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 nitrogen (N) concentrations during all years compared with 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 2 of 3 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 2 of 3 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. Using 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.

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‘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 ha⁻¹ with a mean of 4.3 t ha⁻¹ (Castagnoli and Vasoncellos, 2006). Anderson et al. (2008) reported nearly 4-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 ha⁻¹ to hasten ripening and achieve quality in a cool climate (Uzes and Skinkis, 2016). Although 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 long-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 (Ferreere et al., 2001). In addition, 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 (Scheiner 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., 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-Alvarez et al., 2015) or affecting fruit ripening (Giese et al., 2015; Monteiro and Lopes, 2007; Pérez-Alvarez 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 et al., 2015; Monteiro and Lopes, 2007; Monteiro et al., 2015) or affecting fruit ripening (Giese et al., 2014; Schreiner et al., 2010) or reducing yield (Giese et al., 2014; Schreiner et al., 2010; Celette et al., 2009; Celette and Gary, 2013) or by retaining only the basal cluster on the vine rows for vines in the Full Crop and Half Crop treatments at the beginning of veraison for length and leaf area. Leaf areas were determined with a nondestructive 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 Jan. 2013 and Dec. 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.

**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. Vines were cane pruned to a bilateral Guyot system with a head height of 0.6 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 2.2 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 (B) at a total application rate of 1.12 kg·ha⁻¹ per year between April and August (Solu bor®; 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 budbreak in 2007. A 4-year study occurred from 2007 to 2010 using 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 roto tiller (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·ha⁻¹ during dormancy. During 2012 and 2013, the weed-free strip was maintained by the use of a grape hoe (Braun Maschinenbau GmbH, Waltham, MA). Foliar fertilizers were analyzed for total carbon and N using CNS-2000 Macro Analyzer (Leco, St. Joseph, MI), and leaf area was determined using a leaf area meter (Delta-T Devices, Cambridge, England) in 2012 and 2013. Leaf area measurements were obtained from an on-site weather station and were managed with commer-

**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 (great- 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, photo-synthetic 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 μmol·m⁻²·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, midcanopy, and upper canopy (0.6, 1.2, 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 (θv) 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 before 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 midplot 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 θv 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 (Ψs) was measured within 1 h of solar noon on cloudless days starting after bloom and continuing until postvéraison. Healthy, fully expanded primary leaves located midcanopy were sealed in Mylar zip-close bags. Leaves were removed from the vine after at least 1 h, 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 midcanopy 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 (LI-COR 6400-XT; LI-COR Inc., Lincoln, NE) between 1100 and 1245 h Pacific Daylight Time (PDT), between 1310 and 1450 h PDT at solar noon, and between 1430 and 1535 h PDT in the afternoon on clear, sunny days during bloom, pease, véraison, and ripening in 2012 and 2013. The flow meter was set to 400 μmol·s⁻¹, the CO₂ mixer to 400 ppm, and the temperature and relative humidity to the ambient conditions. Measurements across all plots were completed within 60 min to avoid variable readings due to differences in environmental conditions. Photosynthesis rate (Pn) and stomatal conductance (gs) were calculated from gas exchange measures.

Yield components. A five-cluster sample was harvested from four vines in each plot around weekly, starting 3 weeks before harvest to track ripening. Fruit was harvested from the other four vines in the plot the same day or up to 2 d before 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 h 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 YAN. The remaining juice was measured for TSS, pH, and titratable acidity (TA). TSS was measured in Brix using a digital temperature-compensating refractometer (Digital Refractometer 3000024; 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). TA was determined by using a 5-mL juice sample diluted in 45 mL of distilled water and titrated to a pH endpoint of 8.2 with 0.1 N sodium hydroxide and is expressed in g·L⁻¹ of tartaric acid equivalents. YAN content was determined by measuring N from primary amino acids (excluding proline and hydroxyproline) and ammonia using separate assays. N 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, and a 0.5-mL aliquot was diluted 1:1 v/v with distilled water. A juice sample and a juice blank, containing no o-phenthaldehyde (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 o-phenthaldehyde, depending on whether juice samples or juice blanks were being measured. After 10 min, samples were measured by spectrophotometer (Genesys 10S ultraviolet-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·L⁻¹ N).

