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The Effect of Spur Position and Pruning Severity on Shoot Development

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Abstract: Adjusting yearly pruning severity is a common vineyard management practice employed to manipulate vegetative and reproductive growth in grapevines. Although the effects of pruning on total vegetative growth are well documented, there is little research on the effects of adjusting shoots meter^{-1} via dormant season pruning on addressing mid-cordon shoot weakness and developmental delays. Cordon-trained, spur-pruned vines are thought, by many growers, to be especially prone to weaker positions and delayed development at mid-cordon positions. This phenomenon is also thought to become more exaggerated as the vine ages. Therefore, the effects of shoot density manipulation, implemented via dormant pruning practices, to homogenize shoot and cluster development along the length of the cordon were examined. In this research, Cabernet Sauvignon grapevines were pruned to either 5.5 shoots meter^{-1} (5.5) or 11.1 shoots meter^{-1} (11.1). To control for variations in light interception into the fruiting zone, a control of 11.1 shoots meter^{-1} with sensor guided leaf thinning (11.1LT) was implemented at full berry set to match the canopy light of the 5.5 shoots meter^{-1} treatment. It was found that individual shoot growth and yield were directly impacted by manipulation of pruning severity. Shoot growth response varied primarily by growing season, including shoot length and internode length. Yield components were significantly lower in the 5.5 treatment during the first two years of the study but were not significantly different during the last year of the study. The 5.5 treatment resulted in the highest pH and total soluble solids at harvest in 2016 and 2017.

Keywords: pruning; phenology; cordon-trained; phenology; *Vitis vinifera*

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1. Introduction

Grapevine (*Vitis vinifera* L.) pruning is a common management practice to remove excess plant material and direct growth. Pruning allows for the selection of fruitful buds along the vine to accomplish uniform growth across the vine which would then help control crop load and maintain productivity and berry quality [1–3]. An important factor of pruning is the level of pruning severity, and the resulting number of buds meter^{-1} that are retained. The number of fruitful buds retained on the vine during winter pruning partially determines the yield and quality of grapes in the upcoming season [1,4]. Pruning is commonly done by hand, but the increasing cost and scarcity of labor is pushing for the implementation of more widespread mechanized pruning [5,6]. The use of mechanical pruning drastically reduces the amount of man hours required and lowers the cost to prune grapevines over hand pruning, but mechanical pruning removes less bearing wood than that of hand pruning [5,7,8]. This method, referred to as minimal pruning, has shown an increase in yields and production during the first initial years [1,5]. However, several studies have shown that yield and berry quality begin to decline over several years of mechanical pruning due the increased number of buds retained per vine due to the reduction of pruning severity [5,9].

The training system and pruning severity determines the size of the canopy which then affects the canopy microclimate and amount of light that reaches the cluster zone within the canopy [1,10,11]. Numerous studies have shown that decreased light within the canopy due to increased shading reduces bud fruitfulness, which in turn leads to a decrease in yield [10,12]. The reduction in yield is often attributed to fewer shoots per node, clusters per shoot, flowers per inflorescence, and cluster size.

One of the most frequently implemented training and pruning methods used in the production of grapevines is cordon-trained spur-pruned vines. For grapevines to achieve success using this training method, spur position height must be controlled to prevent positional apical dominance [11]. However, maintaining proper arm and spur positioning across the cordon can be quite challenging due to initial training and establishment challenges associated with establishing a cordon, spur-pruned vine. When apical dominance becomes an issue, several problems arise such as variation in the timing of budbreak, shoot growth, cluster development and cluster ripening. Higher positioned shoots that display apical dominance hinders the growth and development of lower buds and restricts more basal buds and subsequent shoot development [13]. Another issue that arises is the variation in the timing and uniformity of cluster development along the cordon [13–15]. This variation among positions along the cordon is perpetually amplified over the course of several seasons as weaker positions lead to continued weaker growth [16]. These weaker positions along the cordon are speculated to struggle in building up carbohydrate reserves which subsequently impacts bud fruitfulness [17]. Moreover, very little research has been conducted to examine different possible methods to resolve the issue of non-uniformity of shoot and cluster development along the cordon. Some growers will remove some clusters at véraison in order to achieve uniform ripeness and meet a certain yield target [18]. Therefore, the objective of this study is to evaluate the effect of shoot density on vine development across multiple positions along the cordon and to explore the homogenization of growth through variations in pruning severity in mature cordon-trained, spur-pruned vines.

2. Materials and Methods

2.1. Vineyard Site and Experimental Design

The study was conducted at a research vineyard located in Oakville, ON, California (38°25′16.4″ N 122°24′02.3″ W) during the 2015, 2016, and 2017 growing seasons. The experiment was conducted on sixteen-year-old *Vitis vinifera* L. cv Cabernet Sauvignon vines grafted onto 101-14 MGT rootstock. Vines were trained as bilateral cordons and spur-pruned on a vertical shoot position trellis and oriented north-south on a spacing of 1.8 × 2.5 m with cordons located 1 m above the ground. The soil was classified as a Bale Gravely Loam [19]. Two pruning severity treatments and a control were imposed across the vineyard as a complete randomized design with eight replicate vines (n = 8) per treatment. Pruning took place in the dormant season to a designated number of dormant buds based on treatment. At budbreak vines were monitored to ensure the desired number of shoots per treatment was properly met. When appropriate, suckering was performed in the vineyard to maintain the designated number of primary shoots per vine during the growing season based on treatment. The initial treatment was pruned to one bud spurs and resulted in 5.5 shoots meter^{-1} (11 shoots total per vine); second treatment was pruned to two bud spurs resulting in 11.1 shoots meter^{-1} (22 shoots total per vine). The control was pruned to industry standard practice (11.1 shoots meter^{-1}) and underwent additional leaf thinning (LT) at full berry set such that the photosynthetically active radiation (PAR) in the fruiting zone was homogenized to the fruiting zone PAR of the 5.5 shoots meter^{-1} treatment each year. PAR was measured at the fruiting zone during solar noon using an Accupar® LP-80 ceptometer (METER Group, Inc. USA, Pullman, WA, USA). The implementation of leaf thinning to the control vines was performed to discern the differences between the effect of shoot density and that of differences in PAR within the canopy. The control was designated as 11.1LT shoots meter^{-1}. Climate data was collected from the California Irrigation Management Information System (CIMIS) using weather station number 77, in Oakville, California (38°25′43″ N/122°24′37″ W), located 1.175 km from the research site. Cumulative growing degree days (GDD) were calculated from 1 April to 31 October of each year using the average daily temperature and a baseline of 10 °C.

