Pomology/ Original Article

Agroeconomic viability of 'Farta Velhaco' banana plantations at increasing planting densities in the state of Mato Grosso, Brazil

Abstract – The objective of this work was to evaluate the morphological characteristics, yield, fruit quality, and profitability of the 'Farta Velhaco' banana (AAB, Plantain subgroup) subjected to increasing planting densities. The treatments consisted of four planting densities – 3,333, 2,222, 1,666, and 1,333 plants per hectare, whose spacings between plants were, respectively, 1.0, 1.5, 2.0, and 2.5 m in the planting rows, arranged in a randomized complete block design, with four replicates. The planting density of 3,333 plants per hectare (4.0x2.0x1.0 m) provided yield increases, without affecting the fruit commercial standards. Although this spacing resulted in a higher production cost (US\$ 5,634.06), it provided a higher operating profit (US\$ 13,444.48). Therefore, the increases in planting density of up to 3,333 plants per hectare increment crop yield, without affecting the commercial quality of the fruit. The economic profitability is higher when using 3,333 plants per hectare (4.0x2.0x1.0 m), which is the most suitable plant density, considering the main morphological characteristics, as well as yield and fruit quality, in a production cycle.

Index terms: *Musa*, Plantain subgroup, planting spacing, production cost.

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Viabilidade agroeconômica de cultivos de banana 'Farta Velhaco' a densidades crescentes de plantio no estado de Mato Grosso

Resumo – O objetivo deste trabalho foi avaliar as características morfológicas, a produção, a qualidade do fruto e a rentabilidade da banana 'Farta Velhaco' (AAB, subgrupo Terra), submetida a densidades crescentes de plantio. Os tratamentos consistiram de quatro densidades de plantio – 3.333, 2.222, 1.666 e 1.333 plantas por hectare, cujos espaçamentos entre plantas foram, respectivamente, 1,0, 1,5, 2,0 e 2,5 m nas linhas de plantio, em arranjo em delineamento experimental de blocos ao acaso, com quatro repetições. A densidade de plantio de 3.333 plantas por hectare (4,0x2,0x1,0 m) proporcionou aumentos de produtividade, sem afetar os padrões comerciais dos frutos. Embora esse espaçamento tenha resultado em um custo de produção maior (US\$ 5.634,06), proporcionou um lucro operacional superior (US\$ 13.444,48). Portanto, os aumentos de densidade de plantio de até 3.333 plantas por hectare aumentam a produtividade do cultivo, sem afetar a qualidade comercial dos frutos. A rentabilidade econômica é maior quando se usam 3.333 plantas por hectare (4,0x2,0x1,0 m), que é a densidade de plantas mais adequada, quando se consideram as principais características morfológicas, bem como produtividade e qualidade dos frutos, em um ciclo de produção.

Termos para indexação: *Musa*, subgrupo Terra, espaçamento de plantio, custo de produção.

Introduction

Bananas (*Musa* sp.) are grown in more than 135 countries, mainly in the Caribbean, Latin America, Asia, Oceania, and Africa, contributing for food safety and generation of income for approximately 400 million people (FAO, 2020). The banana world production in 2019 reached 116.7 million Mg in an area of 5.1 million hectares. Brazil is the fourth largest world producer of this fruit, with 5.8% of the global production, after India (26%), China (9.9%), and Indonesia (6.2%) (FAO, 2020).

'Farta Velhaco' is the most planted banana cultivar of the Plantain subgroup, in the state of Mato Grosso, Brazil. These plantations are mainly grown by family farmers, and the consumption of these fruit is a habit of the local population (Marcilio et al., 2014; Pereira et al., 2015). 'Farta Velhaco' banana plantations generate employment and income, contributing for the local economic growth and development. However, despite the potential generation of income for farmers, it requires a high investment in production technologies (Rambo et al., 2015).

The recommended planting spacings for the cultivation of plane trees are in 3.0x2.5 m single rows, with 1,333 plants ha^{-1}. Spacings at 4.0x2.5x2.5 m (1,231 plants ha^{-1}) and 2.0x3.0 m (1,666 plants ha^{-1}) have been used for 'Farta Velhaco' banana planting (Marcilio et al., 2014; Martins et al., 2016). However, these densities are low and may have a better use for the area through higher densities.

Thus, the use of higher planting densities combined with the annual production cycle (one harvest) is a technology that has been shown to be more efficient to increase fruit yield and, consequently, the profitability for banana growers than the conventional systems that produce low yields, in which, after the first production cycle, the longevity of banana plantations is reduced due to the smaller population shelf, plant vigor, productivity, and pressures caused by pests and diseases, such as leaf spots (sigatoka) and banana borer (*Cosmopolites sordidus*) (Prata et al., 2018).

