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Agronomic performance of 'BRS Princesa' banana under fertigation and mulching

Desempenho agronômico da bananeira 'BRS Princesa' sob fertirrigação e cobertura morta

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Highlights

Fertigation enhances yields on mulched soil by using localized irrigation.
Micro-sprinkler provides higher yields than drip irrigation on non-mulched soil.
With mulch, yield increases are greater with drip than micro-sprinkler irrigation.
With micro-sprinklers, fertigation methods without mulch provide the same yield.
Localized irrigation with conventional fertilization increases earliness.
Drip fertigation with mulch increases earliness.

Abstract

Banana is one of the most produced fruit crops in Brazil and has great economic, social and nutritional importance. Factors such as water availability and well-managed fertilization are fundamental to achieving profitable yields. The aim of this study was to examine the agronomic performance and water use efficiency of 'BRS Princesa' banana under combinations of irrigation systems, fertilization methods and mulching, during three production cycles. The experiment was laid out in a randomized-block design with four replicates. Treatments consisted of a combination of the localized irrigation system, fertilization strategy and mulching, as follows: Drip irrigation with manual fertilization; Micro-sprinkler irrigation with manual fertilization; Drip fertigation with mulch; Drip fertigation without mulch; Micro-sprinkler fertigation with mulch; and Micro-sprinkler fertigation without mulch. The plants were irrigated every three days, using three 4-L h^{-1} drippers per plant or a 64-L h^{-1} micro-sprinkler for every four plants. The following variables were analyzed: number of leaves, plant height, pseudostem circumference, number of hands, hand yield, water and nutrient (nitrogen and potassium) use efficiency and earliness. The micro-sprinkler system provided a greater pseudostem

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circumference without the presence of mulch. Plants under micro-sprinkler fertigation with mulching grew taller. The banana yield was higher when fertigation was used than with manual fertilization, regardless of the irrigation system. Plants grown in mulched soil were more productive than those grown in bare soil. The use of mulch increased water, nitrogen and potassium use efficiency when compared with cultivation in bare soil. Drip-irrigated plants showed earlier production than those irrigated with micro-sprinklers..
Key words: *Musa spp.* Water use efficiency. Organic mulching.

Resumo

A bananeira é sendo uma das fruteiras mais produzidas no Brasil e possui grande importância econômica, social e alimentícia. Fatores como disponibilidade de água e adubação bem manejados são fundamentais para obtenção de produtividades rentáveis. Objetivou-se com este trabalho, avaliar o desempenho agronômico e a eficiência no uso da água da bananeira ‘BRS Princesa’ sob combinações de sistemas de irrigação, métodos de adubação e cobertura morta, durante três ciclos de produção. O delineamento experimental foi o de blocos casualizados, com quatro repetições. Os tratamentos consistiram na combinação do sistema de irrigação localizada, estratégia de adubação e uso de cobertura morta: a) Irrigação por gotejamento com adubação manual; b) Irrigação por microaspersão com adubação manual; c) Fertirrigação por gotejamento com cobertura morta; d) Fertirrigação por gotejamento sem cobertura morta; e) Fertirrigação por microaspersão com cobertura morta e f) Fertirrigação por microaspersão sem cobertura morta. As irrigações ocorreram a cada três dias, utilizando-se três gotejadores de 4 L h^{-1} por planta ou um microaspersor de 64 L h^{-1} para cada quatro plantas. As variáveis estudadas foram: número de folhas, altura da planta, perímetro do pseudocaule, número de pencas, produtividade, eficiência no uso da água e de nutrientes (nitrogênio e potássio) e precocidade. A microaspersão proporcionou maior circunferência do pseudocaule sem a presença da cobertura do solo. Plantas sob fertirrigação por microaspersão com cobertura do solo expressam maiores alturas. A produtividade da bananeira foi maior quando utilizada a fertirrigação em detrimento da adubação manual, independente do sistema de irrigação. As plantas cultivadas em solo coberto foram mais produtivas que aquelas cultivadas em solo descoberto. O uso da cobertura morta elevou a eficiência do uso da água, de nitrogênio e de potássio em relação ao cultivo em solo descoberto. As plantas irrigadas por gotejamento apresentaram produção mais precoce que irrigadas por microaspersão.
Palavras-chave: *Musa* spp. Eficiência no uso da água. Mulching orgânico.

Introduction

Banana is the second fruit most consumed by Brazilians, only after orange (Instituto Brasileiro de Geografia e Estatística [IBGE], 2018). Sold in the most varied markets at affordable prices and produced from North to South, it is the most popular fruit in the country. In 2017, Brazil was the fourth largest banana producer in the world, with a total production of 6,675,100 t of fruit (Food and Agriculture Organization of the United Nations [FAOSTAT], 2019). The northeast region of Brazil accounted for 33.73% of the national production, and Bahia, with 866,591 t, was the most representative state of the northeast and the second nationwide (IBGE, 2019).

The yield of banana depends on several factors involved in the production system, such as nutrition, soil water availability, disease control and the production cycle, in the first cycles. Production is greatly influenced by vegetative characteristics, such as plant height and, mainly, the number of leaves at harvest. Yield is also influenced by the irrigation system, especially in semi-arid conditions. A. J. P. Silva (2009) evaluated the yield of banana in the drip and micro-sprinkler irrigation systems and found that micro-sprinkler-irrigated plants were more productive.

In many of the banana-growing regions in Brazil, high yields with fruit quality can only be achieved with the use of techniques such as irrigation and fertilization. which entails meeting the water requirements of the crop. The high water and nutritional requirements of banana orchards require natural fertility in the growing areas, which is not always sufficient to meet these demands through successive production cycles (R. S. Borges, Coelho, & Costa, 2011; Coelho et al., 2012; L. B. Silva et al., 2017; Santos, Donato, Magalhães, & Cotrim, 2019). Depending on the plant requirements, the nutritional supply of banana influences the profitability of the crop as well as economic and environmental sustainability, warranting the use of techniques that allow for improved water and nutrient use efficiency, such as fertigation.

