ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.8, p.594-601, 2022
agriambi
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n8p594-601

Consumptive water use of banana under micro irrigation using a soil-water balance approximation[1]

Uso consuntivo de água da bananeira sob micro irrigação usando uma aproximação do balanço de água do solo

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HIGHLIGHTS:

Time Domain Reflectometry (TDR) allows estimating soil moisture in the root zone for crop evapotranspiration studies.
Banana biomass as a ground cover with localized irrigation for banana cultivation reduces soil water evaporation.
Crop coefficients were lower than those of FAO-56 in the three vegetative phases for micro-sprinkler irrigation under cover.

ABSTRACT: DMulching contributes to the maintenance of soil moisture at reasonable levels for crop growth. It influences the crop water demand and irrigation time. The aim of this study was to estimate evapotranspiration and root water uptake by the 'BRS Princesa' banana cultivar through a simple approach using some components of soil water balance within the root zone in bare and mulched soil irrigated by drip and micro sprinkler systems. The experimental design was completely randomized in split plots with six replicates. The plots consisted of two irrigation systems (drip and micro sprinkler), the subplots consisted of two soil surface conditions: with and without mulch. The alternative approach for soil water percolation in the soil water balance allowed obtaining ETc under field condition with reasonable accuracy. ETc estimated from the root zone water balance is lower than ETc from FAO Penman-Monteith equation. Root water extraction in the mulched soil under drip irrigation is higher than that under micro sprinkler irrigation.

Key words: 'BRS Princesa', mulching, soil water storage, drip irrigation, micro sprinkler

RESUMO: A cobertura do solo contribui para a manutenção do teor de água do solo em níveis razoáveis para o crescimento da cultura. E influi na demanda hídrica da cultura e tempo de irrigação. O objetivo deste estudo foi estimar a evapotranspiração e a absorção de água radicular pela cultivar de bananeira 'BRS Princesa' através de uma abordagem simples utilizando alguns componentes do balanço hídrico do solo na zona radicular em solo nu e mulched irrigado por gotejamento e microaspersão. O delineamento experimental foi inteiramente casualizado em parcelas subdivididas com seis repetições. As parcelas consistiram de dois sistemas de irrigação (gotejamento e microaspersão), as subparcelas consistiram de duas condições de superfície do solo: com e sem cobertura morta. A aproximação alternativa para a percolação da água no solo pelo balanço hídrico permitiu obter ETc em condições de campo com razoável precisão. A ETc estimada a partir do balanço hídrico da zona radicular é menor que a ETc da equação FAO Penman-Monteith. A extração da água do solo pelo sistema radicular sob irrigação por gotejamento e com cobertura de biomassa da bananeira é maior do que a absorção sob irrigação por microaspersão.

Palavras-chave: 'BRS Princesa', cobertura morta, armazenamento de água no solo, irrigação por gotejamento, microaspersão

• Ref. 257168 – Received 18 Oct, 2021
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• Accepted 10 Apr, 2022 • Published 01 May, 2022
Editors: Ítalo Herbet Lucena Cavalcante & Walter Esfrain Pereira

Introduction

Despite the modern, most efficient water application methods in irrigation, there has been a search for higher water use efficiency (WUE), i.e., increasing food production per cubic meter of applied water (Tarjuelo et al., 2015; Nikolaou et al., 2020). Increasing WUE relies on either maintaining or increasing crop yield while using lower amounts of irrigation water. Decreasing irrigation depths without affecting crop development and yields may be attained by using crop residues as mulches, such as dry leaves. Mulching prevents soil water loss by evaporation, thereby maintaining soil water content (SWC) available for root uptake (Daryanto et al., 2017).

The water requirement of the banana crop can be estimated from the lysimeter associated with the soil water balance (Santana et al., 1993). The estimation of water demand by the banana tree is important due to the variations in consumption in the different vegetative stages, which alter the Kc values (Panigrahi et al., 2021). Studies have been conducted in semi-arid regions of Brazil to determine water needs for banana and plantain cultivars (Coelho et al., 2013; Oliveira et al., 2013). However, these studies have not considered water extraction by roots of mulched banana plants under micro irrigation.

Crop evapotranspiration is an unknown component of the soil water balance within the root zone. Water percolation is another water balance component determined under field conditions. Percolation below the root zone, or deep percolation (DP), is easy to determine in lysimeters, but difficult in the field (Kim et al., 2011; Nassah et al., 2017). There are other methods to estimate DP under field conditions (Silva & Coelho, 2014; Ostad-Ali-Askari & Shayannejad, 2015). Campos et al. (2021) evaluated an approximation for soil water balance under field conditions by just using soil moisture content within a whole soil profile without need for soil hydraulic properties.

