Reprinted from *Agronomy Journal*
Vol. 92, No. 5

Yield and Quality of Banana Irrigated with Fractions of Class A Pan Evaporation on an Oxisol

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ABSTRACT

There is a scarcity of information regarding the optimum water requirement for banana (*Musa acuminata* Colla, AAA group) grown with supplemental drip irrigation on an Oxisol. A 3-yr study was conducted on a very-fine, kaolinitic, isohyperthermic Typic Hapludox to determine water requirement, yield, and fruit-quality traits of the plant crop (PC) and two ratoon crops (R2 and R3) of 'Grande Naine' and 'Johnson' 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 ($P < 0.001$) irrigation treatment and crop effects for all yield components, fruit length and diameter, number of leaves at flowering and harvest, and number of hands per bunch. Cultivar and the treatment by cultivar interaction were not significant ($P < 0.05$). The highest marketable yield (70.7 Mg ha^{-1}) was obtained from the R2 crop with water application according to a pan factor of 1.25. Plant crop and R3 plants irrigated using the same pan factor yielded 48 and 65 Mg ha^{-1}, respectively. Increasing the pan factors from 0.25 to 1.25 resulted in weight gains of the third-upper hand of 594 g in PC, 1284 g in R2, and 1429 g in R3. It was concluded that banana grown on an Oxisol should be drip irrigated with a pan factor of 1.0 or more three times a week.

TOTAL WORLD PRODUCTION of banana (*Musa acuminata* Colla, AAA group) in 1998 was estimated at 5.7×10^{10} kg (FAO, 1999). 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 (*Castilla elastica* Sessé subsp. *elastica*), cocoa (*Theobroma cacao* L. subsp. *cacao*), sugar (*Saccharum officinarum* L.), and coffee (*Coffea arabica* L.), one of the five major tropical products entering into world trade (Hallam, 1995).

The banana plant is a tropical herbaceous evergreen that has no natural dormant phase; it has a high leaf area index and a very shallow root system (Robinson, 1995). These factors make the crop extremely susceptible to water shortage. Consequently, banana plants require irrigation during dry periods to prevent reductions in yield and fruit quality.

Depending on the prevailing climatic conditions, estimates of the annual evapotranspiration (ET) of banana plants range from 1200 to 2690 mm (Robinson and Alberts, 1989). Water requirements of drip-irrigated banana grown under semiarid conditions on a Mollisol or on an Ultisol under transient dry periods were determined by Goenaga and Irizarry (1995, 1998). Using Class A pan factors that 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. Young et al. (1985) reported similar results when banana was irrigated according to pan factor treatments that ranged from 0.2 to 1.8.

Little is known about water requirements of banana grown on an Oxisol or about possible differences in water requirements among banana cultivars. A local selection of 'Johnson' banana is thought by some growers to be more tolerant to water deficits than 'Grande Naine', the most common cultivar used in Puerto Rico and many other tropical regions. In fields planted to Grande Naine and Johnson we have observed plants of the latter with more vigorous growth and better fruit quality during dry periods.

Updated procedures for calculating crop evapotranspiration were established by FAO (Allen et al., 1998) after this study was completed. The Class A pan, however, is still used as a tool to calculate crop evapotranspiration in many banana-growing regions of the world where meteorological data, equipment, or both are often limited or nonexistent. Our objectives were to determine, using the Class A pan, the optimum water requirement for Johnson and Grande Naine banana grown on an Oxisol and to examine how yield, fruit size, and other bunch and plant traits were affected by various levels of irrigation.

MATERIALS AND METHODS

An experiment was conducted from 1995 to 1998 at the research farm of the USDA-ARS Tropical Agriculture Research Station, Isabela, Puerto Rico. The Coto soil is a well-drained Oxisol (very-fine, kaolinitic, isohyperthermic, Typic Hapludox) with pH of 6.1, bulk density 1.4 g cm^{-3}, 2.0% organic C, and 8.3 cmol$_c$ kg^{-1} exchangeable bases in the first 14 cm of soil. The 23-yr mean annual rainfall is 1649 mm and Class A pan evaporation is 1672 mm. Mean monthly maximum and minimum air temperatures are 29.8 and 19.9°C (Goyal and González, 1989). Total monthly rain and pan evaporation during the experimental period are shown in Fig. 1, and average monthly irrigation supplied to plants is in Table 1.

