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Yield Performance of Banana Irrigated with Fractions of Class A Pan Evaporation in a Semiarid Environment

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ABSTRACT

There is a scarcity of information regarding the optimum water requirement for banana (*Musa acuminata* Colla, AAA group) grown under semiarid conditions with drip irrigation in the tropics. A 3-yr study was conducted on a fine-loamy, mixed, isohyperthermic Cumulic Haplustoll to determine water requirement, yield, and fruit-quality traits of the plant crop (PC) and two ratoon crops (R1 and R2) of 'Grande Naine' banana subjected to five levels of irrigation. The irrigation treatments were based on Class A pan factors that ranged from 0.25 to 1.25 in increments of 0.25. Drip irrigation was supplied three times a week on alternate days. Results showed significant ($P \leq 0.01$) irrigation treatment and crop effects for all yield components, fruit length and diameter, days to flower, and days from flowering to harvest. Highest marketable yield (86.3 Mg ha^{-1}) was obtained from the R2 crop with water application according to a pan factor of 1.25. Plant crop and R1 plants irrigated using the same pan factor yielded 45.3 and 70.3 Mg ha^{-1}, respectively. Increasing the pan factor from 0.25 to 1.25 resulted in weight gains of the third-upper hand of 70% in PC, 90% in R1, and 122% in R2. Irrigation according to increasing pan factors resulted in significant increases on the number of hands per bunch and the length and diameter of fruits in the third-upper and last hands in the bunch. It was concluded from this investigation that, to attain high yields, banana grown under semiarid conditions should be irrigated with a pan factor of not less than 1.0.

TOTAL WORLD PRODUCTION OF BANANA is estimated at 4.14 × 10^{10} kg, produced on ≈4 million ha. In many tropical regions, banana is grown either in wet-and-dry climates characterized by erratic rainfall patterns and prolonged dry periods, or in fertile but semiarid lands under irrigation (Ghavami, 1974; Hedge and Srinivas, 1990; Hill et al., 1992). Depending on the prevailing climatic conditions and method of measurement, estimates of the annual evapotranspiration (ET) of banana range from 1200 to 2690 mm (Robinson and Alberts, 1989). The high evaporative demand in semiarid environments, combined with the large transpiring surface area and shallow root system of banana, makes it susceptible to lodging and water deficits. Consequently, banana plants require irrigation during dry periods to prevent reductions in yield and fruit quality (Norman et al., 1984).

Semiarid regions comprise a large percentage of the world's arable land (Grove, 1985). Drip irrigation technology permits the efficient use of water and can help maximize the utilization of semiarid lands for agricultural production. This technology is particularly suited to widely spaced crops such as banana. There is little information regarding optimum water requirement for banana in the tropics, particularly under semiarid conditions. In addition, most irrigation studies have emphasized the impact of irrigation treatments on yield (i.e., bunch weight) but have disregarded the effect of water supply on yield components such as fruit size, number of hands (fruit clusters) per bunch, and average hand weight.

This study was undertaken to determine the optimum water requirement for banana grown under semiarid conditions under drip irrigation and to examine how yield, fruit size, and other bunch and plant traits are affected by various levels of irrigation.

MATERIALS AND METHODS

An experiment was conducted from 1990 to 1993 at the Fortuna Agricultural Research Station of the University of Puerto Rico (18°2′ N, 66°31′ W; elevation 21 m) in the semiarid agricultural zone of Puerto Rico. The San Anton soil is a well-drained Mollisol (fine-loamy, mixed, isohyperthermic Cumulic Haplustoll) with pH of 7.5, bulk density 1.4 g cm^{-3}, and 1.7% organic C in the first 14 cm of soil. The 28-yr mean annual rainfall is 917 mm and Class A pan evaporation is 2149 mm. Mean monthly maximum and minimum temperatures are 31.2 and 20.8°C. Total monthly rainfall and evaporation during the experimental period are shown in Fig. 1, and average monthly irrigation supplied to plants is in Table 1.

