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Recirculation intervals of nutrient solution in hydroponic acclimatization of banana seedlings[1]

Intervalo de recirculação da solução nutritiva na aclimatização hidropônica de mudas de bananeira

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HIGHLIGHTS:

The recirculation frequency affects banana seedling growth.
The effect of the recirculation frequency is higher in the summer.
Energy consumption can be reduced during the acclimatization cycle.

ABSTRACT: The objective of this study was to evaluate the technical viability of using longer recirculation intervals of nutrient solution than those conventionally used for the acclimatization of Prata-Ana banana seedlings grown under hydroponic system. The experiment was carried out in a greenhouse of a banana plantlet production biofactory, in Cruz das Almas, Bahia, Brazil, in a randomized block design with four replications. The use of longer recirculation intervals of nutrient solution (0.75, 3.75, 5.75, 11.75, and 23.75 hours) than those commonly used for vegetables (0.25 hour) was evaluated in the present study in two seasons: winter and summer-autumn. The effect of increasing the interval of nutrient solution recirculation on plant growth was more pronounced when the temperature was higher, during the summer-autumn season. Considering the plant growth period between 15 and 20 days after transplanting, there was no effect of the recirculation frequency, showing the viability of using lower recirculation frequencies or only one recirculation per day in the first 15 days of plant growth. However, the use of shorter intervals after this period is needed because the use of intervals equal to or higher than 0.75 hour decreased plant growth in both seasons. Thus, the use of a 23.75-hour interval in the first 15 days and a 0.25-hour interval after this period allows a decrease in energy consumption, compared to the use of a 0.25-hour interval during the whole plant cycle.

Key words: *Musa* spp., inert substrate, hypoxia

RESUMO: Objetivou-se com esta pesquisa avaliar a viabilidade técnica de adoção de maiores intervalos de recirculação da solução nutritiva na aclimatização de mudas de bananeira 'Prata-Anã' via hidroponia. O experiment foi conduzido em estufa de uma biofábrica de produção de mudas de bananeira, localizada em Cruz das Almas, Bahia, Brasil, em delineamento em blocos casualizados com quatro repetições. No presente estudo, avaliou-se a possibilidade da adoção de intervalos de recirculação da solução nutritiva superiores ao normalmente utilizado em hortaliças (0,25 h), sendo eles: 0,75, 3,75, 5,75, 11,75 e 23,75 horas em duas estações, inverno e verão-outono. O impacto no crescimento das plantas em função do aumento de tempo de intervalo de recirculação da solução nutritiva é mais acentuado quando a temperatura foi mais elevada, durante o verão-outono. Considerando o período de crescimento entre 15 e 20 dias após o transplantio não houve efeito da frequência de recirculação, sugerindo a possibilidade de adoção de frequências menores de recirculação ou apenas uma vez ao dia nos primeiros 15 dias de crescimento das plantas. Posteriormente, há necessidade de adoção de intervalos menores, pois a adoção de intervalo igual ou superior à 0,75 hora promove redução do crescimento em ambas as estações. Assim, a utilização de intervalo de 23,75 hora nos primeiros 15 dias e posterior adoção de 0,25 hora possibilita redução do consumo de energia elétrica em comparação ao uso do intervalo de 0,25 durante todo o ciclo.

Palavras-chave: *Musa* spp., substrato inerte, hipoxia

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Introduction

Nutrient film technique (NFT) is the most used hydroponic system. It consists of passing a thin layer of nutrient solution through the roots (Majid et al., 2020) with a subsequent drainage by gravity (Massa et al., 2020). The recirculating system with intermittent flow of nutrient solution is the most used.

The commonly used interval of circulation of nutrient solution for vegetable crops is 15 minutes (0.25 hour). Studies focused on adjusting this interval have shown favorable (Luz et al., 2008) and unfavorable results (Zanella et al., 2008). The use of longer recirculation intervals should be encouraged, when causing no losses in plant growth and production, to reduce production costs (Baiyin et al., 2021). Thus, studies should be carried out to determine these intervals as a function of crops, climate conditions, phenological stages, and other factors that can affect plant growth and production (Sardare & Admane, 2013).