Statistical analysis. Statistical analyses were performed using SAS Statistical Software 9.3 (SAS Institute, Cary, NC) using PROC MIXED for analyses of variance. When significant differences were found (α = 0.05), separation of means were determined by Tukey’s honestly significant differences. 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 1 (2011) was the coolest of the 3 years and one of the coolest seasons on record for Oregon. Heat unit accumulation from budbreak to harvest was 301 and 133 GDD10 lower in 2011 than in 2012 and 2013, respectively (Table 1). Therefore, the 2011 season spanned ≈10 more days from budbreak to harvest than the other two seasons. The 2012 season was warmer from bloom to harvest than the other two seasons. The 2012

Table 1. Seasonal climate summary by phenology of the grapevine at the experimental site located in Dayton, OR for 2011 to 2013.

| Phenology                       | Dates          | GDD10a   | Mean daily temperature (°C) | Precipitation (mm) |
|--------------------------------|----------------|----------|-----------------------------|--------------------|
| Budbreak to bloom              | 6 May–4 July   | 241      | 13.55                        | 81                  |
| Bloom to véraison              | 4 July–6 Sept. | 241      | 15.72                        | 101                 |
| Bloom to harvest               | 4 July–20 Oct. | 241      | 15.72                        | 101                 |
| Budbreak to harvest            | 6 May–24 Oct.  | 241      | 15.72                        | 101                 |
| Full season                    | 1 Apr–1 Nov.   | 241      | 15.72                        | 101                 |

aGrowing degree days (GDD10) calculated by Σ [(daily maximum temperature (°C) + daily minimum temperature (°C))/2 – 10].

bBudbreak is date at which ≈50% of the buds reached BBCH stage 07, bloom is BBCH stage 65, véraison is date at which ≈50% of the berries reached BBCH stage 83.
season was also the driest from bloom to harvest, with five to six times less precipitation than 2011 or 2013. Rainfall between budbreak and veraison was fairly similar in 2012 and 2013, 140 and 149 mm respectively, however, rainfall between veraison and harvest was much higher in 2013 (55 mm) than 2012 (1 mm, data not shown). The 2011 season had intermediate precipitation during budbreak to harvest compared with the other two seasons.

**Vine growth.** Early season (budbreak 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. 1A). Grass treatments had smaller canopies than Alternate and Tilled, with 19% to 39% lower leaf area per shoot at bloom (Fig. 1B) and 21% to 45% lower leaf area per shoot at veraison in all years (Fig. 1C). At bloom and veraison, Alternate and Tilled had similar leaf area. Cluster thinning resulted in 21% higher leaf area in 2013 (data not shown). In 2012, Alternate and Tilled had lower leaf area at veraison 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). Alternate had intermediate petiole N at bloom compared with 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 B, and for potassium (K) and zinc (Zn) at veraison. K and Zn tended to be lower 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 concentrations in Grass leaf blades than Tilled in 2012 and 2013. Some other macro- and micronutrients differed among treatments but inconsistently, that is, petiole vs. leaf blade, or across years (data not shown). 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), 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 midcanopy in the morning, but crop level did not affect radiation penetration in the upper canopy (data not shown).

**Volumetric soil water content (\( \theta_v \)) and stem water potential (\( \psi_s \)).** The only season-long impact of floor management on \( \theta_v \), occurred in the upper 45 cm of the soil profile from early June to Sept. 2011, where Grass had lower \( \theta_v \), than Tilled (Fig. 3). In 2012, \( \theta_v \) was lower in Grass than in Tilled in August, but only at 15 cm (data not shown). There were no differences in \( \theta_v \), with vineyard floor management at any depth or time in 2013.

Crop level did not influence \( \psi_s \), 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, \( \psi_s \) was 7% to 8% higher in Grass-Half Crop than in Grass-Full Crop at 45 cm (\( P \leq 0.045 \)).

Despite lower \( \theta_v \) in Grass treatments during 2011, there were no differences among treatments in \( \psi_s \), measured on the same dates (data not shown). In 2012, Grass \( \psi_s \) was –0.66 MPa in late August while Tilled was –0.76 MPa (\( P = 0.011 \)) and Grass \( \psi_s \) was –0.77 MPa in mid-September 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 \( \psi_s \), in all years. Overall, the lowest \( \psi_s \) 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. 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, veraison, and ripening, \( P_n \) in Grass was 20%, 23%, and 19% lower than Tilled. However, there was only a difference at bloom (Grass \( \leq \) 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 veraison in 2011 where Full Crop had a \( P_n \) of 18.5 \( \mu \)mol·m\(^{-2}\)·s\(^{-1}\) \( \text{CO}_2 \) and Half Crop had a \( P_n \) of 21.2 \( \mu \)mol·m\(^{-2}\)·s\(^{-1}\) \( \text{CO}_2 \) (\( P = 0.008 \)).

