Scheduling adequate irrigation mitigates postharvest soft scald disorder of Ambrosia™ apples grown in a semiarid eco-zone

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Article

Scheduling adequate irrigation mitigates postharvest soft scald disorder of Ambrosia™ apples grown in a semiarid eco-zone

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Abstract

The effect of irrigation on soft scald (SS) disorder in Ambrosia™ apples was surveyed over 4 years in various orchards in Cawston, BC which is located in a valley having a semiarid eco-zone. The observations were further validated by manipulating irrigation programs in a series of experiments in three commercial orchards. Adequate irrigation (AI) was defined as the amount of water application required to maintain sustainable production as defined in the provincial irrigation guide, while deficit irrigation (DI) reduced irrigation to less than 40% of AI at the same site. Records from the survey study indicated that SS incidence was negatively correlated with the amount of watering ($r = -0.9$). The validation study confirmed that correlation at three different commercial sites. These results suggest that intensive water deficit can cause fruit to be susceptible to SS and that adequate watering during fruit expansion and late season exerts a mitigating effect on SS in Ambrosia™ apples grown in a dry climate region. They also suggest that conducting DI prior to midsummer does not irrevocably cause SS susceptibility in this apple.

Key words: soft scald, water deficit, scheduling adequate irrigation, dry climate

Résumé

Pendant quatre ans, les auteurs ont évalué les effets de l'irrigation sur l'échaudure molle (EM), une maladie des pommes AmbrosiaMC, dans plusieurs vergers de Cawston, en Colombie-Britannique, lieu situé dans une vallée formant une zone semi-aride. Ils ont validé leurs observations en modifiant le régime d'irrigation lors d'une série d'expériences réalisées dans trois vergers commerciaux. Par « irrigation adéquate » (IA), on entend la quantité d'eau nécessaire pour maintenir une production durable, selon la définition qu'en donne le guide provincial sur l'irrigation. Une irrigation déficitaire (ID) correspond à une irrigation de plus de 40 % inférieure à l'IA, au même endroit. Les données de l'étude révèlent une corrélation négative entre l'incidence de l'EM et la quantité d'eau utilisée (r = -0,9). L'étude de validation a confirmé cette corrélation aux trois sites commerciaux. Ces résultats donnent à penser qu'un important déficit hydrique pourrait rendre les fruits sensibles à l'EM, alors qu'un apport d'eau suffisant lors du gonflement du fruit et en fin de la saison atténuerait les effets de la maladie sur les pommes AmbrosiaMC cultivées dans un climat sec. Les données laissent également croire qu'une irrigation déficitaire avant la mi-été ne rend pas cette variété sensible à l'EM de façon irrémédiable. [Traduit par la Rédaction]

Mots-clés : échaudure molle, déficit hydrique, régime d'irrigation adéquat, climat sec

1. Introduction

Ambrosia™ apple (*Malus* × *domestica* Borkh.) is the most promoted and rapidly growing cultivar in Canada and is becoming popular on the global fruit market (Xu and Ediger 2021). This cultivar is gaining major momentum in comparison to older cultivars such as "Royal Gala" (Toivonen et al. 2019). Additionally, it is predicted that the market for Ambrosia™ apples will experience a large increase in the next 10 years (Campbell 2020). However, this cultivar is known to develop the soft scald (SS) disorder in storage for apples from some orchards in some years. Heat is known to negatively affect plant growth and physiological activities (Ingle and D'Souza 1989). Air temperatures above 27 °C cause leaf and fruit injury in some nutritional practices (BC Tree Fruit Production Guide, (BCMAFF 2016)), temperatures above 29.4 °C initiate "heat shock" (Coder 1999), and >30°C air temperature rapidly reduces expression of genes involved in anthocyanin regulation and other transcriptional activation complexes in apples (Lin-Wang et al. 2011). In particular, warm conditions (temperature > 20 °C) during the period when "Honeycrisp" apples have reached 50%–80% of their final size has been shown to result in increased SS susceptibility in that cultivar (Lachapelle et al. 2013).