Sword suckers of Grande Naine and Johnson banana were planted at a 1.8 by 1.8 m spacing (equivalent to 1990 plants ha^{-1}) in a split-plot design with four replications. Each replica-

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Published in Agron. J. 92:1008–1012 (2000).

Abbreviations: ET, evapotranspiration; PC, plant crop; PE, potential evapotranspiration; R1, R2 and R3, first, second and third ratoon crop, respectively; PVC, polyvinylidene chloride; FAO, Food and Agriculture Organization of the United Nations.

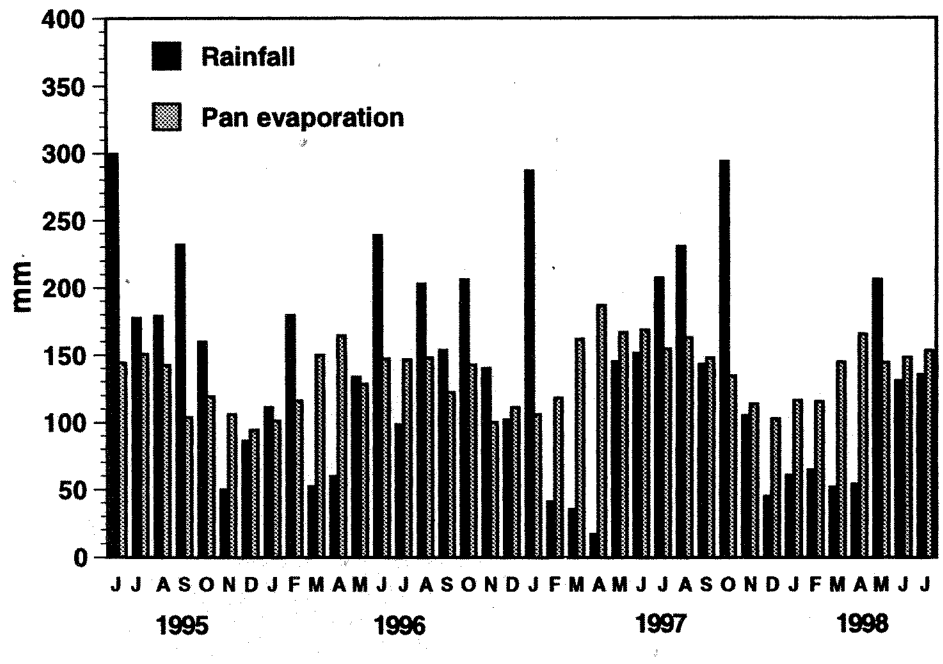

Fig. 1. Total monthly rainfall and Class A pan evaporation during the growth cycle of a plant crop and two ratoon crops of banana at the USDA-ARS Research Station, Puerto Rico.

tion contained five irrigation treatments (main plot) that were split to accommodate both banana varieties. There were two rows per main plot, each with eight experimental plants per variety 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 with potassium nitrate was provided weekly at the rate of 3.6 kg ha^{-1} of N and 12.4 kg ha^{-1} of K. A desuckering program in the plant crop (PC) was implemented during the 5th 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 to establish the second ratoon crop (R2). On 10 Sept. 1996, Hurricane Hortense completely destroyed R1 plants, which at the time were almost 2 mo away from harvest. Suckers from R1 were not affected by the hurricane. Therefore, a new sucker (R2) was selected from R1 plants and the experiment was continued until a third ratoon crop (R3) was harvested. Yellow sigatoka, nematodes, soil-borne insects, and weeds were controlled following recommended cultural practices (Puerto Rico Agric. Exp. Stn., 1995).

The equation of Young and Wu (1981) was used to determine the amount of irrigation applied to plants:

$$AI = 10.03 \times APE \times PA \times PF$$

where AI (L plant^{-1} d^{-1}) is applied irrigation, 10.03 is a constant (100 289 L ha cm^{-1}/9996 m^2 ha^{-1}), APE (cm d^{-1}) is the average daily Class A pan evaporation, PA (m^2) is the plant area, and PF is pan factor treatments (0.25, 0.50, 0.75, 1.0, and 1.25).

However, since evaporimeter data cannot be correlated to crop water use directly (Van der Gulik, 1999), AI values were multiplied by a pan coefficient (K_p) of 0.70 and an average crop coefficient (K_c) of 0.88 (Doorenbos and Pruitt, 1977) to obtain an AI value equivalent to theoretical potential evapotranspiration (PE). The use of pan factors in the equation, which ranged from 0.25 for treatment 1 to 1.25 for Treatment 5, in increments of 0.25, therefore, allowed us to replenish plants with fractions of water lost through PE.