The aim of this study was to estimate evapotranspiration and root water uptake by the 'BRS Princesa' banana cultivar through a simple approach using some components of soil water balance within the root zone in bare and mulched soil irrigated by drip and micro sprinkler systems.

Material and Methods

The work was carried out in the experimental field of Embrapa Mandioca e Fruticultura in Cruz das Almas, Bahia state, Brazil (12° 48' S, 39° 06' W, and 225 m of altitude) (Figure 1). The climate in the region is tropical Af according to Köppen-Geiger classification. Mean annual precipitation is 1,136 mm (at: https://en.climate-data.org/south-america/brazil/bahia/cruz-das-almas-43358/). The soil physical properties were determined in laboratory according to EMBRAPA (2017) and the results were 568 g kg^{-1} of sand, 85 g kg^{-1} of silt and 345 g kg^{-1} of clay. The soil water contents were 0.29 and 0.17 cm^3 cm^{-3} at field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}), respectively.

The banana cultivar was 'BRS Princesa' planted at a 2.50 x 2.50 m spacing. The study was conducted during the periods of November 2015 (442 to 474 days after planting – DAP), December 2015 (475 to 503 DAP) and February 2016 (535 to 565 DAP), corresponding to the vegetative, flowering and fruiting stages, respectively, of the second crop cycle. Two irrigation systems were used: micro sprinkler and drip. The micro sprinkler system consisted of one lateral line between two plant rows with one emitter of 64 L h^{-1} flow rate, placed at the center of four plants. The drip irrigation system consisted of one lateral line per plant row, with three emitters per plant, each having flow rate of 4.0 L h^{-1}. For both systems, the application efficiency was set at 90%.

The calculation of the amount of irrigation water was based on the reference evapotranspiration (ETo) (Figure 2) calculated by the FAO's standard method Penman-Monteith (Allen et al., 2006) using meteorological data collected by an automatic weather station located at 100 m from the experimental area. Daily irrigation depths for November 2015 were calculated based on the cumulative reference evapotranspiration (ETo) of the days since the previous irrigation. A 15-day ETo average was used to calculate the irrigation water depth for the months of December 2015 and February 2016. The average water depths were 6.5 mm (December 2015) and 6.9 mm (February 2016). Adopting this assumption during a period of small variation in ETo allowed the use of a fixed irrigation water depth; thus, each irrigation cycle was considered as a repetition of treatment.

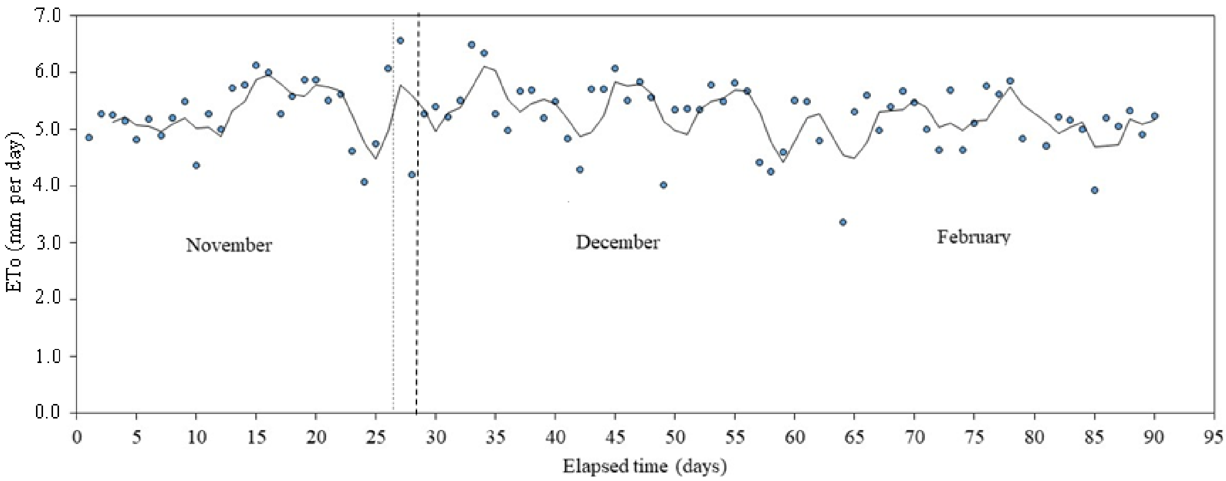

Figure 1. Reference evapotranspiration (ETo) by the Penman-Monteith-FAO method for the months of November and December 2015 and February 2016