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·m\(^{-2}\)·s\(^{-1}\) \( \text{H}_2\text{O} \), Tilled 0.38 mol·m\(^{-2}\)·s\(^{-1}\) \( \text{H}_2\text{O} \, P = 0.006 \)). 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·m\(^{-2}\)·s\(^{-1}\) ; 2012) and the lowest was at ripening in Half Crop (0.15 mol·m\(^{-2}\)·s\(^{-1}\) \( \text{H}_2\text{O} \), 2012).

**Yield components.** Differences in inflorescences per shoot were found in 2012 and 2013, with Grass having fewer inflorescences per shoot than Tilled (Table 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 with Grass and Tilled treatments. There were no differences in inflorescences per shoot, florets per inflorescence, or fruit set found by crop level.

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 3). At harvest in 2011, Grass had fewer berries per cluster than Tilled or Alternate, but in 2012 and 2013.
Table 2. Petiole and leaf blade nitrogen concentrations (%) at bloom and véraison from 2011 to 2013 by vineyard floor management treatments.

| Treatments       | 2011 Blade | 2011 Petiole | 2012 Blade | 2012 Petiole | 2013 Blade | 2013 Petiole |
|------------------|------------|--------------|------------|--------------|------------|--------------|
| Grass            | 0.6 c      | 2.0 c        | 0.4 c      | 2.6 c        | 0.7 b      |
| Alternate        | 0.9 b      | 2.4 b        | 0.5 b      | 2.8 b        | 0.8 ab     |
| Tilled           | 1.0 a      | 2.7 a        | 0.8 a      | 3.0 a        | 0.9 a      |

P value

| F     | F n.d. | <0.001 | <0.001 | <0.001 | 0.039 |
|-------|--------|--------|--------|--------|-------|
| C     | n.d.   | n.d.   | n.s.   | n.s.   | n.s.  |
| F × C | n.d.   | n.d.   | n.s.   | n.s.   | n.s.  |

Clover (F) n.d. = not determined. Leaf blades were separated for analysis.

*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.

**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.

*d.n. = 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.

**Different letters following means within a column represent differences by Tukey’s honestly significant differences at α = 0.05.

**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.

there were similar numbers of berries per cluster among floor treatments. In 2012, post-fruit set berry counts were lower 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 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. 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. 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 (data not shown).

Vineyard floor treatments affected dormant pruning weights. Grass had lower pruning weights compared with Tilled, while Alternate was intermediate (Table 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.** TSS and pH were more affected by crop level than by floor management (Table 5). However, in 2012, TSS from Grass was lower than Tilled. Juice pH was unaffected by vineyard floor treatment in any year. TA was lower in Grass compared with 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 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% higher YAN concentrations compared with 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. 5). YAN generally increased with increasing tissue N at all times measured in all years, but bloom petiole tissues responded nonlinearly depending on year (data not shown). There was no tissue type or timing that was best related with YANs consistently over the 3 years. Tissue N concentrations that predicted the target minimum YAN of 140 mg L⁻¹ N were determined separately from each equation, resulting in an average of 2.7% in bloom leaf blades, 0.38% in véraison petioles, and 2.11% in véraison leaf blades over the 3 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...
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; Kliewer 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 with 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; Pérez-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 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 gₛ was above 0.15 mol·m⁻²·s⁻¹ H₂O, 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 (ψₛ) of less than –1.2 MPa (Williams and Baeza, 2007), which is about –0.91 MPa for stem water potential determined from the relationship between ψₛ and ψᵣ (Williams and Araujo, 2002).

The temporal and spatial uptake of water by the grass in the alleyway compared with vines may account for differences in θₛ 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 drier conditions. Lower N, was found in the upper soil profile of Grass plots mainly in 2011 but did not impact \( \psi_r \). In August and September of 2012, the Grass treatment likely had reduced \( \Theta \), 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). 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., 2008). In addition, Grass had reduced leaf area and \( g_s \) was lower compared with Tilled, which likely reduced vine transpiration, as has been seen when comparing small canopy vines with those of 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 have grown with restricted N also showed reduced \( P_n \), in grass compared with herbicide-treated soil (Krohn and Ferree, 2000b). Similar to the current study, lower \( P_n \) has been found in vines grown in the presence of grass compared with herbicide-treated soil (Krohn and Ferree, 2000). Work with vines grown with restricted N also showed reduced \( P_n \) due to the reduced leaf blade N which is an important factor in photoassimilation (Boussadit 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 with Tilled. Alternatively, because of the higher leaf area of Tilled, \( PPF \) reaching the interior canopy was lower due to 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).