Although increases of plant density result in higher yields, the plant response to a higher number of plants in the area may vary according to plantation location, genotype, and environmental conditions (Magalhães et al., 2020). A higher planting density of banana may affect the morphological characteristics of plants, increase the production cycle time, affect bunch production and fruit quality, and increase the production costs (Prata et al., 2018; Gasparotto et al., 2019; Donato et al., 2020; Magalhães et al., 2020).

Some agronomic and economic results verified by Gasparotto et al. (2019) have shown that the cultivation of plantain at higher densities is a highly viable investment during the first year of planting, due to higher banana productivity and economic return to the producer, without the need to expand new cultivation areas, in addition to contribute to greater fruit offering.

The objective of this work was to evaluate the morphological characteristics, yield, fruit quality, and profitability of 'Farta Velhaco' banana plantations (AAB, Plantain subgroup) subjected to different planting densities.

Materials and Methods

The experiment was carried out from October 2019 to December 2020, at the experimental area of the Universidade do Estado de Mato Grosso, in the municipality of Tangará da Serra, in the state of Mato Grosso (MT), Brazil (14º37'55"S, 57º28'05"W, at 488 m altitude). According to the Köppen-Geiger's classification, the region shows a tropical humid megathermal climate (Aw), with two well-defined seasons, that is, a rainy season in the summer and a dry season in the winter. From climatic data collected in the meteorological station of the experimental area, the mean air temperature during the banana cycle was of 25.6ºC, and the total rainfall depth was 1,755 mm (Dallacort et al., 2011).

The soil of the area is classified as a Latossolo Vermelho distrófico, according to the Brazilian Soil Classification System (Santos et al., 2018) and Rhodic Ferralsols by the World Reference Base for Soil Resources (IUSS Working Group WRB, 2015). The analysis results of the soil at 0–20 cm soil depth were: 5.2 for pH (water); 1.48 mg dm^{-3} P; 80 mg dm^{-3} K; 0.12 cmol$_c$ dm^{-3} Al; 0.85 cmol$_c$ dm^{-3} Ca; 0.29 cmol$_c$ dm^{-3} Mg; 3.75 cmol$_c$ dm^{-3} H + Al; 1.3 cmol$_c$ dm^{-3}, sum of bases; 5.05, cation exchange capacity at pH 7.0; 25.75% base saturation; and 12 g dm^{-3} organic matter. The soil was prepared using the conventional method, with hoeing, harrowing, and opening of furrows. Soil fertilizer applications were carried out at planting as topdressing, based on the results of the soil analysis and recommendations for Plantain banana (Borges, 2016).

Micropropagated seedlings of the 'Farta Velhaco' banana were acquired from a commercial company in the municipality of Cruz das Almas, in the state of Bahia, Brazil, and transplanted into plastic bags containing 1 L commercial substrate, where they remained for 60 days in protected environment conditions, until reaching 40 cm average height. The banana seedlings were planted in October 2019.

A randomized complete block design was used, with four replicates. The seedlings were planted in a double-row system, with 4.0 m spacing between double rows and 2.0 m between rows. The treatments consisted of the following planting densities: 3,333, 2,222, 1,666, and 1,333 plants ha^{-1}, resulting from the spacings between plants in the planting rows: 1.0, 1.5, 2.0, and 2.5 m, respectively. The plots consisted of 12 plants; and the eight central plants were evaluated, disregarding the plot borders.

The experiment was conducted following the recommended cultural practices for banana plantations (Borges, 2016). However, the banana plantation was carried out with a single plant per pit (parent plant), which required a thinning of surplus suckers to keep the established plant density. Periodical inspections showed the presence of pests and diseases, including defoliator caterpillars, thrips, and black sigatoka. Thus, the insecticides Methomyl 215 g L^{-1} and Imidacloprid 700 g kg^{-1}, and the fungicides Trifloxystrobin 100 g L^{-1} and Tebuconazol 200 g L^{-1} + Difeconazol 250 g L^{-1} were applied. Applications were carried out following the recommendations for banana plantations, according to the product labels.

