Evaluation of microirrigation levels for growth and productivity of avocado trees[1,2]

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J. Agric. Univ. P.R. 93(3-4):173-186 (2009)

ABSTRACT

Avocado (*Persea americana* Mill. cv. Simmonds) is an important fruit among consumers in Puerto Rico and in the Hispanic community in the United States. During the last years, orchard establishment has increased considerably in Puerto Rico, where production of this fruit is third behind mango and oranges. Currently growers need to deal with lack of information on proper irrigation management in orchards under conditions observed in Puerto Rico. Typically, growers are encouraged to adopt an irrigation scheduling method to ensure tree establishment and adequate productivity, and thus to reduce problems associated with improper irrigation management. The Universities of Puerto Rico and Florida recommend the use of tensiometers to schedule irrigation for fruit trees. An avocado orchard was established during 2001 for evaluating the effect of soil water tension measured by tensiometers on growth and productivity of avocado trees under microirrigation. The predominant soil series at the experimental site is Coto clay, classified as Typic Eutrustox. Planting distance was 9.1 m × 9.1 m. Trees were submitted to two microirrigation treatments scheduled by using tensiometers installed at 30-cm and 45-cm depths. Trees were irrigated when tensiometer readings reached a low depletion level (10 to 15 kPa) or a high depletion level (40 to 45 kPa). A rainfed treatment was included as check. Variables measured were canopy volume, fruit weight and number, and irrigation applied. Canopy volume of trees growing under rainfed conditions was significantly lower than that of trees submitted to either 10 to 15 kPa or 40 to 45 kPa microirrigation treatment. Trees submitted to 40 to 45 kPa showed the maximum canopy volume, 148 m^3/tree, which was not significantly different from that of trees submitted to 10 to 15 kPa. Only in 2005, trees irrigated at low depletion levels produced 68 fruits per tree, an amount which was significantly greater than that of the other two irrigation treatments. In general, avocado trees submitted to high depletion level significantly increased their growth and yield.

[1]Manuscript submitted to Editorial Board 25 March 2008.

[2]The authors thank Edwin Monroig for experiment management and data collection, and Miguel Vázquez for determining the water retention curves in the Soil Physics Laboratory at Río Piedras, University of Puerto Rico. This research was initially funded by a special project grant (SP-329) from the University of Puerto Rico and was continued with funds of a Hatch Regional grant H-402 (W-1128).

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Key words: microirrigation, evapotranspiration, tensiometers, avocado

RESUMEN

Niveles de microriego y su efecto sobre el crecimiento y productividad de árboles de aguacate

El aguacate (*Persea americana* Mill. cv. Simmonds) es una fruta de mucha importancia en Puerto Rico y en la comunidad Latina en los Estados Unidos. En los últimos años, el establecimiento de huertos de aguacate en Puerto Rico ha aumentado considerablemente; la producción de esa fruta se colocó tercera, después de la de mango y la de las chinas. Para asegurar el establecimiento de los árboles, la productividad y la reducción de los problemas asociados al manejo inapropiado del riego, se promueve que los productores adopten algún método para calendarizar el microriego. La Universidad de Puerto Rico y la Universidad de Florida recomiendan el uso de tensiómetros para calendarizar el microriego en árboles frutales. En el 2001 se sembró un huerto de aguacate para establecer un experimento para evaluar el efecto de la tensión hídrica, medida con tensiómetros, en el crecimiento y productividad de árboles de aguacate bajo microriego. La serie de suelo predominante en el predio experimental es Coto arcilloso, clasificado como Typic Eutrustox. La distancia de siembra de los árboles fue de 9.1 m × 9.1 m. Los árboles se sometieron a dos tratamientos de microriego calendarizados utilizando tensiómetros instalados a 30 y 45 cm de profundidad. En ambos tratamientos, los árboles se regaban cuando la tensión hídrica del suelo alcanzaba los valores críticos predeterminados, entre 10 y 15 kPa y entre 40 y 45 kPa. Se incluyó un tercer tratamiento sin riego como testigo. Las variables utilizadas para medir la respuesta de los árboles a los tratamientos de microriego fueron rendimiento, volumen de la copa, número y peso de frutas por árbol, y la cantidad de riego aplicada. El volumen de la copa de los árboles a los cuales no se les aplicaba microriego fue significativamente menor que el de los árboles con los dos tratamientos de microriego probados. El volumen de la copa máximo registrado fue de 148 m^3/árbol, obtenido cuando la tensión hídrica del suelo alcanzaba de 40 a 45 kPa; éste no fue significativamente diferente al obtenido cuando se regaba a 10 a 15 kPa. El rendimiento más alto fue 84 kg/árbol y se observó en los árboles regados cuando la tensión superaba los 40 a 45 kPa. Solo en el 2005, el número de frutas por árbol en el tratamiento 10 a 15 kPa superó significativamente a los demás tratamientos, con 68 frutas por árbol. En términos generales, los árboles de aguacate sometidos a una tensión hídrica en el suelo de 40 a 45 kPa produjeron significativamente mayor crecimiento y rendimiento.

