Using micro-tensiometers to manage water stress to maximize fruit size of apple orchards

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Abstract

The number of apples per tree can be controlled by precision crop load management but final fruit size is also affected by plant water status. The first objective of this experiment was to study apple fruit growth dynamics in two irrigation treatments. The second objective was to understand apple fruit growth dynamics and relate it to water stress for maximizing fruit size and crop value in 'Gala' apple. During the 2021 growing season we continuously measured stem water potential using micro-tensiometers (MT; FloraPulse sensors) embedded in the trunks of trees. We also measured fruit diameter each week and related fruit growth rate and stem water potential. Two different water regimes were compared (fully irrigated and rain exclusion to induce water stress). All treatments had similar fruit numbers per tree. Our results suggest stem water potential was effectively measured in apple trees with the MT. Trees subjected to rain exclusion showed lower stem water potential values (greater stress) compared to fully irrigated trees. The fully irrigated trees had the highest fruit growth rate per day (mm diameter increase day^{-1}) which declined over the course of the season. The rain exclusion trees had lower fruit growth rate day^{-1} throughout the season and lower final fruit weight and less fruit color when compared to fully irrigated tree. This study was our first attempt to relate apple fruit growth dynamics and water stress to manage irrigation for maximize fruit size, color and crop value in apple orchards. Our future work will utilize fruit growth dendrometers to relate daily fruit growth increment with stem water potential to fully automate irrigation management.

Keywords: *Malus* × *domestica,* stem water potential, water management, FloraPulse sensors, fruit size, fruit quality, fruit color

INTRODUCTION

The profit apple farmers make per ha is affected by yield level, fruit size and fruit quality. The criteria established for first class (Extra Fancy) products at harvest is fruit color >60% of fruit surface with a good red color development, and fruit size >70 mm. Not achieving these quality parameters greatly reduces the potential income per hectare. Achieving optimum crop load management by inducing a sufficient reduction of fruit number tree^{-1} to achieve optimum fruit size and adequate return bloom, but without an excessive reduction of yield is the most important management practice done annually by growers (Robinson et al., 2016). However, when the summer turns out to be dry and the fruit do not achieve the expected fruit size, crop value can be severely compromised. To precisely manage fruit size requires both precision crop load management by pruning and chemical thinning and precision in irrigation.

Currently, there are a number of parameters related to plant water status that are being used as water stress indicators for irrigation scheduling (Fernández, 2017). One system for evaluating plant water status is the manual measurement of leaf or stem water potential using a Scholander pressure chamber (Pagay, 2022). Stem water potential is a direct physiological measurement of what is going on with the water status in the fruit trees. Previous studies reported that the best time to evaluate stem water potential was midday (Naor, 2000) because that is the time with maximum insolation and the moment with maximum water stress. However, the pressure chamber cannot provide continuous information on plant water status.

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Recently, micro-tensiometers (FloraPulse sensors) have been developed for continuous evaluation of tree water status. This sensor is embedded into the woody tissue of the tree trunk and can measure stem water potential every minute during the day. By this method the level of water stress in the plant could be used control the amount of irrigation based on plant water status. There are a few previous studies with these micro-tensiometers in pear and vineyards but only one recent study of the use of these sensors in apples orchards (Blanco and Kalcsits, 2021). The first objective of this experiment was to study apple fruit growth dynamics in two irrigation treatments. The second objective was to understand apple fruit growth dynamics and relate it to water stress for maximizing fruit size and crop value in 'Gala' apple.

MATERIAL AND METHODS

Study site and plant material

The trial was conducted in 2021 in an apple orchard of the Cornell's Agritech Campus in Geneva, New York State, using mature, uniform Ultima 'Gala' apple trees grafted on G.11 rootstock. The training system was tall spindle, and the trees were planted at 2240 trees ha^{-1} in 2014.

Treatments

The trial compared two different water regimes (fully irrigated and rain exclusion to induce water stress). All trees selected in the experiment had the same trunk cross-section area (TCSA; ±2 cm^2 TCSA^{-1}) and the crop load was adjusted at 7 fruits TCSA^{-1}. During the early part of the season during the fruit set period all trees received the same water treatment. Hand thinning was performed after fruit set to 1 fruit per cluster. To induce water stress the rain exclusion treatment was done by covering the trees with a portable greenhouse only during the raining periods.

