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Scientific Article

Performance and leaf nutritional content of banana cultivars intercropped with lemongrass

Desempenho e teor nutricional de cultivares de bananeira consorciados com capim-limão

Paulo R. R. de Jesus[1], Sarita Leonel[1]*, Magali Leonel[2], Hebert T. Cândido[1], Nicholas Z. Molha[1], Vinicius M. Domiciano[1], Lucas F. dos Ouros[2], Marco A. Tecchio[1]

[1]Department of Crop Science, Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu, SP, Brazil. [2]Center for Tropical Roots and Starches, Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu, SP, Brazil.

ABSTRACT - Diversifying cultivars and intercropping with lemongrass can innovative strategies for banana growers to enhance the variety, profitability and sustainability of their orchards and to adapt to climate change. This study took place in the state of São Paulo, a subtropical region of southeastern Brazil and assessed the duration of the cropping cycles, growth and yield performance, and leaf nutritional content of banana cultivars BRS FHIA Maravilha, SCS 451 Prata Catarina, BRS Pacoua and Prata Anã when intercropped with lemongrass. The field experiment spanned two consecutive growing seasons. The growth, yield and nutrient content in the leaves of banana cultivars exhibited similar performance in both monoculture and intercropping with lemongrass. A shorter cycle was observed only in the first harvest with the lemongrass intercrop. The Prata Anã cultivar stood out for its earlier cycle, lower plant height and higher average yield per year. These findings are valuable for planning cultivar diversification in new orchards, exploring the potential for intercropping with lemongrass, and identifying the genotypes and cropping systems that are better suited to adverse climatic conditions.

Keywords: Climate changes. Cropping systems. *Cymbopogon citratus*. Genotype diversification. *Musa* spp.

RESUMO - A diversificação de cultivares e o cultivo consorciado com capim-limão podem ser uma abordagem inovadora para os produtores de banana aumentarem a variedade, a rentabilidade e a sustentabilidade dos pomares e se adaptarem às mudanças climáticas. O estudo foi conduzido no estado de São Paulo, uma região subtropical do sudeste do Brasil, e avaliou a duração dos ciclos de cultivo, o desempenho do crescimento e da produção e os teores nutricionais foliares das cultivares de bananeira BRS FHIA Maravilha, SCS 451 Prata Catarina, BRS Pacoua e Prata Anã em consórcio com capim-limão. O experimento de campo foi conduzido durante dois ciclos de cultivo consecutivos. O crescimento, a produtividade e o teor de nutrientes nas folhas das cultivares de bananeira apresentaram o mesmo desempenho em monocultura e em consórcio com capim-limão. O ciclo mais curto foi observado apenas na primeira safra com a cultura intercalar de capim-limão. A cultivar Prata Anã se destacou pelo ciclo mais precoce, menor altura de plantas e maior produtividade média por ano. Esses resultados são úteis no planejamento da diversificação de cultivares para novos pomares, na identificação da possibilidade de consorciação com capim-limão e na determinação de genótipos e sistemas de cultivo mais adaptados às condições climáticas adversas.

Palavras-chave: Mudanças climáticas. Sistemas de cultivo. *Cymbopogon citratus*. Diversificação genotípica. *Musa* spp.

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***Corresponding author:**
<sarita.leonel@unesp.br>

INTRODUCTION

Brazilian banana farming has undergone technological changes in recent years, with the use of appropriate cropping management, harvesting and postharvesting (PEREIRA et al., 2019). Intercropping is the simultaneous cultivation of two or more species with different cycles and architectures in the same area, with development that follows all or part of the main cropping cycle. The agronomic compatibility of these crops results in positive biological interactions, leading to optimized yields, as well as crop density and fertilization (ALMEIDA et al., 2019). When managed well, intercropping offers advantages over monocropping, including improvements in the physical, chemical and biological properties of the soil, increases in the circulation and efficiency of nutrient use and the recovery of degraded areas and control weeds, and reduced production costs, diversifying and stabilizing incomes on farms (KHANAL et al., 2021; MATTALIA et al., 2022).

Medicinal plants can be an option for intercropping, improving sustainable crop management and promoting additional profits through the sale of products or by-products. It also contributes to the phytosociological balance and to the entomofauna of crops, reducing the costs and possible environmental damage caused by the excessive use of pesticides (OLIVEIRA et al., 2018; BAKSHI et al., 2019).

Cymbopogon citratus (D.C.), known as lemongrass, holy grass and citronella grass, is native to southwest Asia and belongs to the Poaceae family. It is a plant grown worldwide for its medicinal properties and applications in the pharmaceutical and food industries due to its citral-rich essential oil, as well as being consumed as a tea from its leaves (CARVALHO NETA et al., 2021). The plant has the potential to stimulate or inhibit the development of other plants, making it an option for intercropping (OLIVEIRA et al., 2018).

Banana and other fruit farmers engage in crop diversification for a variety of reasons, including maximizing banana yields and mitigating adverse weather conditions, as well as establishing a permanent intercropping system in which both crops are produced over several years and establishing a temporary intercrop to improve the economic viability of implementing a banana plantation (PERDONÁ; SORATTO, 2015). The inputs used for fertilization can be directed to the banana crop without the need to select specific fertilizers for lemongrass (KHANAL et al., 2021). In addition, lemongrass can facilitate banana crop management by reducing weed control in crop rows (KISHORE; RUPA; SAMANT, 2021).