Evaluations of variables related to phenological cycle were carried out considering the number of days from planting to flowering (vegetative cycle), from flowering to harvest (reproductive cycle), and from planting to harvest (total cycle). The evaluated characteristics related to plants were: height from ground level to the shoot apex leaf (m), pseudostem circumference at 30 cm above ground level (cm), number of active leaves (more than 50% green area) at the flowering and harvest stages, and increase percentage of height and pseudostem circumference, which was evaluated using the following equation: Increase (%) = [(FV - IV)/ IV] ×100, where: IV is the initial value, first evaluation at 90 days after planting; and FV is the end value, final evaluation at the flowering stage.

The production characteristics evaluated at harvest were: bunch weight (kg), number of bunches, hand weight (kg), yield (kg ha^{-1}), number of fruit per bunch, stalk length (cm), stalk diameter (cm), and stalk weight (kg). The physical and chemical analyses were carried out when fruit reached the maturation stage 6, considering the fruit length (cm), fruit diameter (mm), fruit weight (g), pulp and peel weights (g), pulp to peel ratio, solid soluble contents (ºBrix), titratable acidity, and pH (Dadzie & Orchard, 1997). The data were subjected to the analysis of variance and fitted to regression models. In all cases, the fitting to regression models considered the adequacy to the biological phenomenon studied, the R^2 value, and the significance of regression coefficients by the t-test, using the R statistical program (R Core Team, 2018).

Banana production costs and plantation profitability were evaluated according to recommendations by Martin et al. (1998), based on the plant density corresponding to the different spacings used, and consisted of evaluations of effective operating cost (EOC), total operating cost (TOC), total production cost (TPC), gross income (GI), gross margin of EOC; gross margin of TOC, gross margin of TPC, equilibrium points, operating profit, profitability index, and cash flow. Then, different situations were developed, with decreases of 10% up to 50% of marketing value per kilogram of banana fruit (Plantain subgroup), based on the studies by Rodrigues et al. (2018).

Results and Discussion

The planting spacing had no significant effect on the phenological cycle time of 'Farta Velhaco' banana (Plantain subgroup). The periods were 287 days from planting to flowering (vegetative cycle), 79 days from flowering to harvest (reproductive cycle), and 359 days from planting to harvest (cycle total). This information is important for banana growers to establish the best harvest and marketing times and to avoid low-price periods in the market, when the fruit availability is high (Paull & Duarte, 2011).

The spacing had significant effect on plant height (Figure 1 A). The 2.00 m spacing between plants resulted in the lowest plant heights (3.43 m), representing 9.7% height decrease than the 1.0 m spacing between plants. This indicates a competition for light in the densest plantation. These results are consistent with those by

Prata et al. (2018) and Gasparotto et al. (2019), who reported that plant height tends to increase as plant density increases.