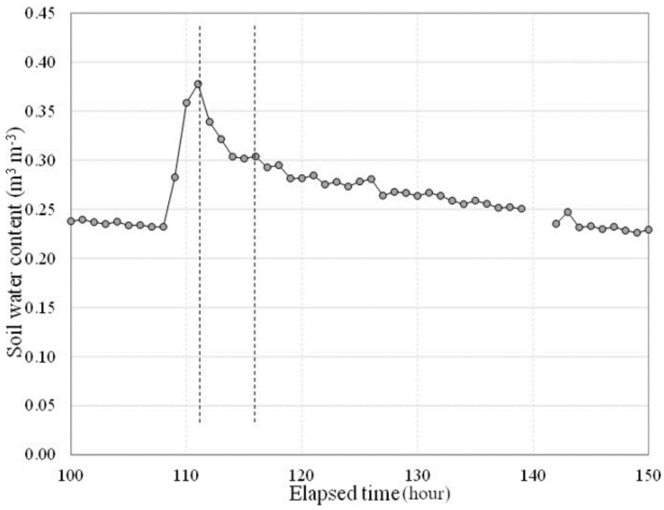

Figure 2. Soil water content as a function of time at 0.25 m distance from plant and 0.40 m depth from soil surface

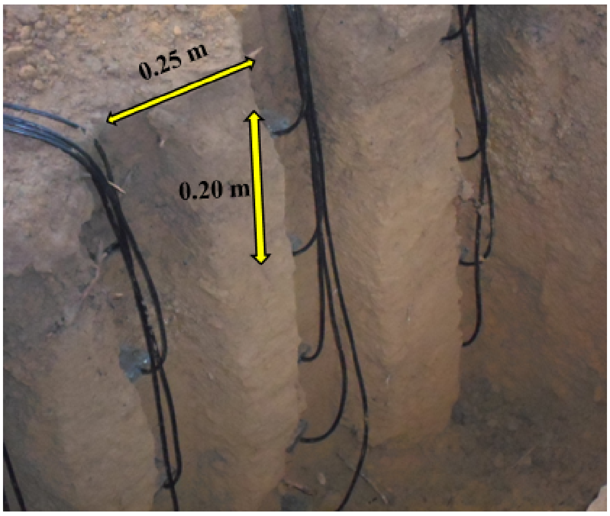

Figure 3. Distribution and installation of TDR probes within the soil profile

0.10 m-long TDR probes with 3.50-m-long cable (Coelho et al., 2005) were built and connected to multiplexers of SMDX type. A reflectometer TDR 100 was connected to the multiplexers and to a data acquisition and storage system (datalogger) composing an automatic system for soil water content (SWC) data acquisition. Soil water content was determined through a model (Eq. 1) (Silva & Coelho, 2013) calibrated for the soil of the experimental area.

$$\theta = 5.65\times10^{-5}\times Ka^3 - 0.003516\times Ka^2 + 0.080439\times Ka - 0.432714 \quad (1)$$

where:

θ - soil water content ($cm^3\ cm^{-3}$); and,

Ka - bulk dielectric constant of the soil.

For the drip irrigation system, TDR probes were installed into the soil profiles, from a plant to halfway between the next plant in the same row; for the micro sprinkler system, probes were installed between a micro sprinkler and a plant in each experimental plot. The probes were installed within the soil profiles to form two-dimensional planes, with horizontal distances from the plant of 0.25, 0.50, 0.75 and 1.00 m and soil depths of 0.20, 0.40, 0.60 and 0.80 m (Figure 3). The probes made up a grid of 16 units, under both drip and micro sprinkler irrigation systems, with and without mulch. Mulching was composed of a 0.10-m-deep banana biomass residue cover on the ground all over the area of a plant.

Percolation, a component of the soil water balance, was calculated between two irrigation events. The soil water balance was evaluated using SWC data measured by TDR probes every one hour within a 24-hour period, from the beginning of an irrigation event to the beginning of the next one. A data acquisition period was selected when reference evapotranspiration (ETo) data were somewhat constant, with mean variations of ± 0.64 mm. The periods were during the months of November and December 2015 and February 2016. The month of January 2016 was not selected due to rainfall. We considered ETo, crop coefficient (Kc) and evaporation coefficient (Ke) as constant during these short periods with small variations of ETo. Therefore, constant ETc values, resulting in constant irrigation water depths, were used for both irrigation systems. Each irrigation cycle of the selected period was a replicate of the experiment.

