primordia within the bud. A. Year $P < 0.001$, diameter $P < 0.001$, $R^2 = 0.70$. B. Year $P < 0.001$, cane weight $P < 0.001$, $R^2 = 0.72$. C. Year $P < 0.001$, diameter $P < 0.001$, $R^2 = 0.84$. D. Year $P < 0.001$, cane weight $P < 0.001$, $R^2 = 0.84$.

Table 5.1. Bud fruitfulness and integrated fruitfulness index (IFI) based on cane origin from a 'Pinot noir' vineyard floor management trial conducted in Oregon during 2015 and 2016.

			Fruitfulness[z]		IFI[y]	
			2015	2016	2015	2016
Primary bud	Floor mgt. (FM)[x]	Grass	1.6 b[w]	1.4	5.7 b	4.2
		Alternate	1.7 ab	1.4	6.3 b	4.7
		Tilled	1.8 a	1.5	7.5 a	5.1
	Cane origin (CO)[v]	2-year cane	1.6 b	1.3 b	5.9 b	4.1 b
		Renewal spur	1.8 a	1.5 a	7.1 a	5.2 a
	P-value	FM	0.004	NS[u]	<0.001	NS
		CO	0.003	0.006	<0.001	<0.001
		FM x CO	NS	NS	NS	NS
			Fruitfulness		IFI	
			2015	2016	2015	2016
Secondary bud	Floor mgt. (FM)	Grass	0.1 b	0.1 b	0.3 b	0.2 b
		Alternate	0.1 b	0.2 ab	0.3 b	0.3 ab
		Tilled	0.2 a	0.2 a	0.5 a	0.4 a
	Cane origin (CO)	2-year cane	0.1 b	0.1 b	0.2 b	0.2 b
		Renewal spur	0.2 a	0.2 a	0.5 a	0.5 a
	P-value	FM	<0.001	0.002	<0.001	0.009
		CO	<0.001	<0.001	<0.001	<0.001
		FM x CO	NS	0.024	NS	0.040

[z]Mean number of inflorescence primordia in a bud from node positions one to ten measured at dormancy by visual dissection.
[y]IFI = the sum of the widest diameter of the inflorescence primordia within the bud (in tenths of a millimeter) determined at dormancy by visual dissection. The mean IFI values are shown for node positions one to ten.
[x]Floor management treatments: Grass – alleyways flanking vine row composed of resident vegetation, Alternate – one alleyway composed of resident vegetation while the other kept free of vegetation, and Tilled – both alleyways kept free of vegetation by tilling.
[w]Means separation by Tukey's HSD at $\alpha = 0.05$; different letters following means within a column are not significantly different.
[v]Cane origin = buds were dissected from nodes one to ten on 1-year canes arising from 2-year canes or renewal spurs.
[u]NS- Non-significant at $P > 0.05$.

CHAPTER 6

CONCLUSION

Competitive cover cropping proved to reduce vine vegetative vigor of ‘Pinot noir’ on a site that was conducive to vegetative growth in the cool Willamette Valley of Oregon. Presence of a perennial grass in the alleyways did not compete with vines for water, making this an effective long-term management strategy for dry-farmed sites. The perennial grass likely competed with vines for nitrogen (N) as above and below ground vine tissues had lower N concentrations compared to vines that were grown with vegetation-free alleyways. Vines with lower N concentrations had less leaf area and lower pruning weights. These vines also had lower fruit yeast-assimilable N, in which case concentrations should be monitored for healthy primary fermentation. The reduction of vegetative vigor, allowed higher solar radiation to infiltrate the canopy and cluster zone. The increased exposure of fruit in lower vigor vines may have affected some measures of berry composition such as lower titratable acidity, higher total tannins and total phenolics, but interestingly, not total anthocyanins. Berry composition was likely also affected by other inherent factors that occurred when vine vigor was reduced and could not be separated in this study. Cluster thinning had the most impact in the highest yielding, cool year in the study as total soluble solids were higher and pH was lower. The variable seasons in the Willamette Valley made vine balance metrics unreliable across years. Although cluster thinning can increase total soluble solids, the effect is limited by season and may not be able to mitigate unfavorable ripening conditions in cooler years. Vines with reduced vigor were also met with a reduction in yield. This resulted in vines with similar vine balance, as determined by leaf area to yield, allowing fruit to ripen adequately.