Irrigation is virtually the sole water source for apple trees during the summer in the Okanagan-Similkameen region due to the normal occurrence of limited rainfall. How much water should be provided to a tree? It depends on two factors: crop factors and environmental evaporative demand (Boland et al. 2002). As for crop factors, water use varies with seasonal conditions and the need for water changes with different growth stages. By contrast, pan evaporation depends on climate elements: temperature, humidity, rainfall, drought dispersion, solar radiation, and wind (Farnsworth et al. 1982). The Similkameen Canyon in British Columbia is geographically located in the heart of a semiarid ecozone that is Northwestern America's most water challenged and yet most biologically diverse eco-region (Xu and Ediger 2021).

The SS disorder is characterized by sunken brown lesions with clearly defined edges that are generally localized to the peel and subdermal tissues. As the disorder progresses, browning can extend into the cortical tissues of the apple. The symptoms begin to show between 1 and 3 months in storage and intensify with longer storage. Occasionally, it can occur earlier in cold storage or even show on the tree in late stage of maturation. SS is a chilling-triggered physiological disorder (Delong et al. 2009; Toivonen 2019). Low-temperature storage (<3 °C or <37 °F) will lead to injury in susceptible apples. Although this disorder mainly occurs in the postharvest stage of the fruit, the susceptibility to SS is likely determined during fruit growth and development. Some major factors that cause the apple fruit to be susceptible to SS have been documented and include overmaturity at harvest (Tong et al. 2003; Prange et al. 2011), nutritional influences (Tong et at. 2003), and heat and water stress (Fidler 1957; Wilkinson and Fidler 1973). Cool weather in late season increased the incidence in "Honeycrisp" (Moran et al. 2009). To date, there has been a lack of attention on the effect of irrigation practice on an orchard's relative susceptibility to SS in storage. Beginning with testing reflective row covers in 2015, it was observed that SS incidence was significantly higher in apples collected from orchards where irrigation was stopped for a few weeks prior to harvest (Toivonen et al. 2019). Toivonen (2019) showed that SS increased in severity and incidence with maturity only when an orchard where irrigation was terminated several weeks before harvest. In an experiment where a solid film Mylar™ silvered row cover was compared with an open-weave white polyethylene row cover it was observed that water pooled on top of the solid row cover and apples from that field treatment, in that orchard, suffered severe soggy breakdown in storage (Toivonen et al. 2019). Soggy breakdown has a similar in cause as SS and quite often they occur concurrently if the disorder levels are severe.

Based on our observations in several orchards with yearly experiments, we were able to determine that reducing the amount of watering or intentionally interrupting irrigation during the summer increased Ambrosia™ susceptibility to SS. Thus, we hypothesized that increasing irrigation during certain phases of apple growth may mitigate SS susceptibility in Ambrosia™ apples. Therefore, this work was conducted to test this hypothesis and to evaluate the effects of manipulating irrigation in relation to subsequent SS incidence in Ambrosia™ apples in storage.

2. Experimental design and methods

2.1. Orchard profiles and conditions

Three conventional orchards were selected within a land area of 6.0 × 2.5 km at lat. 49.12–49.19°N and long. −119.73 to −119.75°E in Cawston, BC, a semiarid region in the Similkameen Valley. Precipitation in this location during the summer is historically less than 10 mm and wind velocity exceeds 10 km/h in over 80% of the days (data obtained at the "farmwest.com" weather data site found at BC/Okanagan South/Cawston EC at website https://www.farmwest.com/climate, accessed 21 July 2020).