Bananas require a large amount of nutrients (RODRIGUES FILHO; NEVES; DONATO, 2021) and are highly efficient in phytomass production (LEONEL et al., 2020). Evaluating the nutrient content in the leaves of cultivars intercropped with lemongrass is very interesting, as it may be an indicative criteria for recommending this system.

The diversification of banana cultivars is necessary to increase the variety and profitability of orchards, adapt to environmental changes, and define cultural practices and the destination of production.

The cultivar BRS FHIA Maravilha (AAAB) is the result of crossing the cultivar Prata Anã (AAB) with the diploid SH3142 (AA) and is resistant to black leaf streak, black Sigatoka (*Mycosphaerella fijiensis,* Morelet) and Fusarium wilt (*Fusarium oxisporum f. sp. cubense*) (NAPOLEÃO; JESUS; LEONEL, 2021). The cultivar SCS 451 Prata Catarina (AAB) is a natural mutant of the Prata subgroup and stands out for its greater tolerance to *Fusarium* wilt compared to the Prata cultivar (PEREIRA et al., 2019). The BRS Pacoua (AAAB) cultivar, a hybrid between Pacovan (AAB) and Calcutta (AAA), is resistant to Sigatoka leaf spot, yellow Sigatoka (*Mycosphaerella musicola,* Leach) and *Fusarium* wilt and has medium resistance to black leaf streak and black Sigatoka (NAPOLEÃO; JESUS; LEONEL, 2021). The Prata Anã (AAB) cultivar is the most widely grown banana of the Prata group in the country, with a high yield and acceptance by growers and consumers. It is cold tolerant but susceptible to yellow and black Sigatoka and Moko (*Ralstonia solanacearum*), moderately susceptible to *Fusarium* wilt and moderately resistant to nematodes and the rhizome borer (*Cosmopolites sordidus*) (GUIMARÃES et al., 2014).

The aim of this study was to assess the cropping cycle duration, growth, yield and leaf nutritional content of four banana cultivars in monocropping and intercropping systems with lemongrass, over two harvest seasons, in a mesothermal climate in the subtropical region of the state of São Paulo, Brazil.

MATERIAL AND METHODS

Site description and climate

The experiment was conducted at São Manuel Experimental Farm, of the Botucatu Agriculture School of São Paulo State University, São Paulo state, Brazil (22°44’28” S, 48°34’37” W) located at an altitude of 740 m a.s.l. The region has a Cwa climate or warm temperate (mesothermal) and humid, according to the Köppen classification system (CUNHA; MARTINS, 2009). The soil is classified as a sandy -textured Latossolo Vermelho distroférrico according to the Brazilian system of soil classification (SANTOS et al., 2013). Daily precipitation (mm) and the maximum, minimum and average temperatures (°C) throughout the experimental period were obtained from a weather station located 300 m from the experimental area (Figure 1A).

The water balance was determined by adopting an average root system depth of 40 cm and an available water capacity of 100 mm (Figure 1B). To determine the evapotranspiration of the banana crop, the crop coefficient (Kc) recommended by Doorenbos and Pruitt (1977) for tropical climate conditions was used. The values adopted were 0.4, 0.45, 0.5, 0.6, 0.7, 0.85, 1, 1.10, 0.9 and 0.8, corresponding to planting to the 12th month for the first year of cropping (mother plant). In the second year (daughter plant), the Kc used was 1.1, as established by Oliveira et al. (2005).

Prior to experimentation, soil samples (0 to 20 cm depth) were collected. The chemical characteristics were determined as follows: pH($CaCl_2$) = 5.4; organic matter = 11 g dm^{-3}; P_{resina} = 9 mg dm^{-3}; H + Al = 15 mmol$_c$ dm^{-3}; K = 1.1 mmol$_c$ dm^{-3}; Ca = 16 mmol$_c$ dm^{-3}; Mg = 6 mmol$_c$ dm^{-3}; sum of bases = 23 mmol$_c$ dm^{-3}; cation exchange capacity = 38 mmol$_c$ dm^{-3}; base saturation (%) = 60; S = 2 mg dm^{-3}; B = 0.3 mg dm^{-3}; Cu = 1.4 mg dm^{-3}; Fe = 32 mg dm^{-3}; Mn = 8.5 mg dm^{-3}; and Zn = 2.2 mg dm^{-3}. Seedlings were produced by micropropagation, acclimatized in the nursery, and planted in the field when they had 5–6 leaves and were approximately 30 cm tall in November 2020. Plant field spacing was 3 m between rows and 2.5 m between plants (i.e., 1.333 plants ha^{-1}) in a non-irrigated orchard. Weed control, tiller thinning, pest and disease control, male inflorescence elimination, pistil removal, and harvesting were performed according to recommended practices for the crop (NOMURA et al., 2020).

Based on soil analyses and banana crop recommendations, the experimental area was previously prepared by plowing, sorting and liming. Liming with dolomitic limestone was performed two months before planting over a total area, with the goal of elevating the initial soil base saturation to 70% and increasing the magnesium content above 9.0 mmol dm^{-3}. The liming rate applied was 400 kg ha^{-1}. Complementary nutritional management was conducted based on soil analyses and guidelines for banana crops (NOMURA et al., 2020).

