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Pruning style and long term irrigation regime effects on 'Sunpreme' raisin quality and fruitfulness

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Abstract

Crop harvest suitability and raisin quality were examined for the new natural dry-on-the-vine raisin cultivar 'Sunpreme' as influenced by irrigation and pruning style. Cane- and spur-pruned vines were evaluated under three irrigation regimes: full evapotranspiration (ET), 50% ET and a further reduced "Shock" treatment. Irrigation regimes were established on the vines in 2007, six years prior to the onset of the test in 2013. Vine fruitfulness and dormant pruning mass were compared during each of the study years, as were product moisture content and raisin quality. Vines irrigated at Full ET, both cane- and spur-pruned, were consistently lower in juice total soluble solids as compared with other irrigation treatment x pruning style combinations during 2014. Full ET treated vines had significantly higher product moisture content at harvest as compared with Shock-treated vines in both years of the study. 'Sunpreme' raisin quality was very high (> 93% B or Better) across irrigation plots during 2013 when crop load was adjusted to 62% of available clusters. A higher percentage of crop load (81%) was allowed in 2014, and B & better percentage was 91% for Full ET treated vines, but was considerably lower in other irrigation plots. B & better percentages did not differ significantly across pruning styles in either study year, but the percentage of substandard raisins was lowest for Full ET in 2014 when there was a higher crop load.

Raisin production in California has developed over the last 100 years into an 80,000+ ha industry currently producing approximately 3.94 T/ha (California Department of Food and Agriculture, 2014). An important export commodity, California raisins are shipped throughout the world with active marketing campaigns now in 18 countries to promote sales (California Raisin Marketing Board, 2014). The industry was initially based on *Vitis vinifera* L. cv Thompson Seedless grape, with mature fruit clusters being hand cut and laid on paper trays for drying between rows of vines. A variety of other harvest procedures have since been developed to improve raisin production efficiency and improve growers' profit margins. While the climate of California's central San Joaquin Valley is very suitable for the culture and drying of raisin grapes, early winter rains can sometimes occur with the raisins still on the ground, causing problems during harvest and field pickup.

Irrigation quantity and timing has significant effects on berry maturity, canopy density and general fruit quality. Deficit irrigation during the early season, prior to flowering, reduced vegetative growth as well and had an irreversible negative effect on berry size (Matthews et al., 1987; Ojeda et al., 2001), whereas reduced irrigation after verasion could help management of vegetative vigor in shifting photosynthate to reproductive sinks and away from cane/leaf development (Chaves et al., 2007). Yield efficiency and average berry weight of 'Thompson Seedless' was maximized between 0.6 – 0.8 of vineyard

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evapotranspiration (Williams et al., 2010). Drying down the soil profile in raisin vineyards after verasion is a logical step in hastening the ripening process, as well as a necessary step in preparing vineyard rows as a drying bed for the paper trays of harvested grapes.

To combat problems of early winter rains, raisin grape breeders developed new cultivars with earlier maturity dates. 'Fiesta' was introduced in 1973 by the Agricultural Research Service (ARS), providing growers with a raisin grape harvestable 12-14 days prior to 'Thompson Seedless' (Weinberger, 1973). Other ARS raisin cultivar releases followed, including 'DOVine' (Ramming, 1995) and 'Selma Pete' (Ramming, 2001), with each release having successively earlier fruit maturity dates.

Mechanized raisin production practices begun in the early 1950s first focused on harvest techniques. Mechanical cutting and shaking devices were devised to remove grape clusters cleanly from vines to save labor hours (Winkler and Lamouria, 1956, Winkler, et al., 1957). While cane or cluster cutting technology efficiency improved each year, it became apparent that the maturity window of 'Thompson Seedless' in the raisin grape region of the central San Joaquin Valley was simply too late to effectively and consistently dry down the fruit after cane cutting (Studer and Olmo, 1973). However, newer earlier-maturing raisin grape cultivars changed mechanized raisin production in California. Fruit maturity of 'DOVine' and 'Selma Pete' raisin cultivars are sufficiently early for drying fully on the vine with severed canes (Fidelibus et al., 2008).