The SWC values were recorded at each point within the soil profile at: (i) immediately before the irrigation event, (ii) when the irrigation water (wetting front) reached the closest probe to the plant (0.25 m) and at 0.60 m deep; and (iii) at the time immediately before the next irrigation event. The percolation and evapotranspiration were the unknown variables in the soil water balance (SWB) equation (Eq. 2).

$$\int_0^L\int_0^R\left[\theta_{t1}(r,z)\right]\partial z\partial r + I + Pe - ETc - dp = \int_0^L\int_0^R\left[\theta_{t2}(r,z)\right]\partial z\partial r \quad (2)$$

where:

θ_{t1} (r, z) - soil water content ($m^3\ m^{-3}$) immediately before the irrigation;

θ_{t2} - SWC before the next irrigation event, at all points (r, z) in the soil profile;

ETc - crop evapotranspiration during the interval $t_1 - t_2$ (mm per day);

Pe - effective precipitation, considered zero because no rainfall occurred between irrigation events (mm);

I - amount of irrigation water (mm);

dp - total water percolated within the layer below the effective rooting depth down to the depth of the soil profile, L = 1.0 m during the interval $t_1 - t_2$; and,

(r, z) - distance r from the plant and the soil depth z.

The banana rooting depth was assumed as 0.60 m in order to assure that the amount of water below this depth would be due to percolation. This depth was larger than the one found in the literature for trickle irrigation (Donato et al., 2012; Santos et al., 2016), but was within the layer 0.40-0.60 m recommended for micro sprinkler system (Coelho et al., 2008). The water flow within the layer 0.60-0.80 m was assumed to be due to only water percolation. This assumption is supported by the study of Silva et al. (2015), who reported that water extraction at 0.70 m depth by banana was equal to or smaller than 14% of the total water extracted within the soil profile during flowering and fruit growth stages. Eq. 3 gives the water storage (Sti) within the layer (0.60-0.80 m) at a time (ti).

$$S_{ti} = \int_0^{0.8}\int_0^{1.0}(\theta_{ti})_{r,z}\,\partial z\partial r - \int_0^{0.6}\int_0^{1.0}(\theta_{ti})_{r,z}\,\partial z\partial r \quad (3)$$

The percolation (dp) at a time interval $t_i - t_{i+1}$, $dp_{ti-ti+1}$ was given by the difference in water storage (St) within the layer0.60-0.80 m during the interval (Eq. 4).

$$d_{p_{ti+1}} = \frac{S_{t_{i+1}} - S_{t_i}}{t_{i+1} - t_i} \quad (4)$$

The total water percolated during the 24-hour interval between the beginnings of two consecutive irrigation events was calculated by Eq. 5. We assumed no percolation from the beginning to the end of an irrigation event because the applied water replaced the water depleted from field capacity during 24 hours after the last irrigation, when percolation was not relevant. After obtaining dp every hour (i = 1 to 24), the mean dp values every six hours were computed in the period from 0 to 24 hours. The total percolation (DP) below 0.60 m during this time was calculated by Eq. 5.

$$DP_{0-24h} = \sum_{j=1}^{4} dp_{6j} \quad (5)$$

where:

$DP_{0\text{-}24h}$ - total percolation (mm) during the period between the beginning of two consecutive irrigation events; and,

dp_{6j} - percolation (mm) at 6, 12, 18 and 24 hours after the irrigation.

The crop evapotranspiration (ETc) during the interval $t_i - t_{i+1}$ was calculated by the difference between the input and output of water within the effective root zone (Eq. 6).

$$ETc_{t_i - t_{i+1}} = \Delta St_{t_i - t_{i+1}} + I_{t_i - t_{i+1}} - d_{p_{t_i - t_{i+1}}} \quad (6)$$

where:

ΔSt - variation in water storage (mm) between t_i and t_{i+1};

I - water applied by irrigation (mm);

dp - total water percolated in the layer below the effective root depth (mm); and,

t_i - t_{i+1} - corresponded to the interval between irrigation events (24 hours).