A replicated trial was conducted during two consecutive cropping cycles. The first cycle occurred from November 2020 to May 2022 and the second from August 2022 to May 2023. The first cropping cycle corresponded to the period between planting and harvesting, whereas the second cycle occurred between inflorescence emission and harvesting.

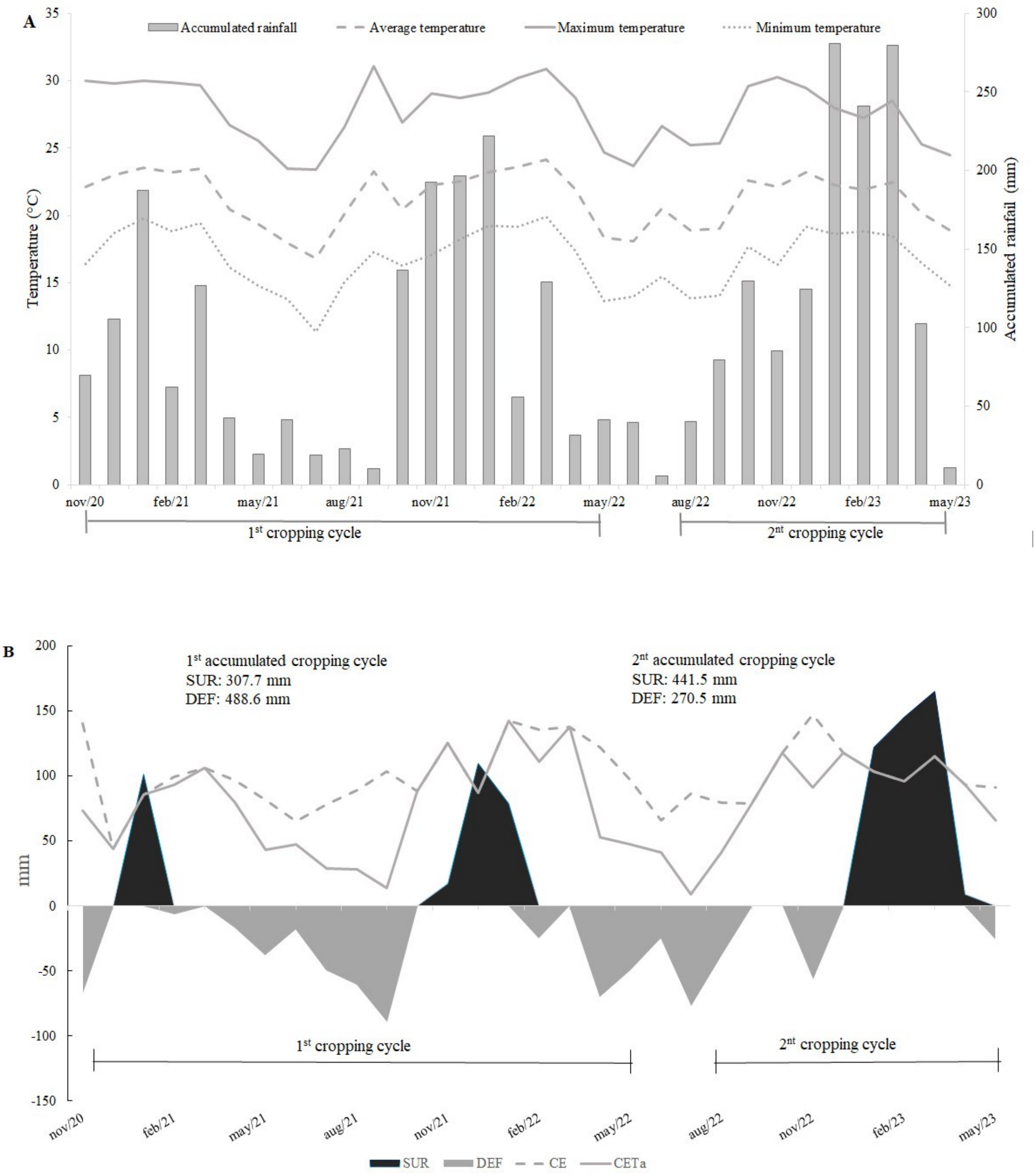

Figure 1. A. Maximum, minimum and average temperatures (ºC) and accumulated rainfall (mm) in the months of November/2020 to May/2023, in the municipality of São Manuel - SP. B. Climatic water balance. SUR = Water surplus. DEF = Water deficit. CE = Crop evapotranspiration. CETa = Actual crop evapotranspiration.

Intercropping

Lemongrass seedlings were obtained from the medicinal plant garden and made in the nursery of the São Manuel Experimental Farm of UNESP. At the time of planting, the leaves were cut close to the insertion of the sheath to optimize setting. The seedlings were planted in 20 × 20 × 20 cm holes, previously prepared and fertilized with 5 L of tanned cattle manure per hole in February 2021. The lemongrass was planted at a spacing of 60 cm between plants in the banana row, totaling the cultivation density of two lemongrass plants between banana plants in the row. Lemongrass was cut at 10 cm above soil level three times a year at four-month intervals during the two cropping cycles evaluated.