The spacing between plants had no significant effect on the pseudostem circumference, which showed a 69.72 cm mean value. Low pseudostem circumferences may cause plant tipping due to wind, or bunch weight. The high plant density of the plantations (up to 4,166 plants ha^{-1}) is not a limiting factor for the pseudostem development of 'D'Angola' banana plants (Plantain subgroup) during the first production cycle, in the states of Ceará and Bahia,
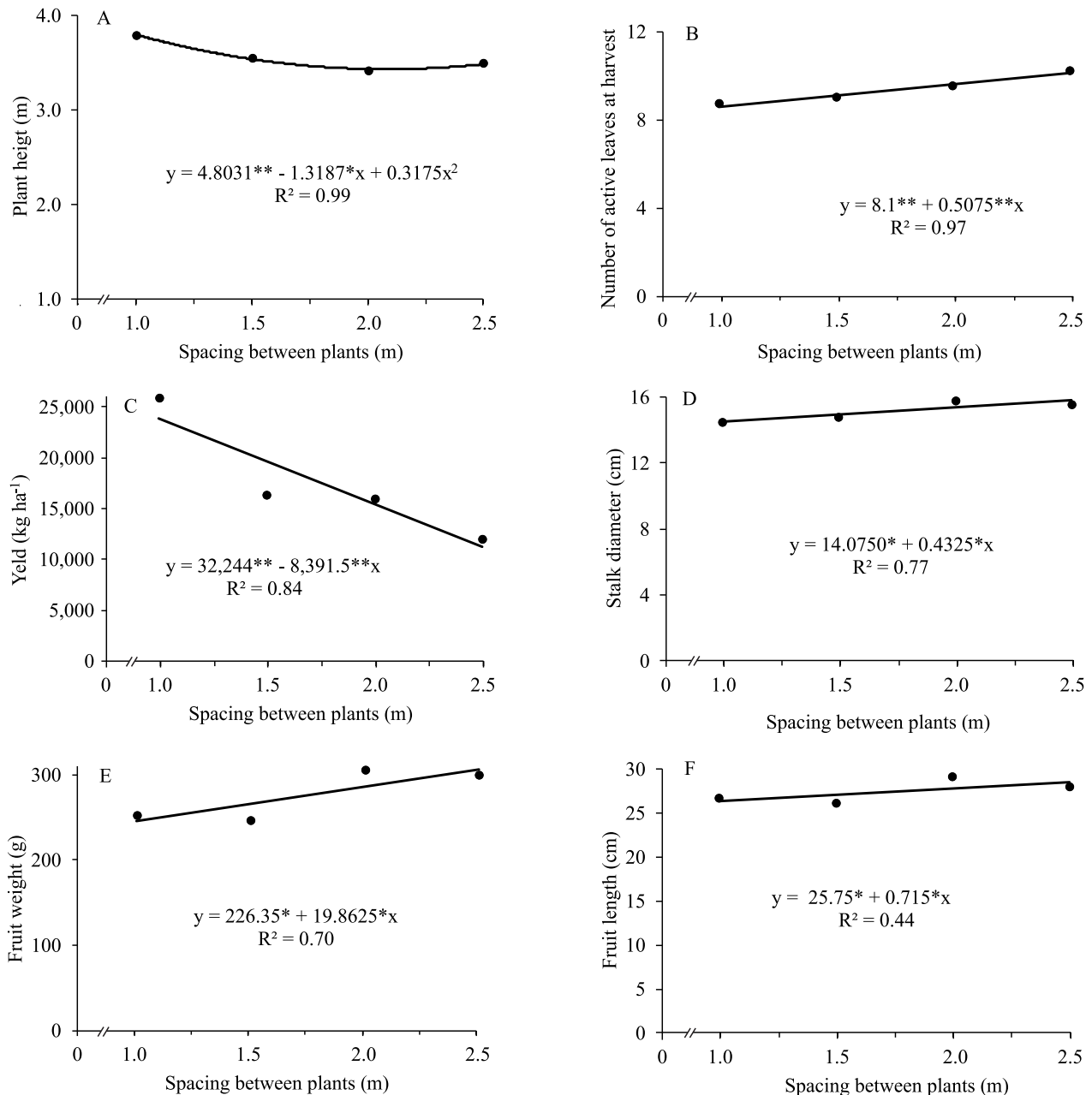
Figure 1. Effect of spacing between plants, in the planting row, on the following characteristics of 'Farta Velhaco' banana (*Musa* sp.) plants: A, plant height; B, number of active leaves at harvest; C, yield; D, stalk diameter; E, fruit weight; and F, fruit length, in the municiapality of Tangará da Serra, in the state of Mato Grosso, Brazil. **, *Significant at 1% and 5%, respectively, by the t-test.

Brazil (Prata et al., 2018; Rodrigues Filho et al., 2020), as also found for 'Farta Velhaco' banana.

The spacing had also no significant effect on the number of active leaves, at the flowering stage, which showed 12.72 leaves mean value. This quantity of leaves is considered adequate because, during the flowering and harvest periods, the number of 6 to 12 leaves does not affect the bunch weight nor the quality of fruit and its post-harvest ripening (Rodríguez González et al., 2012). However, a significant effect (1% probability level) was found at the harvest stage (Figure 1 B). The planting density of 1,333 plants ha^{-1} at 2.5 m spacing resulted in the highest number of leaves, which decreased as the spacings were decreased, reaching the minimum number of leaves in the densest plantation 3,333 plants ha^{-1} (1.0 m spacing). Denser planting conditions have resulted in a decreasing quantity of active leaves at harvest due to the competition between plants for space and light, which can be attributed to the lesser spacing between plants in the planting rows (Donato et al., 2020).

The increase percentage of plant height and pseudostem circumference were not affected by the spacings between plants, and resulted respectively in 217.05% and 139.78% mean values. Banana plant height and pseudostem circumference increase continuously and stabilize after flowering, when the production of photoassimilates is directed for bunch growth and development (Almeida et al., 2019a).

The spacing between plants had no significant effect on bunch characteristics, which showed 9.40 kg bunch weight, 8.43 kg total weight of hands (without stalk), 6.26 hands per bunch, and 28.09 fruit per bunch. Bunch weight and number of fruit of Plantain banana are related to bunch weight and indicate a strong genetic correlation between these characteristics (Arantes et al., 2010). The number of fruit is an important characteristic, mainly for Plantain banana, whose fruit are commonly marketed in street markets and supermarkets as fingers or units, differently from other banana subgroups, such as 'Maçã', 'Prata', and 'Nanica' which are marketed as bunches.

