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YIELD OF BANANA GROWN WITH SUPPLEMENTAL DRIP-IRRIGATION ON AN ULTISOL

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SUMMARY

A three-year study was conducted on an Ultisol to determine the water requirement, yield and fruit-quality traits of three ratoon crops (R1, R2, R3) of 'Grande Naine' banana (*Musa acuminata* Colla, AAA group) subjected to four levels of irrigation. The irrigation treatments were based on Class A pan factors ranging from 0.0 (rainfed) to 1.0 in increments of 0.25. When needed, drip irrigation was supplied three times a week on alternate days. Results showed significant ($p < 0.01$) irrigation treatment and crop effects on bunch weight, yield, bunch mean hand weight, weight and fruit diameter of the third and last hands, and length of fruits of the third hand. Highest marketable yield (47.9 t ha^{-1}) was obtained from the R2 crop with water application according to a pan factor of 1.0. It was concluded that irrigating the crop according to a pan factor of 1.0 was sufficient to justify the investment of a drip-irrigation system for a farm in the mountain region.

INTRODUCTION

Total world production of banana in 1995 was estimated at 54×10^6 t. While most of the global banana production is for local consumption, bananas are the world's second most important traded fruit after citrus and, along with rubber, cocoa, sugar and coffee, one of the five major tropical products entering into world trade (Hallam, 1995). In many Caribbean Basin countries, banana production for export markets represents an important source of foreign exchange earnings, income and employment.

The banana plant is a tropical herbaceous evergreen which has no natural dormant phase; it has a high leaf area index and produces a very shallow root system when grown in heavy textured soil (Robinson, 1996). These factors make the crop extremely susceptible to water shortage. Water requirements of banana are met by effective rainfall and by irrigation. Stover and Simmonds (1987) reported a consumption of 900–1800 mm water during the growth and production cycle of banana plants grown in a tropical environment. Water requirements of drip-irrigated bananas grown under semi-arid conditions on a Mollisol were determined by Goenaga and Irizarry (1995). Using Class A pan factors that

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ranged from 0.25 to 1.25, they found that all yield components for the plant crop and two ratoon crops were significantly improved with an increase in water applied.

Many banana-producing regions of the humid tropics experience bimodal rainfall patterns in which rainfall intensity decreases considerably during the months of June and July and from January to March. These dry periods may reduce yield and fruit quality.

This research was conducted to determine how marketable yield and fruit-quality traits of banana grown on a heavy-clay soil of the highland region of Puerto Rico are influenced by four levels of supplementary drip-irrigation based on Class A pan evaporation. To provide practical irrigation recommendations to growers, projections were made on crop productivity, gross sales and on the costs associated with the installation of a drip-irrigation system for a 20-ha banana planting in the highlands.

MATERIALS AND METHODS

An experiment was conducted from 1993 to 1996 at the Corozal Agricultural Experiment Substation of the University of Puerto Rico (lat 18°20′N, long 66°31′W, altitude 185 m) in the highland agricultural zone of Puerto Rico. The Corozal soil is a well-drained Ultisol (clayey, mixed, isohyperthermic Aquic Haplohumults) with a pH of 5.1, bulk density 1.4 g cm^{-3}, and 2.28% organic carbon in the first 14 cm of soil. The 27-year mean annual rainfall is 1863 mm and Class A pan evaporation is 1391 mm. Mean monthly maximum and minimum temperatures are 29.7 and 19.8°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.

Conventional sword suckers of Grande Naine banana (*Musa acuminata* Colla, AAA group) spaced at 2.4 × 2.1 m (1921 plants ha^{-1}) were used as planting material to establish the plant crop in 1992. The experiment was established using the first ratoon crop which maintained the same plant density as the plant crop. Five treatments representing different moisture regimes were arranged in a randomized complete block design with four replications. There were four rows of 12 plants per plot. Data were recorded only from 10 plants of each of the inner two rows from each plot. Experimental plots were surrounded by alleys of 2.4 m, with two guard plants at the end of each row and by a trench about 0.6-m deep to prevent overlapping of the irrigation treatments.