Further raisin breeding efforts at ARS led to the development of 'Sunpreme' (B82-43), a raisin grape capable of drying naturally on the vine in the central San Joaquin Valley without severance of canes (Ramming, 2015). 'Sunpreme' fruit ripen early, with berry wilting and raisining being a natural progression after verasion. Actual harvest suitability of 'Sunpreme' is both crop load and accumulated degree day dependent, but the new cultivar has typically been harvested with adequately dried raisins prior to September's end during the last 10 harvests.

The release of 'Sunpreme' for propagation and culture further facilitates mechanized raisin production by eliminating the cane severing operation. Cane severance and removal after harvest has been estimated at $326/ha, or 36% of total harvest/postharvest costs for San Joaquin Valley raisin vineyards (Vasquez et al., 2003). Vines of the new cultivar have been grown under several irrigation regimes since 2007 to examine long-term effects on crop productivity and vine health/vigor. Our current objective was to examine raisin quality and harvest suitability of cane- and spur-pruned vines grown in different irrigation plots.

Materials and Methods

*Plant Materials.*Vines used for the study were own-rooted clones of *Vitis vinifera* L. cv Sunpreme raisin grape, planted in 2005 at the research vineyard of the San Joaquin Valley Agricultural Sciences Center in Parlier, CA. 'Sunpreme' is a newly-released natural dry-on-vine raisin grape bred by the Agricultural Research Service (Ramming, 2015). Vines to be maintained as spur-pruned were trained to quadrilateral cordons with seven two-bud spur positions per cordon. Cane-pruned vines were trained with six canes to split heads centered between the staked trunk and each lateral wire. Vines were cultured on a single cross arm (91 cm) T trellis positioned approximately 142 cm above the soil surface. Vine spacing was 2.44 m between vines and 3.66 m between rows (1122 vines/Ha).

Irrigation treatments. Three irrigation treatments were imposed on 'Sunpreme' vines: 100% evapotranspiration (ET), 50% ET and a further reduced "Shock" treatment. Irrigation treatments were imposed on vines starting in the third leaf (2007), the first year production was allowed on the vines. As such, vines were accustomed to these irrigation volumes and timings, with six

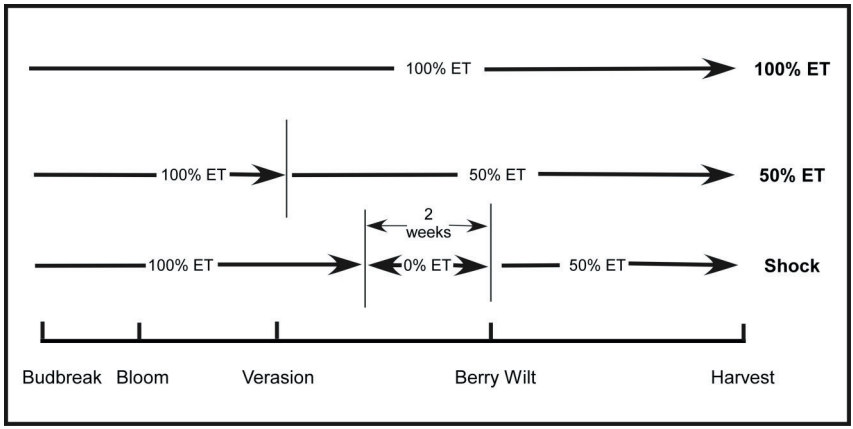

Fig. 1: Representation of three imposed irrigation treatments on 'Sunpreme' raisin, expressed as a percentage of evapotranspiration (ET), relative to phenological stages of grape berry development.

years of applied treatments prior to the onset of this study. Volumes of water applied to the various treatments were based on the San Joaquin Valley Drip Irrigation Scheduler (Peacock and Christensen, 2006). Input values used for running the scheduler during the 2013 and 2014 harvest years included an estimated 55% mid-July vineyard canopy coverage, 90% irrigation system efficiency and a vine density of 1,122 vines/ha. Application time was then calculated for each treatment and adjusted weekly through the growing season. After harvest, all vines were irrigated heavily to re-fill the soil profile. Specifics of the irrigation treatments relative to phenological stages in raisins are presented in Fig. 1.