Corms of Grande Naine banana were planted at a 1.8- by 1.8-m spacing (equivalent to 1990 plants ha^{-1}) on 10 May 1990. Five treatments representing different moisture regimes were arranged in a randomized complete block design with four replications. There were two rows per plot, each with eight experimental plants and surrounded by alleys of 3.7 m, with two guard plants at the end of each row to prevent overlapping of the irrigation treatments.

At planting, each plant received 11 g of granular P provided as triple superphosphate. Throughout the experimental period, fertilization through the drip system was provided weekly at the rate of 10.2 kg ha^{-1} of N and 28.5 kg ha^{-1} of K, using urea and potassium nitrate as nutrient sources. Weekly fertilizations also included 0.26 and 0.08 kg ha^{-1} of Zn and Fe, respectively, supplied in their EDTA chelate forms and 0.29 kg ha^{-1} of Mn supplied as DTPA chelate. A desuckering program in the plant crop (PC) was implemented ≈5 mo after planting to allow the development of only one sucker, which represented the first ratoon crop (R1). Similarly, only one sucker was allowed to develop from R1 plants in order to establish the second ratoon crop (R2).

The equation of Young and Wu (1981) was used to calculate the amount of irrigation applied to plants. The equation assumes that the ET of a banana plant is equal to the evaporation from a body of water with a free surface equal to the plant area as determined by a Class A pan evaporimeter. In this study, the equation was modified to include a pan coefficient (k_p) value of 0.70 and a modified average crop coefficient (k_c) of 0.88 (Doorenbos and Pruitt, 1977) to obtain a theoretical value of potential evapotranspiration (PE).

Class A pan factors (proportion of pan evaporation), ranging from 0.25 for Treatment 1 to 1.25 for Treatment 5 in increments of 0.25, were used to obtain fractions of PE. A pan factor of 1.0 means that the water applied to the plants of that treatment replaced that lost through calculated evapotranspiration; this was hence considered the theoretical optimum.

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Abbreviations: DTPA, diethylenetriamine pentaacetic acid; EDTA, ethylenediaminetetraacetic acid; ET, evapotranspiration; PC, plant crop; PE, potential evapotranspiration; R1 and R2, first and second ratoon [crop], respectively.

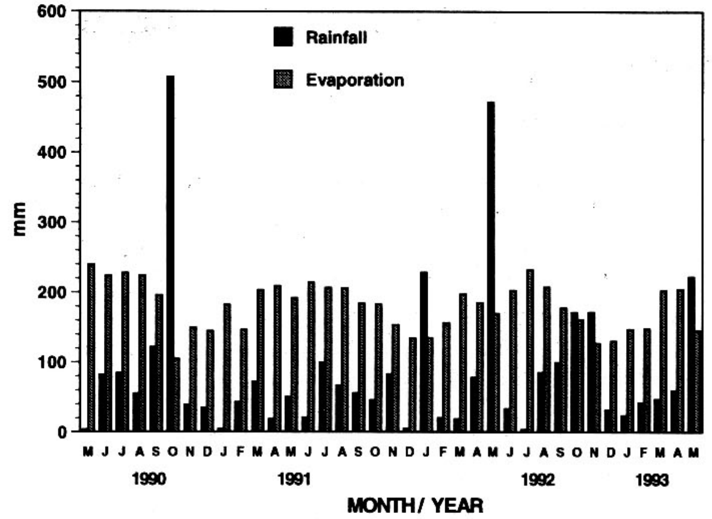

Fig. 1. Total monthly rainfall and Class A pan evaporation during the growth cycle of a plant crop and two ratoon crops of banana at the Fortuna Agricultural Research Station, PR.

The plants were subjected to the five moisture treatments starting ≈2.5 mo after planting. The amount of water applied varied weekly, depending on Class A pan evaporation and rainfall. The previous week's evaporation and rainfall data were used to determine the irrigation needs for the following week. Irrigation was supplied three times during the following week on alternate days, and no irrigation was provided when the total rainfall was >19 mm wk^{-1}.

The water source was a well-fed reservoir. Submain lines equipped with volumetric metering valves to monitor the water from the main line were provided for each treatment. Lateral lines equipped with built-in 4 L h^{-1} emitters spaced 61 cm apart branched out from the submains along the inner side of each plant row and ≈21 cm from the pseudostems.