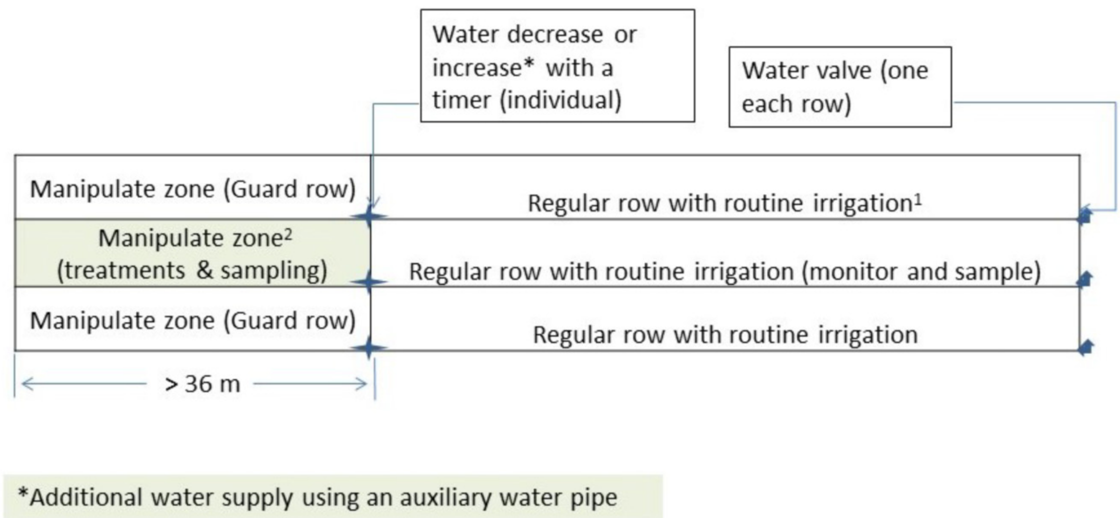
All selected orchards were composed of 12–15-year-old healthy trees with a super spindle system under conventional management. The spindle system was situated along a four-wire trellis with other trees, spaced approximately 45 cm apart, in rows 300 cm apart, on an M.9 dwarfing rootstock. Each tree yielded 40–50 apples in years 2016–2017 with proper pruning and thinning. Summer trees formed short simple branches, and the canopy width with new shoots was approximately 60 cm. Fruit samples collected at harvest were sound without bitter pit, scab, or cavity, and had no other biological defects. None of the three orchards had received foliar N sprays or plant growth regulators. Orchard-1 is located on flat land with loamy fine soil, orchard-2 stands on a flat hillside with gravelly sandy loam with coarse fragments, and orchard-3 lies on a riverbed with silt fluviatile sandy loam (soil information cited from provincial soil survey: BC Soil Information Finder Tool—Province of British Columbia (gov.bc.ca), accessed 30 October 2020). Orchard-1 and orchard-2 both had adequate irrigation (AI) in 2016–2017. Orchard-3 was routinely given inadequate irrigation.

Relative humidity of orchard air was monitored with HOBO® U23 Pro v2 Temperature/Relative Humidity built-in data logger (Onset Co., MA, USA) with a 10 min interval, and consecutive recording was performed 24 h per day during midsummer. For each orchard, three devices were installed on supports at a 150 cm height and protected against direct sunlight. Devices were installed in the center of experimental rows.

2.2. Irrigation treatments

Two irrigation treatments were implemented: AI is defined as the amount of water volume at a frequency required to maintain sustainable and optimal production as defined by calculations in the BC Tree Fruit Production Guide—Irrigation Management Guide (BCMAFF 2016), while deficit irrigation (DI) was a reduction in volume and frequency of irrigation to less than 40% of AI at the same site. In the validation experiments, the DI treatment was initiated in orchards 1 and 2, starting on 20 July (11 weeks after full bloom (AFB)). In contrast to orchards 1 and 2, in orchard 3 the AI treatment

Fig. 1. Illustration of water controlling system in Ambrosia orchards. [1]All the three orchards use same type of *Maxijet*® sprinkler (blue) with 33.4 L per h. [2]Manipulate zone consisted of three plots under DI and three plots under AI randomly.



needed to be achieved by increasing the irrigation on 20 July. The experimental design is illustrated in Fig. 1.