Palabras clave: microriego, evapotranspiración, tensiómetros, aguacate, cv. Simmonds

INTRODUCTION

Mexico, Chile and the United States dominate avocado production worldwide, with Mexico being the largest producer, supplying over one-third of the world total production (WHTUSEO, 2006). In Puerto Rico, avocado is becoming a major commodity among fruits because of favorable growing conditions and the potential for obtaining high yield and high fruit quality. Factors such as avocado diseases, inadequate orchard management, and poor edaphic conditions limit avocado production in northwest and southwest Puerto Rico. Limited information is available on avocado growth and yield response as influenced by irrigation. For example, improper management of irrigation may increase the incidence of *Phytophthora cinnamomi* in the root system or may cause nutrient losses through the soil profile. The goal of an irrigation-scheduling program is to provide growers with guidelines for timely and adequate irrigation to increase yield. Through proper irrigation, it should be possible to apply the amount of water that matches crop evapotranspiration, thus reducing water and nitrogen losses.

The University of Puerto Rico and the University of Florida recommend the use of tensiometers to schedule irrigation (Goyal, 1989; Li, 2000). In Puerto Rico, research in irrigation has been oriented mostly toward fruits such as banana and papaya and toward vegetable crops (Goenaga and Irizarry, 1995; Goyal, 1989). In California and Florida, research on irrigation has been conducted mostly on avocado management and production. However, differences in soil and climate conditions make difficult the transfer of all of this information to Puerto Rico. Providing local avocado growers with accurate information on the amount of irrigation needed, and on expected yield and growth responses, requires further research. Thus, the objective of this research was to evaluate the effect of soil water tension on growth and productivity of young avocado trees grown on an Oxisol in Puerto Rico, with microirrigation.

MATERIALS AND METHODS

An avocado orchard was established at the Isabela Agricultural Experiment Substation located in Northern Puerto Rico (18°27'N and 67°03'W). The soil series at the experimental site is a well-drained, very fine Oxisol, kaolinitic, isohyperthermic Typic Eutrustox (Beinroth, 2003), with the following chemical characteristics: pH, 5.3; organic matter, 2.7%; Zn, 2.4 mg/kg; Mn, 112 mg/kg; Fe, 6 mg/kg; Cu, 8.9 mg/kg; P (Bray 1), 19 mg/kg; K, 252 mg/kg; Ca, 960 mg/kg; Mg, 47 mg/kg; and CEC, 8.5 cmol/kg.

Avocado trees (*Persea americana* Mill. cv. Simmonds) grafted on 'Gripiña' rootstock were planted 4 October 2001 at a distance of 9.1 m × 9.1 m. Trees were submitted to a formative pruning during the first year to induce lateral branching and a single trunk within the first meter. Branch pruning continued every year after harvest. Other management practices followed the recommendations of the Technological Package for Avocado Production (AES, 1998). Cultivar Simmonds belongs to the West Indian race and produces a green fruit, with an average fruit weight ranging from 450 to 950 g. Maturity dates occur between 25 June and 15 September (Crane et al., 2000).

During the first two years of growth, trees were fertilized every three months with a 15-5-10-3 granular formulation at a rate of 2.27 kg/tree. After the third year, we used the formulation 12-6-16-3 at the same rate as the previous year. Rows were kept weed free with regular glyphosate applications; vegetation between rows was mown periodically.