Crop evapotranspiration (ETc) was evaluated by the soil water balance during the periods from 442 to 474, 475 to 503, and 535 to 565 days after planting (DAP) at the vegetative, flowering and fruiting stages, respectively. Crop evapotranspiration was also estimated as the product of reference evapotranspiration (ETo) and crop coefficient (Kc) for banana, according to Allen et al. (2006). Kc was determined by the ratio of ETc evaluated by the soil water balance to ETo (Eq. 7). ETo was obtained from a weather station at 150 m from the experiment by FAO's modified Penman-Monteith equation (Allen et al., 2006).

$$Kc = \frac{ETc}{ETo} \quad (7)$$

Root water uptake was calculated based on the fact that it took about six hours after an irrigation event for water redistribution to become negligible in the soil of the experiment (Campos et al., 2021). This was verified through the rate at which SWC decreases over time in all locations (r, z) of the soil profile where TDR probes were inserted (Figure 2). We also assumed no soil evaporation after this period and a predominant water flow within the root zone (0-0.60 m) due to percolation and water uptake.

The uptake (τ) at time interval, j – j + 1, j starting six hours after irrigation, corresponded to the difference between the water storage at time j and j + 1 within the layer 0-0.60 m (Eq. 8) and the percolation at the same interval (Eq. 9).

$$S_{j-j+1} = \left[\int_0^{60}\int_0^{100}\theta_j\partial z\partial r - \int_0^{60}\int_0^{100}\theta_{j+1}\partial z\partial r\right] \quad (8)$$

where:

S_{j-j+1} - water storage (mm) within the layer 0-0.60 m during the period from j to j + 1 after six hours following the end of the irrigation.

The percolation (d_p) below the layer 0-0.60 m during the period of j to j + 1 was given by Eq. 9.

$$\begin{aligned} dp_{j-j+1} &= \left(\int_0^{80}\int_0^{100}\theta_j\partial z\partial r - \int_0^{60}\int_0^{100}\theta_j\partial z\partial r\right) - \\ &- \left(\int_0^{80}\int_0^{100}\theta_{j+1}\partial z\partial r - \int_0^{60}\int_0^{100}\theta_{j+1}\partial z\partial r\right) \end{aligned} \quad (9)$$

Therefore, root uptake (τ) every one hour within the layer 0-0.60 m (mm) during the interval of j to j + 1 after six hours following the end of an irrigation event was given by Eq. 10.

$$\tau_{j-j+1} = S_{j-j+1} - dp_{j-j+1} \quad (10)$$

Total uptake during a period from 6 to 24 hours after the irrigation is given by Eq. 11.

$$\tau_{6-24h} = \int_6^{24}\tau dt \quad (11)$$

where:

τ - in mm h^{-1}; all integrals were solved numerically by the trapezium method.

One experiment with four treatments was installed as already described. Two statistical analyses were performed. One considered the experiment following a randomized block design with four treatments arranged in split plots with six replicates. The factors were irrigation system (main plot, drip and micro sprinkler) and soil cover (with and without). This statistical design was used to evaluate the effect of the irrigation systems and soil cover. The dependent variables were percolation, crop evapotranspiration (ETc) and root water uptake. The other analysis considered an experimental design following randomized blocks with five treatments and six replicates. Treatments were: drip irrigation on soil with mulching (TM), drip irrigation on bare soil (TB), micro sprinkler on soil with mulching (MM) and micro sprinkler on bare soil (MB). This analysis aimed to compare the dependent variable (crop evapotranspiration) of the four treatments with the one correspondent to ETc (C-ETc) calculated from ETo and Kc (Eq. 7) for the same variety of banana (BRS Princesa). Kc values were obtained as 0.85 of the Kc recommended by Doorenbos & Kassam (1984). Water percolation, ETc and soil water extraction by roots (root uptake) were the response variables. The percolation, ETc and root water uptake were tested by the analysis of variance and the F test of Snedecor. In case of significant effect of treatments on ETc, means were compared based on the Tukey test.

The ETc obtained from the soil-water-balance was also compared with the calculated ETc (Eq. 7) by the statistical indicators: root-mean-square error (RMSE) (Eq. 12) and the normalized errors (NE) (Eq. 13).

$$\mathrm{RMSE}=\sqrt{\frac{1}{n}\sum_{i=1}\left(O_i-E_i\right)^2} \quad (12)$$

$$\mathrm{NE}=\sum_{i=1}^{n}\left(\frac{O_i-E_i}{O_i}\right)\times 100 \quad (13)$$

where:

n - number of observations;

O_i - value calculated by the soil water balance; and,

E_i - value estimated by Eq. 7 (Allen et al., 2006).

