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Yield in a Haden mango orchard controlled by micro-sprinkler irrigation systems

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Abstract

Mexico is the world's leading exporter of mango and needs to produce high quality fruit. A Haden mango orchard was irrigated using an automatic sprinkler system placed between the rows of trees. Groups of micro-sprinklers were placed at the ends of the tree crown and irrigation was applied every 2 d for 0.5 h periods. This study analyzed the effect of irrigation with only two, three or four micro-sprinklers per tree, providing yield, firmness, soluble solids content, acidity and fruit weight per tree. Since trees did not have the same morphology and biological characteristics, there were changes in yield, ripening and fruit size. Root content helped to determine how many sprinklers to install per tree, the ideal area where fertilizer should be dosed, and the correct place to measure soil moisture. By applying water all around the tree, a delay in production was observed and premature mango drop was avoided.

Keywords: Quality, root content, Haden mango, Micro sprinklers, yield.

Introduction

Mango (*Mangifera indica* L.) was the sixth most produced fruit worldwide in 2019 (56 million tons per year), being surpassed by bananas, apples and grapes (FAOSTAT, 2021). Mexico, with a production of 8.98 $t \cdot ha^{-1}$, is doing a good job to increase exports that include Kent, Keitt, Haden and Ataulfo varieties. Organic practices have been implemented in the country with more than 110 000 farmers (FAOSTAT, 2021).

Currently, agriculture consumes 70 % of available freshwater and the challenge is to produce the same amount of fruit using less water. The use of good irrigation and fertigation practices ensures fruits with high quality, good size (> 300 g) and ideal income in a mango orchard (Schulze, K., Spreer, W., Keil, A., Ongprasert, S., & Müller, J., 2013). Deficit irrigation (DI) has been widely used in Spain in several mango orchards, including Gomera-1 variety (Lipan et al., 2021), as well as regulated deficit irrigation (RDI) and partial root zone irrigation (PRI). Spreer, W., Ongprasert, S., Hegele, M., Wünsche, J. N. and Müller, J. (2009) reported that mangoes grown under RDI conditions increased total soluble solids (TSS) after 6 d of ripening. In experiments conducted in Egypt during 2015 and 2016, Aly, M. A. M., Abdel-Nasser, G., Ismaeil, A. A., and Bayoumi, G. F. M. (2018) reported that mangoes grown under RDI conditions increased total soluble solids (TSS) after 6 d of ripening. In experiments conducted in Egypt during 2015 and 2016, Aly, M. A. A. M., Abdel-Nasser, G., Ismaeil, A. A., and Bayoumi, G. F. M. (2018) reported that irrigations corresponding to 100 % ET (evapotranspiration) increased yield, fruit weight, number of fruits per tree, and fruit firmness compared to deficit irrigations of 75 and 50 % ET.

Fruiting period is very sensitive to water stress, being critical during the first six weeks. With good water management, high yields and excellent quality can be achieved. Quality is affected by changes in environmental conditions during ripening and storage, showing variations in total soluble solids (TSS) content, pH, carotenoid content, and sugar to acid ratio (Abu, M., Abbey, L. D., & Amey, N. K., 2021; Galán-

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Sauco & Lu, 2018). Consumers of exported Haden variety mangoes treated with hot water detected excellent aroma, high fiber content, and bitter taste when the fruit was very firm. As Haden mangoes softened, they developed greater sweetness and juice, but decreased their acidity (Nassur et al., 2015).

In periods with low rainfall, growers have been forced to acquire automated irrigation systems that control the amount of water applied. Micro-spray irrigation reduces water consumption and increases crop yields (Wei, J., Liu, G., Liu, D., & Chen, Y., 2017). This water mist application system is effective, but its distribution is not always uniform, with many variables that affect it (Koumanov, K. S., Hopmans, J. W., & Schwankl, L. W., 2006). This research determined yield, size and weight of mango fruit when using different micro-sprinklers irrigation on the periphery of the tree. An analysis of the root revealed the area to be irrigated.

