Mango Stem Response under Different Irrigation Regimes

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ABSTRACT

Mexico has dominated the international mango trade having high yields and excellent fruit quality. The use of soil, plant and environmental sensors can monitor plant hydric status and optimize water application. Linear resistance dendrometers were developed and installed in a high-density 8-year old commercial mango orchard during two seasons; 10 in 2019 and 40 in 2020. Stem diameter fluctuations were acquired every 10 minutes to obtain maximum diameter (MXD), minimum diameter (MND), morning slope (MS) and afternoon slope (AS). Mango stem response during flowering, fruit-fall and fruit-growth was analyzed after applying daily irrigation (DI) or reduced deficit irrigation (RDI). Yield was similar for both treatments, but water use efficiency was higher with deficit irrigation. A new variable known as negative integral (NI) was obtained from the dendrometer signature after adding all the values between 8:00 and 18:00. NI provided a stem shrinkage magnitude, peaks attributed to transpiration and slopes showing flow transport to and from the trunk. NI presented a high correlation of 0.85 against T7 during the flowering stage for RDI-1. If NI crossed zero, a severe stress was present; a high AS present in the evening, indicates nutrient solution provided to fruits. Fruit yield depends on panicle number and fruit-drop during the first production stages, being RDI-1 more efficient in retaining fruits.

KEYWORDS

Dendrometer; regulated deficit irrigation; mango tree; yield; fruit drop; signatures

Introduction

Mango is a popular fruit in tropical countries but its global market has just developed in the last decade. Mango trade has increased significantly in both volume and geographic scope with the rapid expanding consumption in the USA, China and the Netherlands. Mexico dominated the international mango trade from 2012 to 2016 with a 16% of market share, reaching US$328 million in 2015 (UNComtrade, 2016). Mexico with a production of 8.98 MT ha\(^{-1}\) is doing a good job of determining shifting market demands for different varieties that include Kent, Keitt, Tommy Atkins, Haden, Ataulfo, among others. An organic upgraded mango is offered, satisfying a growing niche of consumers who are looking for products with no chemicals and that protects the environment. It is estimated that more than 110,000 farmers use organic practices in the country, higher than any other country in the world (Alberts Organics, 2016).

Although mango trees are drought-tolerant plants they have to be irrigated to increase yield. Water supply is critical during the first 6 weeks of the fruit developing process, and drought will induce late-stage fruit drop and reduced fruit mass (Singh, 2005). Proper irrigation management is applied to maximize yield with minimum water use. Water use efficiency (WUE) is significantly higher in deficit irrigation treatments than with daily irrigation scheduling (Santos et al., 2014; Spreer et al., 2009a). Effective water-saving irrigation techniques without affecting crop production have been studied extensively (Cotrim et al., 2011; Léchaudel et al., 2005; Pavel and de Villiers, 2004; Spreer et al., 2009b, 2009a; Subbaiah et al., 2017). Regulated deficit irrigation (RDI) withheld water during certain growing stages of the plant. Average yield added during 4 years under daily irrigation of “Chok Anan”
mango trees was of 83.35 kg tree⁻¹ and of 80.16 kg tree⁻¹ when 50% RDI was applied (Spreer et al., 2009a). Water deficit can create a balance between vegetative growth and fruit growth by reducing vegetative growth in certain stages, such as flushes, and promoting fruit growth at the same time, since fruit represent the final product and dominant sink in the tree (Bustan et al., 2016; Levin et al., 2018; Naor, 2014).

Micro-sprinkling irrigation can effectively reduce water consumption and has the advantages of both dripping and sprinkling irrigation (Levin et al., 2018; Shah et al., 2018; Wei et al., 2017). Soil or climate based methods for irrigation scheduling in fruit tree plantations are questionable. Limitations in the monitoring of soil water status are simultaneously related to the non-uniform nature of soils. (Salgado and Cautín, 2008). The indirect connection between soil and climate based methods and fruit tree crop coefficients are very imprecise, generating differences between real and estimated water requirements (Goodwin et al., 2006). A reliable index of plant water status can only be obtained from plant measurements (Naor et al., 2008; Ortúño et al., 2004).

Since plant water status controls many physiological processes and crop productivity, this information is fundamental for irrigation scheduling. Many researchers are focused in obtaining useful indicators based on stem diameter variations for irrigation scheduling (Conejero et al., 2011; Goldhamer and Fereres, 2004; Livellara et al., 2011; Moreno et al., 2006; Ortúño et al., 2004). Dendrometers monitor physiological activity, including the plant transpiration cycle and the plant water storage capacity (Coccozza et al., 2018). Diurnal stem contraction is an indication of the fraction of the water taken up at night that is lost from elastic stem tissues during the day, as a result of transpiration (Yazgan et al., 2006), and not yet replaced (Devine and Harrington, 2011). The majority of diurnal stem diameter changes result from elastic cambial and phloem tissues fluctuations.

Several studies have been done in orchards to assess the effects of water deficit at different phenological stages. Peach (Cohen et al., 2001; Mercier et al., 2009) and apple (Du et al., 2017) have been studied by using maximum daily stem shrinkage (MCD) sampling, during flowering and fruit growth. The main objective of this research is to analyze dendrometer signature fluctuations under deficit irrigation regimes, so that it can be used for efficient water management in mango orchards. Mango yield, WUE, panicle number and fruits retained were obtained together with daily dendrometer measurements during flowering, fruit-drop and fruit growth stages during the 2019 and 2020 seasons. This information should help programming reduced deficit irrigation for optimal fruit production. A new variable, denoted as negative integral, should provide a better forecast of plant hydric status than a unique daily stem value.

**Materials and Methods**

**Field Site for Experiment Trial**

Field experiment was conducted during two seasons in the years 2019–2020 in a high-density commercial mango orchard located at Loma Bonita (17° 25' 47” N, −101° 11’ 19” W, 17 m ASL), in the state of Guerrero, Mexico. A weather station (Vantage Pro2, Davies Instrument, USA) located at the orchard acquired the meteorological variables during 2019 and 2020. The station recorded a mean annual rainfall of 1345 mm in 2019 and 1225 mm in 2020; the average during the las 5 years was 1250 mm. The lowest rainfall typically occurs from January to May and the raining months from September to November. The trial site is caracterized by basaltic clay-loam red soil. Its bulk density was obtained from 30 soil cores taken randomly from 10 to 40 cm of depth, being its average density of 1.1 gcm⁻³. A 0.15 m deep circular furrow was dig to retain water beneath the trees canopy. The furrow presented soil-cover around the trunk to avoid direct water contact.

The experiment was run from the March 13, 2019 up to harvest on July 15, 2019 and from March 17, 2020 to July 10, 2020. The eight-year-old mango trees had 8 m between row and 4 m in-row spacing. During 2019, thirty mango trees 8 years old variety “Kent” were selected randomly within
the same site having the same soil type for the study; only 9 had a dendrometer installed. During the 2020 season, 40 trees 9 years-old variety "Kent" were randomly selected within the same site; some of them were measured last year.

Tree orchard management included pruning, irrigation and fertilizer practices. After harvest and just before pruning, water was applied daily, adding a fertilizer application per tree of 250 g N, 70 g P₂O₅ and 210 g K₂O. Tree pruning was done in mid-September 2018 and mid-September 2019 with a tight pruning intensity of 30 cm from the apex. Trees with proper canopy opening allowed maximum radiation income, so shoot thread tightening by tutors was used. After pruning, trees were subjected to 3–4 months of stress, until floral buds appeared. After the stress period two different irrigation strategies were employed: daily irrigation (DI) and reduced deficit irrigation (RDI).