Treatments

The treatments corresponded to the four banana cultivars: Prata Anã, SCS451 Prata Catarina, BRS FHIA Maravilha and BRS Pacoua, planted with and without lemongrass (*C. citratus*) intecropping. Thus, the trial had 8 treatments (4 cultivars with lemongrass and 4 cultivars without lemongrass).

Phenological cycles

The phenological stages of the plants were determined through weekly inspections of the banana trees. In the first cycle, the periods between planting and flowering (number of days from planting until inflorescence emergence) and between planting and harvesting (total number of days until the first production cycle) were assessed. The number of days between flowering and harvest was assessed in both the first and second cycles.

Growth

Evaluations consisted of measurements of plant height, pseudostem circumference and the number of leaves. These biometric variables were measured at 120, 240 and 360 days after planting and at the time of inflorescence emission. Plant height was the distance between the soil level and inflorescence insertion, and pseudostem circumference (PStC) was measured at 30 cm from the soil surface by measuring the circumference. The leaf number was obtained by counting the number of leaves per plant in which more than half of the green leaf area was captured.

Yield

For each crop cycle, four bunches per plot were harvested when the fruits of the second hand had a minimum diameter of 34 mm, which was the harvest stage established for Prata group cultivars. Corresponding to the first maturity stage (green peel) according to the maturity scale. The yield was estimated from the fresh mass of marketable bunches per plant divided by the number of days in the total cycle (planting to harvest) and multiplied by 365 days (kg^{-1} $plant^{-1}$ $year^{-1}$). The cumulative yield corresponded to the sum of the two cropping cycles evaluated.

Leaf nutrient content

Leaf tissue samples were taken from the four banana cultivars grown in monoculture and intercropped with lemongrass. Leaf collection was performed when the inflorescence was within all uncovered female clusters (without bracts), and at least three clusters of male flowers occurred. To determine the nutrient content in banana leaves, a 10 cm wide strip was collected from the central region of the third leaf from the apex, discarding the petiole and edges (NOMURA et al., 2020). The leaf samples were washed, dried and ground, and the nutrient content was determined.

Experimental design and statistical analysis

The experimental design was a randomized block with four replicates in a split-plot arrangement (4 × 2). The plots were represented by four banana cultivars and subplots by treatments with and without intercropping with lemongrass. Replicates consisted of four useful plants per experimental plot and guard plants outside the trial. Each cropping cycle was analyzed separately.

All variables evaluated were subjected to the Shapiro–Wilk normality test. Analysis of variance (ANOVA) was carried out at 1 and 5% probability, and the means were compared using the Tukey test. The computer program R v.4.3.1 (R CORE TEAM, 2023) was used for all analysis.

RESULTS AND DISCUSSION

Orchard microclimate

The climate was atypical in the subtropical region, especially in the 2021 and 2022 crop seasons. Differences in rainfall patterns were observed during the two years of assessment (Figure 1A). The years 2021 and 2022 were characterized by an uneven distribution of rainfall, with a long water deficit period. In 2021, the accumulated rainfall was 1056 mm, and in 2022, it was 982 mm. The highest banana yield is associated with a total annual rainfall of 1900 mm, which is well distributed throughout the year (BORGES; SOUZA, 2021). The accumulated water deficit (486.2 mm) in the period between planting and the first harvest (Figure 1B) mainly affected the growth and, consequently, the phenological cycle of the banana cultivars. The second cycle began in August 2022 with typical rainfall, and from August 2022 to May 2023, the water balance showed an accumulated surplus, allowing the resumption of growth and banana production. Temperatures varied during the study period, as expected for the region, but in 2021, there were more days and hours of minimum temperatures during the winter, which delayed the start of bunch emission for the banana cultivars evaluated.

Intercropping is proposed as a potential cropping system that is environmentally sound in the actual climate change scenario. Intercropping can enhance radiation and water use efficiency. Increased ground cover due to intercropping may also reduce runoff and soil erosion (PERDONÁ; SORATTO, 2015). Other reported benefits of intercropping are an increase in organic matter, earthworm and soil microbial activity, and improvement in soil structure (KISHORE; RUPA; SAMANT, 2021). Growing crops with different root depths further enhances the efficient use of belowground resources (MATTALIA et al., 2022). On-farm crop diversification through intercropping can enhance the outputs and stability of banana production in the face of seasonal variability and changing climates. This is because different species react differently under different environmental conditions; thus, if one species is negatively affected by adverse seasonal weather, other component species within the system may still produce a viable yield (KHANAL et al., 2021).

This was one of the main results of this study, in which the banana cultivars performed differently depending on the climatic conditions, and lemongrass showed better adaptation to the climatic variations that occurred in the trial, such as water deficit and low temperatures. The main hypothesis for this result is that lemongrass needs to be harvested three times a year, at four-month intervals, during the two crop seasons evaluated, allowing for greater competitive performance. This result suggests the need for ongoing evaluations, especially regarding the productivity, profitability and sustainability of intercropping lemongrass with banana cultivars.