Materials and Methods

The experiment was conducted during 2020 in a mango orchard located in Loma Bonita, Guerrero (17° 25' 47" N, -101° 11' 19" W, 17 masl). The orchard soil had a clay loam composition and 40 35-year-old trees from the variety Haden arranged in four rows were selected. Tree management included conventional pruning, irrigation and fertilization practices. The automatic system considered for the experiment was one using micro-sprinklers, because it requires less energy and, operates with low pressure ranges (1-3 $kg.cm^{-2}$) and a discharge of 120 $L \cdot h^{-1}$. Micro-sprinklers are highly desirable because fewer sprinkler heads are required to cover a large area.

The experiment consisted of four groups with different irrigation each; three of them used micro-sprinklers and the control used a hose to wet superficially all the soil under the periphery of the tree. Micro-sprinklers are emitters that spread water through the air. These sprinklers are attached by tubing to side pipes located on the periphery of the tree crowns (Figure 1a). Each sprinkler was mounted on a support stake at a height of 25-30 cm (Figure 1c), for the water mist to move and cover the maximum irrigation area (1.5 m radius). Each micro-sprinkler treatment consisted of 10 trees each and differed in the number of sprinklers per tree and their positioning. Trees of the first experiment EXP1 had four 120 $L \cdot h^{-1}$ sprinklers on their periphery (Figure 1ª and Figure 3). Three and two sprinklers, respectively, were placed on the outline of trees of experiments 2 and 3 (EXP2 and EXP3) (Figure 1a). The micro-sprinklers showed the same flow rate than those in EXP1 (Figure 2 a). In experiments EXP1, EXP2, and EXP3, water was applied for half an hour every 2 d, with each tree receiving 200, 150, and 100 L, respectively. The control was irrigated with a hose (Figure 2 b) and supplied 300 L every 2 d to each of the 10 trees.

Each experiment counted the number of days after fruit set (DAFS), which corresponds to the period between fruit emergence (pin size) after flowering until harvest. The number of fruit set per tree was counted on July 1 and 15, 2020. When fruit were cut, length and weight of each fruit were measured to calculate yield per tree. Fruit firmness was measured one day after cutting on 20 randomly selected fruits per treatment and the maximum force (N) required to break the fruit peel corresponded to firmness of the peel. Measurement was performed using a texture analyzer (model TA + HDi, Stable Micro Systems, UK) equipped with a 50 kg load cell and a 2 mm diameter stainless steel probe (Jha, S. N., et al., 2010). Total soluble solids (TSS) content, expressed in °Brix, was measured with a portable digital refractometer (mod HI96801, Hanna Instruments, USA). Measurement was made after placing a drop of mango pulp juice in the window of the device. Titratable acidity was determined by the AOAC method 942.15 (AOAC, 2000) and pH by the AOAC method 981.12/90 (AOAC, 2000) using a digital potentiometer (Mettler Toledo S40). A total of 20 mangoes were used per treatment for all these qualitative measurements. The SAS package was used to perform statistical analyses using averages and ANOVA.

Once the experiment was completed, two trees were randomly selected, and soil was carefully removed from the trunk to the tree outline (Figure 4). A 0.3 m × 0.3 m grid was used as an outline to take photos with a cell phone. Data was processed and segmented using the Fiji program based on ImageJ to count branches and root length. Fiji is an open-source software to introduce new algorithms for biological image analysis to ImageJ (Schindelin et al., 2012).

Results and Discussion

A tree irrigated with a hose (Figure 2 b) had a greater number and larger mangoes (Table 1) than those harvested from a tree irrigated with four micro-sprinklers (Figure 2 a). The increase in fruit yield with irrigation is due to less fruit drop (Spreer, et al., 2009). The average area flooded by the hose under the canopy was 62 m^2 (π*4.5 m^2), while the area irrigated by the four micro-sprinklers covered 28.2 m^2 (4*π*1.5 m^2), which corresponded to a deficit irrigation of 45 %. The latter irrigation is not uniform because there are areas which are not wetted. In the study on Kent mango fruits, soil moisture was measured with sensors and branch contraction-expansion with dendrometers (Hahn, 2021). Branches above the sprayed (wet) areas showed a good fruit yield and had contraction-expansion of 0.12 $mm \cdot d^1$. Daily branch growth above the area without soil moisture was half and the trunk provided carbohydrates and water.