Table 1 presents the average and standard error of the variables from the trees selected randomly for each treatment. Tree height, leaf number and trunk diameter had similar average values for both years and treatments. The standard error is greater for the treatments carried out in 2019 as a lower quantity of trees were used. Average canopy diameter changed from 2019 to 2020. The main bifurcation was found at an average height of 85 cm and the dendrometer was installed 15 cm beneath; Three or four branches departed from the main trunk. Canopy volume, \( V \), was calculated using the equation of a one-half of a prolate spheroid \( V = \frac{4}{3} \pi r^2 \frac{1}{2} h \) based on the radius of the canopy \( r \) and the height \( h \) of the tree (Durán et al., 2011). In order to consider tree pruning, final canopy volume was obtained from 0.55 \( \times \) \( V \). Yield efficiency in \( \text{g cm}^{-2} \) was estimated by dividing fruit yield by canopy volume and trunk cross-sectional area (Durán et al., 2011).

TO REVIEWERS PARAGRAPH ADDED TO EXPLAIN HOW DATA WAS OBTAINED FOR MANY QUESTIONS OF sampling; 10 trees per irrigation treatment each year. Three dendrometers per treatment in 2019 and 10 per treatment in 2020. Therefore, data for Table 1 is from the same number of trees (30). Only one stress tree was measured in 2019 and 10 in 2020.

**Irrigation Treatments**

Three irrigation treatments were applied throughout the field experiment during the 2019 and 2020 seasons:

1. DI (daily irrigation 100% ET)
2. The first day water was applied and the second not (RDI-1 = 0.5 ET)
3. Day one was watered and the next two days were not watered (RDI-2 = 0.33ET).

REVIEWERS COMMENT: IRRIGATION WATERING. LINE 136 EXPLAINING STRESS MOVED TO LINE 150. Paragraph of line 143 brought to next line.

| Table 1. Average and standard deviation from tree height, trunk and canopy diameter, number of leaves, soil absorption, and VWC during 2019 and 2020. REVIEWER: CHANGE OF TITLE. |
|---------------------------------------------------------------|
| **Season 2019** | **Season 2020** |
|-----------------|-----------------|
| **DI** | **RDI-1** | **RDI-2** | **DI** | **RDI-1** | **RDI-2** |
| Number trees | 3 | 3 | 3 | 10 | 10 | 10 |
| Tree height, cm | 256 ± 35 | 253 ± 38 | 276 ± 45 | 246 ± 2.6 | 243.2 ± 2.3 | 244 ± 2.2 |
| Canopy diam., cm | 206 ± 5.6 | 207 ± 4.6 | 206 ± 11 | 191 ± 12 | 194 ± 9 | 199 ± 7.5 |
| Leaf number | 730 ± 44 | 782 ± 20.3 | 760 ± 43 | 760 ± 19 | 767 ± 15 | 776 ± 16 |
| Trunk diameter, cm | 8.67 ± 0.3 | 8.93 ± 0.1 | 8.4 ± 0.4 | 8.73 ± 0.2 | 8.58 ± 0.14 | 8.66 ± 0.13 |
| Primary branches | 3.33 | 3.33 | 3.33 | 3.6 | 3.5 | 3.6 |
| Absorption \( \tau \), min | 58 ± 0.37 | 57.8 ± 0.25 | 58.2 ± 0.2 | .52 | .48 | .48 |
| Max VWC \( \text{cm}^3 \text{cm}^{-3} \) | .3 | .23 | .18 | .3 | .23 | .18 |
Water was delivered by one 120 L h$^{-1}$ micro sprinkler installed at a distance of 0.5 m from each tree trunk. According to tree size and age, 55 l day$^{-1}$ were recommended. Micro sprinkler irrigation maintained wet the soil beneath the trees and was controlled by automatic timers set to run for 30 min at 18:00 just before sunset to avoid soil transpiration.

Treatments with DI and RDI were applied from flowering to fruit ripening (Cotrim et al., 2011). The first phase from early flowering up to fruit set lasted 45 days (Figure 1). It was followed by the fruit drop period (1 month) and by the fruit expansion/ripening period (45 days). During 2019, 10 DI trees were irrigated daily until harvest (Figure 1). Ten trees started to be irrigated with RDI-1 the March 10, 2019, until June 24, 2019 just before harvest; water was applied at 18:00 the watering day. The RDI-2 treatment applied to ten trees consisted in applying water 1 day at 18:00, followed by 2 days without watering; it started on March 10, 2019 ending by mid-June.

During the 2020 season, ten DI, ten RDI-1 and ten RDI-2 trees were monitored continuously through all the phenological stages and were not stress at all; another 10 DI-trees were stressed by removing the water for 2 weeks to analyze its response. During 2019 the same test was carried out with one tree. Stressed trees cycles resulted from withholding irrigation water until plants began to wilt. Mango trees were watered from the March 15, when floral buds were seen, and inflorescences appeared by April 2020. The fruit fall period lasted until 20th May 2020, when fruits started its final growth period until June 20; afterward ripening took place.

**Trunk Growth Measurements**

Point dendrometers were installed at a height of about 0.7 m on selected trees during both seasons. Ten dendrometers (3 per treatment + 1 for stress) were installed during 2019 and 40 dendrometers (10 per treatment and ten for stress) during 2020. The outer bark where the...
dendrometer was installed was lightly brushed to ensure smooth contact with the trunk. A linear current source, fed the linear resistance transducer to avoid output voltage fluctuations caused by the discharge of the lithium battery. A microcontroller acquired ten stem measurements every ten minutes, averaged the values and saved the result in a MSD memory. Changes in tree girth were measured with an accuracy of 0.002 mm. MXD corresponds to the maximum trunk diameter, meanwhile MND the minimum trunk diameter after stem shrinkage (Figure 2A). MXD and MND daily values occur just before sunrise and sometime after solar midday, respectively. Ambient air temperature increases just after MXD, starting evapotranspiration (ET) as stomata open. A morning slope (MS) results from stem shrinkage, as water and carbon compounds stored in trunk cells flow upward. Water starts its storage in the trunk as air temperature decreases in the afternoon slope (AS). Stem night slope (NS) occurs when temperature continues dropping after midnight. Acquisition values are all positive and are centered with respect to zero after subtracting the signature against the measurement at 18:00, time when trees are watered. Values during shrinkage and expansion were obtained from this reference point. A negative integral (NI) index results after adding all the daily negative values for the signature, corresponding to the moments where solar radiation, evapotranspiration and photosynthesis takes place. Each 10 min-measurement is added to obtain NI, being a negative value.

TO REVIEW: NI is explained

![Figure 2](image)

**Figure 2.** Sensing (a) daily temperature and stem growth variables on March 24th 2020, being MXD the maximum diameter, MND the minimum diameter, MS the morning slope, AS the afternoon slope, NS the night slope, MCD the daily trunk growth, MT the maximum temperature, MNT the minimum temperature and (b) volume water content VWC and ultrasonic distance to the water within the furrow.
Soil Water Measurements

An ultrasound sensor (mod S18UUA, Banner, USA) placed 15 cm over the soil measured how the water was absorbed after irrigation. The sensor starts measuring when watering starts and 6 hours later is turned-off. The sensor output voltage increases as the water within the circular furrow gets absorbed by the soil. The time constant (Table 1) specifies the time required for the soil to absorb 63% of the applied water and it was close to one hour in all the treatments. The time taken by the soil to absorb the applied water was not measured in 2019. Volumetric water content (VWC) was measured with a 40 cm probe having a capacitive sensor (mod. VH400, Vegetronix, USA) at the end. Soil moisture measurements were taken from full bloom until harvest, and the values saved by a handheld data-logger; the soil moisture probe was fixed 50 cm apart of the trunk.

COMMENT TO REVIEWERS Only one measurement was taken of soil absorption with a clock as we didn’t have the soil sensors to measure during the first year. The time for the water to be completely absorbed by the furrow was close to 3 hours on March 21st 2019. NOT ENOUGH DATA IN ORDER TO INCLUDE IN Table 1.