The results of using hydroponics in banana crops are incipient. Toyosumi et al. (2020) used an adapted NFT system with 15-min recirculation interval and found that the acclimatization of micro-propagated seedlings of Prata-Ana banana through this system is technically viable. They also found that the use of hydroponics improves plant growth, promoting reduction in the number of days for seedlings to reach the commercial point and, consequently, a decrease in seedling production costs (fertilizer and water) by 57.6%, in addition to enabling an increase in the number of cycles and the number of seedlings produced per year by 65.6% when compared to conventional acclimatization.

In this sense, the objective of this work was to evaluate the technical viability of using longer recirculation intervals of nutrient solution than those conventionally used for the acclimatization of Prata-Ana banana seedlings grown under hydroponic system.

Material and Methods

The study was carried out in the winter (August to September, 2018) and summer-autumn (March to April, 2019) seasons. The experiment was conducted in a greenhouse of a private company (Campo Biotecnologia Vegetal Ltda.), in an area of the Brazilian Agricultural Research Corporation (Embrapa Mandioca e Fruticultura), in Cruz das Almas, Bahia, Brazil (12°40’39”S, 39°06’23’W, and altitude of 225 m). The climate of the region is characterized as dry sub-humid, with a mean annual rainfall depth of 1,131 mm, presenting a slight excess of water during the winter, and a mean daily temperature of 23.9 °C (Silva et al., 2016).

The environmental conditions inside the greenhouse were monitored using a thermo-hygrometer connected to a datalogger CR1000 (Campbell Scientific, USA) programmed to store data every 10 minutes. The mean air temperatures were 22.7 and 26.1 °C, and the mean relative air humidity were 81.7 and 81.4%, in the winter and summer-autumn periods, respectively (Figure 1).

Explants of banana (*Musa* sp.) of the variety Prata-Ana were obtained from in vitro propagation. The explants were available approximately 70 days after rhizome collection and meristem establishment; then, they were kept in the culture medium and left in a greenhouse for 15 days for rooting. Subsequently, they were washed to remove the culture medium and, then, transplanted into trays with cells with capacity of 22.5 mL. The cells were filled with an inert material based on coconut fiber. Then, the treatments were applied.