Reduced yield in lower vigor vines resulted from fewer inflorescence primordia initiating within buds. Consequently, this led to fewer inflorescences per shoot and lower yields. However, vineyard floor treatments did not affect vine vigor in the final year (2016), nearly a decade after implementing treatments. Fruitfulness or yield did not differ in 2016 either, although a non-significant trend of lower fruitfulness and yield in lower vigor vines was still discernable. Lower vigor vines had lower N concentrations in annual tissues, but were found to also have lower N concentrations in storage tissues (roots and trunks). Total non-structural carbohydrate (TNC) concentrations in root tissues only differed between high and low vigor vines at harvest. There was a greater decrease in root TNC in higher vigor vines from bud break to bloom in 2014, which was accompanied by larger canopies with higher N concentrations in the foliage. Upon bud dissection, more and/or larger inflorescences were found in both primary and secondary buds, resulting in more inflorescences per shoot and higher yields in 2015. High and low vigor vines had similar decreases in root TNC in 2015 as well as comparable numbers and sizes of inflorescence primordia in primary buds, resulting in similar yields in 2016. Higher vigor shoots were also found to have more and/or larger inflorescence primordia in primary buds, regardless of cane origin or floor management. Vigor did not change the effects of node position on fruitfulness, therefore the impact of node position may cause differences in whole vine bud fruitfulness between pruning systems as only basal buds are retained in spur-pruned systems compared tocane-pruned systems. Within a block, vine vigor will impact bud fruitfulness, with vigorous canes resulting in more inflorescences per bud.

Future research exploring source-sink dynamics of the bud in relation to the whole vine would provide greater insight into which phenological stages have the largest impact on inflorescence primordia initiation and development. Determining the extent that current season

assimilation and N uptake has on inflorescence primordia development versus stored reserves would help aid in management decisions aimed to affect fruitfulness and yield.

In addition to reducing vine vigor, perennial grass establishment in alleyways may also have ecological, labor, and monetary benefits. Perennial cover crop use in vineyard alleyways is supported by sustainability organizations as it helps prevent erosion, increase infiltration of water, especially during rainy seasons, increase biodiversity, and increase soil organic matter. Less time and labor may be needed for hedging and leaf pulling, and cluster thinning, although yields need to be carefully monitored to ensure yields do not get too low. The vigor and yield changes created by perennial grass presence take several years to take effect and require maintenance to sustain competition between the grass and the vine. However, if vines are too low in vigor, removing the grass may increase vine vigor. Use of floor management is a slow, multi-year tool and large changes in vine vigor from one year to the next should not be anticipated.

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APPENDICES

Appendix A. Leaf blade macro- and micro-nutrient concentrations at bloom from 2012 and 2013 by vineyard floor management and crop level treatments for 'Pinot noir' in the Willamette Valley of Oregon.

Treatments	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Fe (ppm)
					2012				
Floor mgt. (F)[z]									
Grass	0.68	1.09	2.09	0.22	277 a[y]	17 b	28 b	17	86
Alternate	0.72	1.10	1.95	0.21	212 b	21 a	38 a	15	86
Tilled	0.67	1.14	2.03	0.22	204 b	21 a	41 a	16	78
Crop level (C)[x]									
Full crop	0.68	1.11	2.01	0.22	228	19	35	16	86
Half crop	0.69	1.11	2.04	0.22	234	20	36	16	80
P-value									
F	NS[w]	NS	NS	NS	0.004	0.009	<0.001	NS	NS
C	NS	NS	NS	NS	NS	NS	NS	NS	NS
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS
					2013				
Floor mgt. (F)									
Grass	0.64 a	1.29	1.98	0.24	285 a	13	33 b	24	115
Alternate	0.56 a	1.31	2.01	0.25	233 b	14	39 a	25	143
Tilled	0.35 b	1.30	1.79	0.24	174 c	12	39 a	24	120
Crop level (C)									
Full crop	0.49 b	1.30	1.90	0.25	230	13	37	25	128
Half crop	0.54 a	1.30	1.94	0.25	231	13	37	24	125
P-value									
F	<0.001	NS	0.049	NS	<0.001	NS	0.002	NS	0.047
C	NS	NS	NS	NS	NS	NS	NS	NS	NS
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.

[y] Different letters following means within a column represent differences by Tukey's HSD at α=0.05.

[x] Crop Level treatments included Full Crop- no clusters removed, and Half Crop – fruit was thinned to one cluster per shoot (~ 42% clusters removed).

[w] NS – not significant at $P > 0.05$.

Appendix B. Petiole macro- and micro-nutrient concentrations at bloom from 2011 to 2013 by vineyard floor management and crop level treatments for ‘Pinot noir’ in the Willamette Valley of Oregon.

