GUIDELINES FOR IRRIGATION SCHEDULING OF BANANA CROP IN SÃO FRANCISCO VALLEY, BRAZIL[1]. II – WATER CONSUMPTION, CROP COEFFICIENT, AND PHYSIOLOGYCAL BEHAVIOR

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ABSTRACT – The water consumption and the crop coefficient of the banana cv. Pacovan were estimated in Petrolina County, northeastern Brazil, in order to establish guidelines to irrigation water management. Evaluations were carried out since planting in January 1999 to the 3rd harvest in September 2001 on a microsprinkler irrigated orchard, with plants spaced in a 3 x 3 m grid. Average daily water consumption was 3.9, 4.0, and 3.3 mm in the 1st, 2nd and 3rd growing seasons, respectively. Crop coefficient values increased from 0.7 (vegetative growth) to 1.1 (flowering). Even with high soil water availability, transpiration was reduced due to high evaporative demand.
Index terms: *Musa* spp, semi-arid, Kc

ORIENTAÇÕES PARA O MANEJO DA IRRIGAÇÃO DA BANANEIRA NO VALE DO SÃO FRANCISCO. II – CONSUMO DE ÁGUA, COEFICIENTE DE CULTURA E COMPORTAMENTO FISIOLÓGICO

RESUMO – O consumo de água e o coeficiente de cultura da bananeira cv. Pacovan foram estimados em Petrolina-PE, Brasil, com o objetivo de fornecer informações úteis ao manejo de irrigação. As avaliações foram realizadas desde o plantio, em janeiro de 1999, até a terceira colheita, em setembro de 2001, em um pomar irrigado por microaspersão e com plantas espaçadas em 3 x 3 m. O consumo médio diário foi de 3,9; 4,0 e 3,3 mm no primeiro, segundo e terceiro ciclos, respectivamente. O coeficiente de cultura aumentou de 0,7 (desenvolvimento vegetativo) para 1,1 (florescimento). Apesar da alta disponibilidade de água no solo, a alta demanda evaporativa reduziu a transpiração da bananeira.
Termos para indexação: *Musa* spp, semi-árido, Kc

INTRODUCTION

Water is probably the most limiting non-biological factor in banana production. Water requirements of this crop are known by the effective rainfall and by irrigation, and the proportion of water for banana irrigation derived from these two sources and varies widely throughout the world (Robinson, 1995).

Banana has been known as a plant with a rapid growth rate, high consumption of water, shallow and spreading root distribution, roots with weak penetration strength into the soil (Champion, 1968), poor ability to withdraw water from soil which is drying (Hedge, 1988), low resistance to drought and rapid physiological response to soil water deficit (Robinson, 1995).

These factors indicate that banana is sensitive to even slight variations in soil water content and that irrigation scheduling is critical. The water holding capacity of the soil, effective rooting depth of banana, and the percentage of depletion of total available water allowed before irrigation determine the amount of water to apply, while crop coefficient together with the evapotranspiration data determine the irrigation interval (Robinson, 1995).

In the São Francisco Valley, Northeastern Brazil, Petrolina County presents a banana growing area of approximately 4.600 ha, most of them irrigated by under canopy sprinkler and microsprinkler irrigation systems, and the cultivar Pacovan (AAB group, Prata sub-group) is the most cropped (CODEVASF, 2001). In this Brazilian semi-arid region, high solar radiation (363 to 528 cal.cm^{-2}.day^{-1}), warm temperatures (monthly values from 24.2 to 28.2°C), and low air humidity (55 to 71.5%) make possible the banana harvesting continuously over the whole year, but water requirements are known by irrigation as a consequence of the low rainfall (570 mm) falling in a seasonal (90% from October to March) and erratic pattern (Teixeira, 2001a). Nevertheless, useful information about irrigation scheduling of banana crop, obtained from experimentation in this Brazilian fruit crop growing area, such as water consumption and crop coefficient since planting and over successive growing seasons, is not well defined. Hence, the purpose of this research was to obtain guidelines for irrigation scheduling of the banana crop in an irrigation district of Petrolina, Brazil.

MATERIAL AND METHODS

Site and soil

The experiment was carried out in an experimental field at Embrapa Semi-Árido, Petrolina, Pernanbuco State, Brazil (latitude 09°09' S, longitude 40°22' W, altitude 365,5 m), located in the Bebedouro Irrigation District. The soil is a red-yellow latosol, medium texture (Embrapa, 1999). Physical characteristics were determined as described by Embrapa (1997), in soil samples of 0.2 m thickness collected from surface 1 m depth. Results showed high sand content (76 to 90, 2 to 10, and 6 to 16 g.kg^{-1} of sand, silt and clay, respectively); bulk density ranging from 1.23 to 1.60 kg.dm^{-3}, being the highest values found in the upper soil layer; and low water holding capacity (0.077 to 0.122 m^3.m^{-3} at 0.033 MPa, and 0.034 to 0.065 m^3.m^{-3} at 1.5 MPa).