However, the estimated yield of the banana plantation showed positive responses (1% probability level) to spacing between plants (Figure 1 C). The densest plantation, 3,333 plants ha^{-1} at 1.0 m spacing, reached the highest yield, denoting its higher efficiency than the other spacings, with a relative increase of 111%, in comparison to the spacing with the lowest yield (1,333 plants ha^{-1} at 2.5 m). Gasparotto et al. (2019) found a relative yield increase of 129% for the 2.0×1.5 m spacing (3,333 plants ha^{-1}), in comparison to the conventionally used spacing of 3.0×3.0 m (1.111 plants ha^{-1}) for 'Pacovan' banana plantations grown in the state of Amazonas, Brazil.

Spacing had a significant effect (5% probability level) on stalk diameter. There was a small variation in stalk diameter as spacings between plants were increased (Figura1 D); however, the stalk length and weight were similar, showing respectively 64.01 cm and 0.887 kg mean values. Stalk size may affect fruit distribution in the bunch and, consequently, the fruit quality because of possible wounds at harvest (Cavatte et al., 2012).

Fruit diameter was similar in spacing comparisons, with 43.53 mm mean value. However, a significant effect (5% probability level) was found for fruit weight and length. The planting density of 3,333 plants ha^{-1} at 1.0 m spacing resulted in lower fruit weights (Figure 1 E) and lengths (Figure 1 F), and the highest values were found for plants at 2.5 m spacing. Although lower spacings reduce fruit lengths, these lengths are within the values established for the Plantain bananas to be classified as superior, that is, fruit with lengths higher than 23 cm, which show higher commercial value (Ceagesp, 2021).

Fruit pulp and peel weights were not affected by the spacing between plants and showed 84.01 and 88.28 g, respectively, as well as the pulp to peel ratio that showed 2.13 mean. A high pulp to peel ratio is desirable for fresh and cooking bananas, since consumers, as well as processing industries, prefer fruit with higher pulp percentages, as these fruit are more profitable (Roque et al., 2014; Reis et al., 2016).

The fruit chemical characteristics were not affected by the different spacings evaluated, and showed 17.30 °Brix for total soluble solids, 4.47 pH, and 0.12% of malic acid for titratable acidity. These results are consistent with those found by Almeida et al. (2019b), who also found no effect of different growing systems and spacings for 'D'Angola' banana plants, which can be attributed to genetic characteristics of this cultivar.

Production costs per hectare found for the implementation and growth are presented for 'Farta Velhaco' banana (Table 1). The effective operating cost (EOC) increased as the plant density was increased,

Table 1. Estimated production costs of 'Farta Velhaco' banana (*Musa* sp.) grown in 2020 at increasing planting densities, in the municiapality of Tangará da Serra, in the state of Mato Grosso, Brazil.