Environmental Measurements

Two sensors were used to monitor environmental variables. Air relative humidity and temperature were measured with a Sensirion DTH22 sensor. The CMOSens sensors, signal magnifier, A/D switch and 12 C bus interface are integrated in one chip; This chip was placed just over the canopy, approximately at a height of 1.5 m over the soil and connected to the microcontroller. Data are collected every 10 minutes and saved in a MSD memory. An Apogee SP-110 pyranometer measured total solar global irradiance both direct and diffuse in W m⁻². Values were acquired by the microcontroller system every ten minutes and saved in a MSD memory.

REVIEWERS: ALL THE NEXT PARAGRAPH EXPLAINS FRUIT MEASUREMENTS IN PANICLES. IT WAS NOT EXPLAINED.

Counting of Fruit per Panicle and Mango Fruits

Fruit production depends on panicle forming and fruit setting (Hagemann et al., 2014). Panicle fruit-set in pinhead-size started end of April in both seasons, and continued growing into pea and marble size. Pea and marble fruit sizes appeared 14 and 20 days after full flower bloom, respectively. During the 2019 season, the number of panicles per tree were counted in each of the 30 trees and ten panicles per tree were selected to follow fruit growth. Fruits per panicle were counted per tree every ten days and photographs from each panicle acquired with a 9i Huawei smartphone. The image from each panicle having small fruits were introduced to the ImageJ (NIH, USA) software. Segmentation of the pixels were classified into two groups, fruit and background, by means of color and texture information. Afterward, fruits were counted and the data compared with the field value. The number of mango harvested from each tree were counted and weighted with a scale to obtain the yield per tree. During the 2020 season, 30 trees were sampled during fruit-set (10 per treatment) following the same treatment as in the 2019 season. In all the 30 trees (ten DI, ten RDI-1 and ten RDI-2) the number of mangos harvested were counted and weighted.

Statistical Analysis

Every tree provided a signature of 144 daily measurements, together with air temperature and relative humidity signatures and saved in a MSD memory. A filter eliminated spikes, noise and when the difference between two consecutive values was greater than 25, interpolation was done. Signature normalization was obtained for each treatment after measuring the diameter of those trees. The average diameter was multiplied by the tree signature value and divided by the diameter of the
sampled tree. A macro program in Excel obtained the MXD, MND, maximum and minimum air temperatures. Correlations of MXD and MND were carried out against the environment variables, grouped by irrigation treatment and tree phenological stage. Simple regression curves were adjusted using the least squares technique in order to correlate the trunk variables against environmental variables using software R; dew temperature at 7:00 was used in these correlations. Data of fruit yield during 2019 and 2020, WUE, fruit weight, yield efficiency, fruit set and fruit remaining after each week in the drop stage, were evaluated by analysis of variance, and the means were separated by Tukey's test (p < .05). This ANOVA test was carried out in R to obtain how these variables are affected by the different irrigation treatments. Another study determined how were the dendrometer variables (MXD, MND, MCD, NI, MS, AS) affected by the irrigation treatments.

TO REVIEWERS: Normalization is explained and why temperature at 7 was important and ANOVA.

Results

After some field experiments, it was observed that water within the tree circular furrows was still present, three hours after irrigation ceasing (Figure 2B), being soil transpiration minimum. Ultrasonic measurements reflected at the water-surface collected by the tree furrows, showed that water was absorbed by the soil with a time constant of 1 hour having a standard error of 0.2 (τ = 58 ± 0.2 min, N = 10 for DI treatment). Grass cover appeared at the circular furrows after 1 month of irrigation, causing less soil transpiration. Sunset took place at 20:05, during both seasons, 2 hours after irrigation.

A number of soil excavations allowed visual assessment of effective rooting morphology, being the highest root density encountered at a depth of 0.4 m, with fewer roots perceived at 0.6 m. Plant roots occupied space beneath trees canopy edges.

Volumetric water content at a depth of 0.4 m differed in each irrigation treatment. Every day irrigation provided an average of 25% VWC during the entire season. Average VWC throughout the season RDI-2 and RDI-1 was of 13.8% and 19.7%, respectively. During the driest month of May, the lower VWC recorded with the RDI-2 treatment was of 12.8% (0.128 cm⁻³). The clay-loam red soil was still humid after the day without watering with RDI-1 treatment. It took 3 days after the last watering to begin visualizing texture changes in the soil surface. After 8 days, water was still available at the roots at a depth of 40 cm, but water stress was noted 2 days later; wilt was appreciated by leaf color and inclination.

Trunk Measurement with DI and RDI Treatments during Flowering

Mango orchards are characterized by different degrees and types of alternating patterns. Research on the natural characteristics of growth, branching and flowering, improves orchard management and reduce alternate bearing (Normand et al., 2009).

Six weeks after floral bud appearance, peak bloom flowering showed-up at April 26th of 2020; peak bloom flowering occurred at April 20th of 2019, in the previous year. The number of panicles per tree in 2020 for RDI-1 and RDI-2 was of 23 and 18 (Table 2), respectively. Average panicle number in 2020 with DI was higher (32), and coincide with the findings of Sarker and Rahim (2013) that reported an increment of secondary panicles with irrigation. Under daily irrigation the number of panicles was 30 during the 2019-season and trees watered with RDI-1 and RDI-2 treatments produced 22 panicles (Table 2). Panicle malformation characterized by short, thickened and enlarged rachises was similar for all treatments during both seasons (Table 2) and the statistical analysis shows insignificant difference between DI and RDI-1 treatments.

TO REVIEWERS: Previous paragraph was in discussion and was moved to results

Stem diameter and air temperature average signatures for each treatment during the 27–30 April period from each season are plotted in Figure 3; Irrigation scheduling is represented by arrows. After averaging and normalizing the data from 10 DI trees within these days in the 2020 season, the
The blue negative area (Figure 3A) named negative index, NI, corresponds to the period of soil-water circulation heading to the tree organs without being stored in the trunk. During this time, evapotranspiration takes place when solar radiation is available; When the signature crosses zero at the end of blue negative area, sunset takes place. The trunk shrinkage peak obtained with the dendrometer signature from 12:00 to 14:00 is related to stomata closure when air temperature surpasses 33°C (Figure 3B). In both reduced irrigation treatments (RDI-1 and RDI-2), a step after 22:00 appeared in non-irrigated days (Figure 3D). If stem tissues are not fully watered, due to short water availability, it will take a longer time to saturate and fill the tissues by midnight (Larcher, 2003).

Signatures of trees with diameters ranging between 8.12 and 9.8 cm during April 27 and April 28 of 2020 were analyzed and maximum standard error was obtained in MXD. Once signatures were normalized, MXD SE decreased to 0.5 (Figure 3A). In MS, AS, and MND standard errors were much smaller.