Planting time and cultural practices

The banana cv. Pacovan was planted in January 1999 in a 3 x 3 m grid spacing. At 174 days after planting - dap (July 1999) and 603 dap (September 2000), the suckers which originated the 2nd and 3rd season cycles growing seasons were selected, respectively, while the unwanted suckers were regularly eliminated.

Irrigation water application

The banana plants were irrigated by microsprinkler, with one emitter installed between two plants in the row. Field tests were performed

[1] (Trabalho 043/2004). Recebido: 16/04/2004. Aceito para publicação: 28/10/2004. Research supported by CNPq (project 521198/98-4) and by International Foundation for Science (project C-2748/2)
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to estimate the wetted ratio (2 m) and the flow rate (46 $L.h^{-1}$, at 130 MPa). The wetted ratio promoted the wetting of the total soil surface among plants. The soil water content was monitored by three tensiometer sets (devices installed at 0.2, 0.4, 0.6, 0.8, and 1.0 m depth). The values of θ ($m^3.m^{-3}$) were known by the soil water retention curve, using the average values of soil matric potential.

The net irrigation water amount (W_N, mm) was estimated by:

$W_G = (\theta_{FC} - \theta_C).(\Delta z /1000)$

where θ_{FC} and θ_C were considered the soil water content ($m^3.m^{-3}$) at the field capacity matric potential (-10 kPa) and at the critical matric potential (-30 kPa), respectively, and Δz was the soil depth (0.4 m). The gross amount of water to be applied (W_G, mm) was calculated by

$W_G = (W_N .E_f) / 100$

where E_f is the irrigation efficiency (considered 90%).

The irrigation time (Ti, h) was calculated by :

$Ti= (W_G.Sp.Sr) / (n.F)$

where Sp and Sr are the grid spacing (m) between plants (p) and rows (r), n is the number of emitters per plant, and F is the microsprinkler flow rate ($L.h^{-1}$).

Water balance *in situ*

Water balance was performed over three growing seasons for crop evapotranspiration estimation (ETc), from planting in January 1999 to the end of the third harvest (September 2001):

$Ra + I \pm q_i \pm \Delta S \pm Ru - ETc = 0$

where Ra is the rainfall, I is the amount of water applied in every irrigation event, q_i is the downward or upward water flux, ΔS is the variation of the soil water storage (S), Ru is the runoff (Reichardt, 1996). All values from water balance equation were expressed in mm, for a specified period of time (days) within each phenological stage. Ra values were obtained from a pluviometer from the experimental field weather station, while I was determined from Ti and Q previously calculated for each irrigation event. Ru was considered negligible due to flat topography of the area. The component q_i was obtained from the integration of the values of q estimated by the Darcy-Buckingham equation:

$q= - K(\theta)\nabla\psi_h$

where q is the soil water flux (q, $m^3.m^{-2}.day^{-1}$), K(θ) is the unsaturated hydraulic conductivity – soil water content relationship (m day^{-1}), and $\nabla\psi_h$ is the hydraulic gradient (dimensionless).

The hydraulic conductivity was estimated by method proposed by Libardi *et al*. (1980), and represented by the following equation:

$K(\theta)= K_o e\beta^{(\theta - \theta o)}$

where K_o is the saturated hydraulic conductivity (m day^{-1}), ß is the coefficient dependent of the soil and determined by the equation regression, and θ and θ_o ($m^3\ m^{-3}$) are the actual and the saturated soil water content, respectively. The relationship K(θ) was determined besides the experimental area, in a 5 x 5 m plot, which was saturated with water in the 1.5 m soil depth. Three neutron probe access tubes were installed in the middle of this plot to monitore the changes of soil water content over the time by the neutron scattering technique, and the soil surface was covered to avoid soil water evaporation. The total time of neutron probe readings was 14 days.