Results and Discussion

The interaction between irrigation system and soil cover influenced water percolation below the root zone from 442 to 474 days after planting (DAP) during the vegetative stage (November 2015) and from 535 to 565 DAP, during the fruit growth stage (February 2016). A larger percolation was measured under drip irrigation system than under micro sprinkler, for both conditions of soil cover (Table 1) during the period from the beginning of an irrigation event to the next one, at the vegetative and fruit growth stages. Under drip irrigation, water percolation in mulched soil was higher than in bare soil.

Under the micro sprinkler system, soil cover had no significant effect on water percolation (Table 1), at the vegetative and fruit growth stages. The higher coefficient of variation for the fruit growth stage justifies the non-difference of percolation at this stage, despite the larger difference between means.

The effect of the interaction between the irrigation systems and soil cover (Table 1) increased the percolation within the soil below rooting zone under biomass mulch with drip irrigation. Biomass mulching reduces evaporation, so the irrigation water occupies the soil volume without evaporation losses, which causes a greater increase in the soil water content per soil volume unit in the effective rooting zone when compared to the soil layer below it. As a result, total potential gradient and percolation increase (Wang et al., 2015). The percolation within the soil profiles with and without mulch did not differ under micro sprinkler system (Table 1). This is due to the fact that the calculated water amount applied by the irrigation system has wetted a larger surface area and a larger soil volume, resulting in a smaller water volume per unit soil volume (L m^{-3} of soil) or surface area (L m^{-2} soil) when compared to the drip irrigation system. The soil volume wetted by the micro sprinklers is larger than the volume wetted by the drippers (Koumanov et al., 2006; Espadafor et al., 2018); therefore, the micro sprinklers promote a smaller increase in SWC in comparison to the drip irrigation. The water distribution in the soil volume under micro sprinkler is different from that under drip irrigation. The greater wetted area contributes to the reduction of the water depth per unit area and the effect on the total potential gradients between the effective rooting zone and soil layer below it.

The analysis of variance showed statistical differences among means of crop evapotranspiration (ETc) either estimated by the FAO's modified Penman-Monteith equation (Allen et al., 2006) (C-ETc) or estimated under combinations of irrigation system and ground cover, mainly at vegetative and fruiting stages. Only ETc under drip irrigation was different from those under the other conditions at flowering. Mean ETc values determined using the soil water balance (SWB-ETc) were smaller than the mean ETc values (C-ETc) for plants irrigated by the two irrigation systems at all crop stages, except for the micro sprinkler with bare soil (Table 2). The differences between C-ETc and SWB-ETc means ranged from 31 to 26%. The SWB-ETc of drip irrigated crop with mulch showed the smallest mean compared with the one estimated by FAO's modified Penman-Monteith equation (C-ETc). The SWB-ETc means were larger for bare soil condition than SWB-ETc means for covered soil, for both irrigation systems and at all crop

Table 1. Means of water percolation in the soil (mm per day) below the effective rooting depth of 'PRS Princesa' banana, in soil with and without mulch, irrigated by drip and micro sprinkler systems, from 442 to 474 DAP (November 2015) and from 535 to 565 DAP (February 2016)

Irrigation system	Vegetative stage		Fruit growth stage	
	With mulch	Without mulch	With mulch	Without mulch
Drip	0.67 aA	0.29 bB	1.35 aA	0.40 bB
Micro sprinkler	0.28 bA	0.28 bA	0.26 bA	0.56 bA
CV%		35.71		59.65

Means followed by the same lowercase letter in the columns and uppercase letters in the rows are not different by the Tukey test at $p \leq 0.05$

Table 2. Means of SWB-ETc (mm per day) estimated during the vegetative stage (442 to 474 days after planting DAP), flowering stage (475 to 503 DAP) and fruiting stage (535 to 565 DAP)

Treatments	Means		
	Vegetative stage	Flowering stage	Fruiting stage
Drip irrigation with mulching	4.01 b	4.21 b	3.91 b
Drip irrigation on bare soil	4.31 b	5.34 a	5.32 a
Micro sprinkler with mulching	4.33 b	5.03 a	4.33 b
Micro sprinkler with bare soil	5.65 a	5.79 a	5.33 a
Control-ETc calculated	5.63 a	5.78 a	5.92 a
CV%	11.25	9.56	10.28

Means followed by the same letter in the column do not differ according to the Tukey test at $p \leq 0.05$

stages with few exceptions (Table 2). Except for the vegetative stage, the difference of SWB-ETc means under drip irrigation on bare and on covered soil was larger than the difference of SWB-ETc means under micro sprinkler irrigation on bare and on covered soil.

