Postbudburst Spur Pruning Reduces Yield and Delays Fruit Sugar Accumulation in Sangiovese in Central Italy

Tommaso Frioni,[1] Sergio Tombesi,[1] Oriana Silvestroni,[2] Vania Lanari,[2] Andrea Bellincontro,[3] Paolo Sabbatini,[4] Matteo Gatti,[5] Stefano Poni,[5]* and Alberto Palliotti[1]

Abstract: The influence of pruning date on yield control and ripening rate of spur-pruned Sangiovese grapevines was investigated over two years (2013 and 2014). Winter pruning was applied on 1 or 4 Feb (mid dormancy); 1 or 5 March (late dormancy); 2 or 7 April (bud swell); 2 or 7 May (flowers closely pressed together); and 1 or 6 June (40 to 50% of flower caps fallen), respectively. Vine yield and fruit composition at harvest were not affected by shifting from the standard pruning dates of mid and late dormancy to the bud swell stage. In contrast, the number of inflorescences in compound buds was significantly reduced for vines pruned in early May. No inflorescences were retained on vines pruned at the beginning of June. Early May pruning reduced fruit set and berry weight and slowed fruit ripening compared to the other pruning dates. At harvest, must soluble solids and titratable acidity were 1.6 Brix lower and 1.8 g/L higher, respectively, for the May treatment compared to the standard pruning dates. The early May pruning dates also achieved higher total anthocyanins and phenolic concentrations than the standard pruning dates, indicating that this technique can potentially decouple the accumulation dynamics of these components. Further studies are needed to better calibrate winter pruning date for managing yield and berry maturation rate.

Key words: berry composition, bud fertility, leaf area, reserve storage, winter pruning, yield

Climate-related changes in several major grapegrowing regions are leading to earlier vine growth phenology and altered or atypical fruit ripening patterns (Schultze et al. 2014). In many wine production regions worldwide, sugar can accumulate too rapidly, leading to low acidity, low aromatic and phenolic concentrations, and unbalanced wine profiles (Jones et al. 2005). Market analyses currently show that consumers prefer wines with a moderate alcohol concentration, good acidity, and distinct aromatic profiles (Salamon 2006, Seccia and Maggi 2011). Accordingly, many growers are searching for innovative management practices to delay fruit soluble solids accumulation (Keller 2010, Gu et al. 2012, Palliotti et al. 2013a, 2013b, Poni et al. 2013, Palliotti et al. 2014).

Winter pruning is intended to regulate vine vigor and yield and consequently, to achieve desired must chemical composition by harvest. In Mediterranean growing areas, it is normally carried out any time after leaf fall and before budbreak.

Delaying pruning to late winter or early spring has been well studied (Anticliff et al. 1957, Barnes 1958, Coombe 1964, Bouard 1967). A primary reason for late pruning was to delay budburst and prevent spring frost damage in cool growing areas (Howell and Wolpert 1978, Trought et al. 1999). Spur-pruning at the swollen bud phenological stage is expected to delay vegetative growth, flowering, fruit set, and fruit maturation. Pruning performed on Merlot in New Zealand when apical shoots on the canes were ~5 cm long resulted in lower sugar and higher organic acid content in grapes (Friend and Trought 2007).

Delaying pruning until after budbreak is likely to cause a sudden and severe source limitation due to two main mechanisms: storage reserves used to support initial stages of vegetative growth are removed by pruning and, if performed following budbreak, pruning can remove a fraction of the foliage producing carbohydrates. Any primary leaf that has reached 30% of its final size becomes a source of carbohydrates; the size ratio is slightly higher for lateral leaves (Champagnol 1984).

Unpruned vines normally commence vegetative growth in early spring with the burst and growth of apical buds; bud emergence proceeds based on apical dominance along the cane. When vines are spur-pruned, they are forced to regrow from the basal buds. Shifting winter pruning to postbudburst is expected to delay vine growth and fruit ripening; it is also expected to change canopy demography (Gatti et al. 2016). The canopy may reach an active carbon balance later in the season and, especially from veraison onward, late-pruned vines may benefit from the enhanced ripening potential of a younger canopy. The aim of our trial was to evaluate the effects of delayed spur-pruning in two consecutive years (2013

and 2014) on vine growth, yield, and fruit ripening of Sangiovese grapevines grown in central Italy.