The first floral buds were seen by mid-march and irrigation started and full bloom arrived by April 26, 2020. Air temperature along April 28, 2020 (Figure 3B) was stable during full blooming; temperature increased from 22.3°C at sunrise (7:20) to 23.5°C at midnight (23:59). A sharp increase in average morning slope MS of DI trees was noted in March 2020. MS average was of −368.2 ± 10.3 before irrigation, increasing after DI to −815.8 ± 10.3; MS average during flowering was −615 (Table 4). In 2019, an average MS of −494.1 ± 34.3 was obtained sampling with 3 dendrometers per experiment. In 2020, 10 dendrometers per treatment were employed. MND values in both seasons with DI varied from −32 in middle of march to −36 by the first week of April in 2019 (Figure 4C). MCD (Figure 4B) and MXD increased, as trunk tissue swelled to satisfy the needs of floral buds and panicles; MCD increased from 56 µm on March 13th to 76 µm on April 26, 2020 (Figure 4B). Plant transpiration lasted 8 hours from 9:30 to 17:40 with a solar radiation over 500 Wm−2 and an air temperature of 28°C. DI irrigated trees present NI values ranging from −121 to −1235 at the end of April 2020 (Figure 3B). In the 2019 season, the NI areas presented different

Table 2. Average fruit yield, fruit per tree, fruit weight, water applied, panicle number, and WUE for each irrigation treatment during 2019 and 2020.

| Irrigation Treatment | Irrigation (m³ tree⁻¹) | Canopy Vol (m³) | Panicle No./malf | Fruit yield (kg tree⁻¹) | Fruit per tree | Fruit weight (g) | Fruit yield (kg m⁻²) | Yield eff (g cm⁻²) | WUE (kg m⁻³) |
|----------------------|------------------------|----------------|------------------|-------------------------|----------------|------------------|---------------------|-------------------|---------------|
| DI (100% ET)         | 5.9                    | 3.0            | 30a/6a           | 30.8a                   | 42.2a          | 729.3a           | 10.1a               | 3.3a              | 5.2a          |
| RDI-1 (50% ET)       | 2.9                    | 3.1            | 22b/6a           | 28.4b                   | 39.3b          | 723.8b           | 9.1b                | 2.9b              | 9.8b          |
| RDI-2 (33% ET)       | 1.9                    | 3.1            | 22b/4b           | 20.8c                   | 29.1c          | 715.5c           | 6.7c                | 2.1c              | 10.9c         |
| ANOVA                |                        |                |                  |                         |                |                  |                     |                   |               |
| Irrigation 2019      |                        |                |                  |                         |                |                  |                     |                   |               |
| RDI-1 (50% ET)       | 3.3                    | 2.8            | 23b/5b           | 28.6b                   | 47.9b          | 596.5b           | 10.0b               | 4.2b              | 8.7b          |
| RDI-2 (33% ET)       | 2.2                    | 2.6            | 18c/5b           | 22.1c                   | 37.3c          | 591.3b           | 8.4c                | 3.0c              | 10c           |
| Interaction          |                        |                |                  |                         |                |                  |                     |                   |               |

* Significant at p < .05; Different letters in the same column are statistically different by Tukey’s test (p < .05).
patterns, but their resultant values ranged between −1198 and −1227. NI values at the beginning of March 2020 (Figure 4A) were close to −1100 as trees were water-stressed and just started their irrigation schedule. NI during the flowering period from March 13th to April 26th increased by 5% in both seasons (Figure 4A).

**RDI Trunk Measurements under Flowering**

Stem and air temperature average signatures from RDI-1 trees were plotted for a four-day period during full blooming (Figure 3C). Watering took place at 18:00 on the 26th of April (not displayed) in Figure 3C and at the same hour every 2 days (April 28 and April 30). A light gray shading on the plot shows the watering day for RDI-1 and RDI-2. On April 27, 2020, MXD and dew temperatures were of 48.76 μm and 23.5°C, respectively; MXD remained constant in 48.8 μm during the next 3 days. The stem diameter remained constant from 22:00 to 23:00 during RDI-1 and RDI-2 non-irrigated days, showing a step afterward; the same behavior was noted in 2019. Stem diameter increased to a MXD of 48.75 μm at 22:00, 4 hours after watering; 1 day later (April 27th of 2020), diameter at 22:00 was of 36.8 μm. Next day after watering, trunk diameter increased to a MXD of

![Figure 3](image-url)
48.75 μm at 22:00. MCD with RDI-1 increased from 54.1 μm at March 13, 2020 to 76.4 μm at April 26, 2020, when trees reached full flower bloom (Figure 4B); MND variation ranged between −30 and −33.6 μm (Figure 4C).

Similar morning slopes (−432.8 ± 18.3) were found during the four blooming days of both seasons with the RDI-1 treatment, non-dependent if water was applied or not the previous day (Figure 3C); DI MS was 42% steeper. Afternoon slopes during the 2020 season were of 270 and 256.5 for watered and non-watered days, respectively; AS values varied between 257 and 301 in 2019. NI showed the greater difference between a watered (April 27, 2020; NI = −1200) and a non-watered day (April 28, 2020; NI = −1100) as can noted in Figure 3C; the double asterisk presents the NI values during the 2020 season. NI with the RDI-1 treatment remained constant (−1100) all March and April (Figure 4A).

With RDI-2, MXD decreased during the second non-watered day by 7.3%, meanwhile soil water moisture showed a deficit of 43%. MXD values varied during full blooming and at the first days of April, maintaining the same differences between watering and non-watering days. Trunk diameter differences during full blooming at 22:00 were noted between irrigated (IR), first dry day (FD1) and second dry day (FD2); FD1/IR and FD2/IR ratios were of 0.77 and 0.66, respectively (Figure 3D). Morning average slope during the flowering stage of 2020 (Table 4) was −436.5 ± 8, and during full blooming was −457 ± 1; MS varied from −385 to −435 in 2019. Afternoon slope with RDI-2 was 259.5 ± 4.2 in the 2020 season, and 265.3 ± 3.1 in 2019; These values are close to the 263 ± 7.6 obtained

Figure 4. Daily stem growth variables obtained during the 2019 and 2020 season under different irrigation regimes showing the (a) negative integral, (b) MCD, (c) MND and (d) continuous irreversible growth.
with RDI-1 in 2020. MCD increased exponentially from 55 µm at March 13, 2020 to 74.3 µm at April 26, 2020, when trees reached full flower bloom (Figure 4B); minimum MND changes were noted (Figure 4C).

NI area differences between irrigated (IR), first dry day (FD1) and second dry day (FD2) were consistent during 2020 as shown by the three asterisks in Figure 3D, being of −1213 ± 23, −1096 ± 21 and 997 ± 19, respectively. In 2019, NI varied also consistently achieving average values of −995 and −1220, for FD2 and IR days. NI values with RDI-2 remained constant (−970 to −990) during March and April (Figure 4A) and can be attributed to soil-water availability.

**Trunk Measurements and Fruit-drop Stages for All Irrigation Treatments**

A period composed of very warm days and nights can become a problem for retaining fruits within the panicles. Solar noon on May 20, 2020, occurred at 13:41 having an air temperature of 35.6°C. An average of 225 pinhead-fruit was counted in five trees in May 1, 2020 with daily irrigation. One week later (May 8th) with DI, the average number of pea-size fruits retained per panicle was 8.6 (Table 3);

| Table 3. Mean number of fruits retained per panicle at different mango growth stages for each irrigation treatment during 2019 and 2020. |
|---------------------------------|
| **IRRIGATION** | **FRUIT SET** | **NUMBER OF FRUITS RETAINED PER PANICLE AT** | **Harvest** |
| **TREATMENT** | **Tree** | **10 May** | **20 May** | **30 May** | **Jun** | **Jun** | **29** | **9** | **Fruits** |
| Irrigation 2019 | | | | | | | | | |
| DI (100%ET) | 181c | 7.5c | 4.1c | 3.4c | 2.4b | 2.1b | 1.9b | 1.8b | 42.2a |
| RDI-1 (50%ET) | 216a | 13.5a | 6.8a | 5.8a | 4.6a | 3.2a | 2.9a | 2.6a | 39.3b |
| RDI-2 (33%ET) | 196b | 10.9b | 9.5b | 4.3b | 2.7b | 2.2b | 1.9b | 1.7b | 29.1c |
| Irrigation 2020 | | | | | | | | | |
| DI (100%ET) | 225b | 8.6b | 4.7c | 2.7b | 2.5b | 2.4a | 2.3b | 2.2b | 52.5a |
| RDI-1 (50%ET) | 264.7a | 14.7a | 7.2a | 5.9b | 4.8a | 4.1a | 3.7a | 3.2a | 47.9b |
| RDI-2 (33%ET) | 215.3c | 13.5a | 6.1b | 5.5a | 4.3a | 3.8b | 3.3a | 2.7ab | 37.3c |
| ANOVA | | | | | | | | | |
| Irrigation 2019 | * | * | * | * | * | * | * | * | * |
| Irrigation 2020 | * | * | * | * | * | * | * | * | * |
| Interaction | * | * | * | * | * | * | * | * | ns |
| * Significant at p < .05; ns, not significant. Different letters within the same column are statistically different by Tukey’s test (p < 0.05). |