Meteorological data

Including precipitation (mm), radiation (langleys) and temperature (°C) data obtained from a weather station near to the orchard at Geneva.

Experimental design

The trial was arranged in a randomized block design with four replicates of 1 uniform tree per elementary plot.

Fruit growth and fruit fresh weights

Fruit diameter measurements were done on 10 fruits per tree (40 fruits per treatment) every 3-4 days between July 2 and harvest day. Fruit diameter was measured with digital caliper (Willowbank Electronics Ltd.). Fruit fresh weights were estimated from the diameters by a regression of weight to diameter, $FW = 0.0012*D^{2.7655}$, $R^2=0.99$, that was developed from pooled sequential fruit harvests in experiments over several years (Lakso, unpublished data).

Stem water potential

Stem water potential was evaluated with micro-tensiometers (FloraPulse, USA). The sensors were embedded into the tree trunk of four trees for each treatment. Stem water potential measurements were recorded every minute using a CR6 data logger (Campbell scientific, Inc.).

Yield assessments

Harvesting was performed during the commercial harvest season all on the same day. Individual trees were harvested and evaluated separately. Fruit weight, diameter, blush color, total fruit yield (kg tree^{-1}) and fruits tree^{-1} were evaluated by an automated Greefa packing line machine. Fruit color distribution was based on USDA grade standards of percentage of red blush area categories (Utility 0-25%, No1 25-40%, Fancy 40-67%, X Fancy 67-80%, XX Fancy 80-100%).

Statistical analysis

Analysis of crop load was performed by ANOVA using SAS 9.4 (SAS Institute Inc., 2009). Means were separated using Duncan's multiple range tests at P<0.05. The analysis of fruit diameter was performed using constrained quadratic linear regression fitting in JMP16 pro statistical analysis software (SAS institute, Inc.). A linear regression analysis was made between temperature and radiation and stem water potential.

RESULTS

Stem water potential and weather data

In the rain exclusion treatment, the water stress was greater during the whole season because the values of stem water potential were lower in comparison with fully irrigated 'Gala' trees. However, the differences between the treatments were lower in the raining periods. In both treatments, the values of stem water potential were higher after periods of rain. Thus, the micro-tensiometers could identify different tree water regimes during the whole season in both treatments (Figure 1).

