SCIENTIA AGRICOLA

Growth and production of 'Prata Anã Gorutuba' banana under different planting densities

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ABSTRACT: Increased planting density, different types of thinning management, and the use of beneficial microorganisms have been adopted as strategic tools in the effort to increase crop yields in a sustainable manner. This investigation evaluated the growth and production of 'Prata Anã Gorutuba' banana (*Musa* spp., AAB) under different plant densities during two production cycles in the semiarid region of Minas Gerais, Brazil. Micropropagated plantlets were also inoculated with endophytic bacteria and cultivated as part of two mat management strategies. Planting density varied between 1,680 and 3,920 plant ha^{-1}. During the experiment, water was less than optimal because of rationing due to drought in the region. Under field conditions, there was no difference between bacterially inoculated and non-inoculated plants. The dense planting system increased the crop cycle. The highest-density planting treatment (3,920 plant ha^{-1}) resulted in the highest yield in the first cycle, but no net income was observed. However, the high-density planting treatments resulted in the highest yields and gross incomes in the second production cycle. Management with thinning of plants up to 10-months-old and thinning up to harvest associated with high planting density increased the length of the production cycles. Although the water restriction experienced in the first and second crop cycles, the vegetative and productive traits of 'Prata Anã Gorutuba' banana did not compromise the objectives of this study.

Keywords: *Musa* spp., *Bacillus* sp., plant growth-promoting bacteria (PGPB), spacing, hydric stress

Introduction

Banana is the most consumed fruit in the world, and Brazil has a prominent position as the world's fourth largest producer (FAO, 2018). The state of Minas Gerais is the third largest banana producing region in the country, favored by adequate soil and climatic conditions associated with irrigation (Donato et al., 2015). 'Prata Anã Gorutuba' (AAB) is a clone selected from the spontaneous mutation of the 'Prata Anã' banana tree cultivated in Northern Minas Gerais (Rodrigues et al., 2012).

The main factors limiting banana crop expansion in arid and semiarid regions are the production costs and water, causing many banana farmers to limit or abandon its production. In recent years, climate change has resulted in long periods of water scarcity in the semiarid region, low water levels in dams and rivers, and mandatory reductions in irrigation, limiting and hindering banana cultivation (Ferreira et al., 2016). Thus, several strategies, such as high-density planting systems, different types of banana plantlet management, and endophytic bacteria utilization, may be considered important to improving the efficiency of water use.

Under conditions of normal planting density and suitable water supply plants grow vigorously and rapidly cover the soil and aerial spaces. Under conditions of normal planting density and water limitations, plants usually present reduced growth (both the roots and aerial parts) and consequently occupy less space. Furthermore, inappropriate plant spacing may allow for greater water loss through direct soil evaporation. For this reason, high planting density can improve the efficiency of water use while maintaining soils with suitable water supply, greater aerial and root cover, and thereby reduce evaporation and transpiration rates (Eastham et al., 1990).

The association of plant growth-promoting bacteria with micropropagated banana plantlets has been reported to be beneficial under many environmental conditions. These microorganisms have been associated with and are responsible for biological nitrogen fixation, resistance to saline and hydric stress, and promotion of plantlet growth as well as root development (Azevedo et al., 2000; Andrade et al., 2014; Souza et al., 2016).

Many reports have been published on how to minimize the effects of biotic and abiotic stresses. For example, recently Donato et al. (2015) suggested a number of simple and efficient strategies, including: (1) scheduling fruit production; (2) increasing water efficiency use; (3) improving root system and whole plant nutrient availability; (4) using efficient management practices; and (5) using cultivars with a high level of resistance to biotic and abiotic stresses.

The objectives of this investigation were to evaluate the effects of plant density, application of plant growth-promoting bacteria (PGPB), and management techniques on the growth and production of 'Prata Anã Gorutuba' banana in the semiarid region of Minas Gerais, Brazil.

Materials and Methods

This study was undertaken in Janauba, MG, Brazil (15°45′09″ S and 43°18′50″ W, altitude 531 m) with three different phases: greenhouse and nursery (Jan to

May 2015); first production cycle under field conditions (May 2015 to Dec 2016); and second production cycle under field conditions (Dec 2016 to Dec 2017).