The plants were subjected to the five moisture treatments starting on 14 Aug. 1995. The amount of water applied varied weekly, depending on Class A pan evaporation and rain, which were recorded daily from a weather station located near the experimental site. The previous week's evaporation and rain data were used to determine the irrigation needs for the following week. Following commercial practices, irrigation was supplied three times during the following week on alternate days, and no irrigation was provided when the total rain was >19 mm wk^{-1}. From tensiometer readings the authors had determined that this amount of rain keeps this soil sufficiently wet (10–15 kPa) to avoid the need to irrigate for 1 wk (unpublished results).

Table 1. Average monthly irrigation applied to banana plants subjected to five levels of irrigation as determined by pan factor (proportional to Class A pan evaporation) during a 3-yr period, 1995–1998.

	Irrigation supplied, as proportion of pan evaporation				
Month	0.25	0.50	0.75	1.0	1.25
	L plant^{-1}				
January	25	50	75	100	125
February	46	92	138	184	230
March	95	191	287	383	479
April	107	214	321	428	535
May	65	130	196	261	326
June	38	76	115	153	191
July	27	55	82	110	137
August	33	66	100	133	166
September	46	93	139	186	232
October	46	93	140	187	234
November	32	65	97	130	162
December	43	86	129	172	215
Total	603	1211	1819	2427	3032
Avg.	50.2	101.0	151.6	202.2	252.7

A surface drip system was used to irrigate the crop. Submain polyvinyl chloride (PVC) lines equipped with volumetric metering valves to monitor the water from the main line were provided for each treatment. Lateral drip lines (Drip In Irrigation Co., Madera, CA) equipped with in-line 4 L h^{-1} emitters spaced 0.61 m apart branched out from each treatment submain along the inner side of each plant row and about 0.21 m from the pseudostems.

At flowering and harvest, the number of functional leaves per plant was recorded. About 2 wk after flowering, the male flower bud and the false hands were removed from the immature bunches. Immediately, the bunches were bagged with blue polyethylene sleeves. Banana bunches were harvested when the fruits were about 75% full, about 110 d after flowering. At harvest, the bunches were weighed and the number of hands 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 ANOVA and GLM procedures, respectively, of the SAS program package (SAS Inst., 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, 1999). Only coefficients significant at $P < 0.05$ were retained in the models.

RESULTS AND DISCUSSION

Cultivar and the treatment × cultivar interaction were not significant ($P < 0.05$) and, therefore, data were averaged over cultivars. Irrigation treatments and crops showed significant effects ($P < 0.01$) on bunch weight and yield, number of hands per bunch, weight and fruit diameter of the third and last hands, length of fruits in the third hand, and number of functional leaves at flowering and harvest (analysis of variance not shown).

Total Class A pan evaporation (5162 mm) was similar to the amount of total rainfall (5277 mm) recorded during the 38-mo experimental period (Fig. 1). Although this may suggest that plants were never exposed to soil–water deficits, it is noteworthy that 30% of the total rain recorded during the experimental period fell during the months of June and September of 1995; June 1996; and January, August, and October of 1997. In 20 of 38 mo, rain was less than Class A pan evaporation, indicating that soil–water deficits would have existed without irrigation. More irrigation was required during the months of March, April, and May (Table 1). The water requirement of banana plants in this study was twice that for plants subjected to similar treatments on an Ultisol (Goenaga and Irizarry, 1998) and about half that for plants grown on a Mollisol in a semiarid environment (Goenaga and Irizarry, 1995).

Bunch weight was linearly related to the amount of water applied (i.e., pan factor) in the plant crop and R2 and R3 crops (Fig. 2). The greatest response to irrigation was obtained in the R2 crop, which produced an average maximum bunch weight of 35.5 kg when irrigated using a pan factor of 1.25. This bunch weight represents increases of 9 and 47% more than those obtained for R3 and PC, respectively, when irrigated using the same pan factor. Similar experiments (Goenaga and Irizarry, 1995, 1998) have also shown greater bunch weight in the R2 crop of banana grown under semiarid conditions with drip irrigation or in humid high elevations with supplemental irrigation. Bunches harvested from PC, R2, and R3 plants that were irrigated with a pan factor of 1.25 had 12, 22, and 13% more hands, respectively, than when irrigated with a pan factor of 0.25 (Fig. 2). Bunches harvested from R2 plants had fewer hands than those of R3 (Fig. 2). Therefore, the increase in bunch weight in R2 plants can be attributed to an increase in individual fruit size and weight (Fig. 3).