Phenological cycles

There was no significant interaction between the cropping system and the banana cultivars (p>0.05) in the duration of the phenological cycles. Furthermore, when considering only the cropping system in the 2nd cycle, there were no differences for the number of days from planting to flowering (NDPF), number of days from planting to harvest (NDPH) and number of days from flowering to harvest (NDFH) (p>0.05) (Table 1).

The NDPF, NDPH and NDFH in the 1st cycle, showed differences between the cropping systems. The banana plant intercropped with lemongrass presented the lowest averages (414, 550 and 136 days, respectively), differing from the banana plant in monoculture (444, 595 and 150 days, respectively) (Table 2). Lemongrass, as an intercrop, can bring benefits to the soil, such as retaining moisture and reducing crop evapotranspiration, providing greater water availability for intercrop growth (CARVALHO NETA et al., 2021). Furthermore, the release of allelochemicals by lemongrass can help reduce weed growth and decrease the population of soil-borne pests (PAIVA; DOMINGUES, 2021).

The Prata Anã cultivar presented the earliest cycle, obtaining the lowest averages of NDPF and NDPH in both cycles, with NDPF values of 369 days for the 1st cycle and 636 days for the 2nd cycle and NPFH of 520 days for the 1st cycle and 786 days for the 2nd cycle. Taulya et al. (2014) stated that thermal conditions and water availability had a substantial influence on floral induction in banana trees, determining the phenotypic plasticity in flowering time. Banana yields can be increased or decreased depending on the length of the growth cycle. This is an important variable in genetic improvement that can reflect the precocity of the genotype. This means that successive cycles are achieved in less time, which increases yield. In addition, reducing the time the plant spends in the field reduces the fruit's exposure to damaging agents, which reduces the need for pesticides (NOMURA et al., 2013).

Table 1. Phenological cycles of banana cultivars, in the first and second cycle, grown in monoculture and intercropped with lemongrass.

	NDPF (days)		NDPH (days)		NDFH (days)	
	1°cycle	2°cycle	1°cycle	2°cycle	1°cycle	2°cycle
System						
Monoculture	444 a	676 a	595 a	821 a	150 a	145 a
Intercropping	414 b	688 a	550 b	828 a	136 b	140 a
Banana cultivars						
Prata Catarina	482 a	716 a	598 a	844 ab	116 b	127 a
BRS Pacoua	429 b	674 ab	588 a	820 ab	159 a	145 a
Prata Anã	369 c	636 b	520 b	786 b	150 a	150 a
BRS FHIA Maravilha	438 ab	701 ab	585 a	849 a	147 a	147 a
Sources of Variation			*p* - value			
System (S)	0.008*	0.100ns	0.003**	0.068ns	<0.001**	0.498ns
Cultivar (C)	<0.001**	0.046*	<0.001**	0.039*	<0.001**	0.148ns
S X C	0.626ns	0.225ns	0.552ns	0.106ns	0.525ns	0.147ns
CV S (%)	7.64	2.22	6.71	5.40	10.9	13.3
CV C (%)	10.1	8.17	8.46	5.35	12.4	14.2

ns = not significant; * = significant at 5%; ** = significant at 1% by the F test. Means followed by different letters in the column within each factor differ by the Tukey test at 5% probability. NDPF - Number of Days from Planting to Flowering. NDPH - Number of Days from Planting to Harvest. NDFH - Number of Days from Flowering to Harvest. CV = coeficiente of variation.

Growth

There were no significant differences between the monoculture and intercropping systems in the growth of the banana plants at 120, 240 and 360 days after planting. Similarly, there was no significant interaction between the cropping systems and the banana cultivars (p>0.05) (Table 2).

Similar results were obtained by Almeida et al. (2019), who found that intercropping with açaizeiro did not interfere with banana growth during the first crop cycle. There was a difference between banana cultivars in plant height assessed at 240 and 360 Days After Intercropping (DAI) (Table 3). In pseudostem circumference, this difference was observed only at 360 days. There was also a difference in the number of leaves between cultivars in all evaluation periods. These results highlight the importance of considering not only the cropping system but also the genotype of the cultivars when adopting new cultural practices.

The BRS Pacoua cultivar had the highest average plant height in both cycles, measuring 155.1 cm at 240 days and 222.3 cm at 360 days. However, this cultivar had the lowest average pseudostem circumference at 360 days, at 48.4 cm. The Prata Catarina cultivar had the lowest plant height, measuring 105.3 cm at 240 days and 173.4 cm at 360 days. This cultivar had the highest average pseudostem circumference, measuring 58.0 cm at 360 days.

Table 2. F-values, coefficient of variation (CV), and means for plant height (PH), pseudostem circumference (PsdC) and number of leaves (NL) at 120, 240 and 360 DAC of banana cultivars in monoculture and intercropping.