During the first year, irrigation was applied by using 7.57 L/h button drippers, installed on polytubing lines with a diameter of 1.9 cm. Drippers were replaced by micro-sprinklers with a discharge capacity of 29.07 L/h; these sprinklers apply water to a diameter of 3.8 m providing a wetted area of approximately 11.8 m^2/tree. Lateral distribution of the system allowed independent water applications to each plot. The micro-sprinklers were installed on plastic stakes under the canopy and raised about 20 cm from soil surface. The area covered by the root system of the trees was assumed to be similar to mean canopy diameter. To estimate sprinkler discharge variability to compensate for pressure losses in the irrigation system, five micro-sprinklers were randomly selected and the actual water discharge was measured at a system pressure of 138 kPa (20 PSI) at the water intake. The irrigation delivered to the plots was adjusted by using the actual water discharge. The volume of water applied per irrigation event was calculated to wet the soil to field capacity. Soil water retention curves were determined in the soil physics laboratory.

Avocado trees were submitted to three microirrigation treatments. In two of the treatments, trees were irrigated when tensiometers reached a low depletion level (10 to 15 kPa) and high depletion level (40 to 45 kPa). A third treatment, consisting of rainfed trees, was included as a check. Irrigation was applied based on average tensiometer readings taken three times per week per plot. These instruments were installed at 30-cm and 45-cm depths and one meter away from the trunk. Soil water tension was measured at each plot by using a digital pocket tensiometer (Soil Measurement System, Tucson, AZ)[6]. Soil tension at both depths was averaged to obtain an average soil water tension per plot. Water applied per treatment was registered by flow meters.

The experimental plots were arranged in a randomized complete block design with four replications. Plots consisted of five trees, and data were collected from the middle four. Soil samples were taken to the laboratory for water retention curve determination.

[6]Company and trade names in this publication are used only to provide specific information. Mention of a company or trade name does not constitute a warranty of equipment or materials by the Agricultural Experiment Station of the University of Puerto Rico, nor is this mention a statement of preference over other equipment or materials.

A computer model developed by Harmsen and González (2005) which estimates reference evapotranspiration (ET) and crop evapotranspiration was used to compare the irrigation applied to each treatment with an estimate of the trees' water consumption. Table 1 shows the input used by the model to estimate avocado's ET. The program calculates the initial crop coefficient (Kc) value. The Kc for the mid and final stages of development of the avocado trees was 0.85 and 0.75, respectively, and maximum plant height was set to three meters (Allen et al., 1998). The computer program estimates ET on a daily basis for a one-year period using four stages of growth and development: initial stage, development stage, mid-stage (mature), and end stage. The length of each stage was established arbitrarily to 50, 120, 105, and 90 days, respectively (Table 1). Estimation of ET began 1 January and ended 31 December of the same year.

The response variables measured were canopy volume, fruit number, fruit weight, and amount of water applied. Tree canopy volume was calculated by using the same approach utilized by Román et al. (1997). Yearly data were statistically analyzed by analysis of variance, and mean separation by using Fisher's LSD at the 5% probability level (SAS Institute, 2002).

RESULTS AND DISCUSSION

Personnel of the soil physics laboratory at the University of Puerto Rico estimated water retention values for Coto clay at the experimental

TABLE 1.—*Inputs to estimate avocado ET at Isabela, Puerto Rico, from 2003 to 2005.*

Input	Value
Latitude	18.47° N
Elevation	126 m
Length of initial crop stage	50 days
Length of development crop stage	120 days
Length of mid (mature) crop stage	105 days
Length of end crop stage	90 days
Interval between irrigation	4 days
Depth of irrigation	45 mm
Type of soil	coarse[1]
Climate zone	northern slopes
Wind speed measured	2 m
Mid stage Kc	0.85
End stage Kc	0.75
Maximum crop height	3 m

[1]For simulation purpose, the variable type of soil was set to coarse (instead of clayey) because Coto series exhibits high water percolation through the profile, even though it is classified as a clayey soil.

site (data not shown). Field capacity (10 to15 kPa) volumetric water content (θ) values varied from 38.9 to 37.5%. Permanent wilting point estimate was θ = 20.7%, resulting in total available water of 18.2%. For 40 to 45 kPa treatment, θ varied from 33.9 to 33.5%. The θ difference between treatments 10 to 15 and 40 to 45 kPa was about 5.0%. In spite of the small difference in θ between microirrigation treatments, the tendency is that avocado responds better when soil tension is less than 40 to 45 kPa.