2.2. Phenology

Target shoot phenology was examined when the entirety of the vineyard block had reached 50% véraison as measured by the Modified Eichhorn-Lorenz (E-L) scale [20] in 2015, 2016, and 2017. This resulted in the numerical ranking of the developmental stage of each pruning treatment as a function of position along the cordon.

2.3. Canopy Architecture and Light Penetration

For each treatment vine, target positions on both cordons were selected at the cordon head, cordon middle, and cordon end. Immediately after winter pruning to establish treatments, the first set of arm diameter measurements were taken (January 2015). Arm diameters of newly established spurs were re-examined as a function of position after the conclusion of the third experimental growing season winter pruning had been completed (January 2018). The diameter of newest portion of the arms, at target positions, were recorded using Neiko 0–200 mm digital calipers (Neiko Tools, Taiwan, China). Measurements were recorded at the base of each arm (two-year old wood) by position along the cordon. Shoot internode length and diameter measurements were also collected using digital Neiko 0–200 mm calipers (Neiko Tools, Taiwan, China) at véraison. Measurements were taken from the aforementioned target shoots at the fourth internode up from the base of the shoot. Diameter was measured at the thinnest part of the internode. Shoot diameter and internode length was examined in 2016 and 2017. Total vine shoot length was taken measured at véraison in 2015 and 2016 but not in 2017 as the vineyard was hedged earlier than anticipated. Light penetration into the fruiting zone was also collected at full canopy, immediately after full véraison of the vineyard block was reached, using a PAR-80 AccuPAR Linear PAR/LAI ceptometer (Decagon Devices, Inc. Pullman, Washington, DC, USA). The ceptometer was inserted into the vine, in the area between the third and fifth internode up from the base of where the shoots originated. The instrument was allowed to stabilize for 5 s before three measurements were recorded, each with a 5 s delay interval. Data were collected in 2015, 2016, and 2017, between 1200 and 1400 h on full sun days where photosynthetically active radiation (PAR) exceeded 1800 µmol m^{-2} s^{-1}.

2.4. Cluster and Pruning Weights

Harvest was commercially determined when composite fruit samples reached 24.5 Brix. Harvest dates were 8 September 2015, 8 September 2016, and 10 September 2017. Fruit was manually harvested for each treatment and separated by position along the cordon (head, mid, and end positions), then counted and subsequently weighed using a field scale. Pruning weights for target positions were collected during normal winter pruning was performed for each treatment (January 2016, 2017, and 2018).

2.5. Berry Chemistry

At harvest in 2015, 2016, and 2017, random samples of 250 berries were collected and then analyzed for berry chemical and physical properties. Brix measurements were collected using a density meter (Anton Paar, Graz, Austria). Titratable acidity (TA) was measured by titrating a mixture of deionized water with 5 mL of juice against 0.067 N NaOH (Fisher Scientific, Waltham, MA, USA) to a pH of 8.2. The pH was measured using a benchtop pH meter (Fisher Scientific, Waltham, MA, USA). In 2015 and 2016, a rapid phenolic panel was performed using HPLC to analyze catechin (which is one of the predominant phenolic compounds in grapes), catechin/tannin ratio, polymeric anthocyanins, polymeric anthocyanins/tannin ratio, tannins, and total anthocyanins of the fruit at harvest (ETS Laboratories). IBMP (3-Isobutyl-2-methoxypyrazine), the main compound responsible for 'green bell pepper' aromas and considered to be one of the most relevant compounds to wine flavor, was analyzed using MS/MS (QQQ) (ETS Laboratories).

2.6. Statistical Analysis

Statistical analysis was performed using JMP 16 statistical software from SAS Institute. Data that were collected only as a function of treatment rather than specific position along the cordon, such as PAR measurements, total vine yield, and berry chemistry data, were analyzed with a one-way analysis of variance. A two-way analysis of variance was performed on data that were collected as a function of both treatment and cordon position such as vine growth parameters and cluster and yield, and those that had a p-value less than 0.05 were considered statistically significant. Normality was assessed using a normal quantile plot and was further evaluated using a Shapiro–Wilk test. Data that did not meet normality assumptions were transformed using a box cox transformation. Homogeneity of variances was evaluated using a Bartlett test. Multiple comparisons were performed on variables that were statistically significant and were evaluated using the Each pair, Student's t-test.

3. Results and Discussion

3.1. Seasonal Climate

The 2015, 2016, and 2017 growing seasons were all classified in different Winkler regions, V, II, and III, respectively. There was substantial variation in degree days between the warmest (2015) and coolest (2016) years of this study, specifically 803.1 (Table 1). The warmest season also had the least amount of annual precipitation (315.86 mm). Additionally, the coolest season (2016) had substantially more seasonal precipitation (144.75 mm) than either 2015 (60.68 mm) or 2017 (25.14 mm). Additionally, average air temperatures during the growing season in 2015 were consistently higher than those in 2016 or 2017 (Table 2). However, maximum air temperature was higher in May of 2017 and in July of 2016 and 2017 than it was in the same period in 2015. The 2016 growing season had warmer minimum air temperatures in April and May compared to that of 2015. Despite not being the coolest year, 2017 did have the lowest minimum air temperatures in April, May, and October.

Table 1. Growing degree days (GDD); Winkler region classification; and precipitation for Oakville, California (USA) CIMIS station 77 for 2015, 2016, and 2017. Intermittent missing climate data from the CIMIS station was pulled from historical regional weather records using the Weather Underground weather station network.

Growing Season	Growing Degree Days (GDD) [1]	Winkler Region	Annual Precipitation (mm) [2]	Seasonal Precipitation (mm) [3]
2015	2217.7	Region V	315.86	60.68
2016	1456.6	Region II	614.31	144.76
2017	1880.55	Region III	926.98	25.14

[1] Calculated from 1 April–31 October in degree Celsius with a baseline of 10 °C. [2] Sum of precipitation from 1 January–31 December. [3] Sum of precipitation from 1 April–31 October.

Table 2. Monthly average air temperature, minimum, maximum air temperature, and maximum air temperature for Oakville, California (USA) CIMIS station 77 during the 2015, 2016, and 2017 growing seasons. Intermittent missing climate data from the CIMIS station was pulled from historical regional weather records using the Weather Underground Weather Station Network.