The hydraulic gradient indicated the direction of q, i.e., positive $\nabla\psi_h$ indicated downward flux, and negative $\nabla\psi_h$ indicated upward flux. The hydraulic gradient was estimated between the hydraulic potential (ψ_h ,kPa) of two soil depths, one above ($\psi_{h\ above,}$ kPa) and another below ($\psi_{h\ below}$, kPa) the soil depth considered as the effective rooting depth, and divided by the distance between them (Δz, m expressed by the equivalent kPa):

$\nabla\psi_h= (\psi_{h\ above} - \psi_{h\ below}) / \Delta z$

The soil water storage (S, mm) was obtained by the θ integration from the soil depths monitored by tensiometers:

$$S = \int_0^z \theta (z)\, dz$$

The ΔS (mm) in a period of time was obtained by:

$\Delta s= S_t – S_{t-1}$

where S_t and S_{t-1} represent soil water storage in the soil profile in the beginning and in the end of a period of time considered over the growing season.

Reference evapotranspiration, crop evapotranspiration and crop coefficient

According to Allen et al. (1998), the reference evapotranspiration (ETo, mm) was estimated by the class A pan evaporation method (A):

ETo = Ep . Kp

where Ep is the pan evaporation, and Kp is the pan coefficient based on wind velocity, relative air umidity and pan boundary (Doorenbos & Pruit, 1975). Also, ETo was estimated by the FAO Penman-Monteith method (FAO-PM). All data were obtained in the weather station of the experimental field. Crop coefficient (Kc) for all phenological stages were estimated by the ratio ETc / ETo and both methods of ETo estimation were considered.

Leaf area measurements

In the 1st growing season, leaf area was measured at 65, 123 and 184 days after planting (dap), with three plants in each time sampling. All leaves of each plant were collected, the lamina was separated from the central nervure and measured by a LICOR LI 3100 Meter. The leaf identification was made from the first heart leaf, which is named “zero leaf”. The following leaves were labeled according with their unrolling sequence. The area of fourth, fifth and ninth leaves were tested for choosing the representative leaf for the total leaf area (TLA, cm^2) estimation. The fourth leaf area (FLA, cm^2) was chosen due to its best fit. At 245 dap, the total leaf area was estimated by this calibration. The absolute leaf growth rate (ALGR, $cm^2.day^{-1}$) was obtained by the difference between two consecutive measurements, divided by the period of time, and the leaf area index (LAI) by the leaf area / plant spacing ratio.

Stomatal resistance, transpiration and leaf water potential measurements

The measurements of stomatal resistance (r_s, $s.cm^{-1}$) and transpiration (T, $ìg.cm^2.s^{-1}$) were performed in the lower surface of the leaves due to higher number of stomata (Robinson & Bower, 1988). They were obtained with a hand porometer Licor LI-1600 at 65, 123, 184, and 245 dap, in three plants, from 6 a.m. (6 h) to 6 p.m. (18 h), in 2 h intervals. Leaf water potential ($Ø_L$, MPa) was measured at the same dates and times, using tissue samples (discs) cut and loaded on C-52 psychrometric chamber for measurement with a HR-33T microvoltmeter, using the dew point methodology (Coombs et al., 1985).

RESULTS AND DISCUSSION

The yield of banana was 10834.4 $kg.ha^{-1}$, 14705.7 $kg.ha^{-1}$ and 15457.4 $kg.ha^{-1}$, respectively for the 1st, 2nd and 3rd harvests. The water consumption for each growing season (Table 1) indicates higher daily values in the first two cycles. The maximum value observed was 7.3 mm on November 1999, in the flowering stage of the 1st growing season. Considering the ratio between the yield and the water consumption of the three seasons, a water use efficiency (WUE) of 11.7 $kg.ha^{-1}mm^{-1}$ was obtained. Hedge & Srinivas (1989) estimated the WUE of banana cv. Robusta ranging from 28 to 37 $kg.ha^{-1}.mm^{-1}$, according to the soil water availability. The WUE values are related to two harvests and the planting density were three times higher (1.8 x 1.8 m spacing grid).

Banana plants of 1st and 2nd seasons, and of 2nd and 3rd seasons developed at the same time. Initially, crop coefficient (Kc) was 0.7±0.3 (A) and 0.8±0.3 (FAO-PM) from planting to the end of the vegetative stage (Jan to Aug 1999 – 0 to 211 dap), followed by increases to 0.9± 0.3

TABLE 1 – Reference evapotranspiration (ETo), crop evapotranspiration (ETc) and daily water consuption (WC) of banana in Petrolina in three growing seasons.

growing season (days after planting – dap)	days	ETo (A)[1] mm	ETo (PM-FAO)[2] mm	ETc mm	WC[1] mm
planting to end of 1st harvest Fev 99 – Apr 00 (10 – 444 dap)	434	2227	1816	1698	3.9
end of 1st harvest to end of 2nd harvest Mai 99 – Nov 00 (445-658 dap)	213	1113	827	861	4.0
end of 2nd harvest to end of 3rd harvest Dec 00- Sep 28 (659 – 976 dap)	317	1535	1307	948	3.0