Response of tree canopy volume to microirrigation treatments was significant during 2003 and 2004, whereas response was highly significant in 2005 and 2006 (Table 2). During the four-year period, trees submitted to rainfed treatment (no microirrigation) showed significantly less canopy volume than those with irrigation treatments (Figure 1). Trees submitted to 40 to 45 kPa soil tension in 2005 produced a significantly higher canopy volume (147 m^3/tree) than trees submitted to 10 to 15 kPa (104 m^3/tree) whereas no significant differences were detected among irrigation treatments in 2006. The lack of response in terms of canopy volume could be attributed to high rainfall registered during 2005 (Table 3).

The avocado orchard was harvested for the first time August 2004. As trees grew older, microirrigation treatments affected production. In 2005, when soil tension was near field capacity (10 to 15 kPa), avocado trees produced 49 kg fruit per tree, yield which was significantly higher than that obtained for the 40- to 45-kPa and rainfed treatments. In 2006, trees submitted to 40- to 45-kPa soil water tension treatment produced the highest yield, with 84 kg fruit per tree (Figure 2). No significant differences in fruit number were detected in 2004 and 2006 (Table 2). In 2005, trees submitted to 10 to 15 kPa soil water tension treatments produced 52% more fruits (68 fruits per tree), than those subjected to a 40- to 45-kPa soil water tension treatment (33 fruits per tree) and to those rainfed (18 fruits per tree) (Figure 3). Tree productivity could have been affected by an outbreak of a foliar disease, preliminarily identified as *Colletotrichum* sp., which reduced foliar tissue dramatically in 2005 (Esteves, C. 2005, Phytopathologist, Agricultural Experiment Station, University of Puerto Rico, Personal Communication.). Foliar applications of systemic and contact fungicides were used to control the disease.

There are no published data on cultivar Simmonds in Puerto Rico. Four-year average yield reported for eight-year-old avocado trees cv. Fuerte submitted to different water use levels was 57.9 kg/tree (Michelakis et al., 1993). Another experiment with six-year-old trees using the same cultivar reported cumulative yield of 314 and 379 kg/tree for wet and dry treatments, respectively, during six years of production

TABLE 2.—*Probability of the F value (P > F) in the analysis of variance by year of canopy volume, fruit weight and fruit number of avocado (cv. Simmonds) as a response to microirrigation treatments scheduled by using tensiometers at Isabela, Puerto Rico.*

	Canopy volume					Fruit weight				Fruit number			
Sources of variation	2003	2004	2005	2006	2007	2004	2005	2006	2007	2004	2005	2006	2007
Block	0.0034	0.0032	NS[1]	0.0259	0.1664	NS	NS	0.0013	0.0138	NS	0.0218	0.0027	0.0312
Microirrigation treatments	0.0249	0.0113	0.0002	0.0003	0.5407	NS	0.0001	0.0120	0.0119	NS	0.0001	NS	0.0441
LSD[2]	4.42	10.72	33.56	25.41	—	—	13.32	19.16	22.65	—	19.24	—	45.86
CV[3]	43.58	28.74	30.37	27.89	9.95	45.43	39.25	41.01	25.29	47.31	44.62	42.25	28.92

[1]NS = not significant.
[2]LSD = Fishers protected least significant difference (α = 0.05).
[3]CV = Coefficient of Variation (%).