	----------------- PH (cm) -----------------			------------- PsdC (cm) -------------		
	DAI					
	120	240	360	120	240	360
System (S)	0.53^{ns}	0.10^{ns}	0.64^{ns}	0.32^{ns}	0.12^{ns}	0.41^{ns}
Cultivars (C)	0.29^{ns}	<0.01**	<0.01**	0.44^{ns}	0.60^{ns}	0.04*
S x C	0.47^{ns}	0.95^{ns}	0.12^{ns}	0.84^{ns}	0.57^{ns}	0.08^{ns}
Means	83.3	129.7	193.7	30.3	41.7	53.0
CV 1	34.5	11.5	15.3	31.2	14.1	17.2
CV 2	26.6	18.1	8.27	26.9	20.9	11.6

	NL		
	DAI		
	120	240	360
System (S)	0.54^{ns}	0.79^{ns}	0.58^{ns}
Cultivars (C)	<0.01**	<0.01**	<0.01**
S x C	0.14^{ns}	0.42^{ns}	0.18^{ns}
Means	11.0	12.0	10.8
CV 1	22.5	13.1	10.5
CV 2	18.0	9.8	9.19

^{ns} = not significant; * = significant at 5%; ** = significant at 1% by the F test. DAI = Days after intercropping.

Table 3. Plant height (PH) and pseudostem circumference (PsdC) of banana plants at 240 and 360 DAI.

	PH (cm)		PsdC (cm)
	DAI		
	240	360	360
Prata Catarina	105.3b	173.4b	58.0a
BRS Pacoua	155.1a	222.3a	48.4b
Prata Anã	137.2ab	173.1b	51.8ab
BRS FHIA Maravilha	121.2b	206.0a	53.9ab

Means followed by different lowercase letters in the column differ by Tukey's test (p<0.05).

The height of the plants must be evaluated together with the pseudostem circumference, as it reflects the load of the bunches. Plants with a high height and smaller diameter tend to be more susceptible to wind and pseudostem tipping, which can be minimized by a lower height (LEONEL et al., 2020). For large banana cultivars, such as BRS Pacoua, the larger the diameter of the pseudostems, the less susceptible they are to toppling, since diameter is directly related to vigor and reflects the bunch's ability to support the weight of the bananas. In addition, the pseudostem diameter is positively correlated with plant production (GUIMARÃES et al., 2014). Nevertheless, this cultivar had the lowest pseudostem circumference and yield. These results suggest that the cultivar was not well adapted to cropping in the subtropical region of the state of São Paulo, as it was developed as a cropping option for growers in the state of Pará, Brazil (NAPOLEÃO; JESUS; LEONEL, 2021).

The cultivar BRS Pacoua had the lowest average number of leaves in all evaluation seasons. The differences in growth and number of leaves between the cultivars can be explained by their genetic characteristics, which confer different degrees of adaptation, resistance and productivity (SAFHI et al., 2023). Banana cultivars show genetic variability for agronomic, morphological, physiological and biochemical traits (SARDÓS et al., 2022), which can influence their performance in different cropping systems.

In addition to the genotypic differences between the cultivars, climate was found to have a major influence on the adaptation of the cultivars to the subtropical region where the experiments were performed.

Cultivars Prata Anã and BRS FHIA Maravilha stood out for having the most leaves. Both cultivars had an average of 12.8 leaves per plant in all evaluation seasons (Table 4).

Table 4. Number of banana leaves at 120, 240 and 360 days after intercropping (DAI).

	N° Leaves		
	DAI		
	120	240	360
Prata Catarina	10.3ab	11.6b	10.7b
BRS Pacoua	9.4b	9.5c	7.4c
Prata Anã	12.3a	14.4a	12.5a
BRS FHIA Maravilha	12.4a	12.8ab	12.8a

Means followed by different lowercase letters in the column differ from each other using the Tukey test ($p<0.05$).

Maia et al. (2020) evaluated the initial growth of banana trees intercropped with green manure and reported 11.5 leaves, on average, 180 days after planting. Almeida et al. (2019) observed an average of 12 leaves and stability in the emission of new leaves 240 days after planting.

Regarding plant height, pseudostem diameter and the number of leaves evaluated at flowering in the 1st and 2nd cycles of banana plants intercropped with lemongrass, there was no interaction between the cropping systems and cultivars ($p>0.05$). Additionally, no differences were observed for the cropping systems ($p>0.05$) (Table 5). This suggests that lemongrass did not interfere with banana growth, indicating favorable compatibility between these plants when intercropped.

The greater height shown by the BRS Pacoua cultivar compared to the others is because it is a hybrid between Pacovan and Calcutta. According to Nomura et al. (2013), banana plants whose parent is Pacovan tend to be taller.

This is consistent with previous studies reporting significant differences in the height of banana cultivars (NOGUEIRA et al., 2018; NOMURA et al., 2013). Plant height at flowering can directly influence banana production. A greater height is undesirable, as taller plants can be more susceptible to toppling due to strong winds, and it is more difficult to harvest bunches. However, this effect can be minimized by increasing pseudostem circumference (LEONEL et al., 2020).

Table 5. Growth variables of banana cultivars in the first and second cycles, grown in monoculture and intercropped with lemongrass.