Materials and Methods

Plant material, climatic conditions, and experimental design. The trial was carried out in 2013 and 2014 in a commercial vineyard near Deruta, Perugia province, in central Italy (Umbria region, lat. 42°58'N; long. 12°24'E, elev. 405 m asl, loamy soil). The vineyard was a 15-year-old planting of Sangiovese (clone VCR30) grafted to 420A stock at 2.5 m × 1 m inter- and intrarow spacing, respectively. The cordon was trained 0.9 m aboveground with three pairs of catch wires on a canopy wall extending 1.2 m above the cordon; vines were spur-pruned to ~10 nodes per vine. In both years, but on different dates individually encoded according to the BBCH phenological scale (Lorenz et al. 1995), five adjacent rows of 80 vines each were selected for completely randomized blocks, with each row as a block. Groups of 16 vines within each row were randomly assigned to winter pruning treatments based on date of application. In 2013 and 2014, 1 and 4 Feb (BBCH0-A) 1 and 5 March (BBCH0-B), respectively, were the pruning dates representative of mid and late dormancy (Table 1). Delayed pruning was applied on 2 and 7 April (BBCH1), the beginning of bud swelling, and on 2 and 7 May (BBCH55), when the apical shoot of unpruned canes had inflorescences elongating and flowers still closely packed together, respectively. The last pruning treatment was applied on 1 June in 2013 and 6 June in 2014 (BBCH64), when ~40 to 50% of apical-shoot flower caps had fallen. In 2015, all vines were pruned 6 Feb (mid-dormancy stage). Standard pest management practices based on scouting and local experience were applied in both years and no leaf removal was performed during the season. Shoots were mechanically trimmed as needed to maintain canopy shape when most started to outgrow the last pair of catch wires. Trial weather conditions were monitored by an automatic meteorological station located nearby the vineyard.

Leaf area development and vine vigor. In both years, 12 fruiting shoots per treatment were randomly collected from 12 vines within the trial blocks. Total leaf area per shoot was measured by an AAM-7 leaf area meter (Hayashi-Denko) and calculated by multiplying mean leaf area per shoot by shoot number per vine. Canes from 20 representative vines per treatment were weighed yearly after spur-pruning to es-

timate annual vine growth and the resulting data was used to calculate the Ravaz index (yield-to-pruning weight ratio, kg/kg; Ravaz 1903). Vine balance was assessed by calculating the total leaf area-to-yield ratio in all treatments.

Vine yield, ripening kinetics, and must composition at harvest. In 2013 and 2014, total soluble solids (Brix), titratable acidity (TA), and must pH were periodically analyzed from 70 and 54 days after full bloom in 2013 and 2014, respectively, until harvest by random sampling of 100 berries in three replicates per treatment. Within each treatment × replicate sample, 25 clusters were sampled to remove two berries from the top and one berry each from the middle and bottom of the cluster. Total Brix and pH were measured with a temperature-compensating RX 5000 refractometer (Atago-Co Ltd.) and a digital PHM82 pH meter (Radiometer). A Titrex Universal Potentiometric Titrator (Steroglass S.R.L.) was used to measure TA by titrating with 0.1 N NaOH to an end point of pH 8.2; the results are expressed as g/L tartaric acid equivalent. Harvest was 105 days after full bloom (DAFB) in 2013 and 113 DAFB in 2014. In both years, vines from all treatments were harvested the same day, when grapes from the mid-dormancy pruning reached an average of 20 Brix. Grapes from all trial vines were individually picked and the crop weight and cluster number per vine recorded. The average cluster weight was calculated and berry fresh weight and number of berries per cluster measured. Total anthocyanin and phenolic concentrations were determined as described (Iland et al. 1993) on 250 berries per treatment (five replicate samples of 50 berries each) and expressed as mg/kg fresh berry weight.