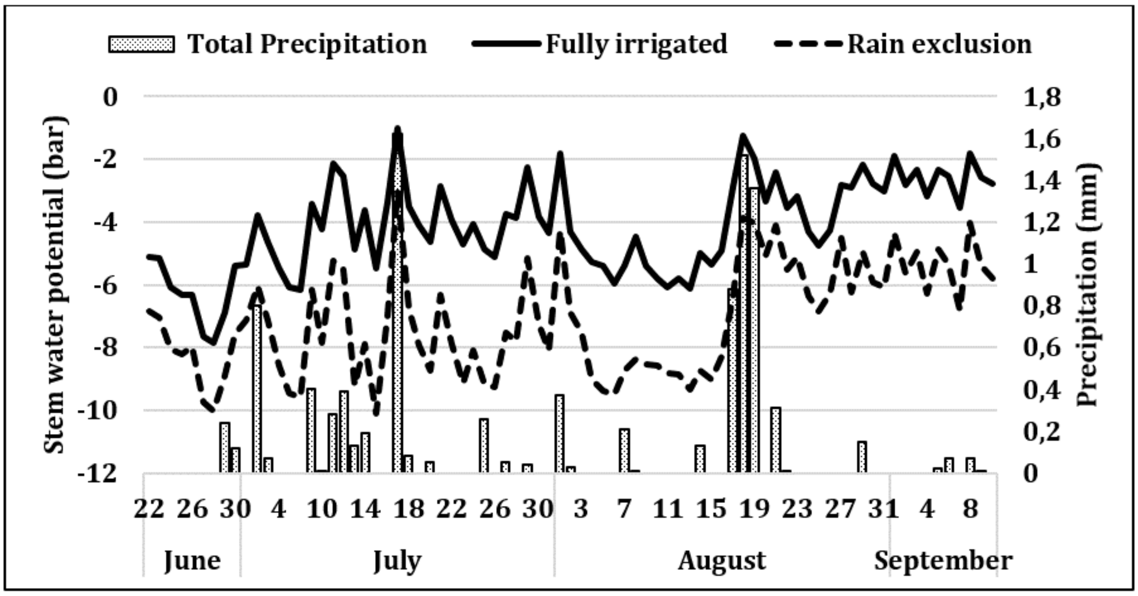

Figure 1. Stem water potential (Bar) and precipitation (mm) during the 2021 season. The value of Stem water potential was the average of the whole day (24 h).

There were significant correlations between stem water potential and radiation and temperature (Figure 2). Additionally, the regression with radiation showed higher values of R^2 compared to the regression with temperature. The different water regimes showed distinct linear dose effects, with an increase in the temperature and the radiation resulting in a decrease in the stem water potential and greater water stress. Moreover, the rain exclusion treatment always showed lower values of stem water potential with the same temperature and radiation in comparison with the fully irrigated treatment (Figure 2).

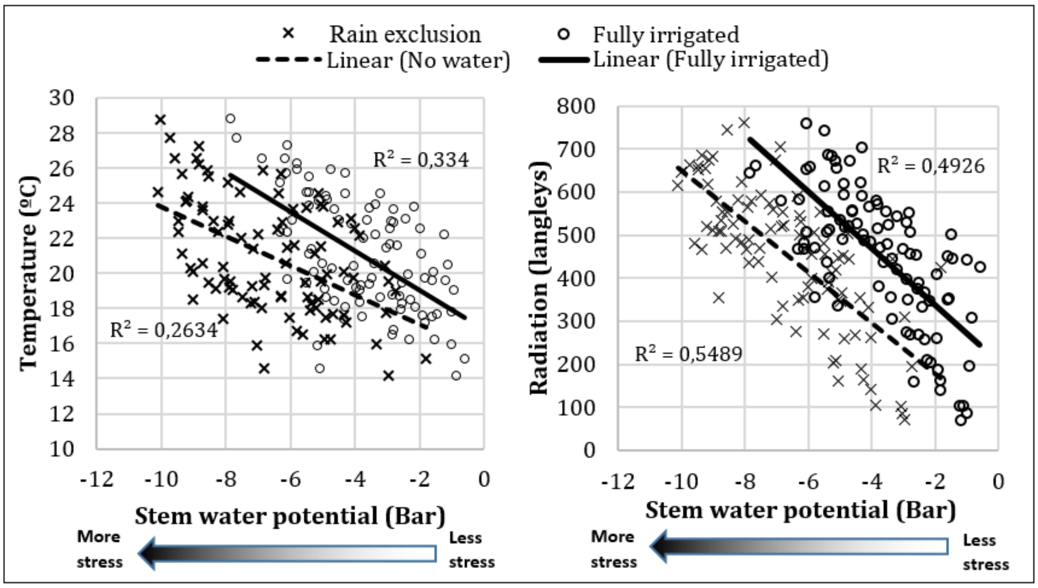

Figure 2. Relationships between stem water potential and weather data (radiation and temperature) during the 2021 season in a 'Gala' apple orchard in Geneva, NY. Each symbol represents the stem water potential (Bar) and weather data average of one day (24 h).

Fruit growth and fruit fresh weights

Fully irrigated trees had greater fruit growth rates throughout the season than the rain exclusion trees. Both treatments showed higher fruit growths during the first two weeks of July. After this period the fruit growth rate of both treatments gradually slowed down over all season. The lowest fruit growth rate was two weeks before harvest in both water regimes (Figure 3).