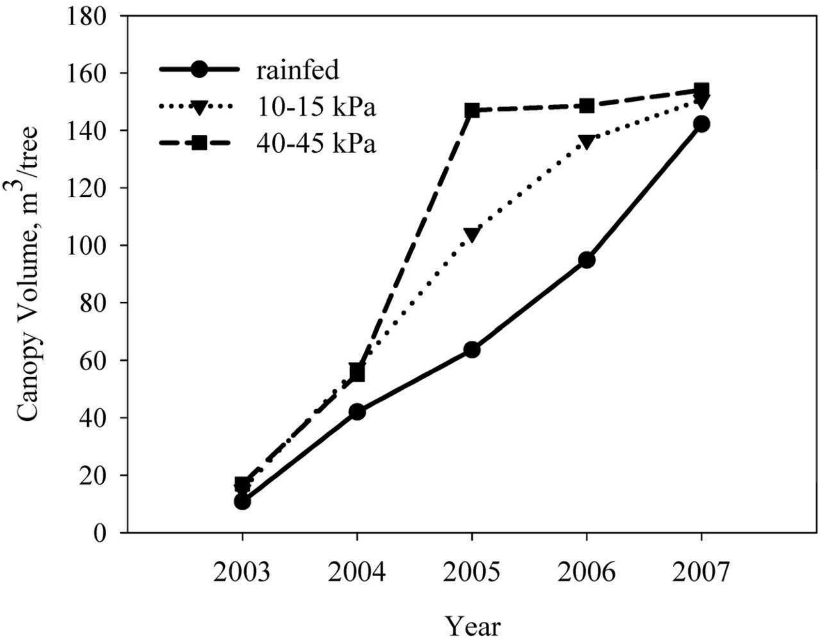

FIGURE 1. Canopy volume response of young avocado trees (cv. 'Simmonds') to microirrigation treatments scheduled by using tensiometers in a Coto clay at Isabela, Puerto Rico.

(Adato and Levinson, 1988). Lahav and Kalmar (1977) reported that yield from a treatment combination of four irrigation intervals and four annual water applications during a six-year period produced a range varying from 41.8 to 37.6 kg/tree and 62.8 to 52.7 kg/tree for cultivars Fuerte and Hass, respectively. In California, eight-year-old Hass trees submitted to three irrigation levels, three N rates, and two Zn rates produced maximum and minimum yields of 26.06 and 14.92 kg/tree, respectively (Tekele et al., 1996). Levinson and Adato (1991) suggested that the effect of irrigation on the number of fruits reaching harvest became greater as the experiment progressed. More than half of the trees in the dry treatment yielded 50% more fruits than average in the sprinkling treatment. Hoffman and du Plessis (1999) reported no significant differences of fruit size and yield for Hass and Fuerte in trees submitted to wet (30 kPa) and dry treatments (60 kPa).

Table 3 includes data on rainfall, number of irrigation events, and amount of irrigation reported in three-month periods; however, ET was estimated daily, and irrigation events and amount of irrigation on a

TABLE 3.—*Estimated evapotranspiration, rainfall, number of irrigation events, irrigation applied to avocado trees cv. Simmonds per microirrigation treatments scheduled by using tensiometers at Isabela, Puerto Rico, during 2003-2005.*

			Microirrigation treatments					
			10 to 15 kPa			40 to 45 kPa		
Time Period	ETc[1] mm	Rainfall mm	Irrigation events	Irrigation applied[2] L/tree	Average weekly irrigation L/tree	Irrigation events	Irrigation applied L/tree	Average weekly irrigation L/tree
2003								
January to March	233	177	9	1,026	85.5	3	342	28.5
April to June	306	654	11	1,254	104.5	5	570	47.5
July to September	315	428	19	2,166	180.5	6	684	57.0
October to December	243	759	4	456	38.0	3	342	28.5
Total	1,097	2,018	43	4,902		17	1,938	
2004								
January to March	239	309	26	2,964	247.0	11	1254	104.5
April to June	306	398	17	3,548	295.6	8	2066	172.0
July to September	318	394	16	1,230	102.5	9	816	68.0
October to December	244	460	13	991	82.5	6	698	58.0
Total	1,107	1,561	72	8,733		34	4,834	

[1]Crop evapotranspiration estimated using computer program PR-ET V1.02 (http://academic.uprm.edu/abe/PRAGWATER/). Crop coefficient values used were Kc_{mid} = 0.85, Kc_{end} = 0.75 and maximum tree height = 3.0 m. Length of initial, development, mid and end stages were 50, 120, 105, and 90 days, respectively.

[2]Irrigation applied per treatment measured with water meters.

[3]Values correspond only to March 2005.