After selection of the first ratoon plant, each mat received nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) as a commercial fertilizer mixture every three months (10N–2.2P–16.6K–3.0 Mg) at 653 kg ha^{-1}. To prevent Mg deficiency in tissue, a common occurrence in banana grown on Ultisols, kieserite ($MgSO_4$, H_2O) was applied at 218 kg ha^{-1} every three months between fertilizer applications. A desuckering programme in R1 plants was implemented about four months after their selection to allow the development of

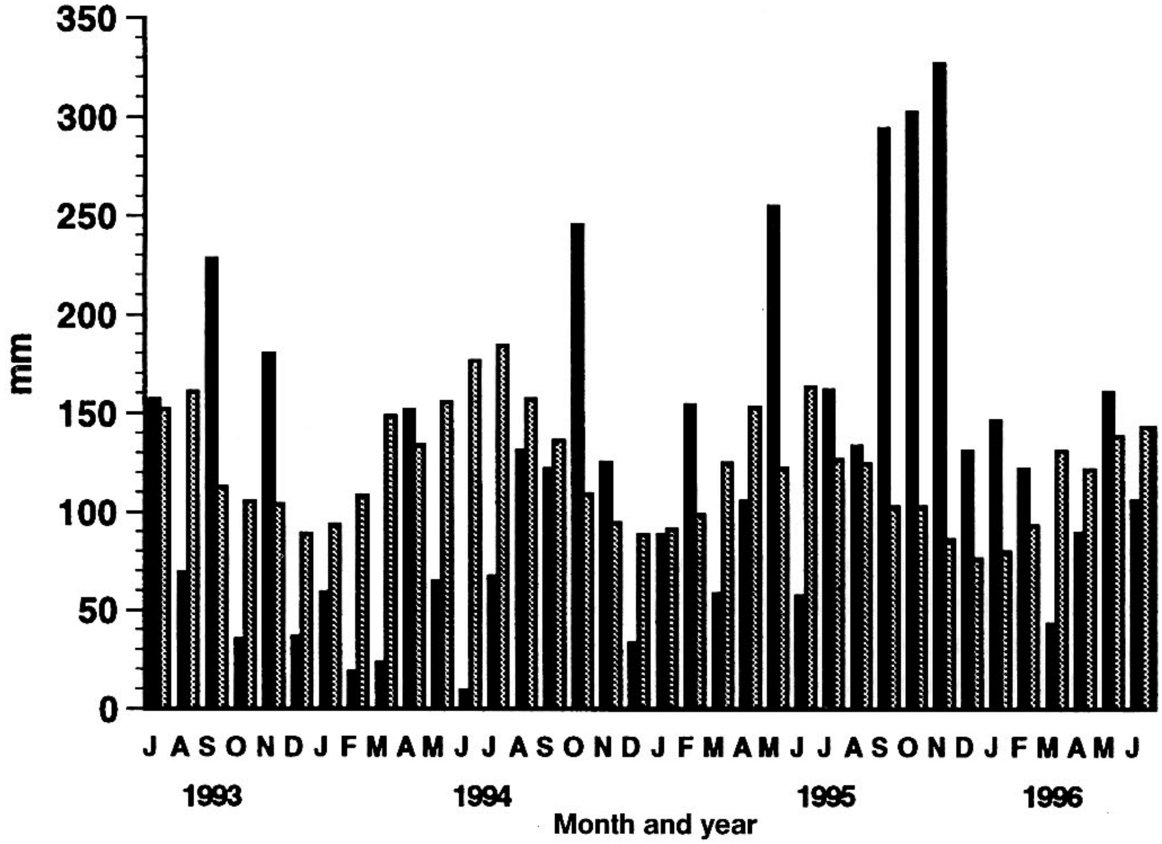


Fig. 1. Total monthly rainfall (■) and Class A pan evaporation (▩) during the growth cycle of three ratoon crops of banana at the Corozal Agricultural Research Station, Puerto Rico.