[1]class A pan method; [2] FAO Penman-Monteith method

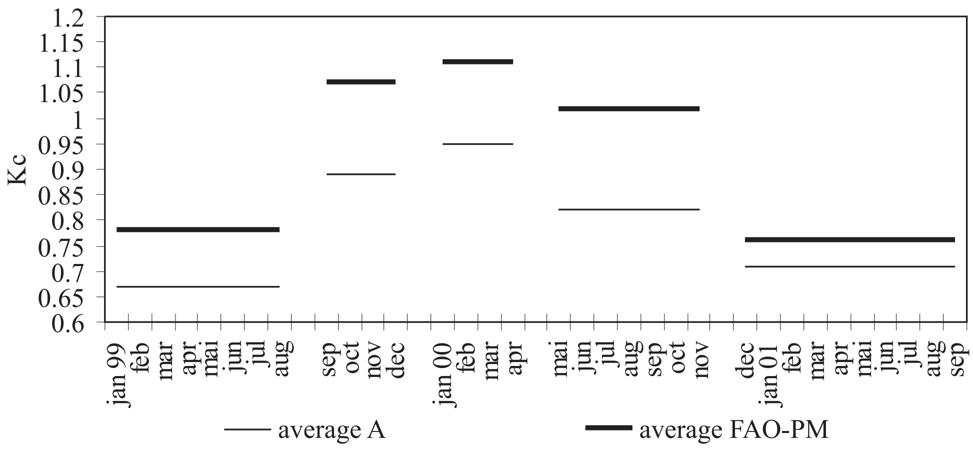

FIGURE 1 – Crop coeficient (Kc) of banana cv. Pacovan in Petrolina throughout three growing seasons, using class A pan (A) and FAO Penman-Monteith (FAO-PM) methods for estimation of reference evapotranspiration.

(A) and 1.1±0.4 (FAO-PM) along the 1st flowering (Sep to Dec 1999 – 212 to 333 dap), and to 1.0±0.5 (A) and 1.1±0.5 (FAO-PM) in the 1st harvesting and part of the 2nd flowering (Jan to Apr 2000 – 334 to 444 dap). This is a consequence of the fast growth of plants and suckers until that time. Values decreased to 0.8±0.4 (A) and 1.0±0.4 (FAO-PM) from the end of April to Nov 2000 (445 to 658 dap), when 2nd flowering was over, 2nd harvest was going on, and the 3rd flowering began. Along the 3rd harvest (Jan to Sep 2001 – 659 to 976 dap), all suckers were systematically eliminated to avoid another growing season, and the Kc reduced to 0.7±0.4 (A) and 0.8±0.5 (FAO-PM). Monthly and average Kc values for phenological stages are presented in Figure 1. The Kc values estimated and their changing along the phenological stages of banana crop were close to other already reported, i.e., from 0.4 to 1.2 (Bhattacharrya & Rao, 1985), from 0.6 to 1.5 (Santana et al., 1993), and from 0.5 to 1.2 (Allen et al.,1998). In this same experiment, a Kc range from 0.6 to 1.3 was observed in the first two growing seasons (from 120 to 650 dap), using the Bowen ratio method for ETc estimation (Teixeira et al., 2002).

Both ALGR and LAI mostly increased until 183 dap (Table 3), showing an intensive leaf growth until flowering, when bud differentiation occurs and leaf emergence decreases (Turner, 1998). In the same experiment, Teixeira (2001b) measured the dissipation of energy absorbed by the banana plant and showed that at 124, 214, 322 and 438 dap, the latent heat flux in the banana canopy (energy used by evaporation of water or transpiration) and the soil heat flux corresponded, respectively, to 75 and 23, 82 and 16, 87 and 12, 94 and 5% of net solar radiation. This indicates that contribution of evaporation to the evapotranspiration process was higher in the beginning of 1st growing season, but reduced as the leaf area increased. Hence, for the all vegetative phases of this 1st season, a single average value of Kc is presented in Figure 1.

Moreover, the ETo (A) values were higher than ETo (FAO-PM) in all growing seasons (Table 1). The methods taken in account the solar radiation, such as the FAO-PM, provide a closer estimation of ETo than class A pan, in comparison with that obtained by a lysimeter, considered as the standard (Medeiros, 1998; Machado & Mattos, 2000). Also, the Kp values used (Doorenbos & Pruit, 1975) are higher than Kp measured for tropical conditions, and consequently an overestimation of ETo occurs when the pan method is used (Pereira et al., 1995). Hence, Kc values estimated with ETo (FAO-PM) were higher (Figure 1).