| Table 4. Dendrometer average measurements (MXD-maximum diameter; MND- minimum diameter; MCD-daily trunk growth; MS-morning slope; AS afternoon slope; NI-negative area index) for each irrigation treatment (DI, RDI-1 and RDI-2) and different growth stage (FL-flowering; FD-fruit drop; FG- fruit growth) during the 2020 season. |
|---------------------------------|
| **Irrigation treatment per stage** | **MXD** | **MND** | **MCD** | **MS** | **AS** | **NI** |
| Flowering | | | | | | |
| DI | 38.8a | −33.1c | 71.9a | −615b | 346a | −1203a |
| RDI-1 | 33.2b | −32.2b | 65.4b | −433a | 263b | −1110b |
| RDI-2 | 30.3c | −31.1a | 61.4c | −436.5a | 259.5c | −982c |
| Fruit drop | | | | | | |
| DI | 43.5b | −33.7c | 77.3a | −400c | 335b | −1237c |
| RDI-1 | 42.9c | −33b | 73.9b | −355a | 278a | −1114b |
| RDI-2 | 43.9a | −31.6a | 75.5c | −365b | 245.5c | −1008a |
| Fruit growth | | | | | | |
| DI | 45.2a | −34.1c | 79.3a | −399a | 403.5c | −1197c |
| RDI-1 | 44.5b | −33.2b | 77.7b | −403b | 416b | −1151b |
| RDI-2 | 43.4c | −32.4a | 75.8c | −409c | 428.3a | −1087a |
| ANOVA | | | | | | |
| Flowering | * | * | * | * | * | * |
| Fruit drop | * | * | * | * | * | * |
| Fruit growth | * | * | * | * | * | * |
| Interaction | * | * | * | * | * | * |
| * Significant at p < .05. REVIEW: CHANGE TABLE, Legend and addition of paragraph |
a higher number of pinhead-size fruits were retained per panicle with RDI treatments. The fruit-drop period ended once fruits achieved the marble size on May 20, 2020. The highest number of marble-fruits retained per panicle was of 5.9 using the RDI-1 treatment on May 20, 2020 (Table 3- RDI-1 (50% ET)/20); in 2019, 5.8 fruits per panicle were retained with RDI-1. A lower quantity of fruit (59.8%) was collected from the floor by May 28, 2020 by using RDI-1 deficit irrigation; 68.8% of fruit was dropped with daily irrigation.

TO REVIEWERS: ADDED PARAGRAPH FROM Table 3

Fruit bearing may affect in this stage as environmental conditions. ANOVA shows very significant differences between treatments and years (Table 3). During 2019 with DI, 45% of the fruit remained in the panicle by the end of May; only 31.3% on 2020. With the RDI-1 treatment 43% remained in the panicle by end of May in 2019; 40.1% in 2020.

Average NI behavior calculated from daily signatures (Figure 4A) shows a constant progression from full bloom to fruit pinhole-size (24 April-1 May). A NI differential of 100 between DI and RDI-1 was obtained (Figure 4A); RDI-2 differential against DI is even higher. As fruit continued growing until the marble size, NI between deficit irrigations varied.

Stem growth measurements were taken between May 20th and May 23th of 2020, and the signatures from 5 trees at full flower bloom were compared against 5 trees having marble fruits (Figure 5C); flowering trees were delayed with respect to the others. MXD fluctuated insignificantly between flowering and marble fruit trees, as well as morning slopes for 2020 DI trees. In 2019, MS ranged between ~350 and ~365. Afternoon slopes for DI fruit and flowering trees were of 335 ± ± 10.7 and 313.9 ± 6.7, respectively during the 2020 season; similar AS values of 331.5 ± 13.4 and 320.8 ± 11.8 were found during 2019.

The greater difference found by the dendrometers in the 2020 season was the NI area, being of −1328 ± 6.48 (Figure 5C) and −1221 ± 5.3 (Figure 5A) for fruit and flowering trees, respectively. Fruit trees NI have their values marked with three asterisks in Figure 5C. MND daily values were larger than −33 for marble-fruit tree signatures and occurred at maximum peak air temperature at 15:00.

Different letters within the same column are statistically different by Tukey’s test (p < .05).

At the end of the fruit drop period, the average signatures from May 20th to May 23th of 2020 were plotted (Figure 5A). In May 22, 2020, there was rainfall with a precipitation of 210 mm which is marked at 19:00 by the side of the irrigation arrow (Figure 5A). Dendrometer signatures tend to follow radiation up to 13:00 when a maximum value is achieved. Air temperature increased along with radiation and reached a maximum of 36.7°C between 14:30 and 15:00 on May 23, 2020. Dendrometer signatures of May 20, 2020 (Figure 5A), corresponding to a sunny day, decreased rapidly in the early morning between sunrise (6:13) and 8:00. Trunk diameter peaked at solar noon (between 13:00 and 13:30), and declined at 15:00 dropping near zero at 18:00. REVIEWERS: Legend Figure 5 changed.

Stem signatures varied with the irrigation treatment (Figure 5A), and MXD decreased by 10% after the second day without irrigation in RDI-2. DI morning slopes were steeper (~400.3 ± 15.2) than with RDI-2, that present an average value of ~365.2 (Table 4). Afternoon slopes varied less, being of 266 ± 9.2 and 245 ± 4.9 for both treatments.

NI presented differences between treatments, being daily values constant for DI, meanwhile values decreased during the 3 days from −1214 ± 16 to −976 ± 15 in RDI-2 (Figure 5A); the asterisks show NI values for the RDI-2 treatment. In the daily irrigation treatment NI varied from −1220 to −1235 throughout the 4 days.

**Trunk Measurement under Water Stress**

After 2 weeks of water shortage to induce water-stress, stem variations were monitored in trees from May 20 to May 23 during both seasons. VWC at a depth of 40 cm, after 4 days of water shortage was of 35%, but felt to 0.1 cm³ cm⁻³ (10%) 6 days later. In this period, MXD
values during 2019 ranged between 24.7 and 11.5 µm (Figure 5B). MXD decreased from 25.83 to 11.9 µm in 2020. MXD values during May 22 and May 23 decreased by 46% and 53.9% with respect to the MXD value obtained on May 20, 2020. Scarce soil water availability combined with high night air temperature of 24.65°C at 7:40 on May 23, 2020, limited trunk growth to 11.92 µm (Figure 5B). Tree stress with leaves wilting were also noted in the 2019 season, and MXD decreased by 45% and 52.3% during May 22 and May 23, respectively. Air temperature increased steadily and at 9:00 it was over 26°C from May 21 to 23 in both seasons (Figure 5B). Eight hours later at 18:00, air was still warm having a temperature of 32°C. Morning slopes differed for the 4 days (-232, -193.6, -182.7 and -102) in 2019, and do not show a common tendency within the trees. Afternoon slopes in 2020 differed also during the 4 days (132, 172, 132 and 66) being considerably lower in May 23, 2020.

The negative area index (NI) decreased from -669 on May 20, 2020 to -321, 3 days later when trees showed extreme leaf wilting. Peaks crossing zero were present during all days after May 21th and are depicted by a red circle in Figure 5B. MND values with maximum trunk shrinkage were of -17.8 and -11.8 µm during May 21 and May 23, respectively. Maximum air temperature was not correlated with MND peaks. Within the NI area of May 23, 2020, more of the trunk measurements were zero or positive due to limited soil-water.