At flowering, the number of functional leaves was recorded. Two weeks later, the male flower bud and the false hands were removed from the immature bunches. Immediately, the bunches were bagged with blue plastic sleeves. The number of days to flower was calculated as the time interval between planting and flowering (bunch-shooting) in the plant crop, and the interval between harvest of the previous crop and flowering of the next in the ratoon crops. Banana bunches were harvested when the fruits were in the mature-green stage, ≈110 d after flowering. At harvest, outer length and diameter were measured in three inner and three outer fruits from the middle section of the third-upper and last hands in the bunch. These measurements were pooled to obtain an average for each hand. Values for bunch weight and yield per area were obtained after subtracting the rachis weight from the total bunch weight.

Analyses of variance and best fit curves were determined using the ANOVA and GLM procedures, respectively, of the SAS program package (SAS Inst., 1987). Only coefficients significant at $P \leq 0.05$ were retained in the models.

Table 1. Three-year average monthly irrigation supplied to banana plants subjected to five levels of irrigation by pan factor (proportional to Class A pan evaporation).

	Irrigation supplied, as proportion of pan evaporation				
Month	0.25	0.50	0.75	1.0	1.25
	L plant^{-1}				
January	77	154	231	308	385
February	78	156	234	312	390
March	133	266	399	532	665
April	87	174	261	348	435
May	97	194	291	388	485
June	84	168	252	336	420
July	159	318	477	636	795
August	165	330	495	660	825
September	85	170	255	340	425
October	36	72	108	144	180
November	33	66	99	132	165
December	73	146	219	292	365
Total	1107	2214	3321	4428	5535
Average	92.2	184.5	276.7	369.0	461.2

RESULTS AND DISCUSSION

Differences among irrigation treatments and crops were highly significant ($P \leq 0.01$) for all the response variables that were studied (analysis of variance not shown). The treatment × crop interaction was highly significant ($P \leq 0.01$), except for fruit length in the bunch last hand and number of leaves at flowering. Therefore, results are reported for each treatment–crop combination.

Total Class A pan evaporation doubled the amount of rainfall recorded during the experimental period. In 22 of the 37 mo, evaporation/rainfall ratios were ≥3.0 (Fig. 1). This indicates that large soil-water deficits would have existed without irrigation. Less irrigation was required during the months of October through December and more was required in March, July, and August (Table 1).

Bunch weight was linearly related to the amount of water applied (i.e., pan factor) in the R1 and R2 crops (Fig. 2).

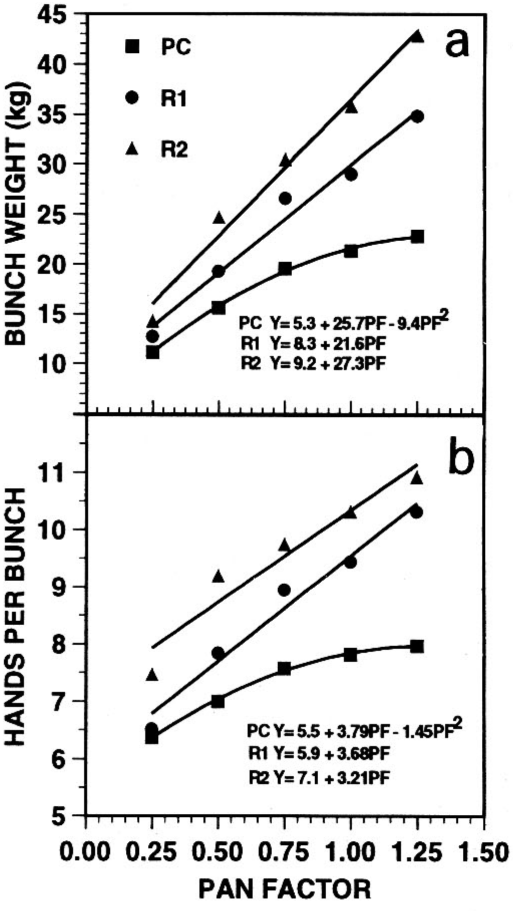

Fig. 2. Bunch weight (a) and hands per bunch (b) of a banana plant crop (PC) and two ratoon crops (R1 and R2) as influenced by irrigation based on proportion of pan evaporation (pan factor).