In irrigated agriculture, fertigation has been a viable alternative to enhance the use of irrigation systems and maximize fertilizer use efficiency (Natale & Rodrigues, 2014). If combined with the use of banana crop residue on the soil surface, this practice can maintain the available water in the crop root zone for longer, which will translate into better crop development as well as greater yields and water use efficiency (WUE).

In this respect, to increase the profitability and sustainability of banana production, it is important to investigate the use of techniques that improve water and nutrient use efficiency. Because WUE is the ratio of yield to evapotranspiration (Zhang et al., 2004; Şimşek, Tonkaz, Kaçira, Çömlekçioğlu, & Doğan, 2005; Jensen, 2007) and the irrigation level applied (Aujla, Thind, & Buttar, 2005), higher WUE values can be achieved by maintaining or increasing yield while using reduced irrigation levels (Santos, Donato, Lourenço, Silva, & Coelho, 2016); by increasing planting density and reducing the irrigation level (Santos et al., 2019); with the use of fertigation (Pramanik, Lai, Ray, & Patra, 2016); with the use of mulch and irrigation levels (Amorim, Coelho, Melo, Lima, & Lima, 2019); and with the use of legumes and irrigation levels (Barbosa et al., 2013).

Additionally, the utilization of mulch can also have a positive synergy with the localized-irrigation method associated with fertigation, since its application to the soil surface helps to conserve soil moisture and the incorporation of nutrients and organic matter can help reduce the need for fertilization over time (Baldotto & Baldotto, 2014; Brito, Fonseca, Bebé, Ramos, & Silva, 2017; Amorim et al., 2019; Ngosong, Okolle, & Tening, 2019).

The use of banana crop residues can contribute to increasing WUE, and this practice has usually been employed in the management of rainfed crops. On the other hand, the influence of mulch, in association with fertigation, on the development of a crop and on the yield and quality of fruits still needs to be investigated.

Another noteworthy point is the duration of the production cycle, in which case a shorter period is expected. Santos et al. (2019) did not observe any changes in the duration of the cycle in response to different water availability levels in the soil. Conversely, when they increased the planting density from 1,600 to 3,333 plants ha^{-1}, the harvest was delayed by approximately 13 days. Pereira et al. (2000) reported that the duration of the cycle is highly influenced by the increase in planting density, tending to be higher in the subsequent cycles, since the late-developing plants are self-shaded.

Research investigating the combined use of these techniques and their possible interactions on the performance and water and nutrient use efficiency of banana orchards, in successive production cycles, is sparse. Therefore, the present study was conducted to examine the agronomic performance and WUE of 'BRS Princesa' banana under combinations of irrigation systems, fertilization methods and mulching, during three production cycles.

Material and Methods

The experiment was developed between the beginning of 2013 and the end of 2015 in the experimental area of Embrapa Cassava & Fruits, located in the municipality of Cruz das Almas, state of Bahia, Brazil (12°40'39" S, 39 °06'23" W, 225 m altitude). The climate of the region is classified as humid to sub-humid, with an average annual precipitation of 1,143 mm, average monthly temperature of 23.7 °C and average annual relative humidity of 81%. Table 1 shows the monthly means of maximum temperature, average temperature and relative humidity throughout the experimental period.

The soil of the experimental area, classified as dystric-cohesive Yellow Oxisol (Santos et al., 2013), has a clayey texture. Physical and water analysis of the soil, at a depth of 0.0 to 0.3 m, revealed the following values of soil density, moisture at field capacity (-10 kPa), permanent wilting point (-1500 kPa), available water, macroporosity, microporosity and total porosity: 1.65 kg dm^{-3}, 0.255 m^3 m^{-3}, 0.105 m^3 m^{-3}, 0.4 mm cm^{-1}, 11.5%, 26.6% and 38.1%, respectively. Table 2 shows the results of initial chemical analysis performed on soil layers at the depths of 0.0 to 0.2 and 0.2 to 0.4 m. Unlike physical soil analysis, chemical analysis was undertaken in two layers to determine possible nutritional influences of previous crops. Nonetheless, the analyzed variables showed similar values.

Table 1
Monthly maximum temperature (Max T.), average temperature (Avg. T.) and relative humidity (RH) means for the years 2012, 2013 and 2014

Month	Year								
	2012			2013			2014		
	Max. T (ºC)	Avg. T. (ºC)	RH (%)	Max. T (ºC)	Avg. T. (ºC)	RH (%)	Max. T (ºC)	Avg. T. (ºC)	RH (%)
Jan	31.3	25.5	77.9	32.4	26.2	77.4	30.9	25.3	79.4
Feb	30.8	25.3	78.4	31.3	25.9	79.0	29.5	23.9	82.5
Mar	31.6	25.5	75.9	32.2	26.3	76.5	30.2	25.2	84.2
Apr	30.5	24.9	81.3	29.8	25.1	83.0	30.4	25.2	83.1
May	28.2	23.7	85.7	28.0	24.0	88.3	27.9	23.4	87.0
Jun	27.0	22.8	87.1	26.6	21.5	84.3	26.8	22.5	89.0
Jul	26.2	21.8	83.9	26.0	22.2	87.4	25.9	21.9	89.5
Aug	26.0	21.3	85.0	26.1	22.0	79.2	26.1	21.3	87.5
Sep	27.6	22.4	80.4	27.5	22.7	84.7	27.2	22.1	85.7
Oct	28.6	23.4	78.6	28.5	23.6	83.2	28.6	22.7	80.2
Nov	30.8	25.2	75.7	29.5	24.3	83.1	29.8	24.2	81.6
Dec	32.1	25.8	72.1	30.9	25.3	79.1	30.2	24.9	80.5
Mean	29.2	24.0	80.2	29.1	24.1	82.1	28.6	23.6	84.2