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Table 3. Yield components measured in vineyard floor management and crop level treatments during 2011 to 2013.

| Treatments | Inflorescences per shoot | Florets per inflorescence | Fruit set (%) | Early berries per cluster | Harvest berries per cluster |
|------------|--------------------------|---------------------------|---------------|---------------------------|-----------------------------|
|            | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 |
| Floor mgt. (F) | | | | | | | | | | | | | | | |
| Grass | 1.4 | 1.5 | 1.4 | 253 | 254 | 234 | 77 | 44 | 73 | 194 | 107 | 166 | 106 | 108 | 88 |
| Alternate | 1.5 | 1.6 | 1.6 | 310 | 265 | 275 | 69 | 46 | 69 | 205 | 105 | 189 | 146 | 102 | 85 |
| Tilled | 1.4 | 1.7 | 1.8 | 380 | 283 | 294 | 63 | 37 | 68 | 225 | 99 | 196 | 150 | 98 | 89 |
| Crop level (C) | | | | | | | | | | | | | | | |
| Full crop | n.d. | 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 |

Table 4. Vine growth and yield variables from vineyard floor management and crop level treatments during 2011 to 2013.

| Treatments | Shoots per vine | Clusters per vine | Cluster wt (g) | Yield (kg·m⁻²·row) | Pruning wt (kg·m⁻²·row) |
|------------|----------------|------------------|----------------|--------------------|-------------------------|
|            | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 |
| Floor mgt. (F) | | | | | | | | | | | | | | | |
| Grass | 19 b² | 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.² | 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) | | | | | | | | | | | | | | | |
| 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 |

²= measured at dormancy when collecting pruning weight.

³Floor 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 alleys were kept free of vegetation by tilling.

⁴Different letters following means within a treatment column represent differences by Tukey’s honestly significant differences at \( \alpha = 0.05 \).

°Crop level treatments included Full Crop-no clusters removed, and Half Crop-fruit was thinned to one cluster per shoot (≈42% clusters removed).

⁵n.d. = not determined; crop level treatment not implemented by time of measurement in 2011.

⁶ns = not significant at \( P > 0.05 \).
Table 5. Basic ripening variables measured at harvest during 2011 to 2013 from vineyard floor management and crop level treatments.

| Treatments | Total soluble solids (°Brix) | pH | Titratable acidity (g·L⁻¹) |
|------------|-----------------------------|----|--------------------------|
|            | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 | 2011 | 2012 | 2013 |
| Floor mgt. (F)  |  |  |  |  |  |  |  |  |  |  |  |  |
| Grass | 20.1 | 22.7 b  | 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)  |  |  |  |  |  |  |  |  |  |  |  |  |
| 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=0.019 0.001 NS NS NS 0.001 NS 0.036 NS 0.001
C 0.002 <0.001 0.022 NS <0.001 0.018 NS 0.036 NS NS
F × C NS NS NS NS NS NS NS NS NS NS

<350 µmol·m⁻²·s⁻¹, which is less than light saturation for optimal Pₐ (1036 µmol·m⁻²·s⁻¹; Cartechini and Pailotti, 1995). In most research on crop-thinned vines, there is lower Pₐ 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 Pₐ, 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; Damí et al., 2006; Kliwer 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 with 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). Other studies have found higher TSS in N-restricted vines as yields were reduced compared with higher N treatments. As in our study, no differences in juice pH were found in vines grown with cover crops to tilled vineyard floor treatments, but the other was tilled; and Tilled the two flanking alleyways were kept free of vegetation by tilling.

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., 2013).
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 L\(^{-1}\) N (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 L\(^{-1}\) N 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 L⁻¹ N in lower yielding years; they did not find relationships between bloom N and harvest YAN. Trying to achieve YAN concentrations of 140 mg L⁻¹ N 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 1 year and the increase in YAN was too small to be of practical value in the winery (24.1 mg L⁻¹ N). 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 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 with 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 later 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 CO₂ 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 crop suggests the impact of N limitation, not water limitation, which may lead to lower yields over time. Although 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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