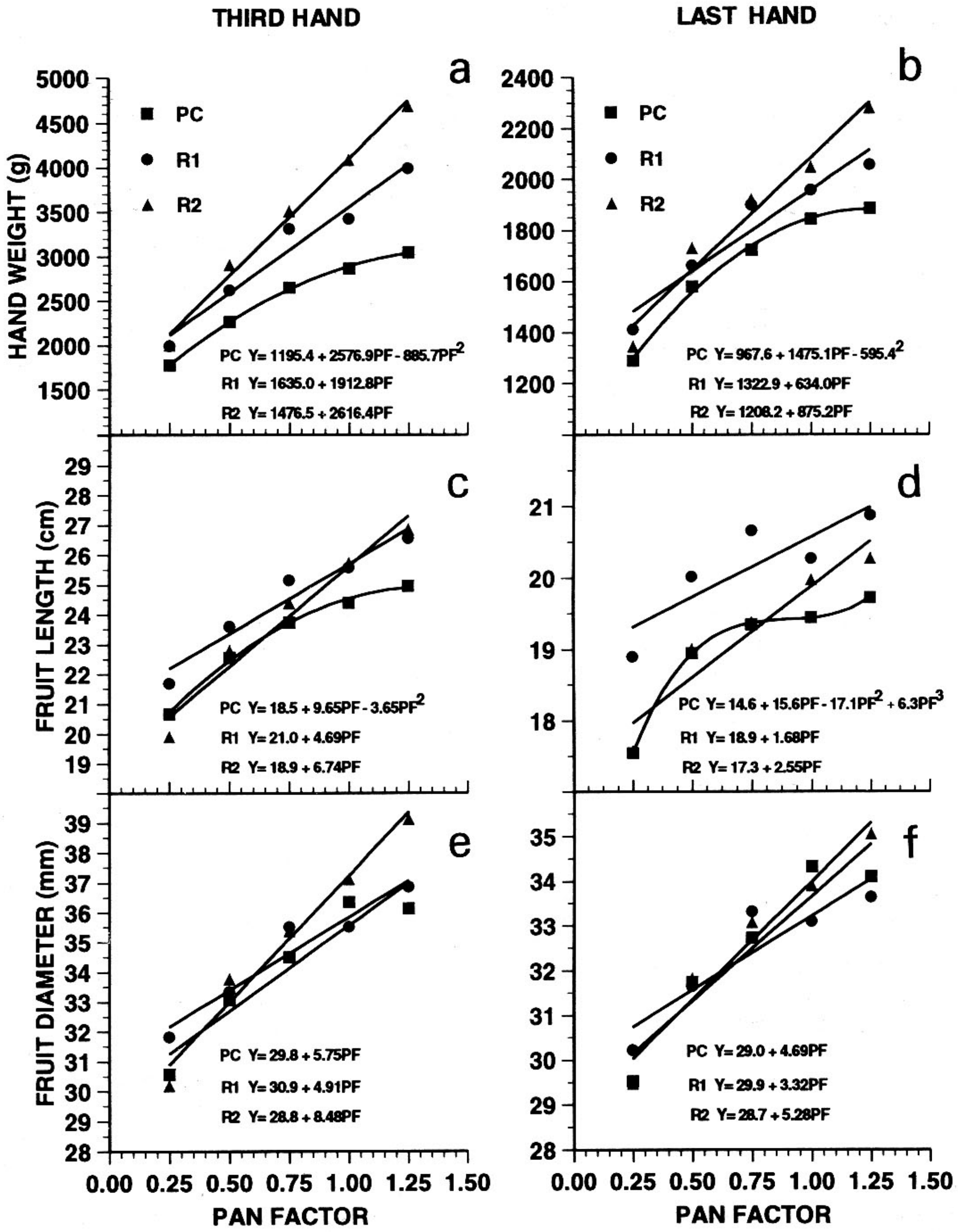

Fig. 3. Relationship between irrigation pan factor and hand weight (a,b), fruit length (c,d), and fruit diameter (e,f) in the third-upper and last hands of the banana bunch as influenced by irrigation based on proportion of pan evaporation (pan factor).