Table 1 shows yield and average fruit size for each irrigation option (hose and DI-sprinkler). Trees with less sprinklers (EXP3) produced 80% less mangoes. When marketing mangoes to Europe, fruit weight should not be

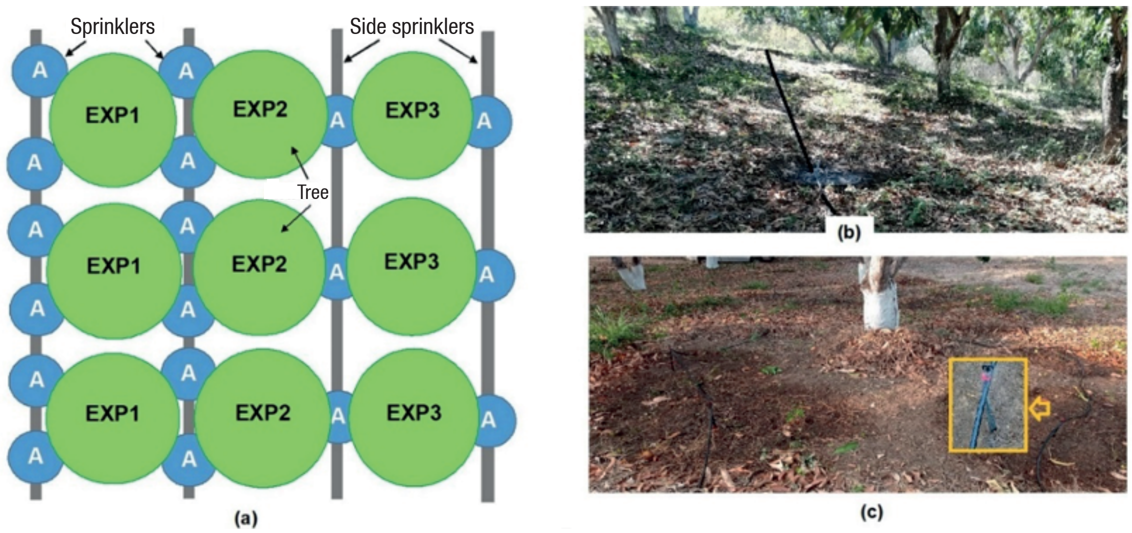

Figure 1. (a) Side pipes with different number of micro-sprinklers for each experiment for mango trees; (b) side pipe among trees; and (c) micro-sprinklers placed around the tree.