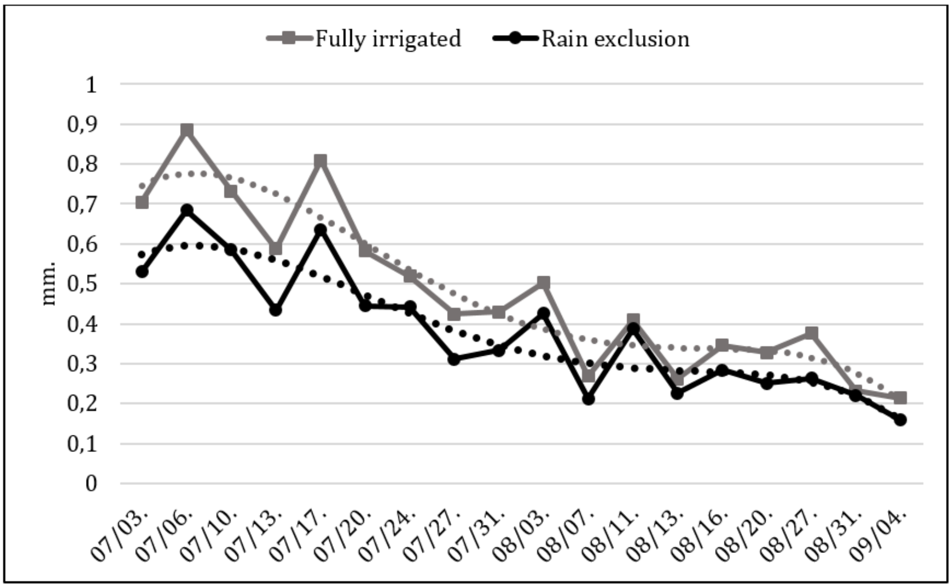

Figure 3. Fruit growth rate (mm day^{-1}) of 'Gala' apples measured every 3-4 days during the 2021 season in apple trees under 2 water regimes. The value of fruit growth rate was calculated with the average of fruit growth between measurements (diameter day 1 - diameter day 2)/number of days).

Fruit diameter and calculated fruit fresh weight were consistently higher in the fully irrigated treatment during the whole season. The measurements started after the cell division in both treatments. For this reason, the fruit diameters showed a good quadratic curve and fruit weight showed a linear fit (Figure 4). In both treatments, fruit diameter increase showed a steeper slope during the first part of the July and then a gradual slowing for the rest of the season (Figure 4), in concordance with the fruit growth rate data (Figure 3). However, the increase in fruit fresh weight was quite constant during the whole season and curve remained linear to harvest. However, the rain exclusion treatment showed a lower slope compared to the fully irrigated treatment (Figure 4).