Table 2
Initial chemical analysis of the soil in the experimental area, at the depths of 0.0 to 0.2 and 0.2 to 0.4 m. Cruz das Almas - BA, 2015

Depth (m)	pH in water	P[1]	K[1]	Ca[2]	Mg[2]	Al[2]	Na[1]	H+Al	SB	CEC	V	OM[/3]
		mg dm^{-3}	---------------------- cmolc dm^{-3} ----------------------								%	g kg^{-1}
0.0-0.2	6.3	40	0.6	2.4	1.9	0.0	0.4	1.5	5.2	6.7	77	14.3
0.2-0.4	6.1	30	0.4	2.4	2.0	0.0	0.3	1.3	5.1	6.5	79	14.8

[1]Mehlich-1 extractor; [2]KCl/1M extractor; [3]Walkley & Black, modified. The analyses were carried out following the methodology proposed by EMBRAPA (2017). SB: sum of bases; CEC: cation-exchange capacity; V: base saturation; OM: organic matter.

The 'BRS Princesa' banana was assessed during three production cycles (seasons). 'BRS Princesa' is a tetraploid hybrid (AAAB) banana, created at Embrapa Cassava & Fruits in Cruz das Almas - BA, originated from the cross between of 'Yanganbi' no. 2 (AAB) and the M53 diploid (AA) bananas. The experimental orchard was established in 2013, at a spacing of 2.0 × 2.5 m (2,000 plants ha-1). Planting was carried out with seedlings that were about 0.1 m high, with three leaves, in open pits with dimensions of 0.4 × 0.4 × 0.4 m. Cultural (plowing, liming, harrowing, hole digging, time-of-planting fertilization) and maintenance treatments (thinning, defoliation, maintenance fertilization, cleaning, among others adopted in the experiment) were performed according to the recommendations of A. L. Borges (2004).

Two statistical approaches were adopted to evaluate the results between the production cycles of the orchard. In both approaches, a randomized-block design was used in a split-time arrangement with four replicates and a usable plot consisting of four plants. The first approach localized irrigation systems and a fertilization strategy or mulching was aimed at evaluating the effects of combining fertilizer application strategies (manual, by solid fertilization; or by fertigation) and the localized irrigation system used (drip or micro-sprinkler). The second drip or micro-sprinkler fertigation combined with the use (or non-use) of mulching was applied to study the combinations and interactions of drip- or micro-sprinkler-fertigated treatments with the use (or non-use) of banana plant phytomass as mulching material.

In the first statistical approach, six treatments were studied, namely, Drip irrigation with conventional fertilization (DICF); Micro-sprinkler irrigation with conventional fertilization (MICF); Drip fertigation with banana residue (DFWB); Drip fertigation without banana residue (DFNB); Micro-sprinkler fertigation with banana residue (MFWB) and Micro-sprinkler fertigation without banana residue (MFNB). In the second approach, using the same data as the first, after excluding treatments DICF and MICF, the data were organized according to the irrigation system (drip and micro-sprinkler) and mulching (with or without).

Fertilizer application was performed by distributing 12 dm^3 matured cattle manure, 0.15 kg single superphosphate and 0.10 kg of a commercial micronutrient formulation (FTE BR12) per hole. The formulation contained 0.1% molybdenum, 1.8% boron, 0.8% copper, 2% manganese and 7% zinc. Topdressing was calculated based on soil analysis and was carried out in two ways: the first in solid form, manually, monthly; and the second as weekly fertigation, following the recommendations of R. S. Borges et al. (2011) and Coelho et al. (2012). In both fertilizer application strategies, phosphorus was used from the single superphosphate source in manual solid fertilization, at planting, and from monoammonium phosphate in fertigation, every three months. Nitrogen was applied through urea and potassium through potassium chloride, both in solid form, manually, and in liquid form as fertigation. Manual solid fertilization was carried out by placing the fertilizer below the drippers in the recommended amount per plant.

Irrigation and fertigation were performed using two localized irrigation systems, namely, drip and micro-sprinkler. In the drip system, one lateral was used per plant row, with two 4-L h^{-1} emitters per plant. In the micro-sprinkler system, one lateral was placed between two rows, with a 64-L h^{-1} emitter positioned in each group of four plants and operated under a delivery pressure of 200 to 220 kPa. The fertilizer injection system involved a Venturi applicator that worked at a flow rate of 100 L h^{-1} and a pressure of 220 kPa in the intake valve.

The irrigation management was based on soil and atmospheric indicators. Water losses were estimated by monitoring crop evapotranspiration, which was estimated as the product of reference evapotranspiration and the crop coefficient (Kc). Reference evapotranspiration was estimated by applying automatic weather station data to a modified version of Penman-Monteith’s equation (Allen, Pereira, Raes, & Smith, 1998). The Kc used were as described by Coelho et al. (2012). The water requirements of the crop were met by the crop evapotranspiration accumulated since the previous irrigation. However, the moment of irrigation was decided by assessing soil moisture every two days. Readings were taken in the early morning, using a time-domain reflectometry device with calibrated waveguides installed at a depth of 0.30 m, at a distance of 0.25 m from the plant and 0.10 m from the dripper, in the plant-dripper and plant-micro-sprinkler direction.

In each production cycle, plant growth and production were evaluated at flowering and at the harvests. For the growth variables, the number of leaves at flowering and at harvest, pseudostem circumference and plant height at flowering were analyzed. Earliness was also evaluated by analyzing the duration in days from planting to harvest in the first cycle and between harvests in the second and third cycles (DBH).

The evaluated production variables were number of hands per bunch, hand yield and water and nutrient use efficiency. Hand yield, in t ha^{-1}, was obtained as the product of hand weight and planting density (2,000 plants ha^{-1}).