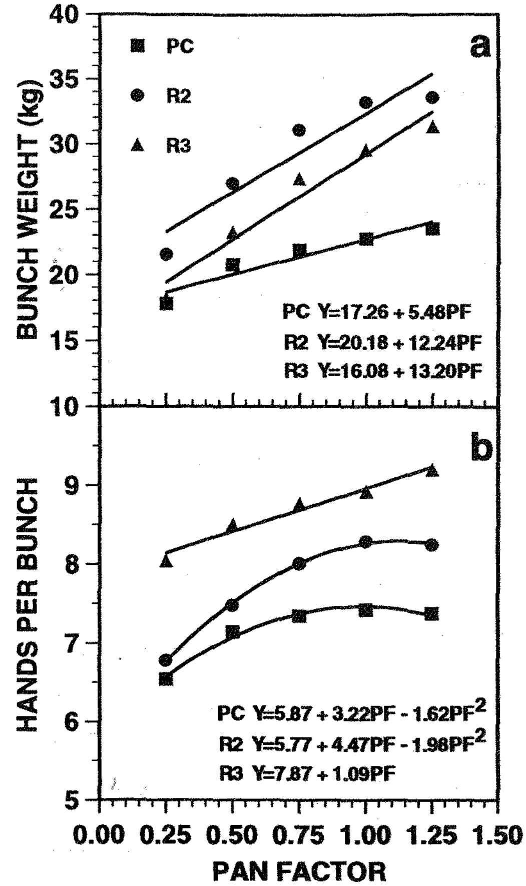

Fig. 2. (*a*) Bunch weight and (*b*) hands per bunch of a banana plant crop (PC) and two ratoon crops (R2 and R3) as influenced by irrigation based on proportion of pan evaporation (pan factor).

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 increases in plants of R2 (Fig. 2). Third-hand fruits in PC, R2, and R3 that received irrigation according to a pan factor of 1.25 were 5, 10, and 12% thicker, respectively, than when the crops were irrigated using a pan factor of 0.25. Similar trends of smaller magnitude were measured on fruits in the last hand of PC, R2, and R3. Increasing the amount of irrigation resulted in an increase in length for fruits in the third-upper hand but not in the last hand (Fig. 3). The weight of the third-upper and last hand in the bunch also in-