Table 1. Average monthly irrigation (L plant^{-1}) applied to banana plants subjected to four levels of irrigation as determined by pan factor (proportional to Class A pan evaporation) over a three-year period, 1993–96.

	Proportion of pan evaporation			
Month	0.25	0.50	0.75	1.0
January	19	37	57	148
February	29	59	87	116
March	30	60	89	120
April	21	42	63	84
May	18	37	54	74
June	31	62	93	124
July	31	62	93	124
August	40	81	121	161
September	17	34	51	68
October	20	41	61	81
November	9	18	27	36
December	23	46	69	92
Total	288	579	865	1228
Average	24.0	48.2	72.1	102.3

only one sucker, which represented the second ratoon crop (R2). Similarly, only one sucker was allowed to develop from R2 plants in order to establish the third ratoon crop (R3). Yellow sigatoka *Mycosphaerella musicola*, nematodes, soil-borne insects and weeds were controlled following recommended cultural practices (Agricultural Experiment Station, 1995).

The equation of Young and Wu (1981) was used to calculate the amount of irrigation applied to plants. The equation assumes that the evapotranspiration 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 (kp) value of 0.70 and a modified average crop coefficient (kc) of 0.88 (Doorenbros and Pruitt, 1977) to obtain an estimate of potential evapotranspiration.

Class A pan factors (proportion of pan evaporation) ranging from 0.25 for Treatment 2 to 1.0 for Treatment 5 in increments of 0.25, were used to obtain fractions of potential evapotranspiration. Treatment 1 (pan factor 0.0) consisted of a rainfed control. A pan factor of 1.0 meant that the water applied to the plants of that treatment replaced the water lost through calculated evapotranspiration; this was considered the theoretical optimum.

The plants were first subjected to the five moisture treatments in July 1993. 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 exceeded 19 mm week^{-1}.

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, pressure-compensated emitters dispensing 4 L h^{-1} and spaced 61 cm apart branched out from the submains along the inner side of each plant row and about 21 cm from the pseudostems.

At flowering and harvest the number of functional leaves were recorded. About two weeks after flowering, the male flower bud and the false hands were removed from the immature bunches. Immediately, the bunches were bagged with blue plastic sleeves. Since no records of flowering (bunch shooting) were available from the plant crop to calculate days to harvest, only days needed for fruit filling were recorded. Banana bunches were harvested when the fruits were three-quarters round, about 120 d after flowering. At harvest, the number of hands were counted and then cut from the rachis. The 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. The weight of these hands was also recorded. 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 GLM procedure of the SAS program package (SAS Institute, 1987). The GLM Solution

Option was used in cases in which significance was found for treatment and crop effects but not for the treatment × crop interaction (Victor Chew, personal communication, 1997). Only coefficients significant at $p \leqslant 0.05$ were retained in the models.

RESULTS AND DISCUSSION

Irrigation treatments and crops show significant effects ($p \leqslant 0.01$) on bunch weight and yield, bunch mean hand weight, weight and fruit diameter of the third and last hands, and length of fruits in the third hand (analysis of varience not shown). The treatment × crop interaction was also significant ($p \leqslant 0.05$), except for fruit diameter in the bunch third and last hands. No significant effects ($p \leqslant 0.05$) of irrigation treatments were found for number of functional leaves at flowering and harvest nor for number of days required for fruit filling. These response variables averaged 11.6 leaves, 6.7 leaves and 117 d respectively.