Year	Month	Average Air Temperature (°C)	Minimum Air Temperature (°C)	Maximum Air Temperature (°C)
2015	April	15.2	7.1	23.2
	May	16.1	9.3	23.0
	June	20.3	11.2	29.4
	July	22.0	14.1	29.8
	August	22.1	12.9	31.2
	September	22.3	11.8	32.8
	October	24.5	12.7	36.2
2016	April	12.5	9.9	15.2
	May	13.3	11.1	15.4
	June	17.5	10.5	24.4
	July	19.8	9.7	29.9
	August	19.4	9.8	29.0
	September	19.2	8.5	29.9
	October	15.6	7.7	23.5
2017	April	14.1	6.8	21.5
	May	17.3	8.2	26.3
	June	20.0	10.7	29.3
	July	21.0	10.8	31.3
	August	21.4	12.2	30.5
	September	20.8	11.3	30.4
	October	16.8	5.7	27.9

3.2. Canopy Architechture

Arm diameters were evaluated as a function of cordon position for each treatment during 2014/2015 winter pruning (Table 3a) and at the end of the trial 2017/2018 winter pruning (Table 3b). Significant differences in arm diameter were observed among treatments (p = <0.0001) and among positions along the cordon (p = 0.0272) after the 2014/2015 winter pruning (Table 3a). The 5.5 shoots meter^{-1} treatment had significantly larger arm diameter measurements than the 11.1 shoots meter^{-1} and the 11.1LT shoots meter^{-1} treatments. The 5.5 shoots meter^{-1} treatment had an average arm diameter of 4.38 cm, and the 11.1 shoots meter^{-1} and 11.1LT shoots meter^{-1} treatments had similar arm diameters at 3.50 cm and 3.59 cm, respectively (Table 3a). For positioning along the cordon, arms located at the ends of the cordon had significantly larger diameters than arms located either at the middle or the head of the cordon (Table 3a). Arms at the ends of the cordon had average arm diameters of 4.04 cm, and arms that were located at the middle and the head of the cordon had average diameters of 3.68 cm and 3.76 cm, respectively (Table 3a). At the completion of the study in 2017/2018, a significant interaction effect between treatment and cordon position (p = 0.0132) was observed (Table 3b). There were no significant differences among cordon positions for the 5.5 shoots meter^{-1} and 11.1LT shoots meter^{-1} treatments, but there were significant differences in cordon position for the 11.1 treatment (p = 0.0132). For the 11.1 shoots meter^{-1} treatment, arms located in the middle of the cordon had significantly lower diameters than those located at the end or head of the cordon (Table 3b). The average mid-cordon arm diameter for the 11.1 shoots meter^{-1} treatment was 1.94 cm, and the average size at the end and head of the cordon was 2.78 cm and 2.77 cm, respectively (Table 3b).

Table 3. Two-way analysis of variance (ANOVA) with interaction showing average arm diameter (cm) by year, treatment, and cordon position at the conclusion of winter pruning 2015/2016 (**a**) and at the conclusion of the experiment in 2017/2018 (**b**) (*n* = 8). Table shows treatment and position means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's *t*-test. Significant *p*-values (<0.05) are displayed in bold.

(**a**)

Year		Arm diameter (cm)
2014/2015	**Treatment**	
	5.5 shoots meter^{-1}	4.38 ± 0.10 a
	11.1 shoots meter^{-1}	3.50 ± 0.10 b
	11.1LT shoots meter^{-1}	3.59 ± 0.10 b
	Position	
	End	4.04 ± 0.13 a
	Mid	3.68 ± 0.11 b
	Head	3.76 ± 0.14 b
	p-value	**<0.0001**
Treatment		**<0.0001**
Position		**0.0272**
T × P		0.7868

(**b**)

Year	Treatment	Position	Arm diameter (cm)
2017/2018	5.5 shoots meter^{-1}	End	2.89 ± 0.16 abc
		Mid	3.17 ± 0.16 ab
		Head	3.28 ± 0.20 a
	11.1 shoots meter^{-1}	End	2.78 ± 0.16 abc
		Mid	1.94 ± 0.18 d
		Head	2.77 ± 0.23 abc
	11.1LT shoots meter^{-1}	End	2.84 ± 0.14 abc
		Mid	2.69 ± 0.25 bc
		Head	2.48 ± 0.19 cd
		p-value	**0.0005**
	Treatment		**0.0005**
	Position		0.2086
	T × P		**0.0132**

Observations of shoot growth weakness or delays in phenological development at the head or middle of the cordon for treatments with higher shoot densities was expected. However, in this study, statistical variation was commonly observed among treatments and not consistently among positions along the cordon, except for the initial arm diameters. At the time of initial winter pruning (January 2015), when the pruning severity treatments were initially implemented, minor differences were observed in positional arm diameters (Table 3a) with end positions being slightly larger (stronger) in diameter than those of arms at the mid or head of the cordons. After three consecutive years of the designated pruning treatments, variation down the length of the cordon was minimized most successfully in the 5.5 shoots meter^{-1} (Table 3b). However, in the 11.1LT shoots meter^{-1} treatment, variation was also minimized as a function of position. In the 11.1 shoots meter^{-1} the mid-cordon position still lagged significantly behind the end and head positions within the treatment, suggesting a failure to homogenize cordon positions for that treatment in the absence of the additional leaf thinning or further reduction in shoot meter^{-1}. Overall, arm diameters were largest in vines where more light penetrates and reaches developing dormant buds. The reduced shoot density treatment and the control resulted in increased sunlight penetration into the canopy pre-véraison (berry growth stages I and II), improved dormant bud development and ultimately homogenized growth and increased the size of arm diameters. Studies have demonstrated removal of leaves and the resulting increase in light penetration into the canopy stimulates an increase in photosynthetic activity within the canopy and increases overall vine performance [21,22]. Similarly, in this study, the likely increase in photosynthetic activity (more photosynthetically active leaves) within the canopy and increased light on developing buds allowed for the homogenization of arm diameters along the cordon positions within the 5.5 and 11.1LT treatments (Table 3b). The observations in arm diameter impacted demonstrate where weaker positions may lie when this phenomenon occurs and how to possibly remedy this issue.

In 2015 and 2016, total shoot length was examined as a function of position for each treatment at the initiation of véraison. Position along the cordon was not found to be significant in 2015 or 2016 (Table 4a,b). However, pruning treatment did result in variations in shoot length for both the 2015 (p = 0.0044) and 2016 season (p = 0.0056). The 5.5 shoots meter^{-1} treatment had significantly longer shoot lengths than the 11.1LT meter^{-1} but did not vary significantly from the 11.1 shoots meter^{-1} treatment during the 2015 growing season (Table 4a). The average shoot length for the 5.5 shoots meter^{-1} treatment was 72.5 cm, while the 11.1LT shoots meter-1 treatment had an average shoot length of 61.8 cm. However, during the 2016 growing season, the 5.5 shoots meter^{-1} treatment had an average shoot length of 62.4 cm, which resulted in the shortest average shoot length compared to the 11.1 and 11.1LT shoots meter^{-1} treatments (Table 4b). When comparing the two 11.1 shoots meter^{-1} treatments, no significant differences were found between the two treatments (Table 4b).