The experiment consisted of a randomized block design with four replications, nine treatments, and 20 plants per plot; the six central plants comprised the area of the plot that was used. Treatments consisted of four plant densities (1,680, 1,960, 3,360 and 3,920 plant ha^{-1}), inoculation of micropropagation plantlets with or without five endophytic bacteria and mother-daughter-granddaughter (MDG) banana mat management or thinning mats to one pseudostem for the first 10 months after planting (Table 1).

Micropropagated plantlets of banana cv. Prata Anã Gorutuba (AAB), measuring approximately 7 cm in height and with at least three fully developed leaves, were transplanted to plastic bags (18 × 24 × 0.02 cm) (24 Feb. 2015). On Mar 23 2015, the second batch of micropropagated plantlets with the same characteristics described above was transplanted to long tubes (6 × 6 × 12.5 cm), comprising Treatment 1. At field planting time, the plantlets grown in plastic bags and long tubes were subjected to 120- and 60-day acclimatization periods, respectively.

Five endophytic bacterial isolates were used: *Bacillus* sp., *Lysinibacillus* sp., *B. subtilis, B. pumilus*, and *Rhizobium* sp. Bacterial suspensions were obtained according to Souza et al. (2013). The five isolates were equally mixed, and 25 mL of the resulting suspension was directly applied to the root system of one half of the plantlets at 20-day intervals. A total of four applications were performed during 2015: 10 Mar, 30 Mar, 19 Apr, and 09 May. Height and leaf number were evaluated in 4-month-old plantlets. Pseudostem diameter was measured only in those plantlets which had been acclimatized in plastic bags. Plantlets grown in long tubes and plastic bags were field transplanted on May 20 2015 to a 0.5 ha commercial area.

In the first production cycle, i) leaf number; ii) pseudostem diameter; iii) leaf area (Zuculoto et al., 2008); iv) a leaf area index (Lopes et al., 2014); v) plant height; vi) relative chlorophyll content (Arantes et al.,

2016); vii) cycle duration from planting to inflorescence emergence and from planting to bunch harvest; and viii) total number of leaves emerged during the cycle were evaluated monthly until inflorescence emerged.

Morphophysiological characteristics assessed at harvest time for the first (2016) and second (2017) production cycles included i) leaf number at harvest time; ii) relative chlorophyll content; iii) fruit bunch weight; iv) stem weight; v) number of hands; and vi) fruit classification (Ministério da Integração Nacional, 2000). Fruits were classified according to their length into three categories: Class 1 (> 14 cm), Class 2 (> 12 cm), and Class 3 (< 12 cm). Fruits from Class 3 were discarded.

Physical and chemical fruit analyses were also performed. Nine fruits from the second hand per bunch per treatment were used. The following traits were evaluated: i) initial fruit weight at harvest; ii) final fruit weight at harvest (fruit weight after ripening); iii) fruit peel and fruit pulp weights; iv) pulp total soluble solids; v) pulp total acidity (AOAC, 2005); vi) pulp pH; and vii) fruit firmness.

The final yield was obtained as the weight of the bunch without the stem and the number of plants per hectare. Economic analyses of gross income (GI) and net income (NI) were performed for each treatment. GI was calculated as follows: GI = Yield * [(% Class 1 fruit * price (0.51) + % Class 2 fruit * price (0.31) + % Class 3 fruits * price (0.0)]. Prices used were those quoted by the Fruit Growers Central Association of the North of Minas Gerais State (ABANORTE) during the Dec 2016 and 2017 harvest seasons, respectively. NI was calculated as NI = GI – the cost of production per hectare. The results of GI and NI were expressed in United States dollars (USD).

Irrigation was applied with a microsprinkler system with sprinklers spaced 7 m between rows and 5 m between sprinklers with a flow rate of 100 L h^{-1}. In the first banana production cycle, banana plants were the same age, and three Kc crop coefficients were used to manage irrigation: Kc_{in} (0.5); Kc_{mid} (1.10); and Kc_{final} (1.0). In the second cycle, the plants reached the reproductive phase in different periods, and Kc_{mid} was the only coefficient used. Thus, crop evapotranspiration

Table 1 – Plant spacing, bacterial inoculation, management scheme and planting density for 'Prata Anã Gorutuba' banana in Janaúba, Minas Gerais State, Brazil.