Fruit and raisin evaluation. To evaluate berry maturity progression, total soluble solids (TSS) was determined weekly from vines in each irrigation plot using 50 berry samples. Berries were collected randomly from cluster mid-regions throughout each quadrant of sampled vines. Sampled berries were macerated before determining TSS with a hand-held refractometer. Samples were collected from the onset of verasion until the first sign of berry wilting (raisining).

For raisin quality evaluations, a composite 1.0 kg sample was collected using random dried clusters from each quadrant of the vine (20 Sept 2013, 10 Sept 2014). Date of harvest was determined subjectively, based on product appearance and feel. Samples were shipped to the USDA/Agricultural Marketing Service Fruit and Vegetable Program, Specialty Crops Inspection Division laboratory in Fresno, CA where raisin quality evaluations were performed. Moisture content was determined with a standard electrical conductivity test on raisin paste and air stream sorters were used for determinations of B & better and substandard percentages present in each sample (Kagawa, 2000).

Vine fruitfulness was evaluated through cluster counts after initial shoot extensions, during mid-April, when clusters were beginning to elongate. After cluster numbers were determined, studied vines were thinned to equal crops levels (77 clusters/vine in 2013; 169 clusters/vine in 2014) for valid comparisons of harvest suitability and product quality.

Experimental design and statistical analyses. When established in 2005, 27 'Sunpreme' vines available for study were divided equally into three plots representing the irrigation treatments (100% ET, 50% ET, Shock). Each irrigation plot was divided

further into three spur-pruned and three cane-pruned vines, with unused cane-pruned guard vines separating each pruning treatment. Irrigation treatments have been imposed on these vines since 2007, six years prior to the onset of this study.

This experiment does not have true replication because the three-vine plot was the experimental unit. Although the experiment had a factorial arrangement of treatments, interaction cannot be tested with analysis of variance (ANOVA) because the model would be saturated. When there is no interaction, the main effects can be analyzed with ANOVA. The presence of interaction was evaluated with graphical techniques and with a heuristic test (Milliken and Rasmuson, 1977). Since the interaction of pruning method and irrigation method was not significant, an ANOVA was performed, where the model contained only the main effects of pruning method and irrigation method using SAS's Proc GLM. When appropriate, means were compared with Tukey's Test. To evaluate the influence of the treatment combinations on the relationship between soluble solids concentration and harvest date, analysis of covariance was performed with SAS's Proc GLM, where pruning and irrigation methods were included in the model as indicator variables and Julian data was included as the regressor.

Results

At the onset of the experiment in 2013, study vines averaged 121.5 clusters/vine across irrigation plots, ranging from 134.7 (Full ET) to 103.2 (50% ET). By comparison, vine fruitfulness was higher in 2014 (207.6 clusters /vine) with cluster counts ranging from 213.3 (Full ET) to 198.3 (Shock). Cluster counts were unaffected by both irrigation method and pruning style in both study years.

Visual differences in canopy size and density were apparent in both study years across the irrigation plots, both during the growing season and in dormancy. Pruning weights were always higher for Full ET-treated vines, ranging from 8.7 kg (2013) to 3.9 kg (2014), but were not significantly different from the other irrigation treatments. Spur-pruned vines consistently had more dormant prunings than cane-pruned vines (6.0 kg vs. 5.0 kg in 2013, 2.7 kg vs. 2.3 kg in 2014, 4.3 kg vs. 2.9 kg in 2015), although these differences were not significant.