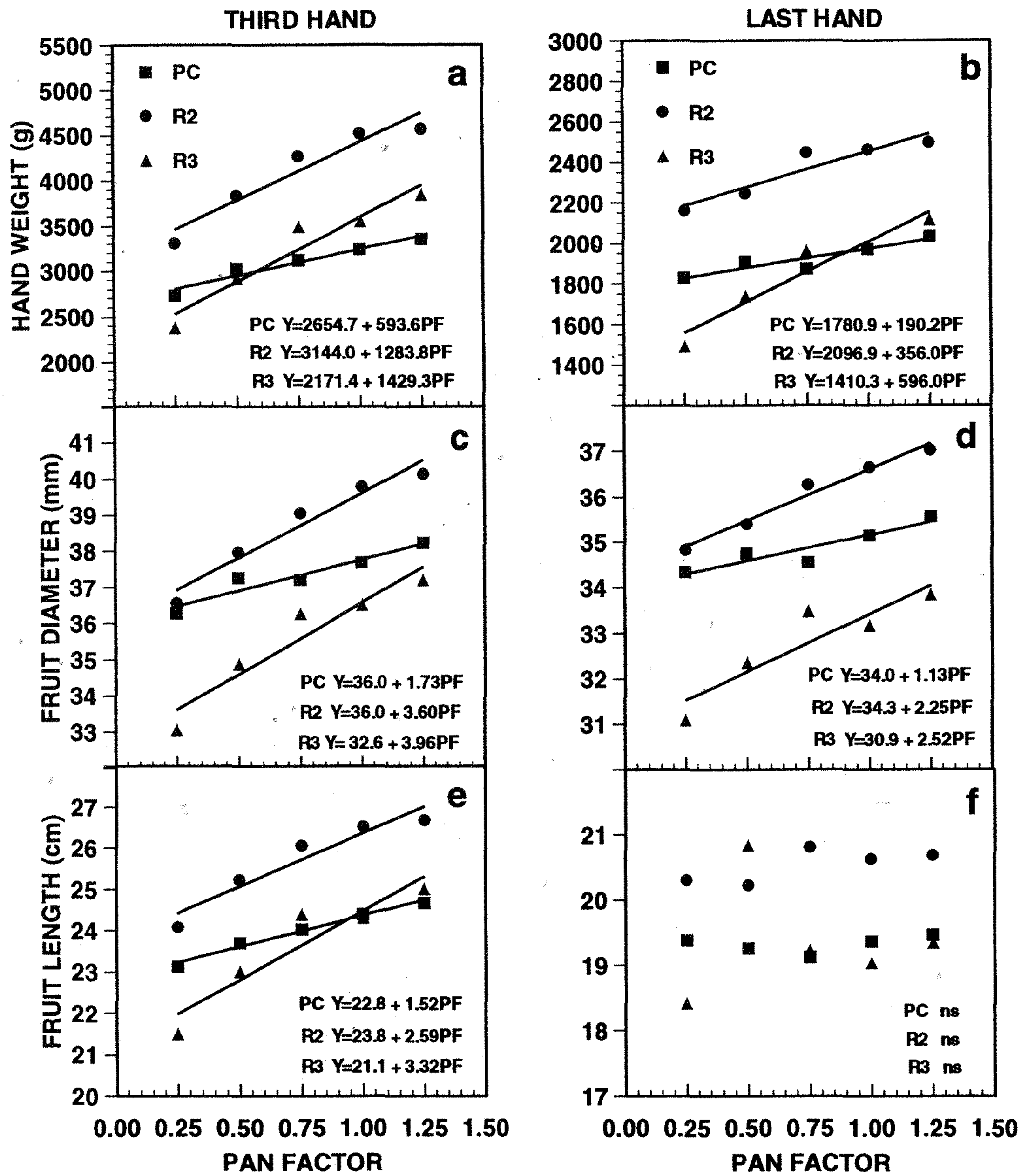

Fig. 3. Relationship between (*a, b*) irrigation pan factor and hand weight, (*c, d*) fruit diameter, and (*e, f*) fruit length in the third-upper and last hands of the banana bunch as influenced by irrigation based on proportion of pan evaporation (pan factor).

creased with pan factor increments (Fig. 3). This response was more pronounced in R2 and R3 where an increase in pan factor from 0.25 to 1.25 resulted in a third-upper hand weight gain of 1284 and 1429 g, respectively, compared with only a gain of 594 g in PC. The same pan factor increment caused a less pronounced effect in the last hand, with weight gains of only 190 g in PC, 356 g in R2, and 596 g in R3.

The number of functional leaves present at flowering and at harvest is an important trait for proper banana fruit filling (Soto, 1985; Robinson, 1996). Increments in pan factor caused significant ($P < 0.01$) increases in the number of functional leaves present at flowering in the study (data not shown). The average number of functional leaves at flowering was 14, 14.5, 15.0, 15.3, and 15.5, respectively, for pan factors 0.25 to 1.25. The average number of functional leaves at harvest (data not shown) ranged from 8.9 to 9.7 for pan factors 0.25 to 1.25. There should be a minimum of 12 functional leaves at flowering, and nine at harvest to achieve maximum bunch filling in banana (Robinson, 1996). Thus, the smaller fruit length and diameter values obtained from PC, R2, and R3 plants subjected to the lower pan factor treatments (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.

Increments in pan factor treatment significantly increased bunch yield in PC, R2, and R3. The highest marketable yield of 70.7 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

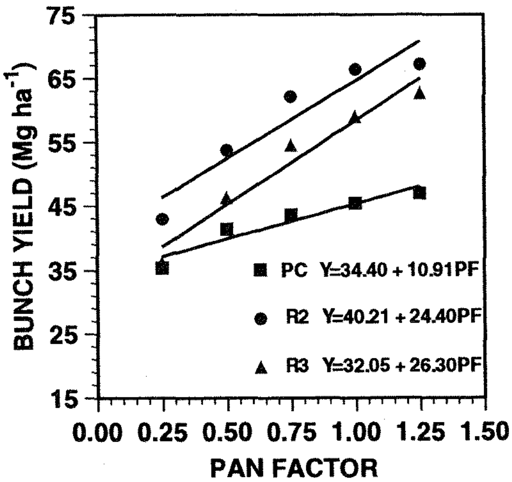

Fig. 4. Relationship between irrigation based on proportion of pan evaporation (pan factor) and bunch yield in the banana plant crop (PC) and two ratoon crops (R2 and R3).

of 23 and 6 Mg ha^{-1} over PC and R3, respectively, when they were subjected to the same pan factor treatment. Even though rain is an important component of the annual water requirement for banana grown in this region, PC, R2, and R3 plants irrigated with a pan factor of 1.25 had a 29, 53, and 68% higher bunch yield than those irrigated with a pan factor of 0.25 (Fig. 4). These results confirm that a banana plantation requires large quantities of water for maximum productivity (Robinson, 1995, 1996).