Item	Unit	Unit Value US$	Spacing (m) / Planting density (plants ha^{-1})
			Quantity	1.0 m / 3,333 (plants ha^{-1})	Quantity	1.5 m / 2,222 (plants ha^{-1})	Quantity	2.0 m / 1,666 (plants ha^{-1})	Quantity	2.5 m / 1,333 (plants ha^{-1})
Mechanized operations										
Hoeing	MH	12.92	3	38.76	3	38.76	3	38.76	3	38.76
Harrowing	MH	19.38	1.5	29.07	1.5	29.07	1.5	29.07	1.5	29.07
Furrowing	MH	23.26	1.5	34.88	1.5	34.88	1.5	34.88	1.5	34.88
Pesticide applications	MH	4.52	23	103.99	23	103.99	23	103.99	23	103.99
Hoeing	MH	12.91	10	129.07	10	129.07	10	129.07	10	129.07
Total (mechanized operations)				335.78		335.78		335.78		335.78
Manual operations										
Soil fertilizer application at planting	Dh	15.50	2	31.01	1.6	24.81	1.3	20.16	1	15.50
Planting	Dh	15.50	7	108.53	5	77.52	3.3	51.16	3	46.51
Transport of seedlings	Dh	15.50	2	31.01	1.6	24.81	1.3	20.16	1	15.50
Weeding	Dh	15.50	10	155.04	10	155.04	10	155.04	10	155.04
Topdressing	Dh	15.50	18	279.07	12	186.05	9	139.53	7	108.53
Removal of leaves	Dh	15.50	8	124.03	5	77.52	4	62.02	3	46.51
Removal of suckers	Dh	15.50	13	201.55	8	124.03	6	93.02	5	77.52
Pesticide applications	Dh	15.50	4	62.02	4	62.02	4	62.02	4	62.02
Hoeing	Dh	15.50	7	108.53	7	108.53	7	108.53	7	108.53
Harvest	Dh	15.50	42	651.16	28	434.11	22	341.09	18	279.07
Total (manual operations)				1,751.94		1,274.42		1,052.71		914.73
Total (mechanized and manual operations)				2,087,71		1,610.19		1,388.49		1,250.50
Inputs										
Soil analysis	Unit	17.44	1	17.44	1	17.44	1	17.44	1	17.44
Seedlings	Unit	0.37	3,333	1227.27	2,222	818.18	1,666	613.45	1,333	490.83
Poultry litter	Mg	29.07	6.66	193.60	4.44	129.07	3.33	96.80	2.66	77.33
Limestone	kg	0.03	690	20.06	690	20.06	690	20.06	690	20.06
Urea	Mg	406.98	1.23	500.58	0.82	333.72	0.61	248.26	0.49	199.42
MAP	Mg	532.95	0.67	357.07	0.45	239.83	0.34	181.20	0.27	143.90
Potassium chloride	Mg	416.67	1.87	779.17	1.25	520.83	0.94	391.67	0.75	312.50
FTE (micronutrients)	kg	0.28	166.65	46.51	111.10	31.00	83.30	23.25	66.65	18.60
Native (fungicide)	L	26.94	2	53.88	2	53.88	2	53.88	2	53.88
Score (fungicide)	L	68.99	1.2	82.79	1.2	82.79	1.2	82.79	1.2	82.79
Evidence (insecticide)	kg	27.13	0.2	5.43	0.2	5.43	0.2	5.43	0.2	5.43
Lannate (insecticide)	L	6.40	1	6.40	1	6.40	1	6.40	1	6.40
Mineral oil	L	2.91	3	8.72	3	8.72	3	8.72	3	8.72
Gramozone (herbicide)	L	7.17	3	21.51	3	21.51	3	21.51	3	21.51
Total (inputs)				3,320.42		2,288.85		1,770.84		1,458.79
Effective operating cost (EOC) = A+B				5,408.09		3,899.05		3,159.33		2,709.30
Other operating costs										
Depreciations				99.96		99.96		99.96		99.96
Total of other operating costs				99.96		99.96		99.96		99.96
Total operating Cost (TOC) = C+D				5,511.72		4,001.64		3,261.44		2,811.11
Other fixed costs										
Cost of land (ha)				125.97		125.97		125.97		125.97
Total of other fixed costs				125.97		125.97		125.97		125.97
Total production cost (TPC) = E+F				5,634.06		4,124.97		3,385.25		2,935.22

US dollar exchange rate was US$ 5.16 on 12/21/2020. MH, machine hour.

and the highest cost was found for the highest density (3,333 plants ha⁻¹). Costs with inputs stood up with the highest representativeness of the EOC that were 62% and 54% for 1.0 m and 2.5 m spacings, respectively. The highest percentages were those of fertilizers, with 57% (1.0 m spacing) and 53% (2.5 m), followed by seedlings, 37% and 34%, respectively. Plant protection products used for the control of pests, diseases, and weeds represented small percentages (5% to 12%) of the total inputs.

Considering that soil fertilizers were applied in the pits at planting, and that the topdressing was carried out monthly for every plant, there was a higher quantity of fertilizers used due to the high number of plants and pits per hectare, and higher costs with the acquisition of micropropagated seedlings for the 1.0 m spacing between plants (3,333 plants ha⁻¹). Thus, manual operations also increased the EOC as the plant density was increased, since their higher densities demanded longer working hours with the cultural practices, mainly for the harvesting, due to increases of the number of plants, which contributed for increases of the production costs.

Regarding the total production cost (TPC), the highest value was found for the densest plantation − US$ 5,634.06 (1.0 m spacing between plants; 3,333

plants ha⁻¹); therefore, this banana plantation required a higher financial investment (Table 1). Gasparotto et al. (2019) found that decreases of spacings and, consequently, increases of planting densities cause significant increases of production costs of 'Pacovan' banana, in the state of Amazonas, Brazil.

In the economic analysis results (Table 2), the calculation showed gross income was US$ 0.80, considering the banana yield (kg bunches ha⁻¹) determined for each plant density used, and the mean selling price per kilogram practiced in the region by farmers, distributors, and street markets in January 2021. The use of 1.0 m spacing between plants (3,333 plants ha⁻¹) resulted in the highest income (Figure 2 A) for the farmers, due to higher yields enabled by the increased number of plants and, consequently, number of bunches in the area.