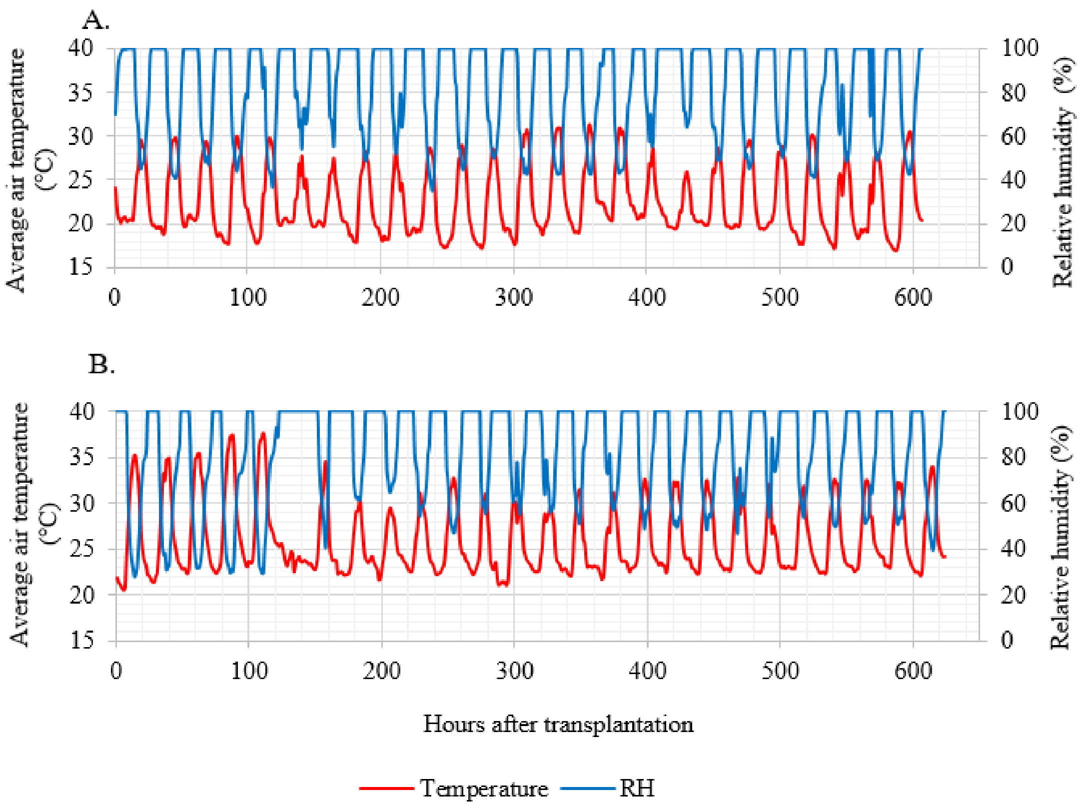


Figure 1. Mean air temperature and relative humidity (RH) in the winter (A) and summer-autumn (B) seasons

Table 1. Recirculation intervals of nutrient solution, daily hours of operation (time of electric power consumption), and pump electricity consumption for hydroponic acclimatization of banana seedlings

Treatments	Daily hours of operation of the electric pumps (hours day^{-1})	Pump electricity consumption (kWh day^{-1})	Total electricity consumption (kWh cycle^{-1})
0.25 hours	6.50	0.2275	5.688
0.75 hours	3.25	0.1137	2.843
3.75 hours	1.00	0.0350	0.875
5.75 hours	0.75	0.0262	0.655
11.75 hours	0.50	0.0175	0.438
23.75 hours	0.25	0.0087	0.218

The experiment was conducted as described by Toyosumi et al. (2020), using the nutrient film technique (NFT) adapted with the method of capillary action (Sardare & Admane, 2013).

A randomized block design with four replications was used, and the experimental unit consisted of 16 explants. Six recirculation intervals of nutrient solution were used in the hydroponic system (0.25, 0.75, 3.75, 5.75, 11.75, and 23.75 hours), totaling six treatments (Table 1). The range of intervals was chosen between the smallest interval used in hydroponics (0.25 hours) and the largest one adopted in conventional systems (irrigation once a day).

The intervals chosen were longer than those usually recommended for NFT systems, because the acclimatization of banana seedlings was carried out in a substrate with a high-water retention capacity (Resh, 2022). Even plants with 25 days of acclimatization presented relatively low decreases in substrate moisture in 24 hours, as shown in Table 2.

The trays containing the inert substrate and explants were distributed over trays where a thin layer of nutrient solution circulated. The solution was pumped using 34-W electric pumps and a flow of 0.2333 L s^{-1}; it returned to the original reservoir through drainage channels. The blocks of the treatment consisted of four interconnected trays, which had the same reservoir, electric pump, and drainage pump system. The six electric pumps used were connected to relays connected to pins of a microcontroller programmed through a software (Arduino IDE), as shown in Table 1.

The nutrient solution proposed by Furlani et al. (1999) for production of leafy vegetables was used. pH was monitored daily and corrected with a pocket pH meter with automatic temperature compensation. When the pH was below 6.0 or above 6.5, it was corrected by applying a solution of NaOH or HCl, respectively. The electrical conductivity (EC) was also monitored daily, with an EC bench meter, to assess the need for replacing nutrients or total replacement of the solution, which was not required, since there was no EC decrease greater than 25%.

Plant height and leaf area were evaluated at 15, 20, and 25 days after transplanting (DAT). The commercialization point was determined as the time when more than 50% of the plants presenting heights higher than 5 cm and the substrate was completely adhered to the roots when uprooted. This time was reached at 25 DAT. The shoot was separated from the root to determine shoot fresh and dry weights.