In the early morning, an increase of transpiration was observed, but it decreased between 10 to 14 h as a consequence of the increasing of stomatal resistance, probably due to an evaporative demand greater than water absorption plant capacity. The soil water matric potential at 0.4 m soil depth was greater than -11.6, -10.6, -14.3 and -8.3 kPa, respectively at 65, 123, 184 and 245 dap, which indicates high soil water availability. Also, pan evaporation was 5.0, 9.3, 7.3, and 8.0 mm; air humidity was 54, 61, 63, 68 %; and wind velocity was 96, 259, 211, and 279 km.day^{-1}, respectively at 65, 123, 184, and 245 dap, indicating favorable conditions to meaningful evaporation. This process went on through the afternoon, being enhanced by the decreasing of luminosity. Higher stomatal resistance was observed in the early morning and in the late afternoon, showing the influence of luminosity on stomatal aperture (Salisbury & Ross, 1969), but the leaf water potential was lower just after

TABLE 2 – Leaf area parameters of banana cv. Pacovan at different days after planting (dap) in the first growing season (1999).

dap	phenological stage	leaf area cm^2	standard deviation	absolute leaf growth rate $cm^2.day^{-1}$	proportion of total leaf area %	leaf area index (LAI)
0	-	0	-	-	0	0
63	vegetaive	9725.12	2468.48	154.37	9	0.11
123	vegetative	37439.08	4475.47	461.90	33	0.42
183	flowering	99541.02	9190.48	1018.06	88	1.11
245*	fruit development	113330.77	4094.31	226.06	100	1.26

*total leaf area (TLA) estimated by the fourth leaf area (FLA): TLA = 11.866.FLA-4476.3 , r^2 = 0.998

TABLE 3 – Stomatal resistance (r_s, s.cm^{-1}), transpiration (T, ìg.cm^2.s^{-1}), and leaf water potential ($Ø_L$, MPa) of banana cv. Pacovan at 65, 123, 184 and 245 days after planting (dap), in the 1st growing season (1999).

day	65 dap			123 dap			184 dap			245 dap		
hour	r_s	T	Ψ_L	r_s	T	Ψ_L	r_s	T	Ψ_L	r_s	T	Ψ_L
6	189.1	0.2	-0.17	11.2	0.4	-0.20	7.0	0.3	-0.13	9.4	0.6	-0.24
8	2.8	4.3	-0.17	2.5	2.1	-0.24	2.1	5.6	-0.22	5.3	1.6	-0.33
10	4.4	10.1	-0.29	4.0	3.9	-0.66	1.9	8.7	-0.47	2.0	5.5	-0.54
12	12.6	4.4	-0.18	11.4	6.5	-0.63	4.4	6.0	-0.55	2.6	6.8	-0.72
14	7.7	5.6	-0.25	18.3	2.9	-0.42	4.8	5.5	-0.33	4.4	4.5	-0.39
16	8.5	4.4	-0.18	15.6	4.3	-0.34	8.5	2.8	-0.12	5.1	4.6	-0.66
18	30.7	0.5	-0.13	775.2	0.1	-0.25	34.5	0.5	-0.0 9	18.5	0.5	-0.41

the beginning of stomatal closure (10-14 h) and became higher in the late afternoon, which values were closer to those in the early morning. It indicates a major role of the plant water status in the stomatal resistance (Table 3). As photosynthetic activity in banana decreases with reduction of transpiration and stomatal aperture (Robinson & Bower, 1987; Eckstein et al., 1995; Eckstein & Robinson, 1996), more favorable condition to photosynthesis were found during the morning.

CONCLUSION

The daily water consumption of the first two growing seasons of banana in Petrolina was close. Crop coefficient increased from planting (0.7 for A and 0.8 for FAO-PM methods) to the first flowering (0.9 for A and 1.1 for FAO-PM methods), and to the first harvesting and part of second flowering (1.0 for A and 1.1 for FAO-PM methods), when the greater Kc took place. After that, Kc values decreased a little throughout the second harvest and third flowering (0.8 for A and 1.0 for FAO-PM methods), and another reduction was observed due to sucker elimination in the third growing season (0.7 for A and 0.8 for FAO-PM methods). Even in an irrigated banana orchard, with high soil water availability, transpiration reduces from midday to afternoon due to high evaporative demand.

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