Total Class A pan evaporation (4487 mm) was very similar to the amount of total rainfall (4384 mm) recorded during the 36-month experimental period (Fig. 1). Although this may suggest that plants were never exposed to soil-water deficits, it is noteworthy that 26% of the total rainfall recorded fell during the months of May, September, October and November 1995. This percentage increases to 37% if the months of September 1993 and October 1994 are also considered. The average annual evaporation and rainfall data collected for over 20 years at the study location were 1391 mm and 1863 mm, respectively (Goyal and González, 1989). Most of the monthly rainfall during 1993 and 1994 was less than average and, hence, these could be considered dry years. The first eight months of 1995 exhibited relatively normal rainfall patterns. Afterwards, rainfall was above the average. More irrigation was required during the months of June to August and January to March (Table 1).

Bunch weight was linearly related to the amount of water applied (the pan factor) in the R1 and R2 crops (Fig. 2). No response was obtained in R3 probably as a result of the heavy rains that fell between September 1995 and February 1996 (Fig. 1). The greatest response to irrigation was obtained in the R2 crop, which produced an average maximum bunch weight of 25.5 kg when irrigated using a pan factor of 1.0. This bunch weight represents an increase of 59% over that obtained for R2 without irrigation. In contrast with other studies (Hedge and Srinivas, 1990; Goenaga and Irizarry, 1995), irrigation treatments did not have a significant effect on the number of hands per bunch (data not shown). Therefore, the increase in bunch weight in plants of R1 and R2 that received more irrigation can be attributed to an increase in individual fruit size and weight.

Fruit diameter and length in the third-upper hand and fruit diameter in the last hand significantly increased with increments in pan factor treatment (Fig. 3). This response was probably responsible for the significant bunch weight increase in plants of R1 and R2 (Fig. 2). The weight of the third-upper and last hand in the bunch also increased with pan factor increments (Fig. 3). This response was