Treatment*	Plant spacing			Bacterial inoculation	Management type	Planting density
	———————— m ————————					plant ha^{-1}
1	4.0	3.0	1.7	No	MDG**	1,680
2	4.0	3.0	1.7	No	MDG	1,680
3	4.0	3.0	1.7	Yes	MDG	1,680
4	4.0	3.0	0.85	No	Total thinning up to 10-months-old	3,360
5	4.0	3.0	0.85	Yes	Total thinning up to 10-months-old	3,360
6	4.0	3.0	0.85	Yes	Total thinning up to harvest	3,360
7	-	3.0	1.7	No	MDG	1,960
8	-	3.0	0.85	No	Total thinning up to 10-months-old	3,920
9	4.0	3.0	1.7	Yes	MDG with 50 % nitrogen reduction	1,680

*Treatment 1 – plantlets acclimatized in long tubes. Treatments 2 to 9 – plantlets acclimatized in plastic bags. **Mother, daughter, and granddaughter (MDG).

(ETc; mm d^{-1}) was calculated as ETc = Kc × ET$_0$ (Allen et al., 1998).

A 2-hour-a-day and 7-day-a-week irrigation schedule was initially planned, with weekly water rates of 60 mm in the first and second cycles. However, water restrictions were imposed as a result of a drought in the Irrigation Gorutuba Project and water had to be delivered two days a week. The irrigation water was supplemented from a private well for an additional day. The irrigation scheduling was redesigned to 2-hours-a-day and 3-days-a-week, with weekly water application rates of 26 mm. From the 2,537 and 2,168 mm of water originally planned, only 1,479 and 1,224 mm were applied in the first and second cycles, respectively. All cultural practices typically recommended for banana cultivation were adhered to (Robinson and Galán Saúco, 2010).

Data were subjected to analysis of variance, and means were compared using the Scott-Knott test at 5 % probability and the Sisvar statistical software program (Ferreira, 2014). Graphs were generated by SigmaPlot, version 11- DEMO (Systat Software, 2011).

Descriptive economic analyses were also carried out to obtain the cost of production and financial return (GI and NI) of each treatment.

Results

Micropropagated plantlet growth

Plant height and pseudostem diameter of plantlets grown in plastic bags were significantly increased by the application of endophytic bacteria ($p \leq 0.05$). At 120 days after inoculation, bioinoculated plastic bag-grown plantlets had plant heights and pseudostem diameters of 38.1 cm and 26.6 mm, respectively. The number of leaves was not influenced ($p > 0.05$) by the treatments, and the mean number of leaves was seven (Table 2).

Growth analyses for the first production cycle

There was no difference ($p > 0.05$) between treatments for leaf number, total number of leaves emerged, pseudostem diameter, leaf area, and plant height until inflorescence emergence (Figure 1).

The maximum leaf emergence rate was observed in the second month after planting. However, plants continued to produce leaves after this period, but at a decreasing rate until the tenth month, when the

emergence of new leaves was interrupted by the emergence of inflorescence by which time plants had a mean of ten leaves (Figure 1A).

The maximum number of leaves in the leaf emergence process was reached during the fifth month after planting, with an accumulated mean of 36 leaves during the first cycle (Figure 1B). The first evaluation of the pseudostem diameter occurred during the second month after planting. The initial and final diameters were 11 and 50 cm, respectively (Figure 1C). The maximum developmental rate of the pseudostem diameter was also reached in the fifth month after planting.

The highest leaf area occurred in the fifth month which presented decreasing rates until the end of the cycle (Figure 1D). At planting, plantlets had a mean height of 3.29 m with the highest rate of plant height growth reached at approximately five months. Mean maximum plant height at flowering was 1.80 m (Figure 1E).

Morphophysiological and productive traits

There were significant differences in 'Prata Anã Gorutuba' banana growth between all the treatments ($p \leq 0.05$) (Table 3).

The number of days from planting to inflorescence emergence was significantly longer for the high plant density treatments compared to the low plant density treatments (Table 3). The lowest number of days from planting to harvest was observed in treatment 9 (1,680 plant ha^{-1}, MDG with 50 % nitrogen reduction with endophytic bacteria inoculation). However, treatments 2 (1,680 plant ha^{-1}, MDG with 50 % nitrogen reduction and no endophytic bacteria inoculation), 3 (1,680 plant ha^{-1}, 215 MDG with endophytic bacteria inoculation and no nitrogen reduction), and 7 (1,980 plant ha^{-1}, MDG and no endophytic bacteria inoculation but with no nitrogen reduction) did not significantly differ from treatment 9 (Table 3).