[z] Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.
[y] Different letters following means within a column represent differences by Tukey’s HSD at α=0.05.
[x] n.d.- not determined. In 2011 iron was not analyzed and crop level effects were not determined because crop level treatments were not yet implemented.
[w] Crop Level treatments included Full Crop- no clusters removed, and Half Crop – fruit was thinned to one cluster per shoot (~ 42% clusters removed).
[v] NS – not significant at $P > 0.05$.

Appendix B. Petiole macro- and micro-nutrient concentrations at bloom from 2011 to 2013 by vineyard floor management and crop level treatments for 'Pinot noir' in the Willamette Valley of Oregon.

Treatments	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Fe (ppm)
					2011				
Floor mgt. (F)[z]									
Grass	0.56 b[y]	2.44	1.78	0.36 b	198	17 b	29 c	85	n.d.[x]
Alternate	0.63 a	2.38	1.78	0.42 a	162	19 a	34 b	93	n.d.
Tilled	0.58 ab	2.42	1.71	0.43 a	149	18 ab	36 a	87	n.d.
Crop level (C)[w]									
Full crop	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Half crop	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
P-value									
F	0.019	NS[v]	NS	0.004	NS	0.031	<0.001	NS	n.d.
C	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
F x C	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
					2012				
Floor mgt. (F)									
Grass	0.56 a	2.75	2.02 a	0.35	182 a	16 b	32 b	87	24 a
Alternate	0.58 a	2.65	1.83 b	0.35	127 b	19 a	37 a	95	23 ab
Tilled	0.52 b	2.72	1.81 b	0.39	108 b	19 a	38 a	95	20 b
Crop level (C)									
Full crop	0.56	2.73	1.94 a	0.38 a	141	18	36	91	23
Half crop	0.55	2.68	1.83 b	0.35 b	138	18	36	94	23
P-value									
F	0.009	NS	0.009	NS	0.002	0.002	<0.001	NS	0.017
C	NS	NS	0.010	0.003	NS	NS	NS	NS	NS
F x C	NS	NS	<0.001	0.003	NS	NS	NS	NS	0.007
					2013				
Floor mgt. (F)									
Grass	0.55 a	3.07	1.89	0.38	216 a	13	26 b	97	29
Alternate	0.51 a	3.01	1.85	0.40	190 ab	15	28 a	109	31
Tilled	0.38 b	2.94	1.73	0.43	160 b	12	29 a	103	28
Crop level (C)									
Full crop	0.46 b	3.02	1.79	0.40	191	13	28	101	29 b
Half crop	0.50 a	2.99	1.86	0.41	187	14	28	104	30 a
P-value									
F	<0.001	NS	NS	NS	0.011	NS	0.002	NS	NS
C	0.046	NS	NS	NS	NS	NS	NS	NS	<0.001
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS

Appendix C. Leaf blade macro- and micro-nutrient concentrations at véraison from 2011 to 2013 by vineyard floor management and crop level treatments for ‘Pinot noir’ in the Willamette Valley of Oregon.

[z] Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.
[y] Different letters following means within a column represent differences by Tukey’s HSD at α=0.05.
[x] Crop Level treatments included Full Crop- no clusters removed, and Half Crop – fruit was thinned to one cluster per shoot (~ 42% clusters removed).
[w] NS – not significant at $P > 0.05$.

Appendix C. Leaf blade macro- and micro-nutrient concentrations at véraison from 2011 to 2013 by vineyard floor management and crop level treatments for 'Pinot noir' in the Willamette Valley of Oregon.

Treatments	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Fe (ppm)
					2011				
Floor mgt. (F)[z]									
Grass	0.32 ab[y]	1.52	2.15 b	0.17 b	190	12 c	23	11 b	108
Alternate	0.37 a	1.48	2.44 a	0.19 a	193	14 a	26	11 b	123
Tilled	0.29 b	1.44	2.26 ab	0.20 a	178	12 b	26	15 a	109
Crop level (C)[x]									
Full crop	0.32	1.45	2.25	0.19	188	12	25	12	113
Half crop	0.33	1.51	2.32	0.18	186	13	25	13	113
P-value									
F	0.041	NS[w]	0.018	0.013	NS	<0.001	0.048	<0.001	NS
C	NS	NS	NS	NS	NS	NS	NS	NS	NS
F x C	NS	NS	NS	NS	NS	0.045	NS	NS	NS
					2012				
Floor mgt. (F)									
Grass	0.28	1.60	1.86 b	0.19	217	9	20 b	17	65
Alternate	0.32	1.68	2.06 a	0.19	199	11	23 a	18	74
Tilled	0.27	1.69	2.09 a	0.21	201	10	24 a	16	65
Crop level (C)									
Full crop	0.29	1.69 a	2.02	0.21 a	212	10	23	19 a	68
Half crop	0.29	1.62 b	1.98	0.18 b	199	10	22	16 b	69
P-value									
F	NS	NS	0.007	NS	NS	NS	<0.001	NS	NS
C	NS	0.032	NS	<0.001	NS	NS	NS	0.002	NS
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS
					2013				
Floor mgt. (F)									
Grass	0.39 a	1.87 a	2.44	0.26	249 a	10	62 a	20 a	71
Alternate	0.32 ab	1.65 b	2.37	0.27	215 ab	7	42 b	18 ab	80
Tilled	0.24 b	1.59 b	2.33	0.29	200 b	9	41 b	17 b	79
Crop level (C)									
Full crop	0.30	1.68	2.38	0.27	225	8	46	17 b	73
Half crop	0.33	1.73	2.38	0.27	217	9	50	19 a	80
P-value									
F	0.002	0.010	NS	NS	0.029	NS	<0.001	0.028	NS
C	NS	NS	NS	NS	NS	NS	NS	0.048	NS
F x C	NS	NS	0.028	NS	NS	0.037	NS	NS	NS