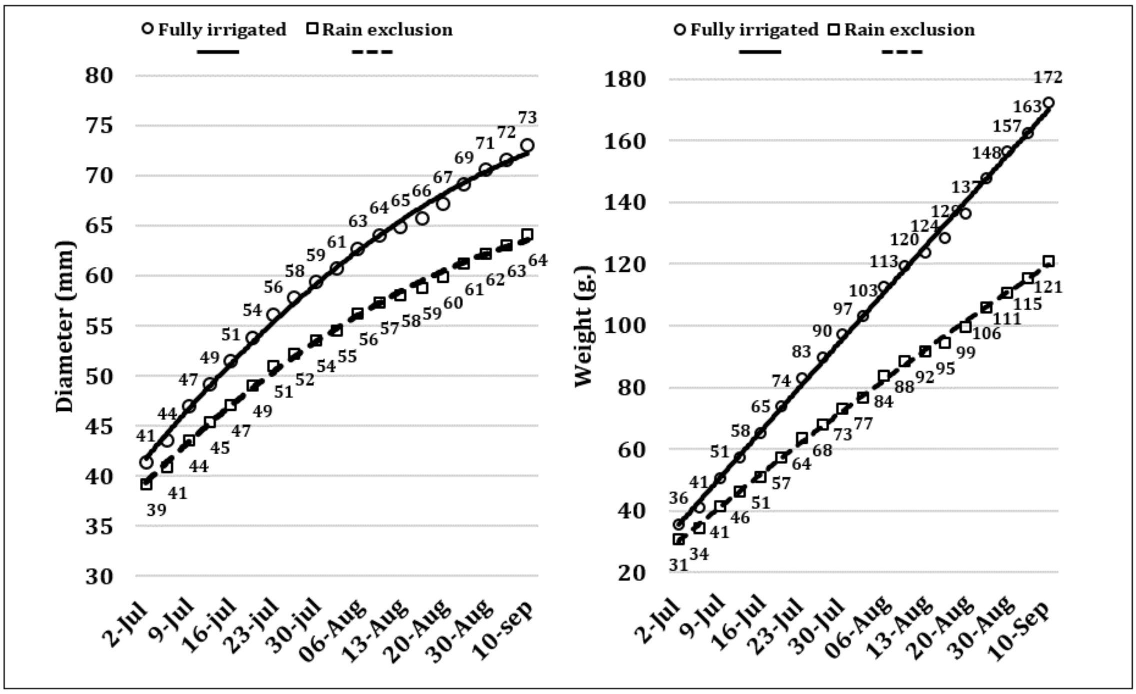

Figure 4. Fruit diameter and fruit fresh weight during the 2021 season of 'Gala' fruit grown under 2 water regimes. The fruit diameters and fruit weight were analyzed by Quadratic linear regression (R^2=0.99 and p<0.0001 in all curves). Fruit fresh weights were estimated from the diameters by a regression of weight to diameter, FW = 0.0012*D^2.7655, R^2=0.99.

Yield parameters

At harvest both water regime treatments had similar fruit number tree^{-1} (176-177 fruits tree^{-1}) indicating that the fruit crop load adjustment done soon after bloom resulted in the same crop load of 7 fruits cm^{-2} TCSA. However, the yield was significant lower in rain exclusion treatment (48 t ha^{-1}) in comparison with a fully irrigated treatment with 67 t ha^{-1} (Figure 5). Therefore, the fully irrigated trees had a higher fruit weight (172 g fruit^{-1}) and larger fruit diameter (73 mm) than the rain exclusion treatment (121 g fruit^{-1} and 64 mm, respectively). Thus, the season long water stress (rain exclusion treatment) showed a reduction in fruit weight of 51 g fruits and reduction in diameter of 9 mm the diameter (Figure 5).

The fully irrigated treatment induced a significant improvement in red color compared with the rain exclusion treatment (Figure 6). The fully irrigated treatment had 36% greater red blush area in comparison with the rain exclusion trees. Moreover, the fruit in the XX Fancy category accounted for 52% of the yield in the fully irrigated treatment significantly higher than from the trees from the rain exclusion treatment which had only 13% of the yield with XX Fancy color.