Table 2 – Leaf number, plant height, and pseudostem diameter in 'Prata Anã Gorutuba' banana plantlets, with or without bacterial inoculation.

Treatment	Leaf number	Plant height	Pseudostem diameter
		cm	mm
Bacterial inoculation	7 a	38.1 a	26.6 a
No bacterial inoculation	7 a	35.6 b	25.7 b
CV (%)	9.8	19.0	15.8

CV (%) = coefficient of variation. Means followed by different letters in the column differ from each other by Tukey's test ($p \leq 0.05$).

Table 3 – Number of days from planting to bunch emergence (DPE), number of days from planting to harvest (NDH), total number of leaves emerged (NLE), pseudostem diameter (DIA), leaf area (AREA), leaf area index (LAI), and bunch weight (BW) of 'Prata Anã Gorutuba' banana plants as affected by different treatments in the first production cycle, 2016.

Treatment	DPE	NDH	NLE	DIA	AREA	LAI	BW
				cm	m		kg
1	327 b	495 b	43 a	60 a	9.66 a	1.75 c	6.02 a
2	291 a	488 b	37 b	50 a	7.47 a	2.00 c	4.51 b
3	301 a	491 b	38 b	52 a	7.80 a	1.75 c	4.40 b
4	323 b	507 b	39 b	40 b	4.94 a	3.00 b	5.04 b
5	315 b	493 b	35 b	43 b	3.14 a	2.75 b	3.60 b
6	321 b	500 b	38 b	43 b	5.03 b	3.00 b	3.34 b
7	299 a	498 b	35 b	49 a	7.02 a	1.75 c	4.26 b
8	328 b	503 b	39 b	43 b	5.07 b	4.00 a	4.67 b
9	274 a	453 a	36 b	55 a	9.68 a	2.05 c	6.86 a
CV (%)	6.76	4.02	6.32	16.67	24.95	23.93	21.64

CV (%) = coefficient of variation. Different letters in the columns indicate significant differences by the Scott-Knott test ($p \leq 0.05$).
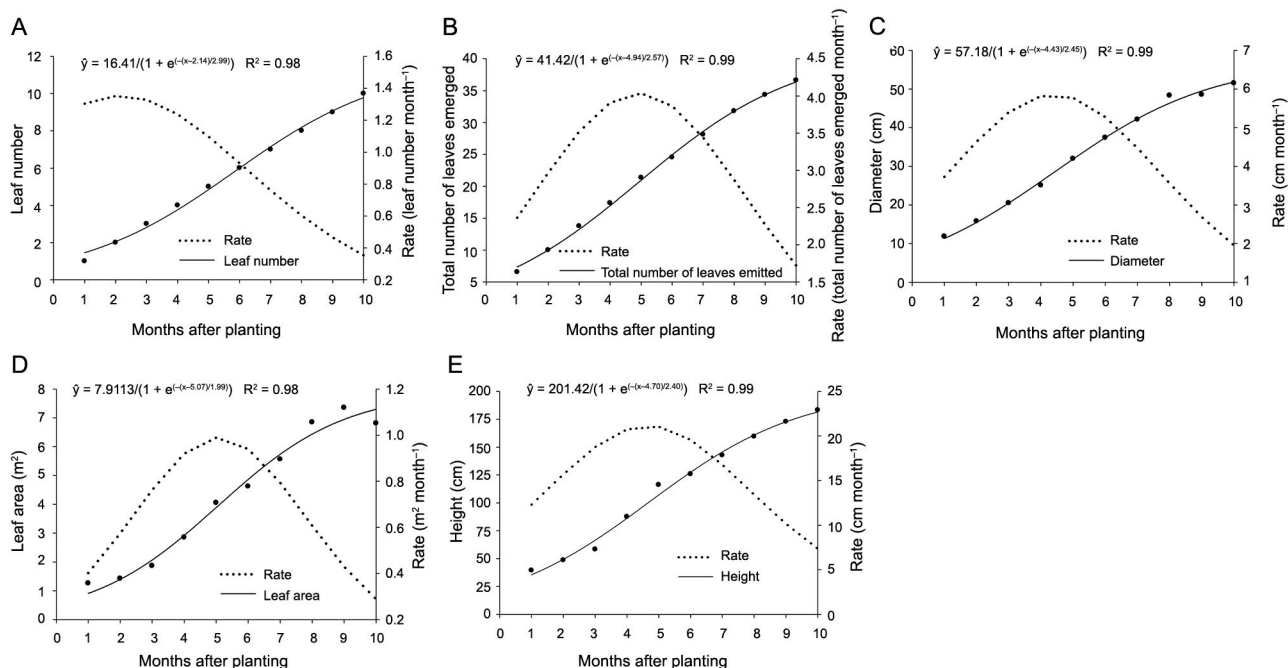
Figure 1 – A) Mean leaf number until flowering; B) Total number of leaves emerged; C) Diameter; D) Leaf area; and E) Plant height of 'Prata Anã Gorutuba' banana, from planting to bunch emergence in Janaúba, Minas Gerais, Brazil, 2016.