The greatest response to irrigation was obtained in the R2 crop, which produced an average maximum bunch weight of 43.3 kg when irrigated using a pan factor of 1.25. This bunch weight represents increases of 91 and 23% over those obtained for PC and R1, respectively, when irrigated using the same pan factor. The increase in bunch weight in plants that received irrigation from the two highest pan factor treatments can be attributed largely to a greater number of marketable hands per bunch (Fig. 2). Bunches harvested from PC, R1, and R2 plants that were irrigated with a pan factor of 1.25 had 25, 54, and 40% more hands, respectively, than when irrigated with a pan factor of 0.25 (Fig. 2). Similar improvements in PC bunch weight and hands per bunch were obtained by Hedge and Srinivas (1990) when the evaporation replenishment was increased from 20 to 120%. In that study, however, bunch weight and number of hands from R1 bunches were considerably smaller than those we obtained. As a result of the increase in the number of hands per bunch with increments in pan factor, the number of fruits per bunch also increased. The number of fruits per bunch between treatment extremes (pan factors 0.25 and 1.25) ranged from 109 to 133 fruits in PC, 111 to 193 fruits in R1, and 133 to 207 in R2 (data not shown).

The weight of the third-upper and last hand in the bunch also increased with pan factor increments (Fig. 3). This

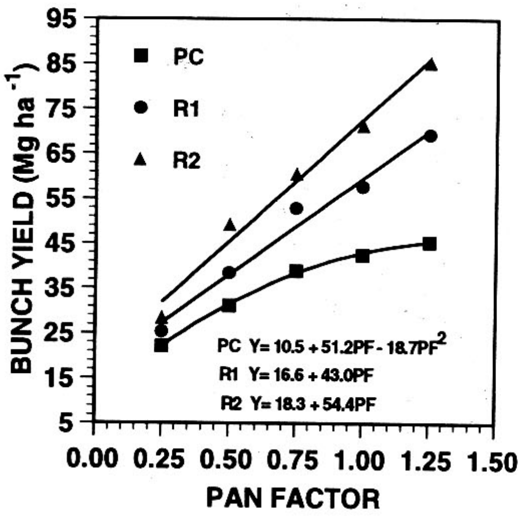

Fig. 4. Relationship between irrigation based on proportion of pan evaporation (pan factor) and bunch yield in the banana plant crop (PC) and two ratoon crops (R1 and R2).

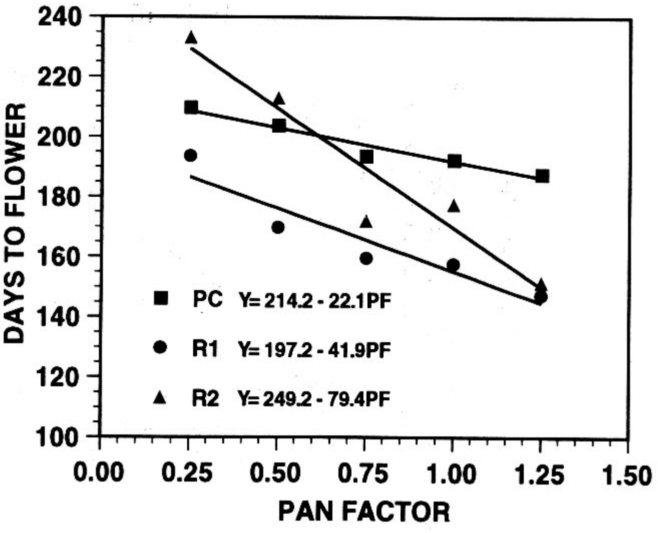

Fig. 5. Relationship between irrigation based on proportion of pan evaporation (pan factor) and days to flower in the banana plant crop (PC) and two ratoon crops (R1 and R2).

response was more pronounced in R2, where an increase in pan factor from 0.25 to 1.25 resulted in a third-upper hand weight gain of 2616 g, compared with gains of 1923 g in R1 and 1248 g in PC. The same pan factor increment caused a less pronounced effect in the last hand, with weight gains of only 582 g in PC, 634 g in R1, and 875 g in R2.