Water use efficiency (WUE) was calculated as the ratio of hand yield to the irrigation level applied (Loomis, 1983; Aujla et al., 2005) (Equation 1) in each treatment.

$$WUE = \frac{YLD}{IL} \qquad (1)$$

where WUE = water use efficiency (kg mm^{-1}); YLD = hand yield for each treatment (kg ha^{-1}); and IL = irrigation level applied to the crop in each treatment (mm).

Fertilizer application efficiency is the ratio of hand yield to the total amount of nitrogen or potassium applied in each cycle, following Dobermann (2007) (equation 2).

$$FUE = \frac{YLD}{N \text{ or } K} \qquad (2)$$

where FUE = fertilizer use efficiency (kg kg^{-1}); and N or K = annual N or K fertilization per cycle for all treatments (kg ha^{-1}).

The data of the variables under study were subjected to Shapiro Wilk’s normality test. When normality of the data was confirmed, analysis of variance and the F-test at 5% significance were performed. Significant interactions were decomposed and variables with significant results were grouped by Scott-Knott’s criterion for the treatment factor and compared by Tukey’s test for the cycle, irrigation system and mulching factors, according to the approaches.

Results and Discussion

Localized irrigation systems and fertilization strategy or mulching

There was a significant interaction effect ($p \leq 0.05$) between the treatment and cycle factors for number of leaves and plant height at flowering, and time (in days) from planting to harvest in the first cycle and between harvests in the second and third cycles (DBH). There was a treatment effect for the variables of yield, number of leaves at harvest, number of hands, WUE, nitrogen use efficiency (NUE) and potassium use efficiency (KUE). The cycle factor affected pseudostem circumference at flowering, number of leaves at harvest, number of hands, WUE, NUE and the KUE of ‘BRS Princesa’ banana.

Table 3 shows the number of leaves, plant height and DBH per treatment and per cycle.

The number of leaves at flowering under drip fertigation without mulch (DFNB) was higher in the third cycle than in the first. In the third cycle, it formed the same cluster with the condition of drip irrigation with conventional fertilization (DICF) and micro-sprinkler fertigation without mulch (MFNB). The treatments without mulch provided a greater number of leaves, specifically in the third cycle, except for the treatment of micro-sprinkler with conventional fertilization (MICF). As described by Donato, Arantes, Marques and Rodrigues (2015), the number of functional leaves for some cultivars such as 'Prata-Anã' and 'Grande Naine' should be 12 to meet the requirement for normal yields. Roque, Amorim, Ferreira, Ledo and Amorim (2014) found 11.66 and 10.0 leaves in the flowering of 'BRS Princesa' banana in the first and second cycles, respectively, demonstrating that the conditions used in the present study provide a satisfactory number of leaves, even those with lower numbers.

Table 3
Number of leaves at flowering (NL), plant height at flowering (PH) and days from planting to harvest in the first cycle and between harvests in the second and third cycles (DBH) per treatment and per cycles (C) in 'BRS Princesa' banana. Cruz das Almas - BA, 2015

Treatment	NL			PH			DHC		
	C1	C2	C3	C1	C2	C3	C1	C2	C3
DICF	12.8Aa	15.1Aa	15.4Aa	2.7Db	3.9Ca	3.9Ca	495.0Aa	194.5Cc	315.0Bb
MICF	13.2Aa	12.8Aa	12.1Ba	3.3Bb	4.1Ba	4.1Ba	481.0Aa	259.5Bc	312.0Bb
DFWB	13.6Aa	14.1Aa	13.9Ba	3.0Cb	4.2Ba	4.2Ba	467.3Aa	254.0Bb	290.5Bb
DFNB	11.9Ab	14.8Aab	17.5Aa	2.7Db	3.6Da	3.6Da	476.0Aa	191.5Cc	354.3Ab
MFWB	13.1Aa	13.4Aa	13.1Ba	3.5Ab	4.3Aa	4.3Aa	479.8Aa	303.8Ab	347.0Ab
MFNB	13.0Aa	12.0Aa	14.8Aa	3.2Bb	4.1Ba	4.1Ba	494.0Aa	262.5Bc	375.5Ab
CV		12.91%			2.67%			8.32%	

DICF - drip irrigation with conventional fertilization; MICF - micro-sprinkler irrigation with conventional fertilization; DFWB - drip fertigation with banana residue; DFNB - drip fertigation without banana residue; MFWB - micro-sprinkler fertigation with banana residue; and MFNB - micro-sprinkler fertigation without banana residue. Means followed by the same uppercase letter in the column form the same cluster by Scott-Knott's criterion and means followed by the same lowercase letter in the row, for each variable, do not differ at 5% by Tukey's test.

Plants under micro-sprinkler fertigation with mulch (MFWB) grew taller and formed a single group in the second and third cycles. All treatments provided an increase in plant height from the first cycle onwards (Table 3). The height variation between the production cycles is the result of the greater intraspecific competition for light after the first cycle, since the orchard plants have an already developed leaf canopy and the younger plants of the mat are shaded by older plants of the same mat and also by more developed nearby plants from another mat. On the other hand, DICF and DFNB contributed to lower plant heights, forming, between themselves, the same cluster in the first cycle and distinct groups in the other cycles (Table 3). Roque et al. (2014) analyzed the agronomic performance of banana genotypes of the same cultivar in Recôncavo da Bahia and found heights of 3.30 m and 3.56 m in the first and second cycles, respectively. Thus, in the present study, the plant height means are in line with those described in another study carried out in the same physiographic condition, except for the DICF, drip fertigation with mulch (DFWB) and DFNB treatments, which provided lower means. This may be related to the smaller area wetted by drip as compared with micro-sprinkler irrigation (Marques, Donato, Pereria, Coelho, & Arantes, 2011; Sant'ana, Coelho, Faria, Silva, & Donato, 2012).

The total days in the production cycle (DBH) of 'BRS Princesa' formed different clusters between treatments only in the second and third cycles of the orchard (Table 3). This result was expected, as the period until harvest is longer in the first cycle, when the mat is formed, so in the subsequent cycles the mat is already established.