Appendix D. Petiole macro- and micro-nutrient concentrations at véraison from 2011 to 2013 by vineyard floor management and crop level treatments for ‘Pinot noir’ in the Willamette Valley of Oregon.

[z] Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling.
[y] Different letters following means within a column represent differences by Tukey’s HSD at α=0.05.
[x] Crop Level treatments included Full Crop- no clusters removed, and Half Crop – fruit was thinned to one cluster per shoot (~ 42% clusters removed).
[w] NS – not significant at $P > 0.05$.

Appendix D. Petiole macro- and micro-nutrient concentrations at véraison from 2011 to 2013 by vineyard floor management and crop level treatments for 'Pinot noir' in the Willamette Valley of Oregon.

Treatments	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Fe (ppm)
					2011				
Floor mgt. (F)[z]									
Grass	0.34	2.91 b[y]	1.40	0.41	162 b	1 c	19 b	57 b	13 b
Alternate	0.40	3.49 a	1.49	0.41	214 a	1 b	20 b	67 ab	16 a
Tilled	0.38	3.88 a	1.46	0.44	204 ab	8 a	25 a	70 a	13 b
Crop level (C)[x]									
Full crop	0.38	3.38	1.45	0.42	191	3	21	63	14
Half crop	0.37	3.47	1.45	0.42	196	3	21	66	13
P-value									
F	NS[w]	<0.001	NS	NS	0.035	<0.001	<0.001	0.012	0.035
C	NS	NS	NS	NS	NS	NS	NS	NS	NS
F x C	NS	NS	NS	NS	NS	NS	0.013	NS	NS
					2012				
Floor mgt. (F)									
Grass	0.30	2.84 b	1.38 b	0.42	294	6 b	20 b	58 b	18
Alternate	0.37	3.70 a	1.53 a	0.45	305	6 a	22 a	72 a	19
Tilled	0.31	3.56 ab	1.51 a	0.48	279	6 ab	22 a	81 a	20
Crop level (C)									
Full crop	0.33	3.32	1.50	0.45	296	6	22	73	19
Half crop	0.32	3.40	1.39	0.45	289	6	21	68	19
P-value									
F	NS	0.023	0.012	NS	NS	0.037	<0.001	<0.001	NS
C	NS	NS	NS	NS	NS	NS	NS	NS	NS
F x C	NS	NS	NS	NS	NS	NS	NS	NS	NS
					2013				
Floor mgt. (F)									
Grass	0.51	3.62	1.73	0.53	299	5 a	32 ab	65 b	15
Alternate	0.55	4.21	1.88	0.58	286	6 a	38 a	83 a	17
Tilled	0.44	4.04	1.78	0.64	258	3 b	28 b	81 a	16
Crop level (C)									
Full crop	0.49	3.92	1.81	0.58	299	6 a	35 a	76	16
Half crop	0.50	3.99	1.79	0.58	263	4 b	29 b	77	16
P-value									
F	NS	NS	NS	NS	NS	0.005	0.025	<0.001	NS
C	NS	NS	NS	NS	NS	<0.001	0.033	NS	NS
F x C	NS	0.004	0.028	NS	NS	NS	NS	NS	NS

Appendix E. Mean (± SE) stem water potential of 'Pinot noir' in the Willamette Valley of Oregon from 2011 to 2013 under three floor management treatments. Floor treatments include Grass -red fescue established in both alleyways flanking the vine row; Alternate- red fescue in one flanking alleyway while the other was tilled; and Tilled- the two flanking alleyways were kept free of vegetation by tilling. *Means significantly different at $\alpha = 0.05$.