Across irrigation plots and pruning styles, juice TSS at verasion was similar in 2013 (10.1%) and 2014 (10.7%). Final juice samples taken prior to berry wilt were also comparable (22.2% in 2013 vs 23.2% in 2014), although the 2014 sampling period lasted a full two weeks longer than in 2013. Multiple regressions were used to examine juice TSS accumulation throughout berry development (verasion through berry wilting) as a function of irrigation method and pruning style. The interaction of irrigation method, pruning style and harvest date was significant in both study years, with the greatest effect on juice TSS accumulation in the 2014 season (Fig. 2). During 2013 when crop load was relatively low (77 clusters per vine), there were only small differences in juice TSS concentration among treated vines at any of the six sampling dates. Variation in juice TSS across sampling dates averaged only 0.58 % TSS among treated vines during the 2013 season. Cane-pruned vines in the Full ET and 50 % ET plots had the lowest juice TSS accumulation throughout berry development (Fig. 2a). With a higher crop load in 2014 (169 clusters per vine) there were larger differences in juice TSS accumulation compared with the previous season. Juice TSS differences averaged 2.9 % during 2014 across the treatment combinations. Full ET-treated vines, both cane- and spur-pruned, were consistently lower in juice TSS as compared with other irrigation treatment x pruning style combinations during 2014 with the larger crop load (Fig. 2b).

With a low crop loads, raisining of the 2013 crop proceeded rapidly and uniformly. By 20 September, mean moisture content of raisins

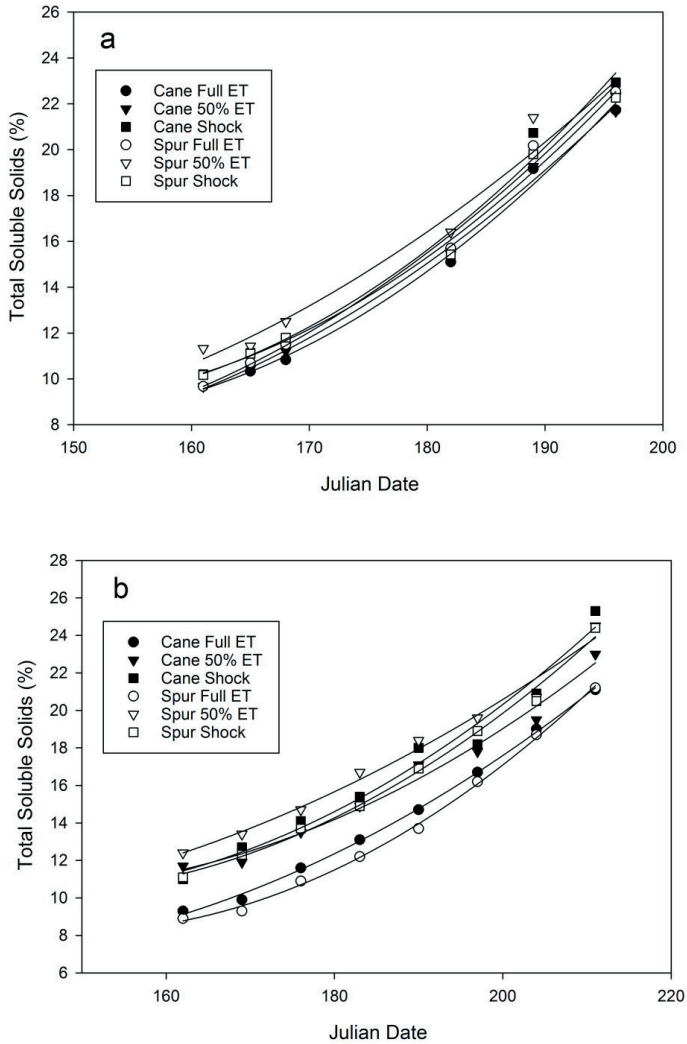

Fig. 2: Juice total soluble solids concentration of 'Sunpreme' grape during 2013 (a) harvested on six dates, and during 2014 (b) harvested on eight dates. Interaction of irrigation method, pruning style and harvest date was significant in 2013 ($P = 0.0308$) and in 2014 ($P < 0.0001$).

sampled across all study vines was 11.6%. Irrigation, but not pruning styles, influenced product moisture content (Table 1). Product from Shock-treated vines averaged 11.0 % moisture, significantly less than product from Full ET-treated vines (12.1 %). Product from 50 % ET-treated vines did not differ significantly in moisture content from the other two irrigation treatments (Table 1). B & better percentage was exceptionally high in 2013, but was not influenced by irrigation treatments or pruning styles. Among irrigation treatments, B & better raisin percentage ranged from 99.8 % (full ET) to 93.9 % (Shock). Similarly small differences existed between cane-pruned (98.1 %) and

Table 1. The influence of main effects of irrigation treatment and pruning style on product moisture, percentages of B & better and Substandard raisins produced during 2013 in Parlier, CA.