Table 4. Two-way analysis of variance (ANOVA) with interaction showing average shoot length (cm), internode length (cm), and internode diameter (cm) by year, treatment, and cordon position at véraison during the 2015 (**a**), 2016 (**b**), and 2017 (**c**) growing seasons (n = 8). Table shows treatment means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's t-test. Significant p-values (<0.05) are displayed in bold.

(**a**)

Year		**Shoot Length (cm)**	**Internode Length (cm)**	**Internode Diameter (cm)**
2015	**Treatment**		n/a	n/a
	5.5 shoots meter^{-1}	72.5 ± 1.53 a		
	11.1 shoots meter^{-1}	66.5 ± 2.36 ab		
	11.1LT shoots meter^{-1}	61.8 ± 2.65 b		
	Position		n/a	n/a
	End	63.3 ± 1.92 a		
	Mid	68.3 ± 2.42 a		
	Head	69.2 ± 2.77 a		
	p-value	**0.0106**		
	Treatment	**0.0044**		
	Position	0.1323		
	T × P	0.2169		

Table 4. *Cont.*

(b)				
Year		**Shoot Length (cm)**	**Internode Length (cm)**	**Internode Diameter (cm)**
2016	**Treatment**			
	5.5 shoots meter^{-1}	62.4 ± 1.79 b	9.79 ± 0.17 a	0.91 ± 0.04 a
	11.1 shoots meter^{-1}	72.5 ± 2.38 a	8.11 ± 0.16 b	0.78 ± 0.03 a
	11.1LT shoots meter^{-1}	69.5 ± 2.79 a	8.73 ± 0.19 b	0.83 ± 0.05 a
	Position			
	End	71.0 ± 2.87 a	8.96 ± 0.26 a	0.87 ± 0.03 a
	Mid	66.8 ± 2.09 a	8.81 ± 0.28 a	0.86 ± 0.04 a
	Head	66.6 ± 2.32 a	8.86 ± 0.28 a	0.79 ± 0.05 a
	p-value	**0.0256**	**0.0001**	0.6131
	Treatment	**0.0056**	**<0.0001**	0.1478
	Position	0.2994	0.8642	0.4758
	T × P	0.2308	0.8547	0.8366

(c)				
Year		**Shoot Length (cm)**	**Internode Length (cm)**	**Internode Diameter (cm)**
2017	**Treatment**			
	5.5 shoots meter^{-1}	n/a	7.03 ± 0.45 a	0.79 ± 0.03 a
	11.1 shoots meter^{-1}		8.11 ± 0.22 a	0.77 ± 0.01 a
	11.1LT shoots meter^{-1}		8.18 ± 0.30 a	0.78 ± 0.02 a
	Position			
	End	n/a	8.02 ± 0.31 a	0.78 ± 0.03 a
	Mid		8.15 ± 0.49 a	0.80 ± 0.02 a
	Head		7.16 ± 0.32 a	0.76 ± 0.03 a
	p-value		0.1699	0.846
	Treatment		0.0507	0.8909
	Position		0.1503	0.549
	T × P		0.7942	0.6983

Aside from arm diameters, much of the statistical variation in this study occurred among treatments, indicating that shoot density influenced shoot growth and development equally across the cordon. For example, shoot length, internode length, cluster number, and yield all had statistical variations among treatments and had no variation among cordon positions. However, statistical variation in vegetative growth oscillated between growing seasons, signifying that grapevine responses to treatments were developing and were probably impacted several seasons after implementation. Shoot length was longest in the 5.5 treatment but not significantly different than the 11.1LT treatment during 2015 (Table 4a), but the 5.5 treatment was the shortest during 2016 (Table 4b). These results demonstrate the oscillation of vegetative growth between growing seasons. Studies have previously reported how pruning severity affected shoot growth, but there did not appear to be consistent results between studies. Sommer et al. (1995) reported when grapevines were minimally pruned, the resulting shoots appeared to be stunted with shorter shoot and internode lengths [23]. Conversely, O'Daniel et al. (2012) reported that as the level of pruning severity increased, the shoot density decreased, but differences in shoot length among pruning treatments were not observed [24]. Another measurement of shoot growth is internode length and this measurement also varied between growing seasons (Table 4). During 2016, internode length was the longest in the 5.5 treatment, but then in 2017, no statistical variation was observed among treatments. Although there is a scarcity of studies with similar internode length results, one study from McLoughlin et al. (2011) found that spur length had no effect on average internode length and was similar to this study's 2017 results [25]. However, their methodology for calculating average internode length differed from this current study's methodology. In the study by McLoughlin et al. (2011), the shoot length was divided by the number of nodes per shoot to obtain the internode length [25].

Apical dominant behavior in vegetative development responded to shoot density treatments but was initially overshot. This observation indicates that the benefit of vegetative homogenization from decreased shoot density may be a temporal response, implicating that these benefits may correct imbalanced arm positions initially, but the vine's nature eventually supersedes the treatment. Future research would be needed to confirm that this factor may benefit vineyard establishment more than ongoing vineyard practices. Further understanding of pruning severity's influence on these developments could better aid growers in anticipating, adapting, and most importantly, homogenizing spur-pruned grapevine productivity and growth.

3.3. Light Penetration

Despite variations in shoots per meter and the leaf thinning imposed at full berry set on the 11.1LT shoots meter^{-1} treatment, photosynthetically active radiation (PAR) in the fruiting zone was not significantly different at véraison for any of the treatments or seasons, except for the 11.1 shoots meter^{-1} treatment in 2017, which resulted in having less light penetration into the fruiting zone (Table 5). The same findings were found when light penetration in the fruiting zone was expressed as a percentage of full sun.

Table 5. One-way analysis of variance (ANOVA) showing average PAR and percentage of full sun values by year and treatment at véraison during the 2015, 2016, and 2017 growing seasons (n = 8). Table shows treatment means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's t-test. Significant p-values (<0.05) are displayed in bold.