2.3. Measurements

2.3.1. Temperature

Thermal properties on the fruit and leaf surfaces on the tree were monitored using miniature remote infrared sensors (OS36SM-K-80F, Omega Technology, Stamford, CT, USA) at 10 min intervals in 24 h per day starting mid-July. Measurements were carried out using a total of 12 sensors (three for fruit and three for leaves for each treatment) that were attached to a datalogger (CR1000, Campbell Scientific, Canada). Each sensor was supported by a rotatable post and secured at a height of 120 cm above ground level. The probe was positioned 5 cm above the fruit and 10 cm above the leaves such that the probe would face the surface of the leaves and fruit hit by sunlight each afternoon. Measurements were taken on healthy trees with normal crop-load in the same plots where fruit was further harvested for assessment.

2.3.2. Temperature-extreme calculations

Temperature-extreme was defined as temperatures over 30 °C. Based on the growing degree hour (GDH) formula (Gu 2016), we propose a new measure, heat degree hours (HDHs), to focus on temperatures above 30 °C (HDH30) to analyze the changes in surface thermal properties of both fruit and leaves between treatments. This unit of measurement is derived from the difference between 30 °C and the average hourly temperature and allows us to simply focus on the effect of heat on SS. HDH30 was calculated by subtracting 30 °C from the average hourly temperature in degree Celsius. Average hourly temperature was calculated by averaging the hourly maximum and minimum temperatures measured in each individual hour. Seasonal (date ranges as shown in the figures) $\text{HDH30} = \Sigma_{\text{hourly}}\,[(T_{\max} - T_{\min})/2 - 30]$, including only values >0.

2.3.3. Harvest, storage, and evaluation of fruit

Two treatments (irrigations) × 8 replicates = 16 batches for each of three orchards. Each batch was composed of 25 apples. Fruit size range was 200–250 g and all were free of defects. Harvest maturation was determined using a DA meter in I_{AD} value (Toivonen et al. 2016). All fruits were placed in a 0.5 °C storage booth on the day of harvest. Fruits were evaluated after 2 months of air storage at 0.5 °C. The incidence of SS was assessed as 0 (absent) or 1 (present, defined as fruit with a lesion of >3 mm diameter), then calculated as a percentage of fruit showing the disorder. The severity of SS (SSS) was evaluated with four score levels: 0 (none), 1 (slight), 2 (moderate), and 3 (severe and unmarketable). The SSS value is presented as a quotient calculated with the formula: Σ_n score each fruit/total number of fruit in a batch, with 3 being the most severe score.

2.4. Data analysis

All data on SS investigation were recorded using eight replicates of 25 fruits in 3 months of storage and the means and standard deviations calculated using the SAS GLM procedure (SAS Institute Inc., Cary, NC, USA). All means were separated by Fisher's protected *t* test (least significance difference). The correlation between irrigation treatments and SS incidences were evaluated with a correlation coefficient value of *r* in 95% confidence using the SAS Correlation procedure.

3. Results and discussion

3.1. Survey results

The data collected over 4 years in three orchards showed that there was a relationship between irrigation rates,

Table 1. Yearly records of irrigation performances, fruit–water distribution ratio, and soft scald incidences, Cawston, BC (20 July to harvest).

			11–14 weeks AFB*		15 weeks AFB to harvest		Seasonal water supply (mid-July to harvest)		
Orchard[a]	Year	Interval of irrigation (days)	Watering frequency	Run h per irrigation	Watering frequency	Run h per irrigation	Water amount total (L/m^2)[b]	Fruit–water quotient (L/kg)	SS incidence (%)[c]
1	2014	10	3	6	4	6	129.84	25.02	38.2 ± 3.8
	2015	10	3	12	4	12	259.68	47.77	0
	2016	10	3	12	4	12	259.68	47.77	0
	2016	10	3	12	4	6	185.49	34.12	8.1 ± 2.1
	2016	10	3	6	4	6	129.84	23.88	35.2 ± 4.5
3	2015	10	3	7	4	7	151.48	27.86	21.8 ± 3.4
	2016	10	3	7	4	7	151.48	23.58	26.5 ± 5.0
S	2013	10	3	6	4	6	129.84	21.02	25.9 ± 3.9
	2014	7	4	10	6	8	272.05	47.87	2.2 ± 0.8
	2015	7	4	10	6	8	272.05	50.04	0