The smaller SWB-ETc means of plants irrigated by either drip or micro sprinkler compared with C-ETc during all crop stages (Table 2) is expected since C-ETc is based on reference or maximum evapotranspiration, since ETc is due to soil evaporation and plant transpiration while SWB-ETc is the actual evapotranspiration (Zelek & Wade, 2014). The maximum difference between the means of SWB-ETc under drip system on covered soil and those of C-ETc is due to the reduction in soil water evaporation associated with the smaller area and soil volume wetted by drip irrigation systems. Therefore, the SWB-ETc under this system was limited to transpiration in all crop stages.

The coefficients RMSE and NE showed the deviation between the ETc means determined by soil water balance (SWB-ETc) and estimated ETc (C-ETc) for both irrigation systems with and without mulching during all crop stages (Table 3). The deviations between the SWB-ETc and C-ETc means were larger for both irrigation systems with mulching in all stages, which emphasizes the effect of the soil cover on the reduction of soil water evaporation. RMSE and NE varied between 1.09 and 1.76 mm per day and 12.9 and 26.8%, respectively, for the micro sprinkler system on soil surface with mulching (Table 3). On the other hand, except for the vegetative stage, the deviations between SWB-ETc and C-ETc under bare soil conditions were much smaller than under mulching, mainly for the micro sprinkler irrigation system. The root square mean errors ranged from 0.73 to 0.84 mm per day and the normalized error between 7.5 and 10.2% for the drip system in the flowering and fruit growth stages, respectively.

The SWB-ETc means of the crop irrigated by both systems with covered soil were smaller than on bare soil due to the reduction of soil evaporation because of the mulch (banana biomass covering). Reduction of ETc due to mulching and increase in water availability within the soil as a result of smaller evaporation rates have been verified by several authors (Li et al., 2013; Alliaume et al., 2017; Gong et al., 2017; Wen et al., 2017). The largest deviation between the SWB-ETc and C-ETc means verified during the fruit growth stage (Table 3) is due to the increase of the shading inside the canopy, which favored the decrease of soil evaporation. The deviations between SWB-ETc and C-ETc based on RMSE and NE for the micro sprinkler system (Table 3) were smaller than for drip irrigation, mainly on bare soil. The reason for that is the larger wetted area characteristic of the micro sprinkler system. The larger the wetted area, the higher the soil water evaporation and crop evapotranspiration. These indicators justify the statistical differences in Table 2. Despite the similarities between SWB-ETc and C-ETc in the flowering stage for micro sprinkler system with mulching, RMSE was below 0.78 mm per day and NE was below 10.1% for micro sprinkler system on bare soil.

The banana crop coefficients (Kc) obtained by the ratio between ETc determined by the soil water balance and the reference evapotranspiration (ETo) for the vegetative, flowering and fruit growth stages under drip irrigation on soil with mulching (Table 4) were 32.31 and 25% smaller than the ones recommended by Allen et al. (2006), respectively. For the same irrigation system, the reductions were 28 and 7% at vegetative and flowering stages, respectively, under bare soil condition. The Kc values obtained from SWB-ETc were not different from the ones recommended for the fruit growth stage and both irrigation systems under bare soil condition.

The Kc values obtained from the SWB-ETc were 21, 15 and 27% smaller than the recommended by FAO-56 at the vegetative, flowering and fruiting stages, respectively, for the micro sprinkler irrigation on covered soil.

There was no difference between the single Kc from SWB-ETc and from the FAO-56 for all crop stages under the bare soil condition (Table 4). The single Kc from SWB-ETc on covered soil was smaller than the Kcb recommended by FAO-56 (Allen et al., 1998), even though transpiration was the main process governing ETc as evaporation was minimized (null coefficient of evaporation). The biomass maintains the soil water content continuously at high levels on the soil surface, which is not expected for the Kcb concept. The values of single Kc from SWB-ETc at flowering and fruit growth stages for both irrigation systems under bare soil condition (Table 4) were close to those obtained by Haijun et al. (2015) for "Grande

Table 3. Root-mean-square error (RMSE) and normalized error (NE) to evaluate the ETc determined by the water balance in comparison to the standard ETc estimated from the recommended Kc and ETo by the FAO modified Penman-Monteith (Allen et al., 1998)