Year	Treatment	PAR [a] μmol m^{-2} s^{-1}	PAR % of Full Sun
2015	5.5 shoots meter^{-1}	106.7 ± 11.8 a	5.33 ± 0.59 a
	11.1 shoots meter^{-1}	84.30 ± 19.6 a	4.21 ± 0.98 a
	11.1LT shoots meter^{-1}	138.8 ± 20.7 a	6.94 ± 1.03 a
	p-value	0.1197	0.1197
2016	5.5 shoots meter^{-1}	147.0 ± 12.2 a	7.35 ± 0.61 a
	11.1 shoots meter^{-1}	82.80 ± 23.9 a	4.14 ± 1.19 a
	11.1LT shoots meter^{-1}	136.8 ± 20.2 a	6.84 ± 1.01 a
	p-value	0.0675	0.0675
2017	5.5 shoots meter^{-1}	281.1 ± 44.9 a	17.2 ± 2.75 a
	11.1 shoots meter^{-1}	155.5 ± 23.4 b	9.54 ± 1.44 b
	11.1LT shoots meter^{-1}	289.0 ± 28.0 a	17.7 ± 1.72 a
	p-value	**0.0165**	**0.0165**

[a] PAR: Photosynthetically active radiation.

3.4. Phenology

Shoot phenology was assessed when the majority of the vineyard block had reached 50% véraison based on the Modified Eichhorn-Lorenz (E-L) scale. Phenology was evaluated by position along the cordon for each treatment during 2015, 2016, and 2017 growing seasons. No significant variation among treatments or cordon positions was observed during all three years (Table 6a–c). In 2015 and 2017, phenology ratings were very similar, with slight variation among treatments and cordon positions (Table 6a,c). In 2016, there was slightly more variation among treatments and cordon positions, but not enough variation within the treatment to be considered significant (Table 6b). The position effect resulted in a significant *p*-value (p = 0.0118), but cautions should be exercised in concluding there was a significant variation in cordon position due to the statistical model not being significant (p = 0.0766) and doing so would increase the likelihood of committing a type I error (Table 6b). Previous studies have looked at the effect of the timing of winter pruning on phenology [26–28], but not many studies have looked at the effect of pruning severity on phenological development.

Table 6. Two-way analysis of variance (ANOVA) with interaction showing average phenology ratings by year, treatment, and cordon position at véraison during the 2015 (**a**), 2016 (**b**), and 2017 (**c**) growing seasons (n = 8). Table shows treatment means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's *t*-test. Significant *p*-values (<0.05) are displayed in bold.

(**a**)

Year		Phenology Rating
2015	**Treatment**	
	5.5 shoots meter^{-1}	33.3 ± 0.10 a
	11.1 shoots meter^{-1}	33.4 ± 0.11 a
	11.1LT shoots meter^{-1}	33.4 ± 0.14 a
	Position	
	End	33.3 ± 0.11 a
	Mid	33.4 ± 0.12 a
	Head	33.3 ± 0.12 a
	p-value	0.9967
Treatment (T)		0.8535
Position (P)		0.7836
T × P		0.9890

(**b**)

Year		Phenology Rating
2016	**Treatment**	
	5.5 shoots meter^{-1}	35.6 ± 0.14 a
	11.1 shoots meter^{-1}	35.5 ± 0.14 a
	11.1LT shoots meter^{-1}	35.2 ± 0.23 a
	Position	
	End	35.9 ± 0.15 a
	Mid	35.3 ± 0.09 b
	Head	35.1 ± 0.24 b
	p-value	0.0766
Treatment (T)		0.1639
Position (P)		**0.0118**
T × P		0.7880

Table 6. *Cont.*

(c)		
Year		**Phenology Rating**
2017	**Treatment**	
	5.5 shoots meter^{-1}	35.0 ± 0.37 a
	11.1 shoots meter^{-1}	35.1 ± 0.24 a
	11.1LT shoots meter^{-1}	35.5 ± 0.32 a
	Position	
	End	35.1 ± 0.34 a
	Mid	35.2 ± 0.24 a
	Head	35.3 ± 0.40 a
	p-value	0.8639
Treatment (T)		0.6491
Position (P)		0.9114
T × P		0.6056

3.5. Cluster Counts and Weight, Pruning Weight

Cluster counts and yield (kg) were collected by treatment and cordon position during 2015, 2016 and 2017 growing seasons. Table 7 shows cluster number and yield for each treatment and cordon position. Cluster number and yield for treatment is displayed as an average across the three cordon positions. During both the 2015 and 2016 growing seasons, there were significant differences in cluster counts and yield among treatments, but not among positions along the cordon (Table 7a,b). However, during the 2017 growing season, there were different results compared to the previous two years. There were no significant differences among treatments or cordon positions for either cluster counts or yield (Table 7c). Cluster numbers were significantly lower for the 5.5 shoots meter^{-1} treatment during both the 2015 and 2016 growing seasons when compared to the other two treatments ($p < 0.0001$ and $p < 0.001$, respectively). The 5.5 shoots meter^{-1} treatment had cluster counts of 4.19 and 5.79 clusters at harvest during the 2015 and 2016 growing seasons, respectively (Table 7a,b). For yield, the 5.5 shoots meter^{-1} also had the lowest yield during both 2015 and 2016 at 0.76 and 0.83 kg, respectively (Table 7a,b). During the 2015 and 2016 growing seasons, no significant differences were found between the 11.1 shoots meter^{-1} and 11.1LT shoots meter^{-1} treatments in cluster number or yield (Table 7a,b). The 2017 growing season had no significant variation in cluster number or yield (Table 7c). However, even though there appeared to be a treatment effect for yield, the p-value of the statistical model was $p = 0.1924$; therefore, one cannot conclude any significant variation (Table 7c).

Winter pruning helps maintain the size and form of the vine, helps maintain a balance between vegetative and reproductive growth, and influences the yield and quality of wine grapes [29]. It has been well documented that the level of pruning influences shoot growth and yield of grapevines; typically, the higher the number of nodes retained at pruning, the higher the yield [30]. This relationship between the number of nodes and yield was also observed initially in this study. Early in the study, cluster number and yield were the lowest for the 5.5 shoots meter^{-1} treatment and were most likely influenced by the lower number of retained nodes at pruning. During the second year of the study (2016), the same results were observed in that the 5.5 shoots meter^{-1} treatment had the lowest number of clusters and yield (Table 7b). However, during the last year of the trial (2017), there were no significant differences in either cluster number or yield among pruning treatments, and this was attributed to the increase in double clusters for the 5.5 shoots meter^{-1} treatment (Table 7c). These yield responses to varying levels of pruning severity suggest that vines had adjusted to the changes in stored carbohydrates after several growing seasons, resulting in stabilization in yield among treatments. However, further studies on the relationship between pruning severity and stored carbohydrates should be investigated to determine if there are changes in stored carbohydrates after several seasons and if vines adjust to these changes. The yield response observed in this study was similar to those published in previous studies in that yield is not only initially affected by the number of nodes but rather is impacted overtime [3,5,6,9].