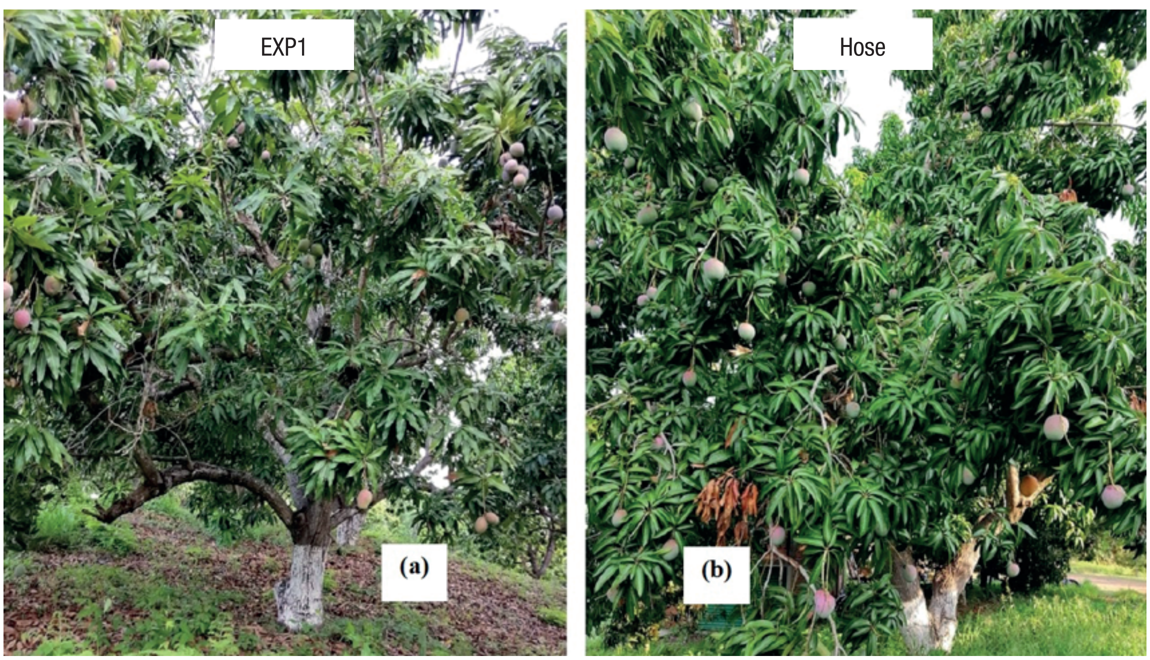

Figure 2. Mangoes in the tree using irrigation (a) with four micro-sprinklers (EXP1) and (b) with a hose.

less than 200 g (Kader, 2008). Mangoes should be classified according to their weight in three categories: A (200-350 g); B (351-550 g) and C from 551 to 800 g. A mango can never exceed 925 g (Kader, 2008). Domestic fruit traders consider top quality fruit to be above 450 g and regular fruit to be between 350 and 450 g. First quality fruit was only obtained from irrigation with a hose, and mangoes harvested from EXP2 and EXP3 were not within the limits considered for marketing. The number of mangoes in experiments 2 and 3 was similar, although fruit size was 13.7 % larger for the three sprinklers (Table 1).

A negative correlation between number of fruits on the tree and average fruit weight was found (Table 1). The relationship between fruit length and fruit diameter was similar for the different treatments during fruit development (Lipan et al., 2021). Drought induces fruit drop at the late stage and reduced fruit mass due to a decrease in fruit size and cell number (Singh, 2005).

It is almost impossible to put all pipes according to the particular topology of each tree in an automated irrigation system. Yield according to the position of the tree in rela-

Table 1. Tree yield, average length and weight per fruit and quantity harvested on July 1 and 15, 2020.

	Yield	Fruits			
	(kg·tree^{-1})	Lenght (cm)	Weight (g)	Quantity July 1, 2020	Quantity July 15, 2020
EXP 1	25.9±3.2^{a}	8±1.5^{a}	370±11.8^{a}	20±5^{a}	45±5^{a}
EXP 2	16.5±3.2^{a}	7.5±1.1^{b}	323±7.8^{a}	18±4^{a}	33±9^{b}
EXP 3	11.2±3.2^{a}	7.2±0.7^{ab}	282±8.8^{a}	8±3^{b}	34±8^{ab}
CONTROL	57.1±10.2^{b}	12.4±0.7^{c}	580±14.2^{b}	5±3^{b}	90±8^{c}

Values with the same letter, within the same column, are statistically equal, according to the Tukey test ($P \leq 0.05$).

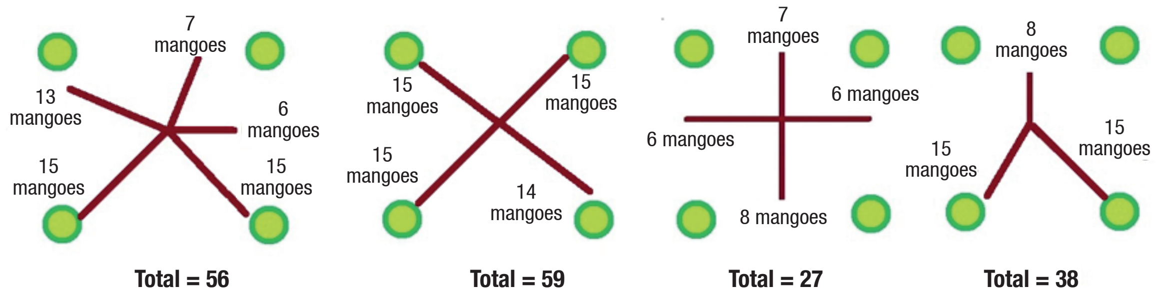

Figure 3. Productivity of mangoes per branch with four sprinklers and different tree topologies.