Carbohydrate storage in permanent vine organs. Roots (fine brown, 1.5 ± 0.2 mm diam., taken at 20 to 30 cm soil depth) and canes (third internode) were sampled at 10 replicates per treatment in December to determine carbohydrate concentration. Alcohol-soluble sugars and starch in both organs were determined using anthrone reagent (Merck) as described (Loewus 1952); absorbance was read at 620 nm with a Jasco V-630 spectrophotometer.

Bud fertility in the year following the treatments. Bud fertility was assessed on 20 vines per treatment in mid-June of both years by counting the number of inflorescences on all shoots. The same measurements were carried out in 2015 in all treatment replicates subjected to winter spur-pruning at mid dormancy.

Statistical analysis. A two-way analysis of variance (ANOVA) was used to analyze winter pruning date and year effects on leaf area development, yield components, grape composition at harvest, and reserve storage in canes and roots using the SigmaStat 3.5 software package (Systat Software, Inc.). Mean separation was performed using the Student-Newman-Keuls test ($p \leq 0.05$). Results of the seasonal evolution of total soluble solids, must pH, and TA are shown as means ± standard error (SE).

Results

Environmental conditions. Accumulated heat expressed as growing degree days (GDD, calculated on a 10°C base

Table 1 Actual pruning dates, description, and classification (BBCH scale) of phenological stages in 2013 and 2014.

Phenological growth stage	BBCH scale (Lorenz et al. 1995)	Pruning date 2013	Pruning date 2014
Mid dormancy	BBCH 0-A	1 Feb	4 Feb
Late dormancy	BBCH 0-B	1 March	5 March
Beginning of bud swelling	BBCH 1	2 April	7 April
Inflorescence elongating with flowers closely pressed together	BBCH 55	2 May	7 May
40 to 50% of flower caps fallen	BBCH 64	1 June	6 June

temperature from 1 April to 30 Sept) was lower in 2014 than in 2013 (1558 versus 1712 GDD, respectively). Total rainfall over the same period was also slightly lower (Figure 1). Rainfall was concentrated in May (239 mm), June (78 mm), and September (151 mm) in 2013, but was more uniformly distributed between spring and summer in 2014, except for an unseasonably rainy July (162 mm). Summer 2013 was marked by high daily max. air temperatures: 30°C in May, 35°C in June, and 38°C in July and August (Figure 1). Despite these trends and the absence of irrigation, no visual symptoms of water stress or significant leaf yellowing were observed in 2013.

Effects of delayed winter spur-pruning on vine yield, grape composition, and ripening kinetics. In both 2013 and 2014, delaying pruning until early April (apical buds at swelling) had no effect on crop weight or yield components (Table 2). Early May pruning reduced yield per vine by ~55%, evincing ~44% lower cluster number per vine, ~26% lower cluster weight, and ~17% fewer berries per cluster than the earlier treatments. Pruning performed early in June, when the apical cane buds were at the phenological stage of 40 to 50% fallen flower caps, resulted in a total absence of inflorescences (Table 2). The May-pruned vines in both years exhibited delayed soluble solids accumulation and juice organic acid degradation compared to the earlier treatments (Figure 2). These vines also showed a late increase in juice pH of ~1.6 Brix lower than the average value of the other treatments, while TA was higher by ~1.8 g/L. Conversely, must pH was unaffected by treatment (Table 3). Anthocyanin and total phenolic concentrations in

May-pruned vines were significantly greater, by 19 and 11% in 2013 and 2014, respectively, compared to the standard pruning timings (Table 3).

Comparing vintages indicates that the cooler weather in 2014 led to a significant decrease in soluble solids content and higher TA than in 2013; must pH, anthocyanin and phenolic concentrations (Table 3), and yield components (Table 2) were unaffected.