In cycle 1, flowering occurred between September and December 2012 and the harvest was between January and March 2013. In the second cycle, flowering was between February and June and the harvest took place from May to October 2013. Lastly, in the third cycle, the harvest was from March to December 2014; i.e., from the second cycle onwards, there was a significant unevenness between the plants. The differences between the mean temperatures in the months preceding the harvest were small (Table 1); thus, the different groups of DBH (Table 3) may be related to the influences of the different treatments.

In the second production cycle, the treatment means were clustered into three groups. The group of means containing the DICF and DFNB treatments had the lowest DBH means. On the other hand, this earliness was only maintained in the third cycle by DICF. In this cycle, there were only two groups of means and the greatest earliness was detected in the group containing the DICF, MICF and DFWB treatments. In the present study, only the DICF, MICF and DFWB treatments provided greater earliness in the production of 'BRS Princesa' and MFWB delayed the harvest by 109 and 32 days in the second and third cycles, respectively, when compared with the DICF treatment. This result may indicate that possible variations in soil moisture without the use of banana biomass and nutrient mulch stimulates earliness in the banana crop.

Figure 1 illustrates the yield, number of leaves at harvest, number of hands, WUE, NUE and KUE as a function of treatments, regardless of the cycles. The DFWB and MFWB conditions provided higher values and even formed a cluster by Scott-Knott's criterion ($p \leq 0.05$) for the variables of yield, number of leaves at harvest, number of hands, NUE and KUE. Water use efficiency was higher for these conditions, but formed the same group as the MICF and MFNB conditions. On the other hand, DICF and DINB were in same group and the lowest WUE values. For yield, number of hands, NUE and KUE, the DICF and DFNB treatments formed the same group with the lowest values. For number of leaves, in turn, the lowest means were under the of DICF, MICF, DFNB and MFNB conditions, which formed the same group by Skott-Knott's criterion ($p \leq 0.05$).

When compared with traditional fertilization (DICF), the drip irrigation system associated with fertigation with banana biomass mulch provided an increase in yield of the order of 42.6%, regardless of the production cycle. For the same treatment without mulch (DFNB), the increase was 11.8%. The yield increase provided by the more marked factors of fertigation and mulch in the drip irrigation system stems from the condition imposed by the mulch with banana biomass on the greater expansion of the banana root system, which has been a limitation to the development of banana and its impacts on yield.

In a condition similar to that tested in the present study, Souza (2016) found that under micro-sprinkler fertigation with mulch in the first cycle, the percentage of available water in the soil was 25% higher than that observed under micro-sprinkler irrigation with conventional fertilization, and 108% higher in comparison to micro-sprinkler fertigation without banana residue. The same author pointed out that this result is due to the reduced exposure of the wetted surface to solar radiation, which reduced water evaporation.

The better plant performance provided by the use of mulch in association with fertigation (DFWB and MFWB) may be linked to decomposition of mulch on the ground, since the use of banana phytomass as mulching can provide a differentiated incorporation of nutrients and organic carbon, as compared with uncovered soil (Brito et al., 2017). Fertigation can also have its effects enhanced, since part of the organic substances incorporated into the soil has a stimulating effect on plant vigor, root activity and nutrient dynamics (Baldotto & Baldotto, 2014).

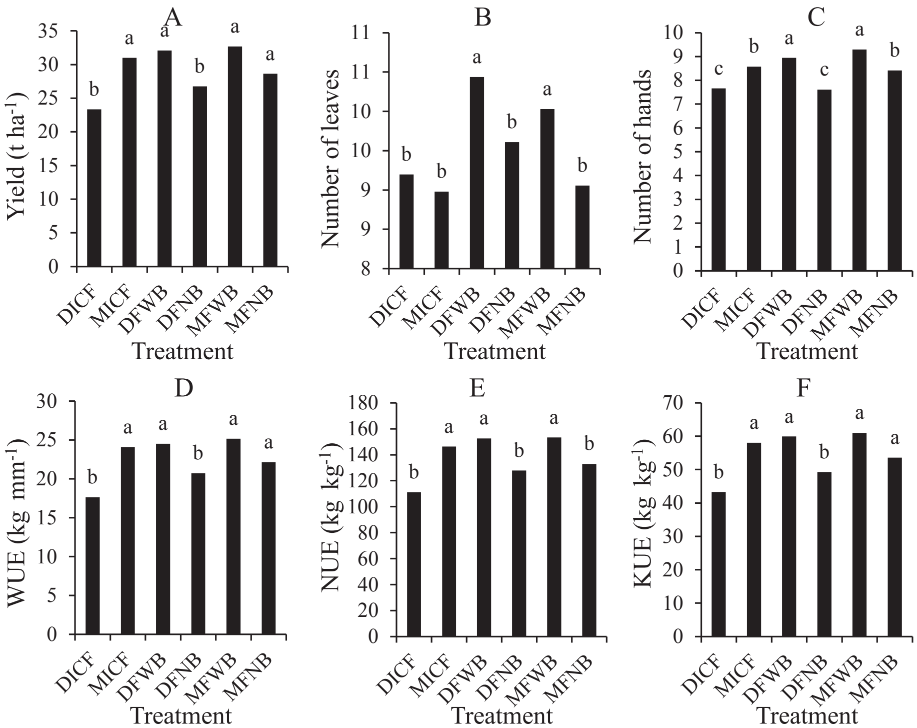

Figure 1. Yield (A) (CV of 15.89%), number of leaves at harvest (B) (CV of 10.92%), number of hands (C) (CV of 9.76%), water use efficiency - WUE (D) (CV of 13.22%), nitrogen use efficiency - NUE (E) (CV of 16.61%) and potassium use efficiency - KUE (F) (CV of 16.16%) for each treatment in 'BRS Princesa' banana. Cruz das Almas - BA, 2015. DICF - drip irrigation with conventional fertilization; MICF - micro-sprinkler irrigation with conventional fertilization; DFWB - drip fertigation with banana residue; DFNB - drip fertigation without banana residue; MFWB - micro-sprinkler fertigation with banana residue; and MFNB - micro-sprinkler fertigation without banana residue. Common letters on the bars, for each variable, belong to the same cluster by Scott-Knott's criterion at 5% significance.