The number of days from planting to harvest (NDH) was significantly shorter for treatment 9 only compared to all other treatments; all other treatments were similar. The total number of leaves emerging was significantly higher for treatment 1 (1,680 plant ha^{-1}, MDG, no endophytic bacteria inoculation, and no nitrogen reduction), and the total number of leaves emerged was similar among all other treatments (Table 3).

The pseudostem diameter and leaf area were significantly greater for the low plant density treatments (i.e., 1, 2, 3, 7 and 9) compared to the high-density treatments (i.e., 4, 5, 6 and 8) (Table 3). The leaf area index increased significantly as plant density increased (Table 3). There were three different groups, 1,680 plant ha^{-1} (treatments 1, 2, 3, and 9) and 1,960 plant ha^{-1} (treatment 7); 3,360 plant ha^{-1} (treatments 4, 5, 6); and 3,920 plant ha^{-1} (treatment 8) (Table 3).

Bunch weight was significantly higher for treatment 1 (1,680 plant ha^{-1}, MDG, no endophytic bacteria inoculation, and no nitrogen reduction) and 9 (1,680 plant ha^{-1}, MDG with 50 % nitrogen reduction with endophytic bacteria inoculation) and did not appear related to plant density or inoculation with endophytic bacteria (Table 3).

The crop intervals between the first and second harvests were significantly lower for low-density plantings, i.e., treatments 1, 2, 3, 7 and 9; 1,680 to 1,960 plant ha^{-1}, with or without inoculation with endophytic bacteria compared to high density plantings, i.e., treatments 4, 5, 6 and 8 (Table 4). Interestingly, there were no significant differences in leaf number at harvest,

Table 4 – Interval between the first and second harvests (IFSH), leaf number at harvest time (LNH), chlorophyll content (CC), bunch weight (BW), stem weight (SW), and number of hands (NH) of 'Prata Anã Gorutuba' banana fruit as affected by different treatments in the second production cycle, 2017.

Treatment	IFSH	LNH	CC	BW	SW	NH
				———— kg ————		
1	310 a	11 a	59.63 a	11.93 a	1.43 a	9 a
2	317a	9 a	60.17 a	10.44 a	1.14 a	9 a
3	342 a	9 a	56.28 a	8.56 a	1.03 a	8 a
4	368 b	9 a	56.94 a	9.09 a	1.08 a	8 a
5	382 b	10 a	58.32 a	9.20 a	1.16 a	9 a
6	373 b	11 a	58.01 a	10.37 a	1.09 a	8 a
7	339 a	11 a	60.42 a	10.33 a	1.18 a	9 a
8	360 b	11 a	57.26 a	10.28 a	1.05 a	8 a
9	320 a	10 a	57.80 a	10.17 a	116 a	9 a
Mean	345	10.1	58.34	10.04	1.15	8.6
CV (%)	9.74	12.20	5.24	23.05	15.90	8.51

CV (%) = coefficient of variation. Different letters in the columns indicate significant differences by the Scott-Knott test ($p \leq 0.05$).

leaf chlorophyll content, bunch weight, stem weight and number of hands of fruit between treatments (Table 4). Almost all physical and chemical fruit characteristics were uninfluenced by treatments during the first and second cycles ($p > 0.05$) (Table 5).