Figure 5. Air temperature and trunk diameter signatures from May 20 to May 23 for (A) DI and RDI-2 trees, (B) trees under water stress and (C) trees flowering and under fruit drop. *NI integration area for RDI2-2020; ** NI integration area for str20 during 2020; *** NI integration area for fruit during 2020.
Stressed trees showed a 50% reduction of pea-size fruits by May 15 in both years. Although fruit-drop is lower in RDI treatments, under complete water removal only one marble size fruit remained in three trees by May 20, 2020; null fruits were found in the other seven trees. REVIEWERS: PARAGRAPH ADDED.

Trunk Measurement during Fruit Growth

As mango entered its development stage, fruit drop decreased being only eight fruits dropped during this stage with RDI-1 in 2020. Fruits reached its final size by June 25, 2020, 15 weeks after full bloom. In the last week of June, mango CV Kent start the maturation process and were picked by the second week of July. ANOVA was unable to show significant differences in mango fruits per panicle just before harvest on July 9 of both years. However, in both years, RDI-1 showed the maximum number of fruits per panicle but it was not enough to provide the higher yield per tree. During all the month of June 2019 and 2020, only one mango was missing per panicle (Table 3).

REVIEWERS: ADDED PARAGRAPH FROM ANALYSIS from Tables 2 and 3.

DI irrigated trees produced the highest average yield during 2019 and 2020, being significant and presenting an average yield of 8.4% and 48% greater than trees with RDI-1 and RDI-2 treatments, respectively, during 2019. In 2020, the yield difference between DI and RDI-2 was still higher (56.5%). In terms of the average number of fruits per tree, it was found a significant difference according to the irrigation system used. Fruit average weight harvested in 2019 varied from 729.3 g to 715.5 g for the DI and RDI-2 treatments, respectively (Table 2). With a higher amount of water (DI) during both seasons, “Kent” trees produced heavier fruits and differed significantly with respect to deficit irrigation treatments; Fruits were lighter in 2020 than during 2019 (Table 2). Daily irrigated trees in 2020 presented more fruits per tree (52.5) with a higher average fruit weight of 658 g (Table 2); average mango weight was of 591 g with RDI-2 in 2020. These results differ from mango cv. Osteen where RDI (50%ET) result in higher yields than 100% ET irrigated trees; RDI (50%ET) trees in Spain produced more fruits per tree and weight was almost similar (Durán et al., 2011). Water use efficiency (WUE) in 2019 was significantly influenced by irrigation treatment (p <.05), varying from 5.2 kg m⁻³ with DI to 10.9 kg m⁻³ with RDI-2. WUE was significantly higher with the RDI-2 treatment and lower with increasing amounts of irrigation water; WUE was 48% higher with RDI-2 than with DI in 2020.

With cloudy and rainy days, NI values changed during June and July; irreversible growth occurs in end of June and beginning of July (Figure 4D). Daily irrigation NI values from June 23 to July 5, 2020 decreased from –1260 to –1100, due to precipitation (Figure 4A). Fruit presence and RDI treatments effect on diurnal dendrometer fluctuations was insignificant. Irrigation treatments were removed during rain so MS was similar for all irrigation treatments. Even with water available in the soil, the presence of clouds and poor irradiation closed leaf stomata. Fruiting increases photosynthetic capacity after decreasing during flowering, but total chlorophyll content of the irrigated plants was half of non-irrigated plants (Faria Silva et al., 2019). REVIEWERS: FROM DISCUSSION During a rainy event between 5th of June and 18th of June 18 of 2019, NI values decreased; NI values also decreased with cloud in the first week of June 2020.

MND reached its minimum value of –35.8 (Figure 4C) in June 11, 2020, but during 2019 MND was almost constant. MCD values for all treatments were similar during the rainy events in both seasons (Figure 5A). MXD difference between RDI-2 and DI was insignificant due to soil-water availability (Figure 6B); during raining events irrigation was shut-off. At the end of the fruit growth period, MS with DI was of –399 ± 7.1 and –431 ± 10.3 for the 2020 and 2019 season, respectively (Table 4). MS with the RDI-2 treatment in 2020 was of –409 ± 5.9 (Table 4). MS on the cloudy day of June 20, 2020, finished when the solar radiation overpassed 75 W m⁻², being the air temperature 31.3°C.

In the sunny day of June 21, when morning slope ends, air temperature reaches 35°C and the solar radiation 250 W m⁻². Afternoon average slopes were of 326.5 ± 10.7 and 261.5 ± 7.3 during the 2020 and 2019 season, respectively. In a sunny day (June 21th, 2020; Figure 6A), AS started with a radiation of 200 W m⁻² and an air temperature of 34.2°C. This slope finished at 20:00 during sunset with
a radiation of 25 Wm\(^{-2}\) and an air temperature of 28°C. Midday temperature during the rainy days of June 20 and June 23, 2020 was 1.8°C beneath below sunny days like June 21 and June 22, 2020 (Figure 6A).

NI average value during the rainy days for DI-2020 was \(-1154 \pm 10.5\), and for the sunny days of June 21\(^{th}\) and 22\(^{th}\) 2020 2010 was of \(-1289 \pm 17.3\) (Figure 6A). NI average value for RDI-2 trees was of \(-1255.7 \pm 19.5\) and \(-1149 \pm 11.5\) for sunny warm and rainy days (Figure 6B); double asterisk indicated NI values for RDI-2. During 2019, rain was not present in these days and NI average was \(-1242.3 \pm 4.1\).

It was observed a trunk diameter peak at 14:00 during these four days, as the stem shrinked more, taking water to the fruits; a red circle highlights this event (Figure 6B).

**Trunk Measurement Analysis and Correlations**

Punctual measurements were analyzed searching for easier prediction algorithms (Table 5). MXD, NI, MND and MCD values were correlated against minimum daily air temperature \((T_{\text{min}})\) and air temperature at 7:00 \((T_{7})\). The correlations used the values acquired from all the trees under a corresponding treatment (DI, RDI-1 and RDI-2). All the values taken during flowering days were considered in a group and all the values of fruit growth in another. For RDI treatments only the values of the watering day were considered or those with rain.
Table 5. Punctual linear correlation $R^2$ of $T_{\text{min}}$ and $T_7$ against MXD, MND and MCD for each treatment applied to trees at the flowering and fruit growth stages. $R_2$ correlation between $T_{\text{min}}$ or $T_7$ (dew) against MXD, MND and MCD for treatment (DI, RDI-1, RDI-2) applied to trees at the flowering and fruit growth stages.

| Daily irrigation | RDI-1 | RDI-2 |
|------------------|-------|-------|
|                  | Flowering | Fruit | Flowering | Fruit | Flowering | Fruit |
|                  | $T_{\text{min}}$ | $T_7$ | $T_{\text{min}}$ | $T_7$ | $T_{\text{min}}$ | $T_7$ | $T_{\text{min}}$ | $T_7$ | $T_{\text{min}}$ | $T_7$ |
| MXD              | .11   | .48   | .63   | .12   | .09   | .68   | .28   | .09   | .66   | .52   |
| MND              | .08   | .32   | .001  | .06   | .006  | .12   | .08   | .24   | .19   | .14   | .001  |
| NI               | .23   | .83   | .14   | .12   | .85   | .19   | .24   | .69   | .19   | .31   |
| MCD              | .48   | .79   | .19   | .51   | .81   | .16   | .19   | .41   | .71   | .43   | .2    |

Trees during its fruit growth and maturation stage (June and July) present poor linear correlation $R^2$ between punctual temperature measurements and MND & MCD variables (Table 5). Fruit-bearing trees showed the best correlation of 0.68 between MXD and $T_7$ for RDI-1 (Table 5); measurements were taken during the non-watered day. $T_7$ against MXD presented poor $R^2$ correlation coefficients in trees during its flowering stage. MCD was highly correlated against $T_7$ for DI and RDI-1 treatments during tree flowering. NI presented a $R_2$ correlation of 0.85 with $T_7$ for the RDI-1 treatment during flowering; its correlation with $T_{\text{max}}$ for RDI-1 during flowering was still higher (0.87). However, NI is not a punctual measurement and requires of further processing by the embedded system.