Increments in pan factor treatment resulted in significant increases in length and diameter of fruits of the bunch third-upper and last hands (Fig. 3). Third-hand fruits in PC, R1, and R2 that received irrigation according to a pan factor of 1.25 were 20, 21, and 32% longer, respectively, than when the crops were irrigated using a pan factor of 0.25. Similar trends of smaller magnitude were measured of fruits in the last hand of PC, R1, and R2. Similarly, increasing the amount of irrigation resulted in an increased diameter for fruits in the third-upper and last hands (Fig. 3). The greatest increase in fruit diameter (8.5 mm) was observed in the third-upper hand of R2 when the pan factor was incremented from 0.25 to 1.25.

The number of functional leaves present at flowering is an important physiological trait for proper banana fruit filling (Soto, 1985). Increments in pan factor caused significant ($P \leq 0.01$) increases in the number of functional leaves present at flowering in this study (data not shown). The average number of functional leaves present at flowering was 14.4 and 15.1, respectively, for pan factors 0.25 and 0.50. Studies by Robinson et al. (1992) showed that retention of eight leaves at flowering is sufficient to avoid significant reductions in yield and fruit size. Thus, the smaller fruit length and diameter values obtained from PC, R1, and R2 subjected to the pan factor increments of 0.25 and 0.50 cannot be attributed to a reduced leaf area that might have hindered translocation of photosynthate to fruits in these treatments. This suggests that fruit growth in those treatments was restricted due to drought stress that reduced the rate of cell expansion.

The highest marketable yield of 86.3 Mg ha^{-1} was obtained from R2 and the application of irrigation according to a pan factor of 1.25 (Fig. 4). This yield represented an increase of 41 and 16 Mg ha^{-1} over PC and R1, respectively, when they were subjected to the same pan factor treatment. After harvest of the plant crop, banana yields tend to increase in successive ratoon crops (Irizarry et al., 1989). In this study, the yield average was 36.1 Mg ha^{-1} in PC, 48.8 Mg ha^{-1} in R1, and 59.1 Mg ha^{-1} in R2. With each increment in pan factor, marketable yield increased by 10.8 Mg ha^{-1} in R1 and 13.6 Mg ha^{-1} in R2. This linear effect was not observed in PC, where a maximum yield gain of 9.3 Mg ha^{-1} was obtained when irrigation according to the pan factor was increased from 0.25 to 0.50. Thereafter, yield gains were significantly reduced with each pan factor increment (Fig. 4).

Increments in pan factor resulted in a significant ($P \leq 0.01$) reduction in the number of days to flower and consequently, the planting-to-harvest cycle was shortened in plants that received irrigation corresponding to the higher pan factors (Fig. 5). The R1 and R2 plants irrigated according to a pan factor of 1.25 flowered 42 and 79 d earlier, respectively, than those irrigated according to a pan factor of 0.25. Range in days to flower between the 0.25 and 1.25 pan factors in PC was only 22 d. This response may have been the result of abnormally high rainfall during the period prior to flowering (Sept.–Oct. 1990; Fig. 1), which probably allowed PC plants irrigated according to the lowest pan factor to partially recover from drought stress conditions.

There was a significant ($P \leq 0.05$) treatment and crop effect on the number of days from flowering to harvest; however, the treatment × crop interaction was not significant (data not shown). Plant crops, R1, and R2 plants irrigated according to a pan factor of 0.25 required 110, 111, and 113 d from flowering to harvest, respectively. When irrigated using a pan factor of 1.25, the number of days from flowering to harvest was 105 for PC, 104 for R1, and 110 for R2. Although the pan factor treatment affected the number of days to flower (Fig. 5), the flowering-to-harvest period appeared to be fixed, regardless of the irrigation treatment.

From this investigation we conclude that banana should be irrigated using a pan factor of ≥ 1.0. The use of a lower pan factor results in significant reductions in yield and fruit quality, particularly in ratoon crops.

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