Another important detail is that mulching provides greater soil moisture conservation as compared with uncovered soil, since water losses through evaporation and variations in soil temperature are attenuated, making the soil a more favorable environment for root development and plant activity (Amorim et al., 2019; Ngosong et al., 2019). The conservation of soil moisture at optimal levels also facilitates the distribution of nutrients in the area effectively occupied by the root system, which can potentiate the effect of fertigation (R. S. Borges et al., 2011; Coelho et al., 2012). In particular, the drip system has a higher concentration of roots close to the emitters, with less soil volume effectively explored by the banana root system, when compared with the micro-sprinkler system (Santana et al., 2020).

The results show the importance of fertigation in the use of drip irrigation. Despite its greater water savings in relation to the micro-sprinkler system, without fertigation, the yield obtained with drip irrigation is lower than that of the banana crop under micro-sprinkler irrigation in any condition, which makes it less efficienct in the use of water and fertilizers. The lack of mulch provides a greater gradient of soil moisture in the layer close to the soil surface, mainly in the drip irrigation system, which leads to a higher root length density, that is, a higher concentration of roots per volume of soil explored (Souza, 2016). This soil moisture gradient, which increases between one irrigation and the next, influences the physiological activity of the plants, reducing the number of photosynthetically active leaves. According to Cavatte, Salomão, Siqueira, Peternelli and Cavatte (2012), the number of live leaves at harvest is associated with fruit size (filling). A lower number of leaves at harvest will translate into lower leaf photosynthetic efficiency, which reduces the availability of photoassimilates for the complete filling of the fruits. As a result, their weight will be reduced and so will hand weight.

Figure 2 illustrates pseudostem circumference at flowering, number of leaves at harvest, number of hands, WUE, NUE and the KUE for the three cycles of 'BRS Princesa' banana, regardless of the condition of the system, mulching and fertigation. Pseudostem circumference at flowering and the number of hands showed different means according to Tukey's test ($p \leq 0.05$) between the three cycles, with an increase from the first to the third cycle (Figure 2A, C). The number of leaves at harvest was lower in the first than in the second and third cycles (Figure 2B).

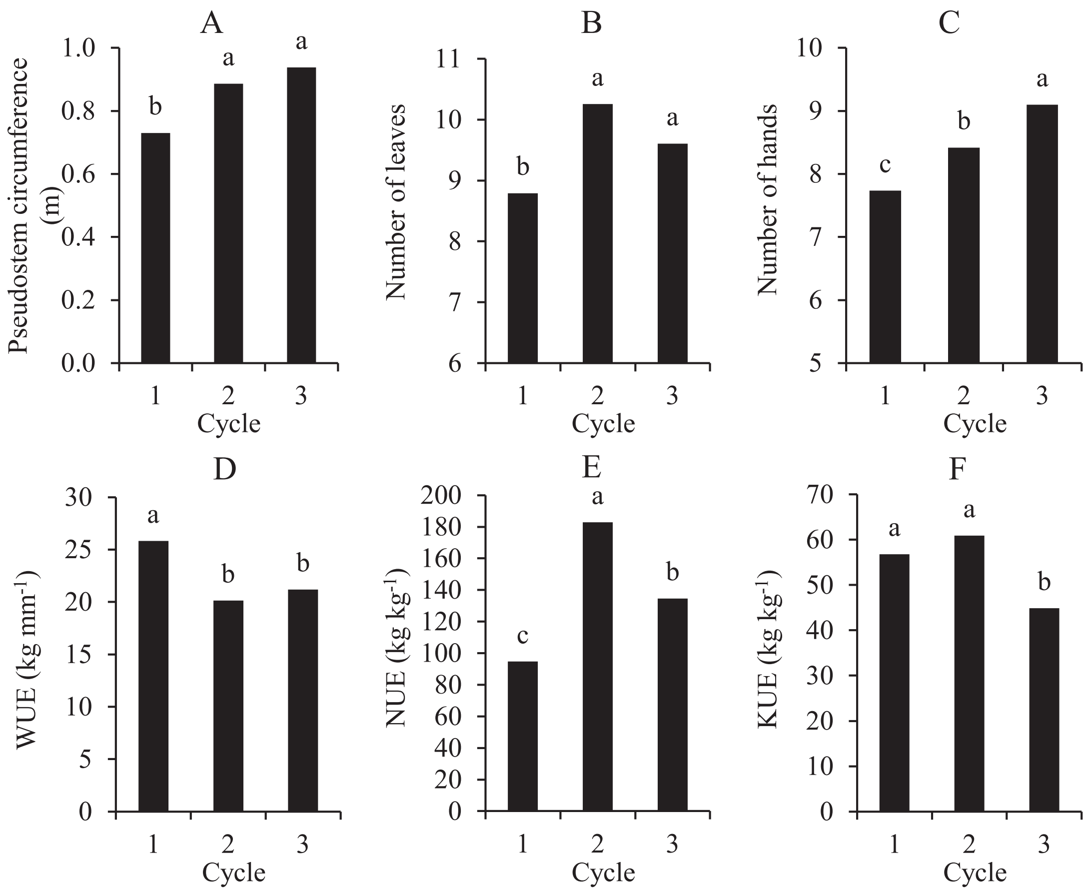

Figure 2. Pseudostem circumference at flowering (A) (CV of 15.37%), number of leaves at harvest (B), number of hands (C), water use efficiency - WUE (D), nitrogen use efficiency - NUE (E) and potassium use efficiency - KUE (F) for each cycle of 'BRS Princesa' banana. Cruz das Almas - BA, 2015. Common letters on the bars, for each variable, belong to the same cluster by Scott-Knott's criterion at 5% significance.