		Raisin Quality Analysis		
Treatment	Level	Moisture (%)	B & better (%)	Substandards (%)
Irrigation				
	Full ET	12.1 a	99.8	0.6
	50 % ET	11.6 ab	97.4	1.3
	Shock	11.0 b	93.9	1.0
Pruning				
	Cane	11.7	98.2	1.5
	Spur	11.5	95.9	0.4
ANOVA *P*-value				
	Irrigation	0.029	0.511	0.490
	Pruning	0.306	0.578	0.123

spur-pruned (95.9 %) vines. Across all study vines, substandard percentage averaged 0.96 %, ranging from 1.3 % (50 % ET) to 0.6 % (Full ET) among the irrigation plots and 1.5 % (cane-pruned) to 0.4 % (spur-pruned) for pruning styles (Table 1). Irrigation and pruning treatments did not significantly affect raisin substandard percentage.

Final sample moisture content was similar for the 2014 crop, averaging 11.4 % moisture across all treated vines on 10 September. Irrigation treatment again had a significant effect on product moisture with Shock-treated vines (10.6 %) having significantly lower moisture content than vines receiving Full ET (12.8 %). Pruning style did not influence product moisture (Table 2). Despite similar product moisture in the two study years, raisin quality differed considerably, with 77.6 % overall B & better percentage across study vines during 2014 vs. 97% in 2013. Neither irrigation treatment nor pruning style influenced the B & better percentages in the 2014 crop. The percentage of substandard raisins was influenced by irrigation treatment, with 50 % ET-treated vines (4.4 %) having significantly more substandards than Full ET-treated vines

Table 2. The influence of main effects of irrigation treatment and pruning style on product moisture, percentages of B & better and Substandard raisins produced during 2014 in Parlier, CA.

		Raisin Quality Analysis		
Treatment	Level	Moisture (%)	B & better (%)	Substandards (%)
Irrigation				
	Full ET	12.8 a	91.0	1.6 b
	50 % ET	10.8 ab	67.2	4.4 a
	Shock	10.6 b	74.5	2.9 ab
Pruning				
	Cane	11.5	79.2	2.6
	Spur	11.4	75.9	3.4
ANOVA *P*-value				
	Irrigation	0.041	0.088	0.048
	Pruning	0.891	0.535	0.158

(1.6 %). Pruning style did not significantly affect levels of substandard raisins.

Discussion

This study was conducted to examine the cumulative effects of long-term irrigation differences on crop maturity progression and raisin quality of the new natural dry-on-vine raisin cultivar 'Sunpreme.' Existing vines used in the study, receiving the same irrigation treatments for six years before the onset of the study, were evaluated for fruitfulness at the start of each growing season. Based on current season cluster counts, crop loads on all vines were adjusted to similar levels before bloom each season. Crop maturity progression was evaluated by measuring juice TSS periodically between verasion and berry wilting. Raisin quality was based on product moisture content at harvest, and sample evaluations with air stream sorters. Crop load levels differed greatly in the two years of the study (77 vs. 169 clusters/vine), leading to seasonal differences in the studied variables.

Although it was possible to analyze data collected from this study with ANOVA and regression, a lack of replication may have influenced the results. The 27-vine plot established for evaluating 'Sunpreme' under different irrigation regimes and pruning styles represents a significant investment in field space and annual maintenance costs, given the perennial nature of the crop. However, the linear arrangement of experimental units, while necessary for efficiency in maintaining plots, can introduce bias through non-randomized experimental units being associated with specific sections of row. It is possible that results may have been influenced by something other than treatment that was unique to a particular row section. Examination of the soil survey for Fresno County, California shows Fresno sandy loam being the dominant soil type in and around Parlier, without variation in the specific location where the 'Sunpreme' plot was established (Strahorn et al., 1914). While there is confidence that the soil type doesn't vary amongst experimental units in this study, other unknown factors associated with the site could have influenced treatment responses measured during this study.