Phenology, vegetative growth, vine vigor, and replenishment of carbohydrate reserves. Full bloom (B) and onset of veraison (V) in vines given a standard winter pruning in February or March occurred 2 June and 1 Aug, respectively, in 2013. In 2014, the same phenological stages occurred with seven and eight days delay, respectively. There were no differences in total leaf area per vine or one-year-old pruning weight across treatments at the end of vegetative growth (Table 4). Due to their lower yield, May-pruned vines had a significantly higher leaf-to-fruit ratio (175%) and lower yield-to-pruning weight ratio (55%) than the other treatments (Table 4). In 2014, a significant reduction of 32% in total leaf area and 24% in yield-to-pruning weight ratio was found below those of 2013, while the leaf-to-fruit ratio increased by ~21% (Table 4). Alcohol soluble sugars and starch concentrations in canes and roots in December did not vary across treatments, while non-structural carbohydrates (soluble sugars + starch) were significantly reduced in both canes and roots in 2014 (Table 5).

Bud fertility. In neither year did April pruning, which retained an average of one cluster per vine, have any effect (Figure 3). Bud fertility was halved by May pruning in both years but recovered to usual values after standard winter pruning in 2015. June pruning in both years left no inflorescences, which increased to 0.55 inflorescences per bud after standard winter pruning in 2015.
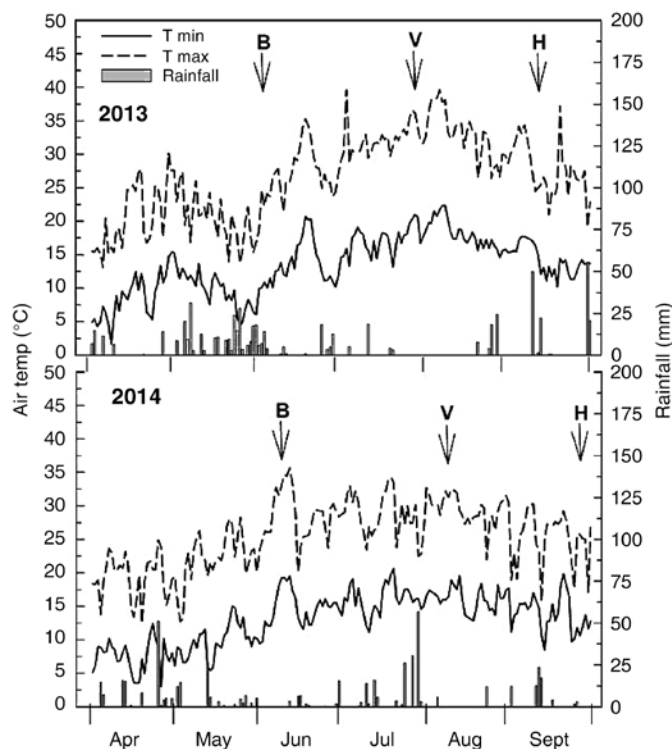

Figure 1 Max., min., and average air temperature and daily rainfall during the 2013 and 2014 growing seasons. B, V, and H indicate full bloom, onset of veraison, and harvest dates, respectively.

Table 2 Crop weight and yield components at harvest on Sangiovese vines pruned in 2013 and 2014 on 1 or 4 Feb (BBCH0-A), 1 or 5 March (BBCH0-B), 2 or 7 April (BBCH1), 2 or 7 May (BBCH55), and 1 or 6 June (BBCH64), respectively.

	Yield/ vine (kg)	Clusters/ vine (n)	Cluster weight (g)	Berry weight (g)	Berries/ cluster (n)
Treatment (T)					
1, 4 Feb	3.55 a[a]	13.4 a	266 a	2.63 a	103 a
1, 5 March	3.40 a	13.0 a	261 a	2.69 a	100 a
2, 7 April	3.45 a	12.6 a	270 a	2.66 a	102 a
2, 7 May	1.55 b	7.3 b	197 b	2.34 b	85 b
1, 6 June	0	0	–	–	–
Signif.[b]	**	**	**	*	*
Year (Y)					
2013	3.30	12.1	275	2.59	107
2014	3.05	10.9	269	2.70	98
Signif.	ns	ns	ns	ns	ns
T × Y	*	ns	ns	ns	ns

[a]Means within columns noted by different letters are different by Newman-Student-Keuls test.
[b]*, **, and ns indicate significant differences between treatments and years at $p \leq 0.05$, 0.01, or not significant, respectively.