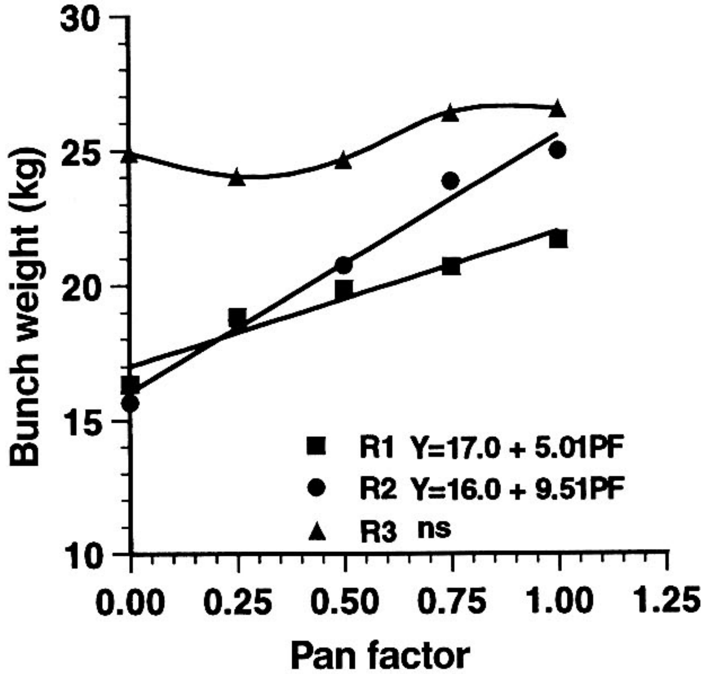


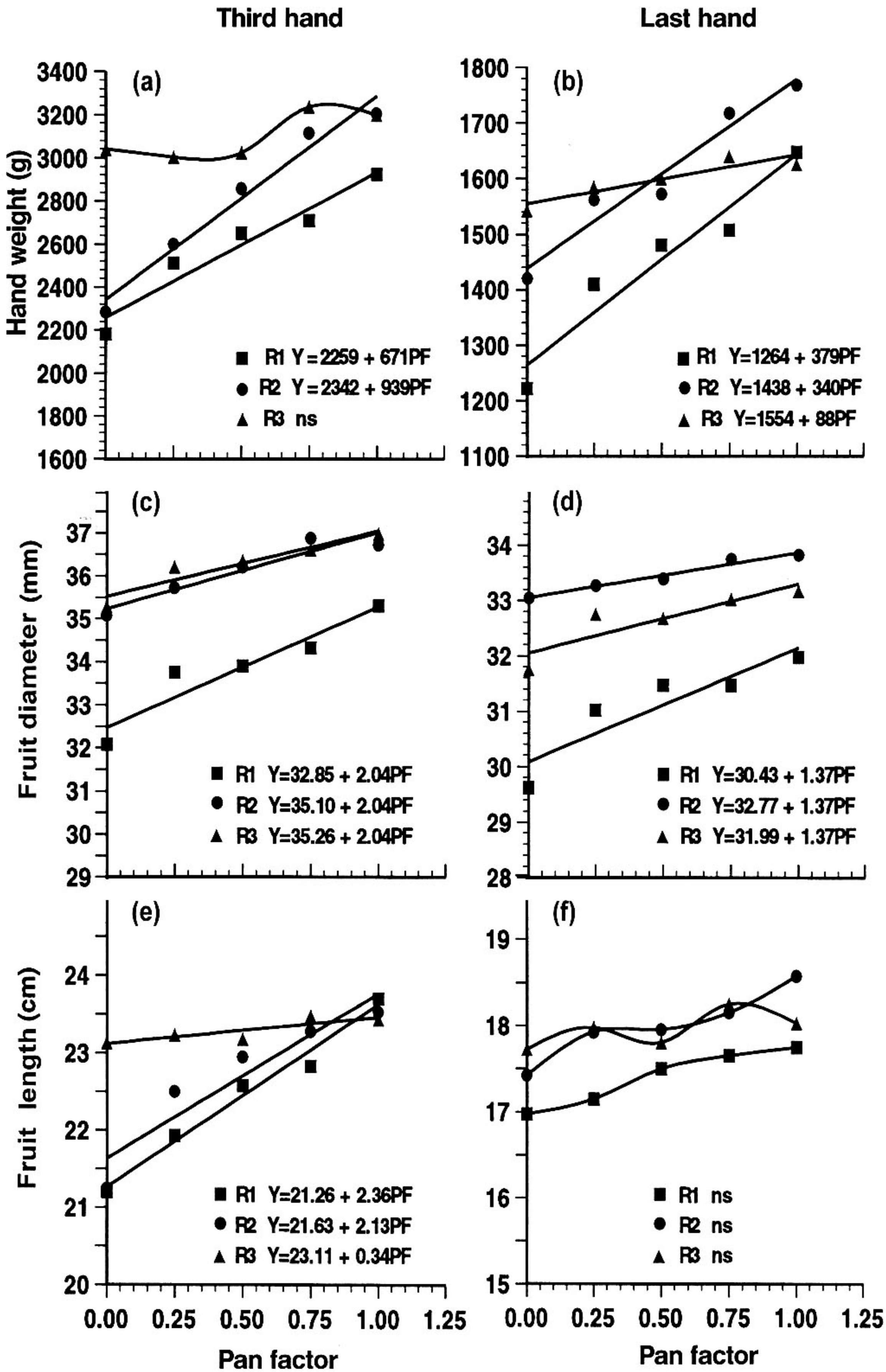
Fig. 2. Bunch weight of the three banana ratoon crops, R1 (■), R2 (●) and R3 (▲, not significant), as influenced by irrigation based on the proportion of pan evaporation (pan factor).

more pronounced in R2 where an increase in pan factor from 0.0 to 1.0 resulted in a third-upper hand weight gain of 939 g, compared with gains of 671 g in R1 and no significant gain in R3. Increments in pan factor treatment from 0.0 to 1.0 resulted in last-hand weight gain of 379 g in R1, 340 g in R2 and 88 g in R3.