Yield

Significant yield differences were found in both production cycles ($p \leq 0.05$) (Table 6). In the first production

Table 5 – Initial fruit weight (IFW), final fruit weight (FFW), fruit peel weight (FPW), fruit pulp weight (FPW), pulp total soluble solids (TSS), pulp total acidity (TA), pulp pH (PH), and fruit firmness (FF) of 'Prata Anā Gorutuba' banana as affected by different treatments in the first and second production cycles, 2016/2017.

Treatment	IFW	FFW	FP W	FPW	TSS	TA	PH	FF (N)
				1st production cycle				
	————————————— g —————————————				°Brix	%		
1	66.90 a	53.51 a	14.15 a	37.67 a	24.62 a	0.64 a	4.74 a	15.93 a
2	68.48 a	46.16 a	13.05 a	33.09 a	25.44 a	0.69 a	4.65 a	21.06 b
3	60.21 a	46.61 a	14.00 a	33.48 a	25.63 a	0.71 a	4.60 a	16.09 a
4	58.66 a	49.29 a	18.90 a	31.67 a	23.55 a	0.75 a	4.72 a	15.25 a
5	65.03 a	55.58 a	18.64 a	39.07 a	24.07 a	0.72 a	4.63 a	16.88 a
6	61.08 a	49.04 a	15.98 a	34.75 a	25.45 a	0.71 a	4.63 a	19.93 b
7	59.27 a	47.53 a	14.20 a	34.80 a	25.39 a	0.62 a	4.64 a	14.67 a
8	64.45 a	51.51 a	12.89 a	38.62 a	24.86 a	0.70 a	4.80 a	14.14 a
9	59.14 a	45.45 a	15.25 a	31.76 a	24.22 a	0.67 a	4.70 a	15.65 a
Average	62.58	49.41	15.22	35.00	24.80	0.69	4.67	16.62
CV (%)	18.45	22.18	20.37	20.70	4.03	10.70	2.51	13.65
Treatment	IFW	FFW	FP	FPW	TSS	TA	PH	FF (N)
				2nd production cycle				
	————————————— g —————————————				°Brix	%		
1	84.12 a	76.57 a	27.42 a	49.15 a	24.24 a	0.60 a	4.44 a	24.27 a
2	98.25 a	87.28 a	28.30 a	58.98 b	22.92 a	0.55 a	4.47 a	24.21 a
3	72.86 a	64.08 a	21.11 a	42.97 a	23.55 a	0.63 a	4.39 a	25.55 a
4	62.72 a	53.28 a	18.48 a	34.80 a	24.11 a	0.61 a	4.42 a	20.03 a
5	80.85 a	70.97 a	25.07 a	45.90 a	21.63 a	0.64 a	4.44 a	24.53 a
6	85.05 a	74.50 a	23.31 a	51.19 a	24.75 a	0.61 a	4.45 a	20.00 a
7	73.43 a	60.35 a	24.35 a	36.00 a	23.71 a	0.59 a	4.48 a	24.26 a
8	56.05 a	47.51 a	14.53 a	32.98 a	24.64 a	0.56 a	4.42 a	22.51 a
9	95.90 a	84.75 a	28.63 a	56.12 b	24.12 a	0.59 a	4.39 a	25.67 a
Average	78.80	68.81	23.47	45.34	23.74	0.60	4.43	23.45
CV (%)	23.68	27.24	32.95	25.11	7.95	11.98	1.43	17.74

CV (%) = coefficient of variation. Different letters in the columns indicate significant differences by the Scott-Knott test ($p \leq 0.05$).

Table 6 – Yield and fruit classification of 'Prata Anā Gorutuba' banana as affected by different treatments in the first and second production cycles, 2016/2017.