Table 7. Two-way analysis of variance (ANOVA) with interaction showing average cluster number and yield (kg) by year, treatment, and cordon position at harvest during the 2015 (**a**), 2016 (**b**), and 2017 (**c**) growing seasons (n = 7). Table shows treatment and cordon position means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's t-test. Significant p-values (<0.05) are displayed in bold.

(**a**)

Year		Cluster #	Yield (kg)
2015	**Treatment**		
	5.5 shoots meter^{-1}	4.19 ± 0.26 b	0.76 ± 0.06 b
	11.1 shoots meter^{-1}	8.10 ± 0.35 a	1.81 ± 0.17 a
	11.1LT shoots meter^{-1}	7.89 ± 0.30 a	1.53 ± 0.07 a
	Position		
	End	7.09 ± 0.63 a	1.41 ± 0.18 a
	Mid	6.39 ± 0.47 a	1.34 ± 0.15 a
	Head	6.70 ± 0.42 a	1.36 ± 0.13 a
	p-value	**<0.0001**	**<0.0001**
Treatment (T)		**<0.0001**	**<0.0001**
Position (P)		0.2927	0.9198
T × P		0.5567	0.872

(**b**)

Year		Cluster #	Yield (kg)
2016	**Treatment**		
	5.5 shoots meter^{-1}	5.79 ± 0.24 b	0.83 ± 0.05 b
	11.1 shoots meter^{-1}	10.5 ± 0.56 a	1.67 ± 0.15 a
	11.1LT shoots meter^{-1}	10.8 ± 0.57 a	1.53 ± 0.10 a
	Position		
	End	8.63 ± 0.70 a	1.33 ± 0.16 a
	Mid	9.50 ± 0.70 a	1.37 ± 0.13 a
	Head	8.96 ± 0.61 a	1.34 ± 0.10 a
	p-value	**<0.0001**	**0.0002**
Treatment (T)		**<0.0001**	**<0.0001**
Position (P)		0.4397	0.955
T × P		0.5397	0.5232

(**c**)

Year		Cluster #	Yield (kg)
2017	**Treatment**		
	5.5 shoots meter^{-1}	7.24 ± 0.62 a	0.63 ± 0.06 a
	11.1 shoots meter^{-1}	7.38 ± 0.43 a	0.91 ± 0.09 a
	11.1LT shoots meter^{-1}	7.27 ± 0.53 a	0.81 ± 0.07 a
	Position		
	End	6.86 ± 0.68 a	0.76 ± 0.10 a
	Mid	7.52 ± 0.36 a	0.82 ± 0.06 a
	Head	7.50 ± 0.52 a	0.77 ± 0.08 a
	p-value	0.6099	0.1924
Treatment (T)		0.9788	0.028
Position (P)		0.6175	0.8662
T × P		0.2421	0.4408

In addition to collecting yield by position for each treatment, total vine yield by treatment was also collected (Table 8). During the 2015, 2016, and 2017 growing seasons, there were significant differences among pruning treatments (p = 0.0016, p = 0.0029, and p = 0.0433, respectively). In 2015 and 2016, similar results to those from Table 7a,b were observed. During the first two years of the study (2015 and 2016), the 5.5 shoots meter^{-1} treatment had the lowest total yield per vine compared to the other two treatments (Table 8). The average total yield for the 5.5 shoots meter^{-1} treatment in 2015 was 2.29 kg, while in 2016, it was 2.50 kg (Table 8). In comparison, the 11.1 shoots meter^{-1} treatment had an average total vine yield of 5.44 kg in 2015 and had an average of 5.02 kg during 2016, around double that of the 5.5 shoots meter^{-1} treatment (Table 8). In 2017, the total vine yield of the 5.5 shoots meter^{-1} treatment was only significantly lower than the 11.1 treatment but was not significantly different from the 11.1LT treatment (Table 8). The average total vine yield for the 5.5 shoots meter^{-1} treatment was 1.89 kg, while the 11.1 treatment had an average total vine yield of 2.73 kg (Table 8). Total vine yield between the 2015 and 2016 growing seasons appeared to be similar while total vine yield during the 2017 growing season seemed to have decreased for all three treatments (Table 8). However, it is quite unclear what caused this decrease in yield from 2016 to 2017, since the climate in 2017 seemed to have a higher accumulation of growing degree days than that of the 2016 growing season (Table 1).

Table 8. One-way analysis of variance (ANOVA) showing average total vine yield (kg) by year and treatment at harvest during the 2015, 2016, and 2017 growing seasons (n = 7). Table shows treatment means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's t-test. Significant p-values (<0.05) are displayed in bold.

Year	Treatment	Total Vine Yield (kg)
2015	5.5 shoots meter^{-1}	2.29 ± 0.17 b
	11.1 shoots meter^{-1}	5.44 ± 0.85 a
	11.1LT shoots meter^{-1}	4.60 ± 0.20 a
	p-value	**0.0016**
2016	5.5 shoots meter^{-1}	2.50 ± 0.09 b
	11.1 shoots meter^{-1}	5.02 ± 0.74 a
	11.1LT shoots meter^{-1}	4.60 ± 0.39 a
	p-value	**0.0029**
2017	5.5 shoots meter^{-1}	1.89 ± 0.13 b
	11.1 shoots meter^{-1}	2.73 ± 0.26 a
	11.1LT shoots meter^{-1}	2.43 ± 0.28 ab
	p-value	**0.0433**

Pruning weights were collected during dormancy after the completion of pruning for each treatment as a function of cordon position. Despite having different levels of pruning severity, there were no significant differences in pruning weights among pruning treatments or among positions along the cordon during 2015, 2016, and 2017 (Table 9). Some studies have suggested that as the pruning severity is reduced, the pruning weights at winter pruning are also reduced [5,6]. Main et al. (2008) and Geller et al. (2013) suggested that when vines are minimally pruned, vines tend to have lower pruning weights [6,8]. Morris et al. (1981) also demonstrated that when vines are mechanically pruned with no additional touch up, leaving a high node count per vine, pruning weights were also significantly lower [5]. However, in another study by Kurtural et al. (2012), there were no significant differences in pruning weights among pruning treatments [31]. The findings in the current study align more with the study by Kurtural et al. (2012) than the other two studies. Since the pruning treatments that were applied in this study did not leave as many nodes per vine as in the mechanical pruning trials, this could be the reason no differences were observed.