CONCLUSIONS

From this investigation we conclude that banana grown on an Oxisol should be irrigated using a pan factor of 1.0 or more. The use of a lower pan factor may reduce bunch yield significantly and affect fruit quality. Similar results were obtained by Goenaga and Irizarry (1995, 1998) with banana grown under semiarid conditions on a Mollisol or on an Ultisol under transient drought periods. Updated procedures recommending the use of the Penman-Monteith method for calculating crop evapotranspiration were published by FAO after this study was completed (Allen et al., 1998). Therefore, it is recommended that this method is used in future studies on irrigation requirements of banana and refinements be made to our recommendation presented in this study if necessary. No significant differences in yield and fruit quality traits were observed between the two cultivars used in this study. Future studies should be directed to the screening of a larger number of cultivars in an effort to identify materials with some drought tolerance.

ACKNOWLEDGMENTS

We thank Roberto Bravo for his excellent field assistance during the course of this investigation.

REFERENCES

Allen, R.G., L.S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. Irrigation Drainage Pap. 56. FAO, Rome.

Doorenbos, J., and W.O. Pruitt. 1977. Guidelines for predicting crop water requirements. Irrigation Drainage Pap. 24. FAO, Rome.

Food and Agriculture Organization. 1999. FAOSTAT statistics database: Agriculture. [Online.] Available at http://apps.fao.org/cgi-bin/nph-db.pl?subset=agriculture (accessed 15 Sept. 1999; verified 15 May 2000).

Goenaga, R., and H. Irizarry. 1995. Yield performance of banana irrigated with fractions of Class A pan evaporation in a semiarid environment. Agron. J. 87:172–176.

Goenaga, R., and H. Irizarry. 1998. Yield of banana grown with supplemental drip irrigation on an Ultisol. Exp. Agric. 34:439–448.

Goyal, M.R., and E.A. Gonzlez. 1989. Climatological data collected in the Agricultural Experiment Stations of Puerto Rico. Agric. Exp. Stn. Publ. 88-70. College of Agricultural Sciences, Univ. of Puerto Rico, Mayaguez.

Hallam, D. 1995. The world banana economy. p. 509–533. *In* S. Gowen (ed.) Bananas and plantains. Chapman and Hall, London, UK.

Puerto Rico Agricultural Experiment Station. 1995. Technological package for the production of plantains and bananas. Agric. Exp. Stn. Publ. 97. College of Agricultural Sciences, Univ. of Puerto Rico, Mayaguez.

Robinson, J.C. 1995. Systems of cultivation and management. p. 15–65. *In* S. Gowen (ed.) Bananas and plantains. Chapman and Hall, London, UK.

Robinson, J.C. 1996. Bananas and plantains. CAB International, Wallingford, UK.

Robinson, J.C., and A.J. Alberts. 1989. Seasonal variations in the crop water-use coefficient of banana (cultivar William) in the subtropics. Sci. Hortic. 40:215–225.

SAS Institute. 1987. SAS/STAT guide for personal computers. Version 6 ed. SAS Inst., Cary, NC.

Soto, M. 1985. Bananas: Cultivation and trading. p. 19–97. (In Spanish.) LIL Press, Tibas, Costa Rica.

Van der Gulik, T. 1999. B.C. Trickle irrigation manual. p. 209–221. British Columbia Ministry of Agric. and Irrigation Industry Assoc. of British Columbia, Abbotsford, BC, Canada.

Young, S.C.H., T.W. Sammis, and I.-P. Wu. 1985. Banana yield as affected by deficit irrigation and pattern of lateral layouts. Trans. ASAE 28:507–510.

Young, S.C.H., and I.-P. Wu. 1981. Final report of the banana drip irrigation studies at the Waimanolo Experiment Station. p. 51–69. *In* Proc. Annual Meeting Hawaii Banana Industry Assoc., 13th Conf. Res. Ext. Service 021. College Tropical Agric. and Human Resources, Univ. of Hawaii, Honolulu.