tion to water application point is shown in Figure 3. Yield decreases as soon as tree branches do not coincide with the irrigation zone. For example, 59 fruits were harvested on the tree where all four branches coincided over the sprinklers, which is more than double the number of mangoes (27) harvested when branches were no coincident.

Similar to yield, irrigation influenced fruit quality. Peel firmness showed no significant variation on the first day (Table 2), but after one week had considerable variations. Peel firmness of mangoes harvested in the first week of July was higher than that of late mangoes (July 15, 2020) as mentioned by Jha et al. (2013). This may be due to less water in fruits from trees irrigated with three and two sprinklers (EXP2 and EXP3). Fruit with lower TSS had the highest amount of water and the sweetest fruit from EXP3 (Table 2), being similar to the Ataulfo mango, which is sweeter and smaller. This corresponded to the results reported for Osteen mango (Durán Zuazo, V. H., Pleguezuelo, C. R. R. R., & Tarifa, D. F., 2011), with greater accumulation of sugars in fruits, which received a smaller amount of water. pH showed higher acidity in fruits with 100 % ET irrigation, tending to a more neutral value of 5.1 in EXP3. As for acidity, it was higher with irrigation with a pipe and lower in EXP2. This result coincided with that reported by several researchers (Durán Zuazo et al., 2021). However, Aly et al. (2018) worked with Keitt mangoes and had higher TSS and acidity values when more water was applied.

The ground below the canopy has the finest roots of the tree buried and scattered between 0.5 and 5 m (Figure 4 a) from the trunk. These roots, whose diameter varies between 0.55 and 2.05 mm, are the main contributors to the absorption of water and nutrients. The fine roots have 9 % of the root content in the first longitudinal meter from the trunk (Figure 4 b). This figure shows that the highest root concentration (76 %) is found at a distance from the trunk ranging between 2 and 3.5 m. The area with micro-sprinklers irrigation has 15 % root content. These fine roots represent 75 % in the area with no moisture and 80.5 % for the area with moisture around sprinklers, as reported by Santos, M. R. dos, Martinez, M. A., Donato, S. L. R. and Coelho, E. F. (2014). In non-irrigated areas, root content decreased and some roots died as a consequence of soil water stress, which, by finding the highest root concentration at a distance of 2.50 m from the trunk, represents the place where the moisture measurement sensor should be placed. The soil has a layer of tepetate at a depth of 60 cm, making it difficult for the fine roots to penetrate. As the roots develop more densely between 2 and 3 m, it is recommended to apply fertilizers (green box) in a 20 cm deep hole in the soil. The circle with red line, in Figure 4 b, shows the area to be wetted by the micro-sprinkler.

After viewing the root content image, it was concluded that a single side pipe cannot be used to irrigate two columns of trees (Figure 1 a). Side pipes should pass 2.5 m from the trunk and have three sprinklers in each half of the canopy. This ensures that the entire area with root content is wet. The introduction of micro-irrigation has a payback time of less than five years, and the use of partial root zone irrigation (PRI) is the most economical system (Satienperakul, K., Manochai, P., Ongprasert, S., Spreer, W., & Müller, J., 2009). For the future, it will be necessary to analyze electrical resistivity patterns in the root

Table 2. Firmness, TSS, acidity, pulp pH and days after fruit set for each irrigation treatment.