Table 9. Two-way analysis of variance (ANOVA) with interaction showing average pruning weights (kg) by year, treatment, and cordon position at harvest during the 2015 (**a**), 2016 (**b**), and 2017 (**c**) growing seasons (n = 8). Table shows treatment and cordon position means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's t-test. Significant p-values (<0.05) are displayed in bold.

	(a)	
Year		**Pruning Weights (kg)**
2015	**Treatment**	
	5.5 shoots meter^{-1}	0.34 ± 0.03 a
	11.1 shoots meter^{-1}	0.45 ± 0.05 a
	11.1LT shoots meter^{-1}	0.38 ± 0.03 a
	Position	
	End	0.46 ± 0.04 a
	Head	0.34 ± 0.04 a
	Mid	0.38 ± 0.04 a
	p-value	0.3177
Treatment		0.1208
Position		0.1066
T × P		0.9855

	(b)	
Year		**Pruning Weights (kg)**
2016	**Treatment**	
	5.5 shoots meter^{-1}	0.60 ± 0.05 a
	11.1 shoots meter^{-1}	0.59 ± 0.04 a
	11.1LT shoots meter^{-1}	0.63 ± 0.05 a
	Position	
	End	0.70 ± 0.05 a
	Mid	0.55 ± 0.04 a
	Head	0.58 ± 0.04 a
	p-value	0.3804
Treatment		0.8062
Position		0.0782
T × P		0.6079

	(c)	
Year		**Pruning Weights (kg)**
2017	**Treatment**	
	5.5 shoots meter^{-1}	0.16 ± 0.01 a
	11.1 shoots meter^{-1}	0.18 ± 0.02 a
	11.1LT shoots meter^{-1}	0.15 ± 0.01 a
	Position	
	End	0.17 ± 0.01 a
	Mid	0.16 ± 0.01 a
	Head	0.16 ± 0.02 a
	p-value	0.4639
Treatment		0.3231
Position		0.9311
T × P		0.2645

3.6. Berry Physical Analysis and Chemical Composition

Berry weight and berry chemical composition were evaluated for each treatment in 2015, 2016, and 2017 (Table 10). Pruning treatment affected titratable acidity during the 2015 harvest (p = 0.0061) but did not have an effect during the harvests of 2016 or 2017 (Table 10). In 2015, the 11.1 shoots meter^{-1} treatment resulted in an average titratable acidity of 5.73 g/L, significantly higher than either of the two other treatments. For pH, soluble solids, and berry weight at the harvest of 2015, statistical analysis could not be carried out due to no variation within pH and soluble solids values and due to no replication of samples for berry weight (Table 10). In 2016 and 2017, statistical variation was found among treatments for pH and soluble solids, but no significant variation was detected in titratable acidity or berry weight (Table 10). In 2016 and 2017, the 11.1 treatment resulted in the lowest pH and soluble solids levels compared to the other two treatments (Table 10). However, in 2016 the pH level of the 11.1 treatment was not significantly different from that of the 11.1LT treatment (Table 10). In addition, the 11.1 treatment did not vary significantly in soluble solids from that of the 11.1 treatment (Table 10). The treatment with the highest pH and soluble solids levels for both the 2016 and 2017 harvests was the 5.5 shoots meter^{-1} treatment, but it did not vary significantly from the 11.1LT treatment except soluble solids during the 2016 harvest (Table 10).

Table 10. One-way analysis of variance (ANOVA) showing average TA (g/L), pH, brix, and berry weight (g/berry) by year and treatment at harvest during the 2015, 2016, and 2017 growing seasons (n = 3). Table shows treatment means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's t-test. Significant p-values (<0.05) are displayed in bold.

Year	Treatment	TA (g/L)	pH	Soluble Solids (Brix)	Berry Weight (g/berry)
2015	5.5 shoots meter^{-1}	5.37 ± 0.07 b	3.44 ± 0.00	25.5 ± 0.00	0.96 ± 0.00
	11.1 shoots meter^{-1}	5.73 ± 0.07 a	3.36 ± 0.00	25.2 ± 0.00	1.07 ± 0.00
	11.1LT shoots meter^{-1}	5.37 ± 0.03 b	3.41 ± 0.00	25.8 ± 0.00	1.01 ± 0.00
	p-value	**0.0061**	-	-	-
2016	5.5 shoots meter^{-1}	5.43 ± 0.15 a	3.53 ± 0.02 a	25.3 ± 0.09 a	1.13 ± 0.01 a
	11.1 shoots meter^{-1}	5.93 ± 0.09 a	3.43 ± 0.01 b	24.2 ± 0.03 c	1.21 ± 0.04 a
	11.1LT shoots meter^{-1}	5.50 ± 0.25 a	3.48 ± 0.03 ab	24.5 ± 0.03 b	1.19 ± 0.01 a
	p-value	0.1717	**0.0217**	**<0.0001**	0.1334
2017	5.5 shoots meter^{-1}	6.49 ± 0.02 a	3.30 ± 0.0002 a	22.7 ± 0.01 a	1.05 ± 0.03 a
	11.1 shoots meter^{-1}	6.80 ± 0.07 a	3.27 ± 0.0100 b	22.3 ± 0.06 b	1.13 ± 0.02 a
	11.1LT shoots meter^{-1}	6.61 ± 0.11 a	3.29 ± 0.0100 a	22.5 ± 0.12 ab	1.10 ± 0.00 a
	p-value	0.0642	**0.0104**	**0.0149**	0.0909

Shoot density affected some parameters of berry chemistry during the study. Titratable acidity was only affected during 2015, while pH and soluble solids were affected in 2016 and 2017. Soluble solids were higher in treatments with more light penetration into the canopy. The 5.5 shoots meter^{-1} treatment had the highest soluble solids in 2016 and 2017, but the 11.1LT treatment was close behind in 2016 and was not significantly different in 2017. This trend of higher soluble solids could likely be attributed to more light penetration into the canopy and fruiting zone due to a lower shoot density. These results were similar to those by Morris et al. (1981) in that soluble solids were lower in treatments with higher node numbers per vine [5]. PH had similar trends as soluble solids did in 2016 and 2017. The 11.1 shoots meter^{-1} had the lowest pH levels in 2016 and 2017, indicating that having higher shoot densities may result in lower pH levels (Table 10). The impact of shoot density on soluble solids, correlated to sugar concentration, can be particularly problematic in cooler grape-growing regions or during growing seasons in which temperatures are lower than usual such as the 2016 growing season where it was classified as a Winkler region II. When temperatures are not high enough, vineyards can struggle to reach targeted maturity levels with respect to soluble solids. Reaching targeted maturity levels is also crucial for regions under higher instances of early-season frost or mold pressure.