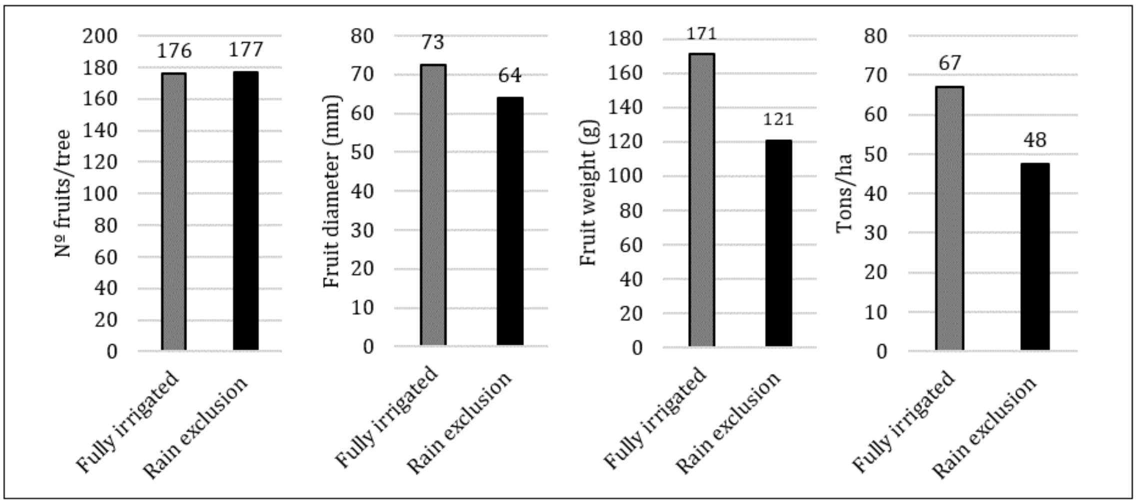

Figure 5. Number of fruits tree^{-1}, fruit weight, fruit diameter and t ha^{-1} at harvest time 'Gala' apple trees grown under 2 water regimes. Fruit diameter and t ha^{-1} shows significant differences (Duncan's range test at P<0.05).

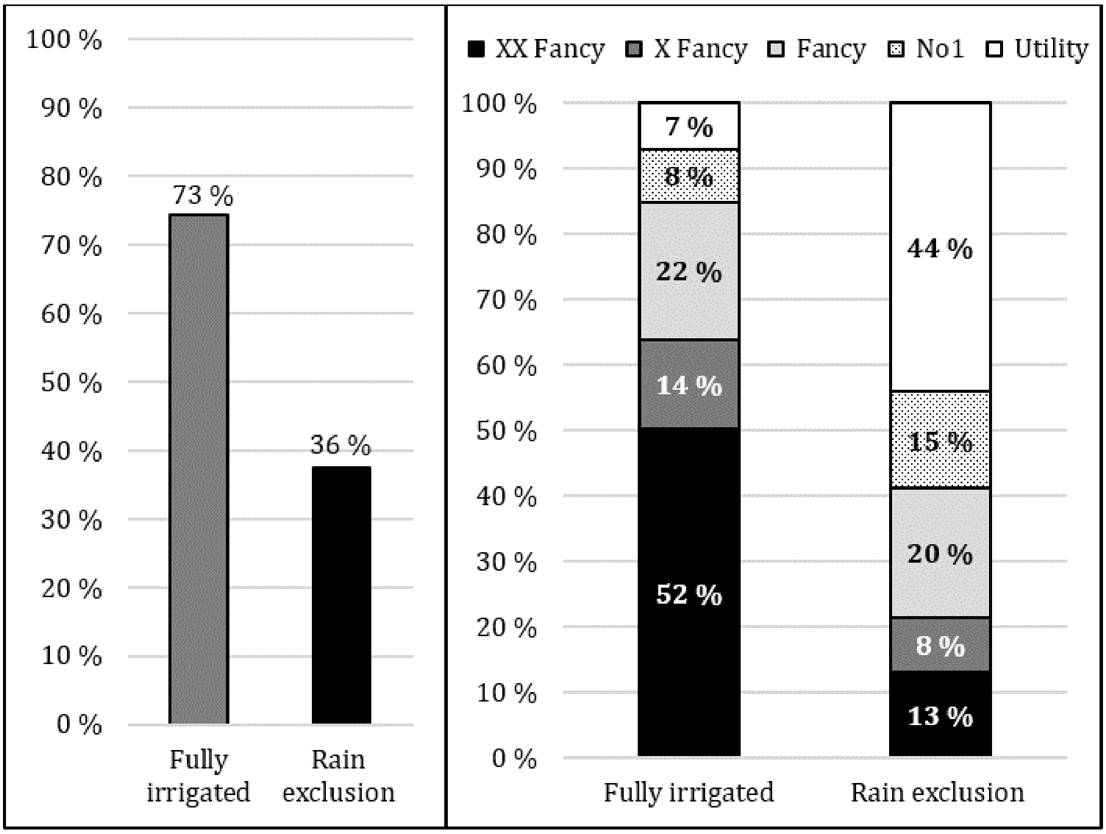

Figure 6. Red blush area (left) and fruit color distribution (right) in different red blush area categories (Utility 0-25%, No1 25-40%, Fancy 40-67%, X Fancy 67-80%, XX Fancy 80-100%) of 'Gala' apple trees grown under 2 water regimes. Red blush area and fruit color distribution shows significant differences (Duncan's range test at P<0.05).