	DAFS (d)	Firmness (N)	SST (° Brix)	Acidity (g)	pH
EXP 1	112	32.2 ± 1.8^{a}	17.8 ± 0.3^{a}	0.32 ± 0.01^{a}	4.2 ± 0.1^{a}
EXP 2	112	36.5 ± 0.3^{a}	18.3 ± 0.1^{b}	0.39 ± 0.01^{a}	4.8 ± 0.1^{a}
EXP 3	112	36.4 ± 0.5^{ab}	18.4 ± 0.3^{ab}	0.45 ± 0.01^{a}	5.1 ± 0.1^{a}
CONTROL	125	34.4 ± 1.9^{ab}	16.2 ± 0.8^{a}	0.48 ± 0.01^{a}	3.7 ± 0.1^{a}

DAFS: Days after fruit set; values with the same letter, within the same column, are statistically equal, according to the Tukey test ($P\leq0.05$).

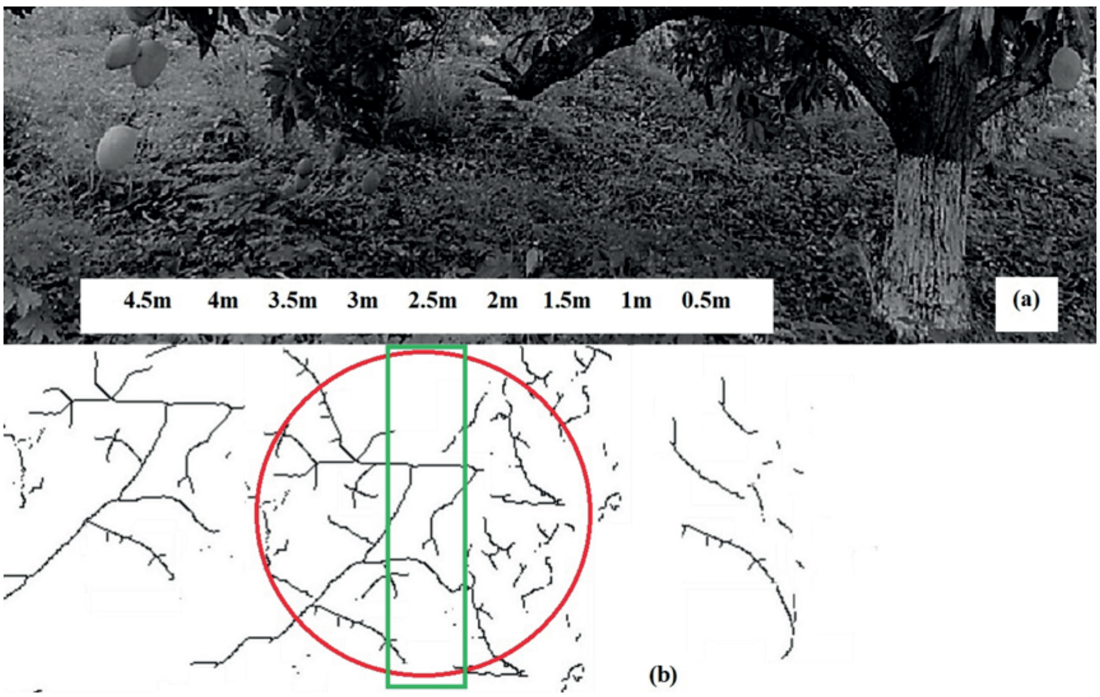

Figure 4. Mango tree with (a) leaves and fruit growing along the branch, and (b) fine root concentration at 10 cm depth.

zone resulting from different irrigation strategies. Italy tested this system with oranges irrigated by RDI, showing variations in the order of 10 Ω*m in electrical resistivity, depending on the presence of water (Mary, B., Vanella, D., Consoli, S., & Cassiani, G., 2019).

Conclusions

The best yield and quality were reached with 100 % ET irrigation and homogeneously under the area delimited under the canopy. When using deficit irrigation and without covering the entire area with sprinklers, low size and lower quality mangos were produced. Deficit irrigation applications with micro-sprinklers had different yields according to the topology of the tree. Moreover, the number of sprinklers per tree has an effect on size, quantity and ripening time. Trees irrigated with less micro-sprinklers produced small mangoes, with high TSS, acidity and pH. Since the highest root content is 2.5 m from the trunk, it is necessary to center the side pipe, the micro-sprinkler and apply fertilizers in that region.

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