Discussion

The marked apical dominance of *Vitis vinifera* inhibits development of subtending median and basal nodes. When basal buds of spur-pruned vines are forced to delay growth, all phenological stages are postponed (Martin and Dunn 2000, Friend 2005). Floral primordium differentiation, flower development, fruit set and fertilization, berry growth, vine yield, and fruit composition were notably influenced by delayed spur-pruning in our trial. Indeed, the February and March pruning at dormant buds elicited similar responses in vine and fruit quality parameters, indicating that winter pruning can be applied until late in this season, i.e., up to the onset of budburst without adversely affecting vine performance.

In neither year did April pruning, coinciding with apical-cane budburst, affect vine growth, yield, or grape composition at harvest, nor were any effects recorded in the following year.
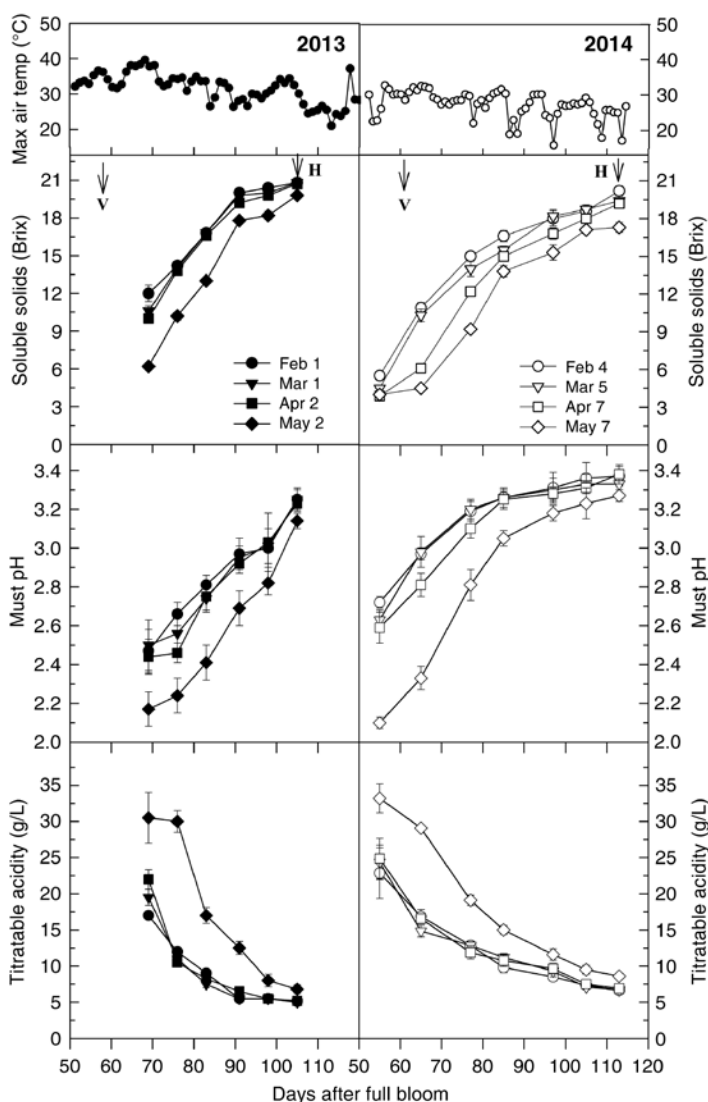
Although April pruning considerably slowed postveraison sugar accumulation during the cool 2014 summer, it did not delay final fruit ripening rate in either year (Figure 2 and Table 3).