MXD, MCD and MND did not show any correlation against RH and solar radiation. Its maximum value was 0.23 between MND and peak solar radiation. MXD in tomato measurements occurred at 6:00 and was barely affected by climate factors such as solar radiation, vapor pressure deficit (VPD) and relative humidity (RH), but was affected by air temperature (T), where a linear correlation of 0.5 was obtained (Meng et al., 2017). MND could be used as the operative parameter in irrigation scheduling protocols with young trees and MCD for mature trees (Ortuño et al., 2004). In well irrigated lemon trees, day to day MCD values correlated against air temperature and global radiation were of 0.4 and 0.52, respectively (Velez et al., 2007).

**Discussion**

Farmers irrigate mango trees to ensure high yields as flowering and fruit-growth stages take place during the dry season. Irrigation water supply influenced the synthesis of total chlorophyll during the flowering stage (Faria Silva et al., 2019). Net photosynthesis and stomatal conductance were substantially lower in leaves close to inflorescences than in leaves on vegetative shoots (Lu et al., 2012; Urban et al., 2008). Once floral buds started to emerge during March of both seasons, water was applied, and nutrients including phosphorus were absorbed from the soil. Irrigation produced healthy panicles, that ended retaining fruit until harvest. Mature leaves nearby the panicles provides the carbohydrates required during full blooming (20–25th April).

To reviewers: bring last paragraph from line 602

Rapid growth of mango fruits starts 30 days after full bloom and ends 40 days after (Spreer et al., 2009a). Individual mango fruit weight by June 1st of 2020 was $120 \pm 3.2$ g and $117.2 \pm 2$ g for DI and RDI treatments, respectively. By June 22th 2020, mango fruits weighted 470.5 \pm 2.8 g for RDI to achieve 607.3 \pm 2.9 g one week later (Table 2). With our irrigation treatments increased fruit yield was based on a higher crop load rather than larger fruit size; similar results were obtained by Wei et al. (2017). At harvest, fruit weight over 700 g was noted for all irrigation treatments during the 2019-season, being fruit length similar for DI and RDI-1. Average fruit weight with RDI-2 irrigation was 11.8% lighter than with daily irrigation. RDI-2 irrigation shortage may reduce leaf net photosynthesis and limit carbon supply during fruit growth (Damour et al., 2009).
Yield difference with reduced irrigation (RDI-1) is close to the daily irrigated trees yield and sometimes the latter do not present the best production (Cotrim et al., 2011). The RDI system, producer-friendly, irrigated the orchard with 100% ET one day and shut-off the pump during the next day. System air produces water application errors which can become a problem in small periods of time; timing compensation was carried out.

Reduced deficit irrigation (RDI-1 and RDI-2) applied less water through all phenological stages. Water use efficiency (WUE) with RDI-2 irrigation showed the higher value of 10.9 kg m⁻³ in 2019. A WUE of 8.7 kg m⁻³ in 2020 obtained by RDI-1 was higher than the 7.1 kg m⁻³ applied at (RDI 50% ET) mango orchards in Spain (Durán et al., 2011). Lower WUE of 5.2 kg m⁻³ was obtained in our orchard during 2020 with DI. WUE in Spanish trees was lower in DI (100 ET) than in RDI-2 (33% ET), having values of 3.1 and 5.7 kg m⁻³, respectively (Durán et al., 2011).

To reviewers: Add paragraph

Our result presented a higher yield in DI than with RDI-1, being in 2020 of 6 kg tree⁻¹. Yield loss with RDI-1 was not significant, but only half of the water was applied. Although there was a yield difference of 6 kg per tree between DI and RDI it represents a total of 1.5 tonha⁻¹ (250 trees x 6 kg tree⁻¹) in this orchard. If water is not available RDI-1 should be applied. In an experiment with ten-year-old trees in Thailand, yield per tree was of 24 kgtree⁻¹ compared with our 34.6 kg tree⁻¹ with a 100% ET irrigation (Spreer et al., 2009b). It decreased by 86% when 50% RDI was applied, similar to the 83% we obtained. Durán et al. (2011) reported that with a 50%ET RDI, yield increased against 12-year-old trees with 100% ET daily irrigation. The 600 trees ha⁻¹ represent a higher density plantation than ours; An increase of 3.96 tonha⁻¹ was reported during 2007 by using RDI (50% ET) instead of 100%ET irrigation. Our yield of 34.6 kg per tree produced in 2020 was 43.6% higher than the one reported by Durán et al. (2011) after irrigating with 100% ET; trees in Spain presented a higher yield of 7.3% with SDI (50% ET) than our Kent trees. In another experiment with ten-year-old trees in China (Wei et al., 2017), water application was based on replenishment of a given percentage of field moisture capacity. Its maximum water application per tree was 2.95 m³tree⁻¹ being close to our RDI-1 of 3.3 m³tree. Their yield per tree was of 39.7 kg tree⁻¹ and an application of 2.6 m³ tree⁻¹ (close to RDI-2) increased the yield by 3.2%. Fruit yield obtained by an equation using the number of fruits harvested (Durán et al., 2011) showed important differences between trees where fruits were counted and weighted; Variations encountered ranged from 4 to 5 kg/tree.

Daily signature analysis of the dendrometer measurements were done under the different growth stages and irrigation regimes. Trunk diameter decreases as water stored within its tissue starts moving upwards to the leaves or fruits, being detected by the morning slope. The morning slope becomes active together with leaf photosynthesis and transpiration (Faria et al., 2016). An increase in stem radius can be produced by replenishing stem tissues with water, or by newly formed cells (Zweifel et al., 2016), resulting in a MXD value. The negative integral variable (NI) adds all the negative values, corresponding to water movement from the soil to the different tree organs. Some moments during the morning and afternoon slope correspond to water moved from and to the stem, respectively. The effect of water stress in leaf wilting is obvious and measurements with dendrometers can provide an important tool to maintain a healthy orchard.

TO REVIEWERS: Discussion of results from Table 4

During flowering (FL), maximum stem growth (MXD; p < .05) is significantly affected by irrigation treatment, providing greater values with water increase. Variables MND and MCD provided significant differences between irrigation treatments. During fruit drop (FD) the greatest fluctuations of MXD and MND were encountered with higher water application, showing a significant difference with RDI-2; MND increases as the amount of water applied is less. MS is more pronounced during flowering as it absorbs a lot of water at dawn, especially with DI; trees coming out of stress uptakes all the water available in the soil. However, MS during the phenological stages of FD and FG have similar values varying ±13%. Afternoon slopes (AS) increase with reduced water application RDI-2 and RDI-1 treatments. The AS slope in the afternoon during FG, increases more than 50% with the RDI-2 treatment as water moves to the trunk in a short time. The negative index (NI) behavior was
significantly dependent on water quantity. With DI, index values were close to −1200, with RDI-1 NI ranged between −1150 and −1100 and with RDI-2, NI values were below −1100. Considering the NI by season and irrigation time, the dendrometers measurements can be considered stable. With the application of DI, measurements varied by ±1.6% between flowering and harvest; for RDI-1 it was ±1.65% and for RDI-2 it was ±5.2%. The latter variations come from the rainy season, as measurements vary from −1087 in FG to −982 in FL.