Treatment	First production cycle				Second production cycle			
	Yield (t ha⁻¹)	Classification (%)			PROD (t ha⁻¹)	Classification (%)		
		Class				Class		
		1	2	3		1	2	3
1	10.21 a	7.9	51.1	41.0	17.64 a	47.02	44.00	8.98
2	6.50 a	5.9	40.6	53.5	15.62 a	46.11	40.89	13.00
3	6.29 a	0.5	27.5	72.0	12.63 a	22.46	63.07	14.47
4	10.41 a	8.3	40.9	50.8	26.93 b	33.32	57.18	9.50
5	10.14 a	0.0	28.6	71.4	27.03 b	32.43	52.31	15.26
6	8.55 a	6.8	29.7	63.4	31.18 b	49.08	42.68	8.24
7	7.43 a	3.8	32.7	63.6	17.93 a	48.07	41.49	10.44
8	16.80 b	14.2	28.8	57.0	36.18 b	42.87	42.66	14.47
9	10.37 a	30.0	42.4	27.5	15.15 a	44.99	44.27	10.74
CV (%)	26.64	-	-	-	24.05	-	-	-

CV (%) = coefficient of variation. Different letters in the columns indicate significant differences by the Scott-Knott test ($p \leq 0.05$).

cycle, the yield of treatment 8 (3,920 plant ha⁻¹) was significantly higher than that of all the other treatments. However, there were no significant differences in the percentages of Class 1, Class 2, and Class 3 fruits. Yields from the second crop cycle were much higher than those from the first crop cycle. Yields from the low-density plantings, i.e., 1,680-1,920 plant ha⁻¹, were significantly lower than those of the high-density plantings, i.e., 3,360-3,920 plant ha⁻¹ (Table 6). This may be attributed to there being more plants per hectare as bunch weights were similar between all the treatments (Table 4).

Gross income and net income

At the end of the first production cycle, treatments 4, 8, and 9 had the greatest gross income due to a higher percentage of Class 1 fruits, although there was no significant difference in the percentages of Class 1, 2 and 3 fruits (Tables 6 and 7). Negative net income were recorded for all treatments at the end of the first production cycle. This may be partly attributed to the high percentage of Class 2 and 3 fruits. In contrast, gross and net income were significantly higher for high density planting treatments compared to low density plantings at the end of the second crop production cycle (Table 7). This may be attributed to increased yields and percentages of Class 1 fruits for the higher density plantings compared to the lower plantings despite the higher cost of production (Tables 6 and 7).

Table 7 – Cost of production, gross income (GI) and net income (NI) of 'Prata Anã Gorutuba' banana as affected by different treatments in the first and second production cycles, 2016/2017.

Treatment	First production cycle			Second production cycle		
	GI	Production cost	NI	GI	Production cost	NI
			USD			
1	1,459.41 a	7,885.51	–6,426.10	6,189.58 a	3,929.86	2,259.71
2	1,008.44 a	7,885.51	–6,877.07	4,951.83 a	3,929.86	1,021.97
3	758.92 a	7,885.51	–7,126.58	4,449.28 a	3,929.86	519.42
4	2,443.03 b	11,616.76	–9,173.72	10,306.08 b	6,337.09	3,969.01
5	960.01 a	11,616.76	–10,700.74	9,534.68 b	6,337.09	3,197.58
6	1,128.78 a	11,616.76	–10,487.98	11,819.02 b	6,337.09	5,481.92
7	1,477.75 a	8,367.29	–6,889.54	7,048.70 a	4,249.05	2,799.65
8	2,888.02 b	13,517.97	–10,629.95	2,573.90 b	8,266.47	4,307.42
9	3,646.33 b	7,885.51	–4,239.18	5,311.12 a	3,929.86	1,381.25
CV (%)	45.64	-	-	26.79	-	-

CV (%) = coefficient of variation. Different letters in the columns indicate significant differences by the Scott-Knott test ($p \leq 0.05$).

Discussion

First and second cycle

The optimum number of days for the banana tree development cycle is approximately 400 under ideal conditions, with approximately 100 days for each developmental phase (Donato et al., 2015). All treatments resulted in increased duration of the first cycle (> 450 days). No association with planting density, type of plantlets, or management practices was observed. The only exception was treatment 9, in which there was an association between bacterial inoculation, 50 % nitrogen (N) reduction, and low density planting (1,680 plant ha⁻¹) which reduced the duration of the first cycle by 8 %. The increase in cycle duration may have been associated with the water restrictions.

The association of bacterial inoculation plus a 50 % nitrogen (N) reduction and low planting density (1,680 plant ha⁻¹, treatment 9) reduced the duration of the first cycle. When considering these results and comparing treatments 3 and 9, the only difference that emerges between them was the reduction in N application. The 50 % N reduction associated with the water restriction was associated with more positive outcomes than the total dose of N applied in treatment 3. Most probably, a number of aspects of the N cycle in the soil were affected, and the plants subjected to treatment 9 performed favorably.