TABLE 3.—*(Continued) Estimated evapotranspiration, rainfall, number of irrigation events, irrigation applied to avocado trees cv. Simmonds per microirrigation treatments scheduled by using tensiometers at Isabela, Puerto Rico, during 2003-2005.*

			Microirrigation treatments					
			10 to 15 kPa			40 to 45 kPa		
Time Period	ETc[1] mm	Rainfall mm	Irrigation events	Irrigation applied[2] L/tree	Average weekly irrigation L/tree	Irrigation events	Irrigation applied L/tree	Average weekly irrigation L/tree
2005								
January to March	242	363	10[3]	1,086	90.5	3[3]	1,166	97.0
April to June	307	728	8	833	69.4	0	149	12.0
July to September	316	563	15	1,206	100.5	1	168	14.0
October to December	239	560	10	702	58.5	2	401	33.4
Total	1,104	2,214	33	3,829		6	1,884	

[1]Crop evapotranspiration estimated using computer program PR-ET V1.02 (http://academic.uprm.edu/abe/PRAGWATER/). Crop coefficient values used were Kc_{mid} = 0.85, Kc_{end} = 0.75 and maximum tree height = 3.0 m. Length of initial, development, mid and end stages were 50, 120, 105, and 90 days, respectively.

[2]Irrigation applied per treatment measured with water meters.

[3]Values correspond only to March 2005.

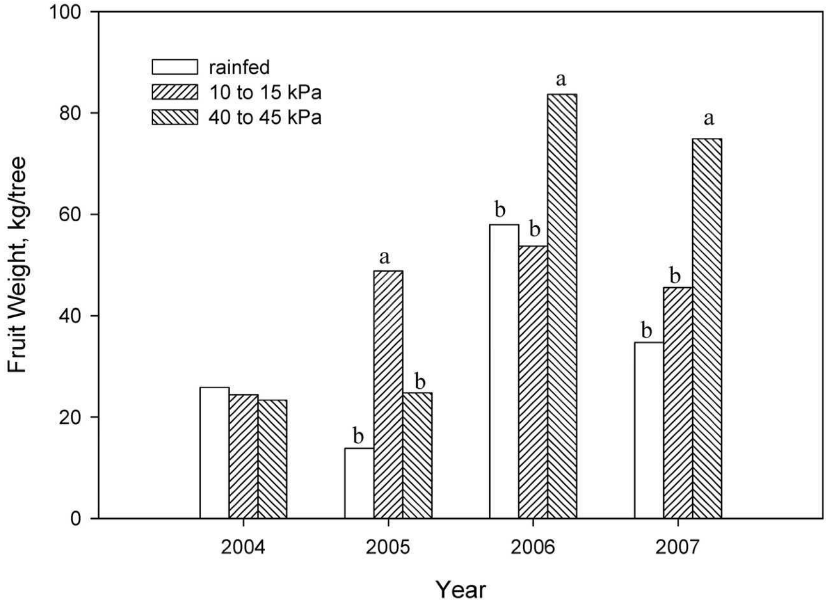

FIGURE 2. Average fruit weight produced by young avocado trees (cv. Simmonds) affected by microirrigation treatments scheduled by using tensiometers in a Coto clay at Isabela, Puerto Rico. (Means of fruit weight within microirrigation treatments for each year with the same letter are not significantly different at the 5% level.)

weekly basis (amount of irrigation applied for 2006 and 2007 is not shown). During 2003, avocado trees submitted to the 10- to 15-kPa treatment required 43 irrigation events, totaling 4,902 L/tree combined with 2,018 mm of rainfall to maintain soil moisture near field capacity (Table 3). To maintain a soil water tension less than 40 to 45 kPa, only seventeen irrigation events were necessary (1,938 L/tree). Trees needed frequent irrigation from July to September 2003, regardless of microirrigation treatment (Table 3). This period was associated with higher temperatures and wind gusts. In 2004, trees required 72 and 34 microirrigation events, respectively, to satisfy the 10- to 15- and 40- to 45-kPa treatment threshold. Rainfall recorded during that year (1,561 mm) was less than in previous years. Each year from 2003 to 2005, avocado trees doubled their canopy volume, thus increasing evapotranspiration and therefore requiring more frequent irrigation. Only six irrigation events during 2005 were needed to maintain soil tension at less than 40 to 45 kPa. The number of irrigation events for the 40- to 45-kPa treatment was 39, 47 and 18% less than the irrigation events required to maintain soil at field capacity in 2003, 2004, and 2005, respectively