3.7. Berry Phenoloics and Color

In 2015 and 2016, berry color and phenolic parameters were evaluated for each treatment at harvest, and the results are listed in Table 11. Significant variation among treatments was detected for catechin levels during harvest of 2015 and 2016 (p = <0.0001 and p = 0.0188, respectively). During both 2015 and 2016, the 5.5 shoots meter^{-1} treatment resulted in higher catechin levels when compared to the other two treatments (Table 11). As for tannins, no significant differences were found among treatments in either 2015 or 2016 (Table 11). No significant differences among pruning treatments were observed for polymeric anthocyanins and total anthocyanins during 2015 and 2016 (Table 11). However, there was significant variation among treatments for catechin/tannin index in both years and significant variation in polymeric anthocyanin/tannin index and IMBP during 2015 (Table 11). The catechin/tannin index was significantly higher in the 5.5 shoots meter-1 treatment when compared to the other two treatments in 2015 and 2016 (Table 11). Polymeric anthocyanin/tannin index was the lowest in the 5.5 shoots meter^{-1} treatment compared to the other two 11.1 treatments (Table 11). For IMBP, there was significant variation among all three treatments, with the 5.5 shoots meter^{-1} treatment having the highest average at 303 ng/kg and the 11.1LT treatment having the lowest at 1.70 ng/kg (Table 11).

The results observed in total anthocyanins and tannins are similar to those presented in Wessner et al. (2013), which also had no differences in anthocyanins or tannins among pruning treatments during all three years of their study [32]. There has also been contradictory results in total anthocyanins among pruning treatments. Main et al. (2008) and Reynolds et al. (2001) demonstrated that different pruning treatments resulted in significant differences in total anthocyanins [6,33]. Additionally, previous studies by Dokoozlian et al. (1996) and Bergqvist et al. (2001) have found that increased sunlight into the canopy resulted in increased berry skin phenolics, which likely explains the differences observed in the studies by Main et al. (2008) and Reynolds et al. (2001) [34,35]. In the case of this current study, no differences were likely observed in tannins or anthocyanins because the differences in photosynthetically active radiation were not great enough to result in observable variation. However, the differences in PAR among treatments during the 2015 growing possibly could have been enough to cause differences in IMBP. Previous studies have documented the effect of light exposure on the accumulation of IMBP and have reported that an increase in light exposure causes a decrease in IMBP [36]. Generally, it has been observed in other studies that multiple factors affect the compositions of the berry, such as variety and regional climatic differences in addition to pruning treatments [37,38], so it can sometimes be difficult to distinguish the relationship between pruning severity and berry composition.

Table 11. One-way analysis of variance (ANOVA) showing Catechin, Catechin/Tannin Index, Polymeric Anthocyanins, Polymeric Anthocyanin/Tannin Index, Tannins, Total Anthocyanins, and IMBP (ng/kg) by year and treatment at harvest during the 2015 and 2016 growing seasons (n = 3). Table shows treatment means followed by the standard error of the mean. Different letters within a column indicate significant differences based on an Each pair, Student's t-test. Significant p-values (<0.05) are displayed in bold.

Year	Treatment	Catechin (mg/L)	Catechin/Tannin Index	Polymeric Anthocyanins (mg/L)	Polymeric Antho-cyanin/Tannin Index	Tannin (mg/L)	Total Anthocyanins (mg/L)	IMBP (ng/kg)
2015	5.5 shoots meter^{-1}	23.7 ± 0.67 a	0.060 ± 0.0020 a	16.0 ± 0.00 a	0.040 ± 0.0003 b	397.3 ± 4.81 a	1258.3 ± 27.1 a	3.03 ± 0.03 a
	11.1 shoots meter^{-1}	15.3 ± 0.33 b	0.041 ± 0.0003 b	16.0 ± 0.58 a	0.043 ± 0.0010 a	369.3 ± 11.7 a	1230.7 ± 33.2 a	2.57 ± 0.09 b
	11.1LT shoots meter^{-1}	16.3 ± 0.33 b	0.043 ± 0.0010 b	16.3 ± 0.33 a	0.043 ± 0.0003 a	381.7 ± 6.39 a	1282.7 ± 10.9 a	1.70 ± 0.06 c
	p-value	**<0.0001**	**0.0001**	0.7865	**0.009**	0.1282	0.4106	**<0.0001**
2016	5.5 shoots meter^{-1}	5.33 ± 0.88 a	0.015 ± 0.003 a	15.0 ± 0.58 a	0.043 ± 0.001 a	353.7 ± 26.3 a	1329.7 ± 70.0 a	2.47 ± 0.22 a
	11.1 shoots meter^{-1}	2.33 ± 0.67 b	0.009 ± 0.000 b	14.3 ± 0.33 a	0.046 ± 0.0003 a	313.0 ± 6.35 a	1382.7 ± 26.7 a	2.73 ± 0.62 a
	11.1LT shoots meter^{-1}	2.00 ± 0.00 b	0.009 ± 0.000 b	15.0 ± 0.00 a	0.046 ± 0.001 a	325.0 ± 8.54 a	1370.7 ± 16.2 a	2.43 ± 0.09 a
	p-value	**0.0188**	**0.0412**	0.4219	0.1177	0.2732	0.6905	0.8373

4. Conclusions

This study explored the effect of pruning severity and spur positioning along the cordon on the growth and development of grapevines. Pruning severity had a more significant effect on shoot growth and yield than the location of the spur along the cordon. However, mid and head positions along the cordon were initially found to be weaker positions and these findings indicate uniformity across positions can be achieved with more severe pruning and/or potentially leaf thinning. This was demonstrated with the homogenization of spur diameters for the 5.5 and possibly 11.1LT treatments towards the end of the study (Table 3). However, our findings also suggested that the differences in shoot growth and yield among the three positions along the cordon were not significant. Grapevines with the more severe pruning treatment (5.5 shoots meter^{-1}) had significantly larger shoot growth measurements and significantly lower yield measurements when compared to the other two 11.1 shoots meter^{-1} treatments, but then were not significantly different towards the end of the study. These results demonstrated initial mid-cordon weakness, and suggested pruning treatment could contribute to the remedying of this issue. Further studies should be conducted to better understand this issue comprehensively in order to homogenize vegetative growth.

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