Water use efficiency was higher in the first cycle, as compared with the second and third (Figure D), whereas NUE and KUE showed different means between the three cycles, with higher values occurring in the second (Figure 2E, F). However, NUE was lowest in the first and KUE in the third cycle.

Marques et al. (2011) evaluated the agronomic traits of banana variety Prata under different irrigation systems and found that under drip irrigation, pseudostem circumference and number of hands were higher in the second and third cycles than in the first cycle, which the present results corroborate. Despite the greater pseudostem circumference, number of leaves and number of hands in the second and third cycles, there was no increase in yield. Therefore, with the lowest irrigation amount in the first cycle, given the lower Kc values, WUE was higher in the first cycle.

Drip or micro-sprinkler fertigation combined with the use (or non-use) of mulch on the soil

There were significant interactions between the cycle and mulching factors for number of leaves at flowering, DBH and NUE. Table 4 shows the result of the Tukey's means comparison test ($p<0.05$).

Table 4
Number of leaves at flowering (NL), days from planting to harvest in the first cycle and between harvests in the second and third cycles (DBH) and nitrogen use efficiency (NUE) for each cycle of 'BRS Princesa' banana with mulch (WM) and without mulch (NM). Cruz das Almas - BA, 2015.

Cycle	NL		DBH		NUE	
	WM	NM	WM	NM	WM	NM
1st	13.4Aa	12.4Ba	473.5Aa	485.0Aa	118.5Ca	97.5Ca
2nd	13.8Aa	13.4Ba	278.9Ca	227.0Cb	245.9Aa	185.8Ab
3rd	13.5Ab	16.1Aa	318.8Bb	364.9Ba	154.2Ba	140.6Ba
CV (%)	14.03		7.66		16.03	

Means followed by the same uppercase letter in the column and lowercase letter in the row, for each variable, do not differ by Tukey's test at 5% significance.

The number of leaves at flowering did not differ in response to the use of mulch in the first and second cycles, and was higher in the third cycle without use of the mulch. In terms of DBH, the second cycle was the shortest and the second was the longest. Mulching provided a higher DBH mean in the second cycle. However, in the following crop, it provided the lowest DBH mean. Kluge, Scarpare and Victoria (1999) investigated the duration of the production cycle and plant density and found that the condition of non-mulched soil contributes to greater earliness.

Nitrogen use efficiency was higher in the second cycle with the use of mulch and remained, in the third cycle than in the first cycle. This response in NUE is indicative of the effect of mulch, whose decomposition processes close to the soil surface provide an increase in nutrient content and root and biological activities (Ngosong et al., 2019).

The micro-sprinkler system without the presence of mulch favored the growth of the banana plant in terms of pseudostem circumference. On the other hand, mulching favored the number of hands per bunch regardless of the irrigation system (Table 5).

The plants receiving micro-sprinkler irrigation and without the use of mulch showed greater circumference of the pseudostem at flowering. The circumference of the banana pseudostem was greater when the plants were irrigated by the micro-sprinklers. As previously reported, the larger wet area provided by this system, in comparison to drip, promotes greater expansion of the banana root system, i.e., the lower the root length density, the greater the volume of water applied. Therefore, banana has a tendency to develop a more robust water absorption system, with a thicker pseudostem. Pseudostem circumference is important because it is related to the ability to support the bunch and to its lodging and/or breaking by the action of the winds (S. O. Silva, Flores, & Lima, 2002; Donato, Silva, Passos, Lima, & Lima, 2003; S. O. Silva, Pires, Pestana, Alves, & Silveira 2006).

Table 5
Pseudostem circumference at flowering and number of hands per bunch for the conditions of mulched soil (WM) and no-mulch soil (NM) under drip (DRI) and micro-sprinkler (MIC) irrigation in 'BRS Princesa' banana. Cruz das Almas - BA, 2015.

Mulching	Pseudostem circumference		N of hands	
	DRI	MIC	DRI	MIC
WM	0.86Aa	0.85Ba	8.94Ab	9.30Aa
NM	0.82Ab	0.97Aa	7.61Bb	8.42Ba

Means followed by the same uppercase letter in the column and lowercase letter in the row, for each variable, do not differ by Tukey's test at 5% significance.

Number of hands was higher when the plants were grown under mulching and micro-sprinkler-irrigated, and lower under drip irrigation and no mulch (Table 5). Pseudostem circumference did not respond positively to mulching, regardless of the irrigation system. Mulching favored soil moisture in both irrigation systems, which is equivalent to an applied effective irrigation amount superior to the condition without mulch. This favored irrigation amount has been polynomially related to pseudostem circumference (Coelho, Oliveira, & Pamponet, 2013) in plantain cultivars. However, the same response was not seen in cultivar Caipira, and pseudostem circumference was not influenced even when mulch was used in organic cultivation (Coelho, Simões, Santos, Melo, & Lima, 2015).

The micro-sprinkler system favored the growth of banana in terms of pseudostem circumference without the presence of mulch. Mulching also favored the growth of micro-sprinkler-irrigated plants and the number of hands per bunch as a consequence of the growth, for both the treatments with or without banana residue. This result is consistent with that obtained by Marques et al. (2011), who used the drip system with a lateral line, where micro-sprinkler irrigation provided superior results due mainly to the difference in wetted area.

Figure 3 describes the means for pseudostem circumference at flowering, number of leaves at harvest, number of hands per bunch, WUE and KUE as a function of the crop cycles; WUE, KUE, plant height at flowering and yield as a function of mulching; and DBH as a function of irrigation systems in the cultivation of 'BRS Princesa' banana.