Bunch mean hand weight was linearly related to increments in pan factor treatments (Fig. 4). Maximum bunch mean hand weight (3364 g) was attained in plants of R2 with the application of irrigation according to a pan factor of 1.0. This represents an increase of 53% over that obtained for the same crop without irrigation.

Increments in pan factor treatment significantly increased bunch yield in plants of R1 and R2, but not in those of R3 (Fig. 5). The higher yield (47.9 t ha^{-1}) obtained in plants of R3 that were not irrigated (pan factor of 0.0) is indicative that the rainfall received by this crop (Fig. 1) was adequate for good productivity. Bunch yields in plants of R1 and R2 that received irrigation according to a pan factor of 1.0 were 30 and 59% higher respectively than when the crops were not irrigated (Fig. 5). The yields obtained in this study are significantly smaller than those obtained for drip-irrigated bananas grown on a fertile Mollisol in a semi-arid environment (Goenaga and Irizarry, 1995). Robinson (1996) indicated that the banana-growing potential in the humid tropics is constrained by a reduction in photosynthesis due to overcast days and by soils that are highly leached and

Fig. 3. Relationship between irrigation pan factor and hand weight (a and b), fruit diameter (c and d) and fruit length (e and f) in the third-upper and last hands of the banana bunch as influenced by irrigation based on the proportion of pan evaporation (pan factor). The three ratoon crops are R1 (■), R2 (●) and R3 (▲); ns = not significant.



Third hand
Last hand
(a)
(b)
(c)
(d)
(e)
(f)
Hand weight (g)
Fruit diameter (mm)
Fruit length (cm)
R1 Y=2259 + 671PF
R2 Y=2342 + 939PF
R3 ns
R1 Y=1264 + 379PF
R2 Y=1438 + 340PF
R3 Y=1554 + 88PF
R1 Y=32.85 + 2.04PF
R2 Y=35.10 + 2.04PF
R3 Y=35.26 + 2.04PF
R1 Y=30.43 + 1.37PF
R2 Y=32.77 + 1.37PF
R3 Y=31.99 + 1.37PF
R1 Y=21.26 + 2.36PF
R2 Y=21.63 + 2.13PF
R3 Y=23.11 + 0.34PF
R1 ns
R2 ns
R3 ns
Pan factor
Pan factor

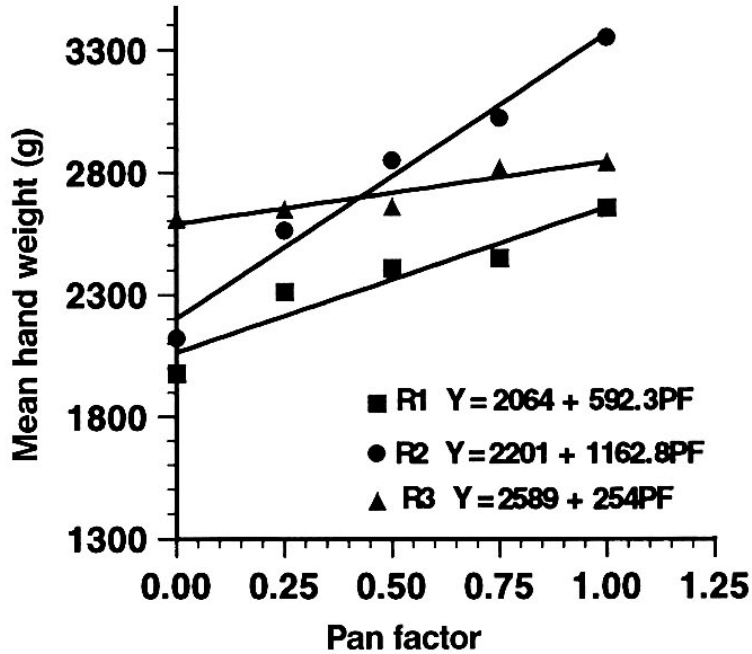


Fig. 4. Relationship between irrigation based on proportion of pan evaporation (pan factor) and mean hand weight in three banana ratoon crops, R1 (■), R2 (●) and R3 (▲).