Profitable raisin production in the California environment requires adequate tonnage of a high quality product being removed from the field prior to the onset of winter rains. 'Sunpreme' yield has been previously quantified and reported annually from vines used in this study (California Raisin Marketing Board, 2015). Yields have ranged from 12.2 T/ha (cane-pruned, 2011) to 8.16 T/Ha (cane-pruned, 2009), and reportedly averaged 10.8 T/ha from mature vines trained to quadralateral cordons (Ramming, 2015). 'Sunpreme' has dried on the vine consistently and adequately at this location prior to the onset of winter rains except during the 2010 and 2011 harvests. During these years, degree day accumulation was approximately 8% (2010) and 5% (2011) less than the eight year average (2007 – 2014) at the Parlier, CA location. Degree day accumulations for crop years 2013 and 2014 at the study site were 2863 and 2957, respectively, slightly above the eight year average (2776) as calculated from 15 April through 15 September with 7°C/45°C thresholds and using the single sine / horizontal upper cutoff calculation method. More accumulated heat during the 2014 growing season was undoubtedly a factor in bringing the heavier crop load to maturity at a similar date compared with the lighter crop in 2013.

There were large and obvious differences between the irrigation plots, and thus the volumes of water applied to the 'Sunpreme' vines used in this study. Phenological stages were used as keys for making changes in the imposed irrigation regimes. The Full ET treatment could be easily determined and adjusted weekly by the San Joaquin Valley Drip Irrigation Scheduler (Peacock and Christensen, 2006). Berry verasion was used as a point of change from Full ET to 50% ET for the 50% ET irrigation treatment. The

imposed Shock treatment required a two-week period where no irrigation was applied prior to berry wilt. From experience gained in this study, imposition of the two-week period should coincide generally with TSS levels of approximately 20% in 'Sunpreme.'

Maintenance of proper vine vigor and prevention of over cropping is necessary for 'Sunpreme' to dry on the vine naturally prior to winter rains (Ramming, 2015). Vines treated with Full ET were visually evident, both cane- and spur-pruned, due to their larger or more dense canopies as compared with vine canopies from the other irrigation plots. Since differences in dormant prunings weights were not significant across irrigation plots, and similarly, irrigation method did not influence significantly vine fruitfulness during the course of this study, little appears to be gained through the use of a Full ET irrigation regime throughout the growing season. Furthermore, drying down the soil profile after verasion through deficit irrigation is a logical step to advance the berry ripening process. Given the current drought situation throughout California, raisin growers would be motivated to save any volume of water when it is not actively contributing to their profit margin.

The use of Full ET throughout the growing season also led to significantly higher sample moisture content as compared with Shock-treated vines, regardless of the pruning style used. This was evident in both study years (Tables 1 and 2), and yet another reason to avoid Full ET irrigation regimes. However, all product samples collected during both study years, regardless of irrigation method or pruning style, were well below the required 16% moisture content for 'natural seedless' raisins (Butler, 1978). In years where degree day accumulation is below average, use of Full ET on 'Sunpreme' will further exasperate the raisining process and may delay harvest further.

Raisin quality was extremely high in 2013, with the reduced crop load (62 % available clusters), from all irrigation plots, being more than 90% B & better overall. However, B & better percentage has averaged 89% from 'Sunpreme' vines during seven consecutive harvest years without any crop reduction (Ramming, 2015). Raisin quality was lower in 2014 with the heavier crop load (81 % available clusters), but only in 50% ET and Shock-treated plots (Table 2). Full ET-treated vines still produced better than 90% B & better raisins with the heavier crop load in 2014.

Throughout this study, pruning style had little effect on any of the variables measured. Hence, the new raisin cultivar can be spur-pruned without loss of potential crop as compared with cane-pruned vines. Presently, no other grape cultivar used for raisin production in California is capable of producing a commercial crop when spur-pruned. Given the proven spur-pruned fertility of 'Sunpreme,' raisin growers will probably mechanically pre-prune vineyards to reduce labor inputs further in vine preparation, making raisin production more efficient and automated. With reduced water availability for agricultural purposes being expected for California producers in the future, studies will continue to examine the balance between applied water, raisin quality and the need to bring the crop off the vine before the onset of winter rains.

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