MCD and NI were the dendrometer variables with higher fluctuations during flowering. MCD daily growth is explained by cell division and enlargement caused by the activity of the cambium (Zweifel et al., 2016). The average MCD value of 71.9 ± 2.7 μm with DI on Table 4 does not resemble its behavior during the flowering stage, as MCD increased daily since middle of March (MCD = 55) until full bloom (Figure 5C). The higher MCD was noticed in those trees having more flowers during April 24th of 2020. With the beginning of the flowering period at March 15th of 2020, trees end with the stress period, and stem tissues start swelling. New cell division produces an irreversible stem growth (Figure 4D), being the higher during the flowering-fruited stages. Growth of the trunk tissue (MCD) helps to transport soil nutrients during flowering and fruit-set.

MND stem diameter shranked more in DI trees than in deficit watered (RDI-2) trees during both seasons at full blooming. This effect during flowering is due to higher photosynthetic rates of full irrigated mango trees (Faria et al., 2016) than trees subjected to deficit irrigation. Photosynthetic rates were 2.36 times higher early in the morning (8:00) than at solar noon at 14:00 (Faria et al., 2016), so we believe that a higher nutrient transport takes place during the morning slope mainly during full bloom. During warm and sunny days, morning slope became steeper, but; trees having less flowers presented a gentler MS. The trunk shrinkage peak observed in the dendrometer signature from 12:00 to 14:00 can also be related to stomata closure when air temperature surpasses 33°C. In both reduced irrigation treatments (RDI-1 and RDI-2), a step after 22:00 appeared in non-irrigated days (Figure 3D). Larcher (2003) explained that if stem tissues are not fully watered, due to short water availability, it will take a longer time to saturate and fill the tissues by midnight.

Irrigation treatments have a marked influence on fruit-set per panicle (Sarker and Rahim, 2013), and an increase in fruit drop can be related to low soil moisture (Spreer et al., 2009b) and to severe drought (Singh, 2005). In both production seasons, best fruit-set per tree was achieved with RDI-1 irrigation. One month after full bloom in the 2020 season, 37.9% of the fruit continued growing. Fruit drop is induced by factors that reduce carbohydrate supply to growing fruits (Léchaudel et al., 2005; Whiley et al., 1999; Wünsche and Ferguson, 2005; Yamada et al., 1996). High air temperatures exceeding 36°C in May 2020 affected the photosynthetic processes in mango and reduced carbohydrates needed for fruit-growth. Increased transpiration rate reduces fruit surface temperature in irrigated mango trees.

We considered that by lowering air and leaf temperature, fruit drop would decrease. A neutral polypropylene shading net (Bartex 90%, Artes Politecnica SrL, Italy) covered the canopy of 3 daily irrigated trees during the first week of May; the net was fixed to a steel structure 2 m over the canopy. Limited capture of solar radiation by the leaves, dropped foliar temperature at midday by 2.5°C, meanwhile air temperature over the canopy decreased by 2°C. Pinhole-size fruit drop decreased significantly by 25% with respect to the seven non-shaded trees. On a clear day, photosynthetic rate and stomatal conductance values of shaded leaves increased sharply in the early morning and remained high between 09:00 and 11:00 (Jutamanee and Onnom, 2016). Although it can increase yield, its investment is costly and other environmental changes should be considered.

Leaf transpiration decreases in crops under water stress, being stomatal closure activated by signals emitted from the roots (Faria et al., 2016). Water is hold inside the trunk, decreasing CO2 assimilation and crop yield; leaf water potential varies according to soil humidity. In soils with high water-holding capacity, daily sap flow declined to 85% when VWC fell below 15% (Lu, 2002). Complete water stress in 10 trees during 2020 began the 13th of May. Trees that did not received water after 8 days, lost all the marble-size fruits hanging from the panicles. If trees are rewatered and panicles removed, new floral
buds appear after 2 weeks in the same node; we believe that stressed trees without strong damage begin to reproduce. Five trees were stressed 5 days more, leaves wilted and those trees never flowered again in the entire 2020 season.

During stress periods in May 2019 and 2020 when maximum daily stem size decreased notably over successive days, it was noticed that the insufficient water in the soil could not recharge the stem overnight. VWC was of 0.1 cm$^3$ cm$^{-3}$ after four days and of 0.05 cm$^3$ cm$^{-3}$, four days later in 2020; upper zones of the soil were drier. In the first day of Figure 5B, there was still water in the soil and shrinkage was not as critical as during the next three days; several peaks were noted in the 10:00–15:00 NI interval. After rainfall and continuous watering, MCD increased all days, and the tree stem experienced an irreversible growth, losing its elasticity. Dry periods occur when tree water is not balanced over 24 h, so stem tissues are not able to re-saturate its tissues overnight (Larcher, 2003). Trees with deeper roots recovers quicker from water stress, depending on its severity and on the amount of water supplied for rewatering.

The period of fruit growth and maturity on June and July presented rain events and cloudy days. On rainy days, transpiration drops due to lower solar radiation, temperature and VPD. Fruiting increases photosynthetic capacity after decreasing during flowering, but total chlorophyll content of the irrigated plants was half of non-irrigated plants (Faria Silva et al., 2019).

Just after an afternoon and night strong precipitation of 210 mm, MXD was 17.9 µm; lack (Figure 5B) and excess water stress the trees. However, two days after, MXD increased to a maximum value of 59.6 µm, producing an irreversible growth within the stem (Figure 4D). Afternoon slopes with fruits growing were steeper (410–425) than under fruit-drop or flowering stages as flow is transported to the fruits (Table 4). We believed that nutrients and water are transported to the fruits in the afternoon. Three trees were covered with a shade during the second week of June, reducing air and leaf temperature at midday by 2°C and radiation by 50%. The NI signature pattern after 15:00 remained as marked by the red circles of Figure 6B, so nutrients and water were flowing through the stem.

Fruit growth pattern was not affected by the irrigation regime or by alteration bearing. Even though alternate bearing was observed in the orchard, it was not possible to see crop load being significantly affected by the irrigation treatments; Similar results were mentioned by Spreer et al. (2009a). Absolute fruit growth has been studied in other fruits, showing a decrease from midnight until sunrise and achieving a minimum value at 14.00 due to transpiration (Schroeder and Wieland, 1956; Zibordi et al., 2009). Afterward, fruit starts to grow and reaches its maximum value around sunset (19.00 h). Fruit shrinkage results from water being lost by transpiration and by xylem backflow to the leaves. It has been reported that the amount of carbohydrates available for stem growth in peaches is reduced during the fruit growing stage (Grossman and Dejong, 1995).

**Conclusions**

It can be concluded from these measurements, that RDI-1 trees provided a similar yield than DI full-irrigated trees, but with 50% less water. The data analysis and discussion from each phenological stage, gives a better understanding of RDI-1 performance, during flowering and fruit drop stages. Tree yield would increase, avoiding any kind of stress, if full irrigation is provided in the period from full bloom to pinhole-size fruit. After fruits achieve its marble-size, irrigation should be switched from DI to RDI-1. Dendrometer values fluctuated with rain, being difficult to interpret. Therefore, if rain events are present, irrigation should be turned off and fruit final size controlled. Mango fruits weighting 750 g each, were difficult to sell in local supermarkets.

Important dendrometer measurements to be considered per stage are shown in Figure 7. As floral buds appear, irrigation should be applied as trees leave their dormant-stress stage, and trees will increase their diameter (MCD) with an irreversible growth. The NI value for RDI-1 trees should be between −1100 and −1200 and the morning slope among −420 and −430. This MS value is important as it assures the tree will be ready to transport the transport of nutrients from the soil, including
phosphorus to the reproductive organs and flowers. During the fruit-drop stage, days and nights are warmer, and leaf temperature increases. If leaf temperature can be controlled by shading or further irrigation, more fruit will be retained. MXD should never be lower than 35, otherwise trees will be stressed. If MXD stays over 45, during fruit growth and maturation, no irrigation will be needed; irreversible growth will take place with MXD > 55. It is essential that AS is over 420 to assure water uptake to growing fruits.

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