The gross margin of EOC, TOC, and TPC was positive and higher than 200% for all spacings, denoting the good performance of the use of dense plantations (Table 2). The spacing of 1.0 m between plants (3,333 plants ha⁻¹) required higher productions to make the activity viable and reach the equilibrium point, since it showed higher costs than the other spacings. However, despite this higher need for production (7,091 kg), it

Table 2. Economic analysis of 'Farta Velhaco' banana (*Musa* sp.) plantations grown in 2020 at increasing plant densities, in the municiapality of Tangará da Serra, in the state of Mato Grosso, Brazil.

Indicator	Unit	Spacing (m) / Plant density (plants ha⁻¹)			
		1.0 m / 3,333 (plants ha⁻¹)	1.5 m / 2,222 (plants ha⁻¹)	2.0 m 1,666 (plants ha⁻¹)	2.5 m / 1,333 (plants ha⁻¹)
Mean selling price	US$	0.80	0.80	0.80	0.80
Yield	(kg ha⁻¹)	23,853	19,657	15,461	11,265
Gross income	US$	18,952.57	15,618.74	12,284.90	8,950.87
Gross margin of EOC	EOC	250.45	300.58	288.84	230.38
Gross margin of TOC	TOC	244.09	290.57	276.92	218.62
Gross margin of TPC	TPC	236.39	278.64	262.89	204.95
Equilibrium point of EOC	kg	6,806	4,907	3,976	3,410
Equilibrium point of TOC	kg	6,932	5,033	4,102	3,536
Equilibrium point of TPC	kg	7,091	5,191	4,260	3,694
Operating profit	US$	13,444.48	11,619.73	9,025.62	6,141.62
Profitability index	%	71.0	74.0	73.0	69.0
Cash flow	US$	13,544.43	11,719.69	9,125.57	6,241.57
Manual operating cost	US$	1,751.94	1,274.42	1,052.71	914.73
Cash flow + manual operations	US$	15,296.37	12,994.11	10,178.28	7,156.30

Effective operating cost (EOC), total operating cost (TOC), total production cost (TPC). US dollar exchange rate was US$ 5.16 on 12/21/2020.

represented only 29.73% of the production needed to cover the TPC.

The values found for the operating profit decreased as spacing between plants increased. Therefore, the highest density (1.0 m) showed the highest operating profit, US$ 13,444.48, which corresponds to the highest technical and economic efficiencies (Figure 2 B). Although the results are positive for the densest plantation, in the first production year, this viability was reached using the recommended management for banana trees and applying the prices obtained in the marketing (Gasparotto et al., 2019).

Regarding the profitability indicators, all evaluated spacings showed positive indexes (Table 2). Although the cost, yield, and profitability, in absolute terms, were higher, the profitability index was lower for the 1.0 m spacing than for the others. This index was affected by the income, since the higher is the denominator (income) in relation to the numerator (operating profit), the lower is the indicator.

However, the cash flow for 1.0 m spacing was 15.54% higher than that for 1.5 m the spacing and, when adding the value of labor, which is usually not paid by family farmers who use their own labor, this value is 17.68% (1.5 m), 50.23% (2.0 m), and 113.70% (2.5 m) higher than that of the other spacings (Table 2, Figure 2 C).

This profitability may vary due to price oscillations in the market, which consequently affect the cash flow of the banana growers. Considering this assumption, some situations are described for 10% up to 50% decreases in the marketing price (Table 3). This analysis allows producers to delineate different scenarios with possible variations on the profitability of banana tree (Rodrigues et al., 2018).