The interval between the first and second harvests was affected by planting density. All high-density treatments (3,360 and 3,920 plant ha⁻¹) had longer intervals between cycles than low-density treatments. In contrast, leaf number at harvest time, chlorophyll content, bunch weight, stem weight, and number of hands were not affected.

The higher number of total leaves emerged in plantlets grown in long tubes was probably due to the age of the plantlets (60-day acclimatization period). During evaluation in the field, these plantlets continued to produce leaves for a more extended period until bunch emergence. The results recorded (treatment 1) for the number of leaves emerging throughout the first cycle were similar to previously reported data, with values varying from 40 to 45 leaves per plant cycle⁻¹ for 'Prata Anã' banana plants (Turner et al., 2007). During the first four months, a higher leaf emergence rate was observed. This fact is associated with the optimal range of local temperatures. According to Robinson and Gálan Saúco (2010), 31 °C is considered an optimal air temperature for leaf emergence.

Plants in the highest planting density treatments (3,360 and 3,920 plant ha⁻¹) had smaller pseudostem diameters but higher leaf area index values. Both characteristics are essential and indirectly associated with yield. The pseudostem diameter is one of the most important traits associated with plant vigor (Rodrigues et al., 2009). In the present study, only one cycle was evaluated. Long-term studies will be necessary to evaluate the impacts of high planting density on yield, longevity, and fruit quality.

'Prata Anã Gorutuba' is classified as a medium-sized cultivar. A previous investigation reported that the cultivar had a mean height of 2.5 to 3 m in the first cycle (Rodrigues et al., 2009). In the current study, the plants exhibited a lower mean height (1.86 m). The reduced plant height in the present investigation may have been due to the water deficit.

The highest planting density (3,920 plant ha⁻¹) significantly increased yield in the first cycle. Nevertheless, fruit quality was not influenced, and the gross and net income data corroborate this finding.

The effects of planting density were more pronounced in the second production cycle, especially those on yield and gross income, compared to the first cycle. According to Rodrigues et al. (2009), 'Prata Anã' banana mean yields of 22 to 35 t ha⁻¹ yr⁻¹ and 10 to 20 t ha⁻¹ yr⁻¹ were achieved under irrigated and nonirrigated conditions, respectively, in the Minas Gerais semiarid region. The yield recorded in the second production cycle for densities above 3,000 plant ha⁻¹ can be considered reasonable, despite the lower percentages of Class 1

fruits. There is no consensus about the effects of high planting densities on banana cultivation. Certain studies have demonstrated that high planting densities have greater yields per unit area, although they affect fruit quality and substantially increase the duration of the cycle (Mahmoud, 2013).

Management practices

Planting density showed the greatest effects on the results of this investigation, mainly by increasing the cycle duration, yield, and economic returns. Increased planting density plus pseudostem thinning is a management strategy that may improve banana crop production. High-density systems may also offer the farmer advantages, such as considerable yield increase and optimization of costs per hectare, greater land use efficiency, labor, and capital. However, higher planting densities usually increase cycle duration and require plant density reduction after the first harvest (Mahmoud, 2013).

Possibly, in an ideal water supply situation, the high planting densities' response would have provided an even greater impact on productivity, the inoculated endophytic bacteria could have had better survival conditions in soils with suitable water, and a significant increment in vegetative and reproductive characteristics in banana plants. While our results support our conclusion, we acknowledge that new studies, focused mostly on the response of "Prata Anã Gorutuba" to water, might be necessary to reinforce our findings.

Conclusions

Microbiolization increased the size of plantlets under nursery conditions. High-density planting increased the crop cycle duration from planting to bunch emergence in the first production cycle. The treatment with the highest planting density resulted in higher yield in the first cycle. The dense planting treatments exhibited the highest yields and gross income in the second production cycle.

Acknowledgments

Authors' Contributions

Conceptualization: Pereira, M.C.T.; Nietsche, S.; Xavier, A.A. **Data acquisition**: Siqueira, C.L.; Mendes, A.H.; Xavier, H.R.A.; Guimarães, R.S.; Lacerda, D.R.

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