[a]Orchards 1 and 3 are numbered same as those in the subsequent validation experiment, while orchard S was only evaluated in this survey.
[b]Water amount shown in Table 1 is calculated with water supplied on the field regardless of daily environmental evaporation rates.
[c]SS incidence was recorded on the samples stored at 0.5 °C in ambient air for 3 months; the numbers are the means of three replicates ± standard deviation.
*AFB, after full bloom.

estimated total water application volumes, fruit–water use quotient (i.e., the volume of water used divided by fruit total weight at harvest), and the incidence of SS in cold storage. It was determined that where DI irrigation was practiced from the midsummer to fall harvest period fruit was susceptible to greater SS incidence in Ambrosia™ apples (Table 1). The correlation coefficient for the relationship between the fruit–water use quotient and SS incidence data in Table 1 was calculated to be $r = -0.9041$.

3.2. Validation study

This experiment was conducted at three orchards which were a part of the survey study 1 year subsequent to completion of the survey (2017). Figure 2 shows the SS incidence and severity in apples harvested from the three orchards and two irrigation treatments after 3 months of cold air storage at 0.5 °C. The irrigation treatments were initiated 11 weeks AFB, prior to which AI had been applied. DI was applied to half of the trees at that point in time until harvest and AI was continued in the other half of the trees (Table 2). The apples from the AI treatment exhibited significantly less SS incidence and severity for fruit from all three orchards after the same period of storage (Fig. 2). These results align with the observations in the survey study and support the hypothesis that irrigation program will influence the susceptibility of Ambrosia apple fruit to SS in subsequent cold storage. In addition, in 2016, we compared the effect of implementing DI at different times in orchard 1. DI was applied 15 weeks AFB to half of the trees in the DI plot and 11 weeks AFB to the other half of the trees (Table 1). The apples from the shorter period of DI (started 15 weeks AFB) showed significantly lower SS incidence and severity than those from the longer period of DI (started 11 weeks AFB) (Table 1; lines 4 and 5 in the data, respectively) in this orchard, which had loamy fine soil. These results indicate that SS is highly correlated with water deficit intensity, which depends on the DI period as well as orchard conditions.

In terms of understanding the mechanism by which the irrigation program influenced the development of SS in Ambrosia apples during cold storage, it has been documented that heat stress will lead to physiological injuries. Hence, leaf and fruit surface temperatures were monitored using remote infrared sensors. The application of standardized temperature summation has proved very useful for modeling crop development and is coined GDHs (Gu 2016). The precision and accuracy using simple temperature recording equipment simple data processing make the GDH model a reliable tool for measuring tree fruit growth and crop development (Gu 2016). While GDH is suitable for modeling crop growth and development, it is not suited to better understand the effects of extreme heat conditions of >30 °C, which are of interest for studying physiological disturbances in plants (Wilkinson and Fidler 1973). Therefore, this approach was adapted to model. The HDH30 accumulated in midsummer (20 July to 12 August) in the air above the fruits and leaves increased by 29% and 103%, respectively (Fig. 3). These elevated temperatures are considered to be associated with disruptions to physiological activities (Lin-Wang et al. 2011) and subsequent changes to phenotype which includes characteristics such as susceptibility to disorders (e.g., SS).