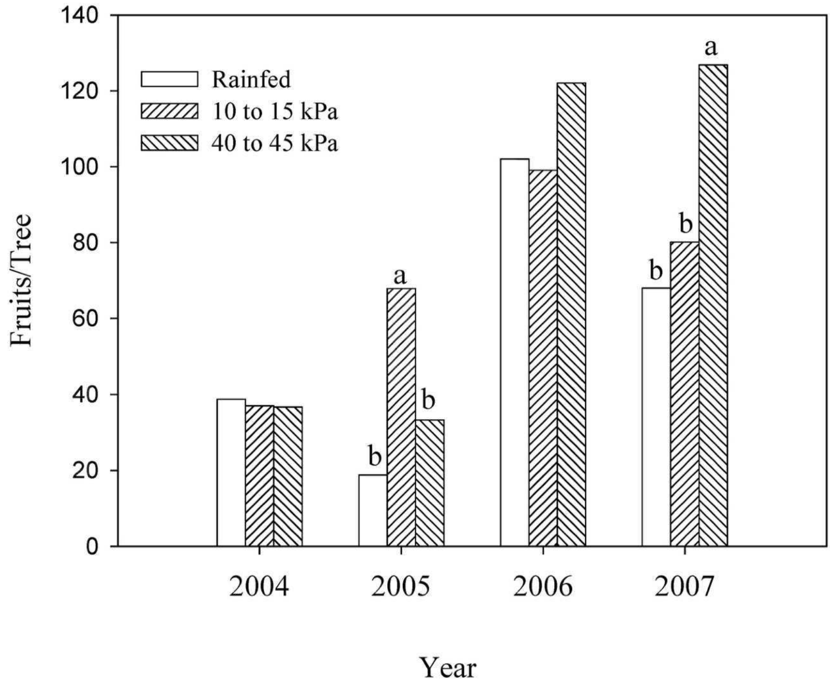

FIGURE 3. Average fruit number produced by young avocado trees (cv. Simmonds) affected by microirrigation treatments scheduled by using tensiometers in a Coto clay at Isabela, Puerto Rico. (Means of fruit number within microirrigation treatments for each year with the same letter are not significantly different at the 5% level.)

(Table 3). In terms of the amount of microirrigation applied, the 40 to 45-kPa treatment required 39, 55, and 49% less irrigation than the 10 to 15 kPa in the same corresponding years. Rainfall registered at Isabela surpassed ET estimates for most of the growing season (Table 3). The period from April to September represented about 57% annual ET from 2003 to 2005. According to ET estimates, the sole period in which trees required irrigation was January to March 2003 (Table 3). However, tensiometer readings indicated that the orchard required irrigation to avoid water stress caused by low soil available water. This fact of greater rainfall than estimated water demand by the trees does not take into account that trees may be in stress by temporary water shortage in the soil profile. Another possibility may be that the computer model underestimated ET under prevailing conditions at Isabela.

The data obtained in this research indicate that cv. Simmonds adapted well to the conditions observed in northern Puerto Rico. During the six-year period, no symptoms of *Phytophthora cinnamomi* were observed in the orchard, possibly because of the high water percolation typically shown by soil pertaining to Coto clay series. High water percolation reduces the chances of fungal infection and eventual tree death. The avocado root system does not tolerate high soil moisture content in the profile. In addition, maintaining the soil at high depletion level reduces the chance of *Phytophthora cinnamomi* infestation. Although in northern Puerto Rico high and well-distributed rainfall is observed throughout the year, it is insufficient to maintain adequate tree growth rate and increased yield. In that environment, microirrigation is necessary for a farmer to maximize yield. Maintaining soil tension up to 40 to 45 kPa significantly increases yield and growth, with water savings up to 47% in a three-year period in comparison with maintaining soil at field capacity. Data obtained in this research also suggest that avocado is sensitive enough to reduce yield when distinguishing as low as 5% of available water in the soil profile.

We recommend the use of tensiometers to schedule irrigation for avocado in the Isabela region because it is relatively simple and relatively inexpensive, compared with the high cost associated with pumping non-required water. However, the use of tensiometers requires some degree of maintenance. Information on the response of trees to soil water tension is transferable among locations, but the irrigation amount needed to reach a specific soil water tension is not. Irrigation is site-specific and depends on several factors, such as soil physical properties and climatic variables.

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