Treatments	Vegetative stage				Flowering stage				Fruit growth stage			
	Soil											
	With mulch		Bare soil		With mulch		Bare soil		With mulch		Bare soil	
	RMSE	NE	RMSE	NE	RMSE	NE	RMSE	NE	RMSE	NE	RMSE	NE
Drip	1.68	28.9	1.70	27.3	1.71	27.2	0.84	7.50	2.12	33.9	0.73	10.2
Micro sprinkler	1.41	23.0	0.42	0.40	1.09	12.9	0.78	0.20	1.76	26.8	0.65	10.1

Table 4. Means of crop coefficient (Kc) from SWB-ETc during November and December 2015 and February 2016, corresponding to 442-474, 475-503, 535-565 days after planting (DAP), respectively, compared with the single Kc recommended by FAO-56 (Allen et al., 1998)

Irrigation system	Vegetative stage			Flowering stage			Fruiting stage		
	With mulch	Bare	FAO56	With mulch	Bare	FAO56	With mulch	Bare	FAO56
Drip	0.75	0.79	1.10	0.76	1.02	1.10	0.75	1.00	1.00
Micro sprinkler	0.86	1.10	1.10	0.93	1.10	1.10	0.73	1.00	1.00

Naine" cultivar at the north of Israel, at the same crop stages. The results found by these authors also corroborate those obtained by Gong et al. (2017), who observed a decrease of ETc and Kc on soil with mulching, when compared with the bare soil condition, during three consecutive years.

The interaction between the irrigation systems and the soil surface with and without cover was significant at the flowering and fruit growth stages. Means of root water uptake per wetted area were higher under mulched soil than under bare soil, for both irrigation systems (Table 5). The plants irrigated by drip irrigation extracted more water per square meter within the root zone than those irrigated by micro sprinkler during the fruit growth stage (Table 5). The differences of root water uptake between treatments with and without soil cover under drip irrigation were significant when compared with the differences under micro sprinkler. There were no differences of root water uptake between the plants under both irrigation systems at the flowering stage.

The greater amounts of water extracted per square meter in mulched soil (Table 5) may be explained by the greater water availability within the soil wetted volume, mainly in the case of drip irrigation (Dasberg & Or, 1999). The SWC is distributed within the root system, increasing water availability within the region of greater extraction according to the findings of Santos et al. (2016). Root length density is more significant within the soil with mulch, mainly under drip irrigation (Jha et al., 2017; Santana Junior et al., 2020). Besides, mulching substantially reduces the evaporation, which results in a greater soil water content available for the plants (Damour et al., 2012; Anjos et al., 2017). Therefore, the plant remains with a greater number of open stomata for a longer period, increasing transpiration (Pallas et al., 1967). These results are in agreement with those reported by Daryanto et al. (2017), who studied the use of plastic mulching with wheat and maize and verified greater water use efficiency for the covered soil condition, due to the greater volume of water available for transpiration and not for evaporation.

Table 5. Means of root water uptake (mm per day) by the cultivar 'BRS Princesa' during the months of November and December 2015 and February 2016, within soil with and without mulch under drip and micro sprinkler irrigation systems

Irrigation system	Flowering stage		Fruiting stage	
	With mulch	Without mulch	With mulch	Without mulch
Drip	2.48 aA	0.74 aB	3.95 aA	2.44 aB
Micro sprinkler	2.27 aA	1.01 aB	2.37 bA	1.42 bB
CV%	31.20		15.34	

Means followed by the same lowercase letter in the column and uppercase letter in the rows do not differ by the Tukey test at $p \leq 0.05$

Conclusions

1. Soil water balance with the approach for estimating deep percolation is suitable for estimating banana root water extraction and crop evapotranspiration.

2. Soil cover (mulching) with banana biomass under drip irrigation promotes greater water percolation below the root zone.

3. The Kc values obtained from the SWB-ETc were 21, 15 and 27% smaller than the recommended by FAO-56 at the vegetative, flowering and fruiting stages, respectively, for the micro sprinkler irrigation on covered soil.

4. The Kc values obtained from the SWB-ETc were smaller than the recommended by FAO-56 by 32, 31 and 25% for the vegetative, flowering and fruit growth stages under drip irrigation on soil with mulching, respectively.

5. The banana root water uptake under drip irrigation with ground cover is greater than under micro sprinkler irrigation, both systems on soil with mulch.

Acknowledgements

We thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) for funding this research through the projects: CNPq 403986/2016-8 and SEG EMBRAPA 13.16.05.018.00.00.

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