4. Conclusions

Heat stress in the Pacific Northwest interior region varies year by year. Climate change causes extreme dry summers, which highly threaten the apple industries located in semiarid zones. DI causes higher temperatures on leaves and fruit and likely leads to increased susceptibility to SS in Ambrosia™ apples. This work suggests that ensuring AI levels from midsummer to harvest will mitigate the development of SS in Ambrosia™ apples grown in dry or semiarid climate

Fig. 2. Soft scald incidence and severity of Ambrosia™ apples after 3 months of air storage at 0.5 °C in 2017. Soft scald incidence (top panel) was assessed as 0 (absent) or 1 (present) and then calculated as a percentage. Soft scald severity (SSS, bottom panel) was evaluated with a 4-score level: 0 (none), 1 (slight), 2 (moderate), and 3 (severe and unmarketable). SSS was presented as mean score that was calculated with a formula: Σ_n score per fruit/total number of fruit. Different letters labeled on data column are significantly different at $P \leq 0.05$ as determined by Fisher's protected t test using Proc analysis of variance in SAS. Abbreviations: AI, adequate irrigation; DI, deficit irrigation.

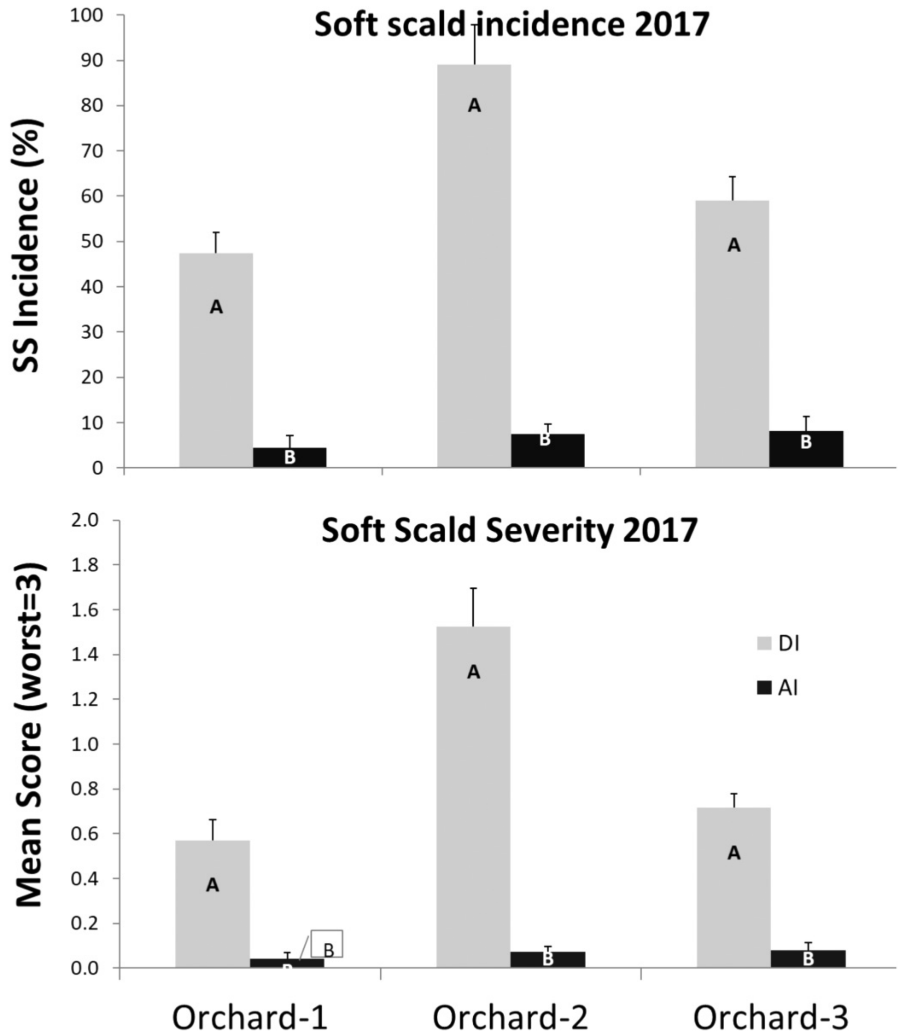
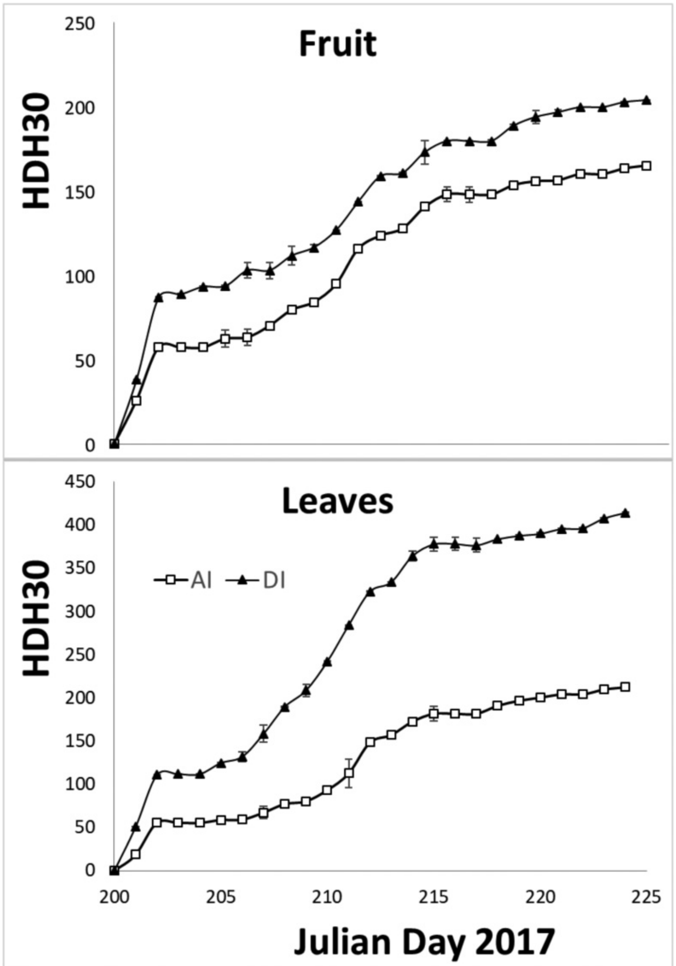