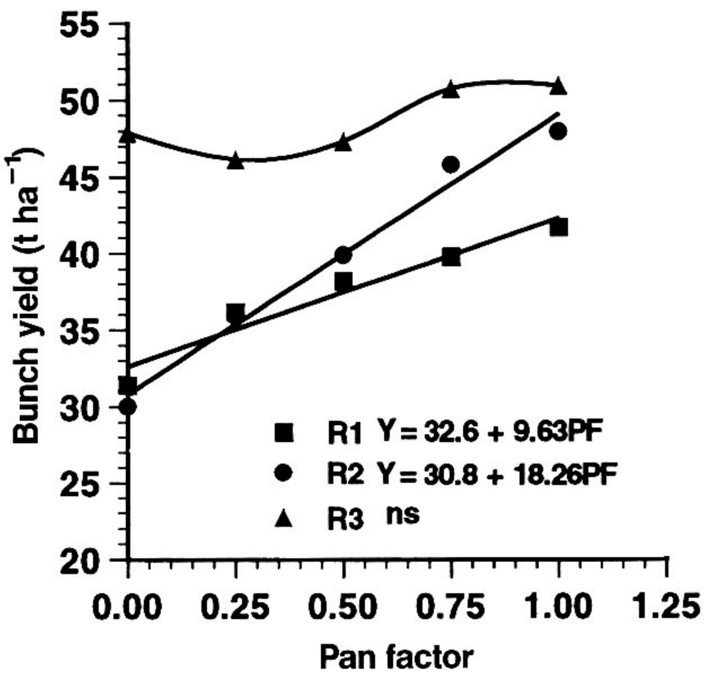


Fig. 5. Relationship between irrigation based on proportion of pan evaporation (pan factor) and bunch yield in three banana ratoon crops, R1 (■), R2 (●) and R3 (▲); ns = non significant.

Table 2. Estimated yield and gross sales of banana supplied with supplemental irrigation according to pan factors of 0.0 (rainfed) and 1.0 in a 20-ha planting in the mountain region of Puerto Rico.

	First ratoon crop			Second ratoon crop		
	Pan factor			Pan factor		
	0.0	1.0	Change	0.0	1.0	Change
Bunch yield (kg)†	586 800	760 140	173 340	554 400	883 080	328 680
Number of boxes of fruits‡	32 348	41 904	9 556	30 562	48 681	18 119
Gross sales (US$)	226 436	293 328	66 892	213 934	340 767	126 833

†From Fig. 5, reflects a 10% yield reduction due to losses caused by wind damage, non-productive plants, and other factors that may reduce production in a commercial plantation; ‡sales based on $7.00 per banana box weighing 18.14 kg.

with low pH and cation exchange capacity. All of these characteristics are commonly encountered in the experimental area used for this study.

Table 2 shows adjusted bunch yields for R1 and R2, numbers of banana boxes, and gross sales obtained by a grower operating a 20-ha planting irrigated according to pan factors of 0.0 (rainfed) and 1.0. Because of a lack of a significant increase in bunch yield between treatment extremes (Fig. 5), data on R3 are not shown. Irrigating R1 and R2 plants according to a pan factor of 1.0 resulted in gross sales that were US$66 892 and US$126 833 respectively higher than in R1 and R2 plants irrigated according to a pan factor of 0.0 (Table 2). The cost of buying and installing a drip irrigation system in 20 ha of bananas grown in this mountain region ranges from US$49 250 to US$82 500. These data suggest that installing a drip system to provide supplemental irrigation for bananas grown in the mountain region is a viable management practice. Supplemental drip-irrigation according to a pan factor of 1.0 is recommended.

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