Even in the worse situation, with a 50% decrease in the marketing price (US$ 0.40 kg), farmers remain with a positive balance in the cash flow, mainly when using 1.0 m spacing for plants, which surpass the financial gain of the 2.5 m spacing in 117% (Table 3).
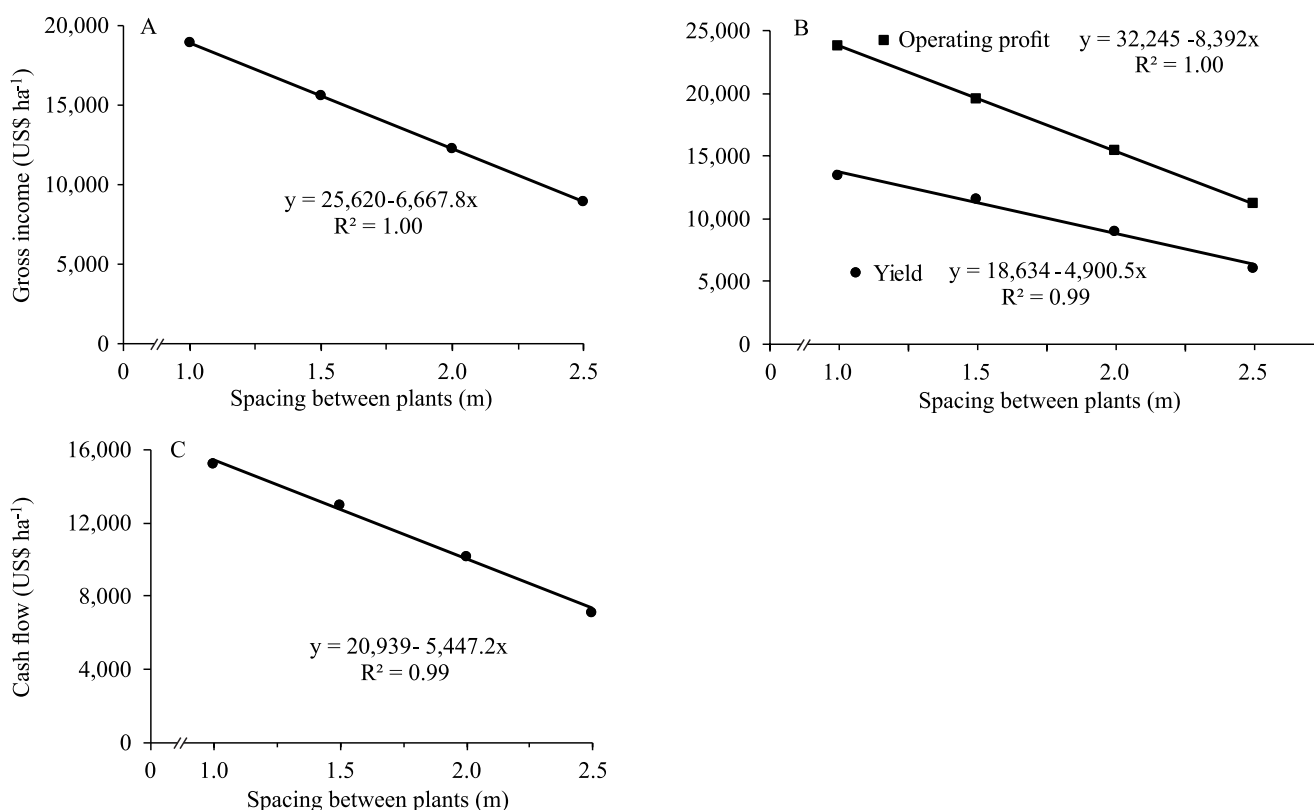
Figure 2. Gross income (A), operating profit and yield comparison (B), and cash flow (C) of 'Farta Velhaco' banana (*Musa* sp.) grown in 2020 at increasing planting densities in the municiapality of Tangará da Serra, in the state of Mato Grosso, Brazil.

Table 3. Simulation of cash flow with the decrease of marketing values for 'Farta Velhaco' banana (*Musa* sp.) grown in 2020 at increasing planting densities, in the municiapality of Tangará da Serra, in the state of Mato Grosso, Brazil.

Scenarios	Price (US$/kg)	Spacing (m) Planting density (plants ha⁻¹)			
		1.0 m 3,333 (plants ha⁻¹)	1.5 m 2,222 (plants ha⁻¹)	2.0 m 1,666 (plants ha⁻¹)	2.5 m 1,333 (plants ha⁻¹)
Decrease of 10%	0.72	13,401.11	11,432.23	8,949.79	6,261.22
Decrease of 20%	0.64	11,505.86	9,870.36	7,721.30	5,366.13
Decrease of 30%	0.56	9,610.60	8,308.49	6,492.81	4,471.04
Decrease of 40%	0.48	7,715.34	6,746.61	5,264.32	3,575.95
Decrease of 50%	0.40	5,820.09	5,184.74	4,035.83	2,680.87

US dollar exchange rate was US$ 5.16 on 12/21/2020.

Conclusions

1. Planting density increases of up to 3,333 plants ha⁻¹ (4.0x2.0x1.0 m) augment the yield of 'Farta Velhaco' banana (*Musa* sp.) plantations, without affecting the commercial quality of fruit.

2. The economic profitability is higher when using planting density at 3,333 plants ha¹.

3. Planting density at 3,333 plants ha⁻¹ is the most suitable one, considering the main morphological characteristics, yield, and fruit quality, in a production cycle.

Acknowledgments

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