Table 2. Seasonal irrigation summary for Ambrosia orchards in 2017.

Orchard and treatment	Water h per run (seasonal average)	Water amount per run (L/m ^{2})	Interval days (seasonal average)	Height of canopy (m)	Crops (Ton/Hect.)	Seasonal water supply: Water amount total (L/m^2)	Canopy water quotient (L/m^2)	Fruit–water quotient (L/kg)
Orchard 1—AI	12	37.1	10	2.7	55	259.7	96.2	47.8
Orchard 1— DI	6	18.5	10	2.7	55	129.8	48.1	23.9
Orchard 2— AI	10	30.9	7	2.7	57.5	309.1	114.5	54.4
Orchard 2— DI	5	15.5	7	2.7	52.5	154.6	57.2	29.8
Orchard 3— AI	12	37.1	10	3.3	65	259.7	78.7	40.4
Orchard 3— DI	7	21.6	10	3.3	62.5	151.5	45.9	24.5

Note: Seasonal irrigation means the period of the irrigation treatments between 20 July and 10 September. Water amounts listed are based on amount of water supplied on the field regardless of daily environmental evaporative demand. All the three orchards use same type of *Maxijet*® sprinkler (blue) with 33.4 L per h.

Fig. 3. Accumulations of heat degree hours above 30 °C (HDH30) above fruit (top panel) and leaves (low panel) in midsummer 2017. HDH30 was calculated by subtracting 30 °C from the average hourly temperature in degree Celsius. HDH30 = Σ_{hourly} [$(T_{\max} - T_{\min})/2 - 30$], including only values >0. Each data point represents the mean of three replicates (orchards) of remote infrared temperature measurement and standard deviations for each mean are presented as bars. Abbreviations: AI, adequate irrigation; DI, deficit irrigation.



regions. SS is clearly correlated with water deficit intensity. However, we admit that there may be other production and (or) environmental factors that might influence susceptibility of Ambrosia apples to SS. The full details of the physiological mechanism as to how water stress caused by inadequate irrigation might increase susceptibility to SS.

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