	PH (m)		PsdC (cm)		NL
	1° cycle	2° cycle	1° cycle	2° cycle	2° cycle
System					
Monoculture	2.03a	2.36a	49.0a	56.7a	10.7a
Intercropping	2.08a	2.40a	52.0a	57.7a	10.2a
Cultivars					
Prata Catarina	2.07b	2.26b	51.6a	61.3a	10.3a
BRS Pacoua	2.32a	2.83a	48.1a	56.1a	9.6a
Prata Anã	1.81c	2.26b	51.5a	54.5a	11.2a
BRS FHIA Maravilha	2.00 b	2.17 b	52.4 a	57.0 a	10.8 a
Source of variation	*p* - value				
System (S)	0.175^{ns}	0.170^{ns}	0.357^{ns}	0.310^{ns}	0.292^{ns}
Cultivar (C)	$<0.001^{**}$	$<0.001^{**}$	0.052^{ns}	0.092^{ns}	0.265^{ns}
S X C	0.741^{ns}	0.900^{ns}	0.078^{ns}	0.139^{ns}	0.460^{ns}
CV S (%)	3.78	2.32	10.7	4.13	9.66
CV C (%)	6.29	8.28	5.93	9.15	15.44

ns = not significant; * = significant at 5%; ** = significant at 1% by the F test. Means followed by different letters in the column within each factor differ by Tukey's test at 5% probability. PH = Plant height at flowering. PsdC = Pseudostem circumference at flowering and NL = Number of leaves at flowering.

There were no differences between the cultivars in the evaluation cycles for pseudostem circumference, with an average of 50.1 cm in the 1st cycle and 57.2 cm in the 2nd cycle. There is a positive correlation between pseudostem circumference and bunch weight, indicating that plants with a larger diameter tend to produce heavier bunches. In addition, pseudostem circumference can also influence the plant's resistance to climate change, contributing to greater plant stability and longevity (GUIMARÃES et al., 2014).

There was no difference in the number of leaves at flowering between the cultivars in the second cycle. In the first cycle, there was a significant interaction between cropping systems and banana cultivars (Table 6).

The Prata Anã cultivar had the highest number of leaves in both cropping systems (14.8 leaves) in the first cycle. The BRS Pacoua cultivar had the lowest averages in both growing systems (9.9 leaves). Leaves are responsible for photosynthesis and consequently affect yield. Therefore, the number of active leaves during flowering is fundamental to fruit weight. The number of functional leaves needed to develop the bunches at flowering is 10–12, on average, to provide fruit growth (NOMURA et al., 2013).

Table 6. Number of leaves at flowering (NLF) of banana cultivars in a monoculture system and in intercropping with lemongrass in the first cropping cycle.

Cultivars	NLF	
	INT	MON
Prata Anã	14.1Aa	15.5Aa
BRS Maravilha	13.8Aa	13.0Ab
Prata Catarina	11.8Ab	13.3Ab
BRS Pacoua	10.2Ab	9.75Ac
Souce of variation	*p* – value	
Systems (S)	0.580^{ns}	
Cultivar (C)	$<0.001^{**}$	
S X C	0.038^{*}	
CVS (%)	13.1	
CVC (%)	7.34	

^{ns} = not significant; * = significant at 5%; ** = significant at 1% by the F test. Means followed by different letters, lower case in the column and upper case in the row, differ by the Tukey test (p≤0.05). NLF - Number of leaves at flowering. INT= Lemongrass intercropped. MON = Monoculture.

Yield

The cumulative yield of banana cultivars in monoculture and intercropped with lemongrass showed no differences between the cropping systems (p>0.05). There was also no interaction between the cropping systems and banana cultivars (p>0.05) (Table 7).

However, there were significant variations between the cultivars. The Prata Anã cultivar had the highest average yield, with 29.7 kg plant^{-1} year. The BRS Pacoua cultivar had the lowest average yield, at 24.2 kg plant^{-1} year^{-1}. The low yield may have been due to the climatic conditions in which the trial was conducted, with a reduction in the number of leaves from flowering to harvest for the banana cultivars evaluated. This may have been due to the low rainfall and low temperatures that occurred during the period between flowering and harvest, especially in the weeks following inflorescence emission (Figures 1A and 1B). The Prata Anã cultivar is more cold tolerant (NAPOLEÃO; JESUS; LEONEL, 2021) and, in previous studies, has shown good performance in the region of this study in subtropical conditions in the state of São Paulo, Brazil (BOLFARINI et al., 2014).

Bananas are considered a key food crop worldwide due to their characteristics, such as rapid growth with a high biomass yield and fruit production, as well as good nutritional value and sensory acceptance. In addition, bananas are a very important and useful food security crop and a source of nutritional security for small farmers. Over the years, the little attention paid to research into appropriate intercropping recommendations has limited production efficiency. The appropriate variety and management of intercrops is certainly a real strategy for their commercial adoption, with a view to improving productivity in various agro-ecologies (BAKSHI et al., 2019). The sustainability of the use of intercropping in banana crops can have benefits by reducing production costs due to the possibility of commercializing lemongrass.

Leaf nutrient content

There were no significant differences between cropping systems and banana cultivars in the average macronutrient contents in banana leaves, both in monoculture and in intercropping with lemongrass, during the second crop cycle (p>0.05) (Table 8). Furthermore, the interaction between these factors was also not significant (p>0.05). These results show that lemongrass did not interfere with nutrient absorption by banana plants, which indicates that the nutritional management of the banana cultivars evaluated did not need to be modified as a result of intercropping. However, in another cropping system, Marques et al. (2022) reported differences between the nutritional content of banana cultivars grown under organic management, in which the leaf contents of potassium (K), sulfur (S), copper (Cu) and zinc (Zn) in the Prata-Anã cultivar differed from those of BRS Platina.