The mean values for pseudostem circumference at flowering, number of leaves at harvest, number of hands, WUE and KUE as a function of crop cycles in this approach (Figure 3A, B, C, D, E) were similar to those obtained when the interactions between fertilization type and irrigation system were analyzed (Figure 2A, B, C, D, F). Despite the higher pseudostem circumference, number of leaves and number of hands in the second and third cycles, as compared with the first, there was no increase in yield. Therefore, with the lower irrigation level in the first cycle, given the lower Kc values, WUE was highest in the first cycle. Marques et al. (2011) found that under drip irrigation, pseudostem circumference and number of hands were higher in the second and third cycles than in the first, which the present findings corroborate.

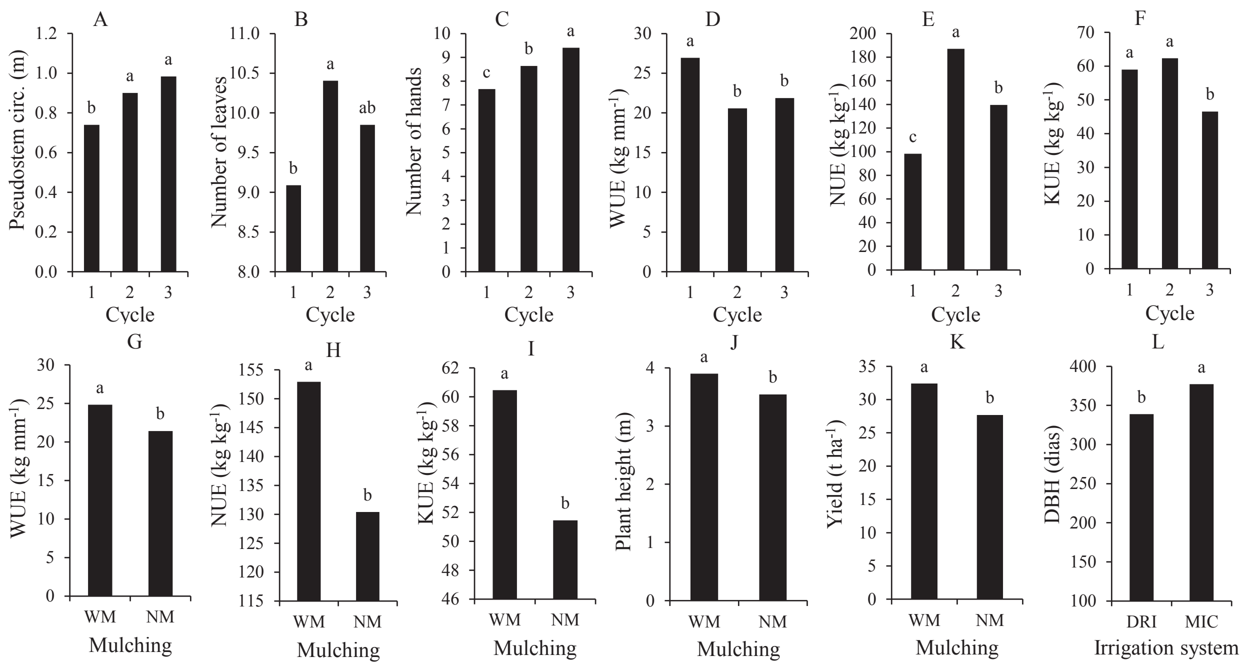

Figure 2. Pseudostem circumference at flowering (A), number of leaves at harvest (B), number of hands (C), water use efficiency - WUE (D) and potassium use efficiency - KUE (E) as a function of the cycle; water use efficiency - WUE (F), potassium use efficiency - KUE (G), plant height at flowering (H) and yield (I) under mulching (WM) and no mulching (NM); and days from planting to harvest in the first cycle and between harvests in the second and third cycles (DBH) as a function of the irrigation system, drip (DRI) and micro-sprinkler (MIC) (J) in ‘BRS Princesa’ banana. Cruz das Almas - BA, 2015. Common letters on the bars, for each variable, do not differ by Tukey’s test at 5% significance.

Water use efficiency, KUE, plant height at flowering and yield in ‘BRS Princesa’ were higher with the use of mulch (Figure 3F, G, H, I). Mulching provided increases of 18.6% in WUE and 22.2% in KUE in relation to cultivation in non-mulched soil (Figure 3F, G). Drip irrigation contributed to a shorter duration of the ‘BRS Princesa’ crop cycles (Figure 3J), which helps to reduce production costs.

The yield of ‘BRS Princesa’ banana was 19.6% higher when the plant was grown under mulch than in non-mulched soil. When subjected to mulching, soils display greater fertility, root growth and root length density (Souza, 2016), which contribute to increased yields (Santana et al., 2020). Therefore, the use of mulching breaks the paradigm that micro-sprinkler is superior to drip irrigation, since individual analysis revealed no significant effect of irrigation system on yield.

Studies develop by Coelho et al. (2012), Cruz (2012) and Sant'ana et al. (2012) show that the yield of banana is higher when the plant is irrigated with micro-sprinklers than with the drip system. This is due to the greater volume of soil wetted by the micro-sprinklers, which allows a better development of the root system in the crop in comparison with drip irrigation. In the present study, the use of micro-sprinklers did not provide higher yields than drip irrigation in 'BRS Princesa' banana; however, the micro-sprinkler system resulted in a greater number of hands and greater WUE. Additionally, mulching associated with fertigation can equal the banana yield under both systems, as observed in the present study.

Conclusion

The hand yield of micro-sprinkler- and drip-fertigated banana is relatively higher when the plant is grown in mulched soil than without mulching.

Mulching increases water, nitrogen and potassium use efficiency of banana crops irrigated with the micro-sprinkler and drip systems.

Drip irrigation provides earlier production in 'BRS Princesa' banana than micro-sprinkler irrigation.

The drip and micro-sprinkler irrigation systems under conventional fertilization, and drip fertigation with banana residue increase earliness in 'BRS Princesa' banana in the third crop cycle.

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