DISCUSSION

In our study, the new micro-tensiometers from Flora Pulse which were embedded in the trunk of an apple tree successfully monitored stem water potential continuously. This should allow these sensors to be used as a tool to manage irrigation. The sensors rapidly detected all of the different tree water regimes during the season, concurring with earlier observations in pear of Blanco and Kalcsits (2021). Stem water potential has been shown to be a sensitive indicator of water stress (Blanco and Kalcsits, 2021; McCutchan and Shackel, 1992). Our results support this conclusion because in each rainy period, values of stem water potential increased indicating lower water stress even with small amounts of rain. Gao (2020) reported that plant water status responds dynamically to variations in both evapotranspiration and soil dehydration. This is why evapotranspiration usually is calculated with temperature, relative humidity, radiation and wind speed. Our results showed that radiation and temperature were related with stem water potential values. As expected, sunny days with high temperatures and high radiation had greater water stress.

Our rain exclusion treatment resulted in a reduction of fruit growth rate and final fruit size. To maximize fruit growth throughout the season water stress should be minimized. In the early part of the season after the flowers have been fertilized, the fruitlet grows by cell division (Lakso and Goffinet, 2013). A period of water stress in this period could cause a lower number of cells and consequently lower potential growth later in the season. In this study, all the trees received the same water regime during the cell division period. Thus, in our study, the differences in fruit size were likely due to differences in cell size not cell number. Our study showed significant differences in the fruit growth rates between the two water regimes which was likely a result of a reduction in cell turgor in response to water stress as suggested by Lopez et al. (2012). Our results showed a declining rate of fruit diameter increase over the season which agrees with work done by Lakso and Goffinet (2017). They reported that the rate of diameter expansion can be deceiving because a 1-mm increase in diameter early in the season is not the same as a 1-mm increase near harvest. They suggested that fruit weight is a better parameter for evaluating fruit growth rate. Our results suggest that fruit fresh weight increase was quite constant during the whole season and the curve remains linear to harvest, again concurring with Lakso and Goffinet (2017).

Water stress can modify important fruit quality traits: size, firmness, color, concentration of sugars, titratable acidity, sugar/acid ratio, concentrations of dry matter, and aroma volatiles (Behboudian et al., 2011; Lopez et al., 2012). The reduction in fruit size from our rain exclusion treatment was expected. Naor et al. (2008) reported that any deviation from minimum water stress may decrease fruit size. However, the reduction in fruit red color our observed could be due to the water stress or could be an artifact of the rain exclusion plastic covered greenhouse which was over the trees whenever rainy periods occurred. A previous reports have indicated that the water stress can modify fruit color (Lopez et al., 2012) but with opposite results. Mills et al. (1994) detected increased red pigmentation in ‘Braeburn’ apple with a lowered water status. On the other hand, Tao et al. (2022) reported that the severe water stress after the last stage of fruit cell division caused a decrease in the color. This is similar to our results which showed a significant reduction in coloration in water stressed trees. but some of the reduction in our study could be due to the reduced light exposure caused by the greenhouse plastic. Other experiments without a rain exclusion shelter are needed to conclude that water stress can cause loss of red color in apple orchards.

CONCLUSIONS

Our study showed Stem water potential measured continuously with micro-tensiometers embedded in the trunk of the tree was a great method to monitor water stress in apple orchards because these sensors could detect rapid changes in water stress due to different tree water regimes or changing weather conditions throughout the whole season.

During all season, the fully irrigated trees had higher fruit growth rates. However, both water regimes showed a declining rate of fruit diameter increase over the season. Moreover, our results suggest that fruit weight increase was quite constant during the whole season and the curve remains linear to harvest.

In our study, both treatments had similar fruit number tree^{-1}. However, the water stressed trees had lower yield, less fruit color and a reduced fruit size when compared to fully irrigated tree.

This study was our first attempt to relate apple fruit growth dynamics and water stress to manage irrigation for maximize fruit size, color and crop value in apple orchards. In the future, our plan to relate daily fruit growth rate to stem water potential to automatically manage irrigation for maximize fruit size, color and crop value.

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