Late winter spur-pruning of Merlot, performed when apical cane shoots were ~5 cm long, delayed grape ripening and lowered Brix and TA at harvest, but significantly increased yield per vine (Friend and Trought 2007). The latter result was explained by greater average berry weight leading to heavier clusters, an increased proportion of large, seeded berries, and fewer shot berries. The authors attributed the findings to enhanced flower fertilization and seed development

Figure 2 Seasonal trends in total soluble solids, must pH, and titratable acidity in 2013 (solid symbols) and 2014 (empty symbols) for Sangiovese vines pruned on 1 or 4 Feb (BBCH0- A), 1 or 5 March (BBCH0- B), 2 or 7 April (BBCH1), or 2 or 7 May (BBCH55) in 2013 and 2014, respectively. Data points are means of three replicates of 50-berry samples. Vertical bars represent SE around means. Top panels report daily max. air temperature. V = onset of veraison; H = harvest.

Table 3 Grape composition at harvest of Sangiovese vines pruned in 2013 and 2014 on 1 or 4 Feb (BBCH0-A), 1 or 5 March (BBCH0-B), 2 or 7 April (BBCH1), and 2 or 7 May (BBCH55), respectively.

	Soluble solids (Brix)	Titratable acidity (g/L)	Must pH	Total anthocyanins (mg/kg)	Total phenolics (mg/kg)
Treatment (T)					
1, 4 Feb	20.5 a[a]	5.85 a	3.31	220 a	1990 a
1, 5 March	20.1 a	5.80 a	3.29	206 a	1988 a
2, 7 April	19.9 a	6.05 a	3.31	214 a	1959 a
2, 7 May	18.5 b	7.70 b	3.21	254 b	2206 b
Signif.[b]	*	**	ns	*	*
Year (Y)					
2013	20.5 a	5.52 b	3.33	210	1983
2014	19.0 b	7.21 a	3.22	248	2091
Signif.	*	**	ns	ns	ns
T × Y	ns	*	ns	ns	ns

[a]Means within columns noted by different letters are different by Newman-Student-Keuls test.
[b]*, **, and ns indicate significant differences between treatments and years at $p \leq 0.05$ and 0.01 or not significant, respectively.

Table 4 Total leaf area, winter pruning weight, and balance of Sangiovese vines pruned in 2013 and 2014 on 1 or 4 Feb (BBCH0-A), 1 or 5 March (BBCH0-B), 2 or 7 April (BBCH1), 2 or 7 May (BBCH55), and 1 or 6 June (BBCH64), respectively.

	Total leaf area (m²/vine)	Leaf-to-fruit ratio (m²/kg)	Pruning weight (kg/vine)	Yield/pruning weight (kg/kg)
Treatment (T)				
1, 4 Feb	3.63	1.02 b[a]	0.68	5.22 b
1, 5 March	3.54	1.05 b	0.78	4.36 b
2, 7 April	3.42	1.04 b	0.80	4.31 b
2, 7 May	3.47	2.87 a	0.74	2.09 a
1, 6 June	3.45	–	–	–
Signif.[b]	ns	**	ns	*
Year (Y)				
2013	4.17 a	1.35 b	0.78	5.38 b
2014	2.83 b	1.63 a	0.71	4.08 a
Signif.	**	**	ns	*
T × Y	ns	*	ns	ns

[a]Means within columns noted by different letters are different by Newman-Student-Keuls test.
[b]*, **, and ns indicate significant differences between treatments and years at $p \leq 0.05$, 0.01, or not significant, respectively.

due to postponement of bloom to a period (October, Southern Hemisphere) when climatic conditions were more favorable than those in July (the standard winter pruning date in New Zealand).

May and June spur-pruning in our environment reduced yield per vine over 50% due to lower berry per-cluster and cluster per-vine number. Yield decreases were mostly due to reduced basal-shoot cluster number following delayed pruning. These results are likely linked to the sudden source limitation to the developing cluster primordia. This source limitation likely resulted from two main components. Apical shoots have some mature leaves as sources of carbohydrates for the sinks that are eliminated by pruning. Sources of carbohydrates and nitrogen compounds derived from storage reserves

Table 5 Cane wood and root reserves at the end of December 2013 and 2014 in Sangiovese vines pruned on 1 or 4 Feb (BBCH0-A), 1 or 5 March (BBCH0-B), 2 or 7 April (BBCH1), 2 or 7 May (BBCH55), and 1 or 6 June (BBCH64), respectively.