The order of concentration of the macronutrients in the dry mass of the leaves was as follows: nitrogen (N) > K > calcium (Ca) > magnesium (Mg) > phosphorus (P) > S.

Table 7. Average yield of banana plants grown in a monoculture and intercropped with lemongrass.

Cultivars	1^{st} cycle	2^{nd} cycle	Cumulative yield (kg $plant^{-1}year^{-1}$)
Prata Catarina	10.7a	17.4b	28.1b
BRS Pacoua	8.8b	15.4c	24.2c
Prata Anã	10.0a	19.7a	29.7a
BRS FHIA Maravilha	10.8a	17.6b	28.4b
Souce of variation		*p* - value	
Systems (S)	0.320^{ns}	0.365^{ns}	0.508^{ns}
Cultivar (C)	0.016^{*}	0.001^{**}	0.002^{**}
S X C	0.177^{ns}	0.733^{ns}	0.849^{ns}
CVS (%)	5.36	5.89	6.58
CVC (%)	8.99	9.57	9.61

^{ns} = not significant; * = significant at 5%; ** = significant at 1% by the F test. Means followed by different letters, lower case in the column and upper case in the row, differ by the Tukey test (p≤0.05).

Table 8. Average macronutrient and micronutrient content in banana leaves grown in monoculture and intercropped with lemongrass.

	N	P	K	Ca	Mg	S
			g kg^{-1}			
Source of variation			*p* – value			
Systems (S)	0.490^{ns}	0.299^{ns}	0.644^{ns}	0.072^{ns}	0.737^{ns}	0.156^{ns}
Cultivar (C)	0.099^{ns}	0.816^{ns}	0.097^{ns}	0.200^{ns}	0.160^{ns}	0.118^{ns}
S X C	0.295^{ns}	0.378^{ns}	0.962^{ns}	0.941^{ns}	0.749^{ns}	0.697^{ns}
CV S (%)	11.8	17.2	13.5	5.86	12.2	8.74
CV C (%)	15.9	15.0	10.5	15.7	24.7	15.0
Means	22.7	1.27	19.5	6.95	3.02	0.84
	B	Cu	Fe	Mn	Z	
			mg kg^{-1}			
Source of variation			*p* – value			
Systems (S)	0.370^{ns}	0.382^{ns}	0.962^{ns}	0.403^{ns}	0.528^{ns}	
Cultivar (C)	0.625^{ns}	0.333^{ns}	0.134^{ns}	0.268^{ns}	0.285^{ns}	
S X C	0.814^{ns}	0.499^{ns}	0.993^{ns}	0.651^{ns}	0.606^{ns}	
CV S (%)	14.3	16.7	12.5	16.2	13.8	
CV C (%)	19.9	17.4	15.3	17.3	16.1	
Means	10.3	6.25	85.3	659	14.1	

ns = not significant; * = significant at 5%; ** = significant at 1% by the F test.

The average content of macronutrients in banana plants is within the standards established by Borges et al. (2006). The average values of the different nutrients are in accordance with the ranges indicated by the same authors: N in the range of 22.3-28.5 g kg^{-1}; P between 1.1 and 2.7 g kg^{-1}; K ranging from 14.3 to 28.7 g kg^{-1}; Ca in the range of 4.8-11.1 g kg^{-1}; and Mg between 2.6 and 5.9 g kg^{-1}. Only the S content showed values below the recommended range of 1.1-2.7 g kg^{-1}. S plays crucial structural roles in the plant, acting as an essential component of amino acids, proteins, vitamins and coenzymes. Although the sulfur levels were lower than recommended, banana plants showed no visual symptoms of deficiency for this nutrient.

The micronutrient content in banana leaves also showed no difference between cropping systems (p>0.05) and banana cultivars (p>0.05) (Table 8). The order of the micronutrient concentration in the dry mass of the leaves was distributed as follows: manganese (Mn) > iron (Fe) > zinc (Zn) > boron (B) > copper (Cu). The average micronutrient content was within the levels established by Borges et al. (2006), with the exception of boron, which had an average of 10.3 mg kg^{-1}, below the standard (15–96 mg kg^{-1}), and manganese, whose concentrations were higher than the established range (132–572 mg kg^{-1}). Despite this, the plants showed no visual symptoms of deficiency or toxicity. However, boron and manganese levels are within acceptable contents (B = 10–25 mg kg^{-1} and Mn = 200–2000 mg kg^{-1}) (NOMURA et al., 2020).

Continuous trials are probably optimal for properly evaluating the diversification of banana genotypes and cropping systems, as well as the use of intercrops that can be efficiently improved for banana orchards. These findings are valuable for planning cultivar diversification in new orchards, exploring the potential for intercropping with lemongrass, and identifying the genotypes and cropping systems that are better suited to adverse climatic conditions.

CONCLUSIONS

Intercropping with lemongrass had no effect on the growth, yield and leaf nutrient content of the banana cultivars. A shorter cropping cycle was observed only in the first harvest season with the intercropping of lemongrass. The Prata Anã cultivar stood out for its earlier cycle, lower plant height and higher average yield per year.

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