	Cane wood		Roots	
	Soluble sugars (mg/g DW[a])	Starch (mg/g DW)	Soluble sugars (mg/g DW)	Starch (mg/g DW)
Treatment (T)				
1, 4 Feb	103.2	104.7	116.0	162.8
1, 5 March	102.9	97.6	110.9	176.0
2, 7 April	98.8	92.1	97.8	157.4
2, 7 May	115.2	101.1	96.0	166.5
1, 6 June	112.6	93.9	99.6	154.7
Signif.[b]	ns	ns	ns	ns
Year (Y)				
2013	123.8 a[c]	84.5 b	111.0 a	170.8 a
2014	88.9 b	107.3 a	97.7 b	156.2 b
Signif.	*	*	*	*
T × Y	ns	ns	ns	ns

[a]DW, dry weight.
[b]*, ns indicate significant differences between treatments and years at $p \leq 0.05$ or not significant, respectively.
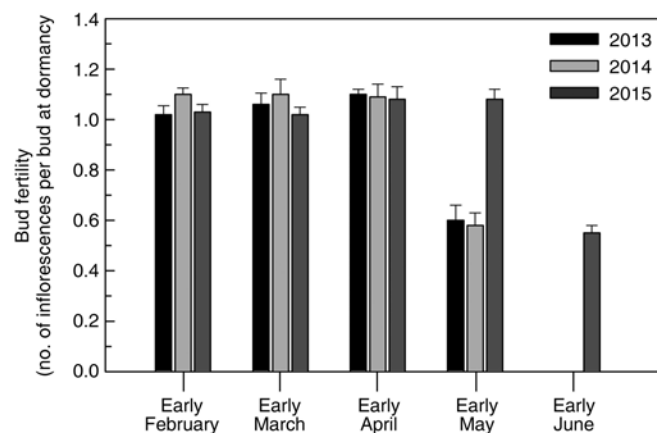[c]Means within columns noted by different letters are different by Newman-Student-Keuls test.

Figure 3 Bud fertility of Sangiovese vines pruned at different dates in 2013, 2014, and 2015: 1 or 4 Feb (BBCH0 - A), 1 or 5 March (BBCH0 - B), 2 or 7 April (BBCH1), 2 or 7 May (BBCH55), and 1 or 6 June (BBCH64) on 2013 and 2014, respectively. In 2015, the winter pruning date was 6 Feb (mid dormancy). Each bar is the mean of 20 vines ± SE.

that are invested in new growth are also eliminated by late pruning and cannot contribute to postpruning development of basal buds (Gatti et al. 2016). The reproductive and vegetative organs of woody species compete for carbohydrates provided by current photosynthesis and/or reserve remobilization (Wardlaw 1990, Smithyman et al. 1998, Lebon et al. 2008, Tombesi et al. 2015). The number of clusters developed in the subsequent season greatly depends on carbon budget and competitive relationships among vine organs during the onset of inflorescence (Candolfi-Vasconcelos and Koblet 1990). Our May 2013 pruning significantly decreased clusters per vine to 8.9 versus 13.3 in earlier pruning treatments, while in 2014 this parameter dropped to 5.6 clusters per vine, suggesting a possible additive, negative effect on bud fruitfulness. Indeed, the main factor influencing bud induction during a much-delayed bud burst is the notably limited vine source at the usual time induction takes place. A non-limiting source-to-sink ratio at the time of bud induction is historically acknowledged as a primary regulator of bud fruitfulness (Coombe 1962). The significant difference in berry number per cluster suggests that delayed pruning can also affect current season fruit set. A likely explanation is that delayed budbreak causes shoot growth to occur at higher daily rates under higher air temperatures, thereby exerting stronger competition among the differentiating bud meristems (May 2004).

Early June pruning, when apical shoots bear flowers with ~40% fallen flower caps, caused complete loss of yield. Basal-bud shoots failed to develop flowers and remained vegetative after pruning. Interestingly, the leaf area produced by June pruning did not differ from that of other treatments despite the fruitless shoots. The greater vine capacity expected to occur due to the absence of competing clusters was fully offset by a shorter season for canopy development.

The increased total anthocyanins and phenolics in May-pruned vines contrasts with final Brix and TA, indicating delayed ripening. Solute concentration due to reduced berry surface area could explain the anthocyanin and phenolics concentrations, but not the decreased sugar concentration. Higher total anthocyanins and phenolics with May pruning could be a consequence of smaller berry size. Although we did not quantify relative skin mass and flesh components, several papers have shown that inferring higher relative skin mass in smaller berries simply based on the geometry of a spherical berry shape can be quite misleading (Roby et al. 2004, Walker et al. 2005, Poni and Bernizzoni 2010). Under an array of conditions and genotypes, both sugar and color accumulation in grapes correlated with the leaf area-to-fruit ratio according to a negative exponential curve featuring a plateau at ~1.5 m²/kg fresh fruit mass (Kliewer and Dokoozlian 2005). This relationship would explain the improved berry color while sharply contrasting with the low final sugar concentration with May pruning. Hints to account for this rather anomalous sugar-storage response are provided by the variation in Ravaz index (i.e., yield-to-pruning weight ratio), which progressively decreased with delay in pruning (Smart and Robinson 1991). We submit that sugar accumulation was primarily delayed due to excessive and/or prolonged

vegetative competition. It remains to be explained, however, why fruit phenolic concentrations were not affected by the same phenomenon. Recent studies have clearly shown that sugar and color accumulation can become decoupled depending on environmental conditions and specific management practices. For instance, a temperature-driven decoupling of sugars and anthocyanins in berries of Shiraz and Cabernet franc was found (Sadras and Moran 2012). Other researchers examined whether the onset and rate of sugar and anthocyanin accumulation can be selectively modified via canopy management practices such as the application of plant hormones (Böttcher et al. 2011), apical-to-cluster late leaf removal (Palliotti et al. 2013b, Poni et al. 2013), or postveraison shoot trimming (Filippetti et al. 2015). A preveraison, anti-transpirant application, alone or in combination with a pre-flowering spray, proved effective in slowing sugar accumulation in Barbera, while avoiding concurrent delay of color development (Gatti et al. 2016). While a similar effect was seen here, more in-depth research is needed to assess how the color/sugar ratio changes during ripening, thereby offering the chance to determine differences in onset and rates of ripening to verify repeatability of such a decoupling under a wider range of conditions. Since all our treatments were harvested on the same day, it was not possible to assess whether prolonged hang time could improve the already remarkable fruit ripening pattern shown by the May pruning (lower Brix and higher color than the earlier prunings). Given the long growing season of the trial site and the well-known relationship between berry color accumulation and temperature, which indicates that 15 to 25°C optimizes accumulation of anthocyanins and phenolics (Spayd et al. 2002) and temperatures >35°C begin to degrade them (Mori et al. 2007), further postponement of harvest via this treatment is likely.

Non-structural cane and root carbohydrates at the end of December were unaffected by pruning timing. This finding suggests that the replenishment of carbohydrate reserves followed the same pattern regardless of pruning date.

Conclusions

Delaying spur-pruning to early spring can reduce vine yield and slow sugar accumulation and can increase fruit anthocyanin and phenolic concentrations. Winter spur-pruning carried out after budburst caused a modulation in ripening, still evident at harvest, with a significant magnitude that may be related to the time elapsed from budburst to pruning. Late pruning caused a yield decline close to 50% due to reduced flower differentiation and development on shoots grown from basal buds. Further delaying pruning elicited vine unproductivity and negative carryover effects in the following year. This study represents the first attempt to understand and calibrate winter pruning date as a management tool in pursuit of the right compromise between mild yield limitation and delayed fruit ripening.

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