Table 2. Mean substrate moisture as a function of time after passing a thin layer of nutrient solution

Time (hours)	Mean moisture (%)
0.25	85.78
0.75	83.58
3.75	81.42
5.75	75.12
11.75	70.45
23.75	68.59

The roots were washed for complete removal of the substrate, placed in a 30% alcohol solution, and maintained under refrigeration (5 °C) until the evaluations of mean total length (cm), diameter (mm), and volume (cm^3) of roots. The root system was analyzed using a scanner (Epson Expression 11000 XL,) and a specific software (WhinRHIZO; Regent Instruments Inc., Sainte Foy, Canada). The roots were then placed in a forced air circulation oven at 65 °C for 72 hours and, then, weighed in an analytical balance to evaluate the dry weight of the root system.

Data of plant height and leaf area at 15, 20, and 25 DAT was used to determine the mean absolute growth rate and relative growth rate within the intervals 15 to 20 and 20 to 25 DAT, using Eqs. 1 and 2, respectively:

$$AGR = \frac{Vf - Vi}{ND} \tag{1}$$

$$RGR = \frac{\ln(Vf) - \ln(Vi)}{ND} \tag{2}$$

where:

AGR - absolute growth rate (cm day^{-1} or cm^2 day^{-1});
RGR - relative growth rate (cm cm^{-1} day^{-1} or cm^2 cm^{-2} day^{-1});
Vf - value of the variable at the end of the period;
Vi - value of the variable at the beginning of the period; and,
ND - interval between evaluations (5 days).

The treatments were considered qualitative, as the hydroponic system turn-on times, i.e., recirculation of nutrient solution, were carried out under different micrometeorological conditions due to the time of day. The explant lot used in the summer-autumn season presented lower quality than that used in the winter, thus, each season was evaluated separately. The data were subjected to analysis of variance using the R program. The Shapiro-Wilk normality test was performed, and when its assumptions were not met, the data was transformed to $\sqrt{x}$. The means of the variables were analyzed by clustering of means using the Scott Knott test ($p \leq 0.05$).

Results and Discussion

A summary of the analysis of variance for plant height and leaf area measured at 15, 20, and 25 days after transplanting (DAT) is shown in Table 3.

Table 3. Summary of analysis of variance for plant height (PH) and leaf area (LA) at 15, 20, and 25 days after transplanting (DAT), evaluated in the winter and summer-autumn seasons

Source of variation	DF	Mean squares					
		PH(15)	LA(15)	PH(20)	LA(20)	PH(25)	LA(25)
				Winter			
Interval	5	0.0499^{ns}	37.199^{ns}	0.4388^{ns}	10.545^{ns}	1.9892^{ns}	215.717**
Block	3	1.8278**	103.143**	2.1358**	161.934**	1.0469^{ns}	141.075*
Residue	15	0.1554	18.434	0.0571	3.777	0.7001	33.713
CV (%)		12.58	38.97	7.28	15.12	15.47	23.28
				Summer-autumn			
Interval	5	0.4783^{ns}	3.6906^{ns}	0.7607^{ns}	34.690**	1.8813**	182.691**
Block	3	1.7994**	22.6211**	0.1271^{ns}	5.575^{ns}	2.3537**	79.374**
Residue	15	0.2443	4.5718	0.3406	3.263	0.0965	9.663
CV (%)		13.44	45.48	17.54	38.02	7.53	32.91

ns, *, ** = not significant and significant at $p \leq 0.05$ and $p \leq 0.01$ by F test, respectively; DF = degrees of freedom; CV = coefficient of variation

The recirculation intervals had no significant effect on plant height in the period between 15 and 20 days after application of the treatments in both periods (Figure 2A and Figure 2B) and on leaf area in the winter season (Figure 2C). The mean plant heights were 3.0 and 3.2 cm at 15 DAT and 3.3 and 3.5 cm at 20 DAT, in the winter and summer-autumn, respectively. However, the mean leaf area was lower in the summer-autumn, ranging from 11.0 to 4.6 cm² at 15 DAT and from 13.0 to 4.8 cm² at 20 DAT in the winter and summer-autumn, respectively. Leaf expansion was affected by intervals longer than 0.25 hours at 20 DAT in the summer-autumn (Figure 2D).

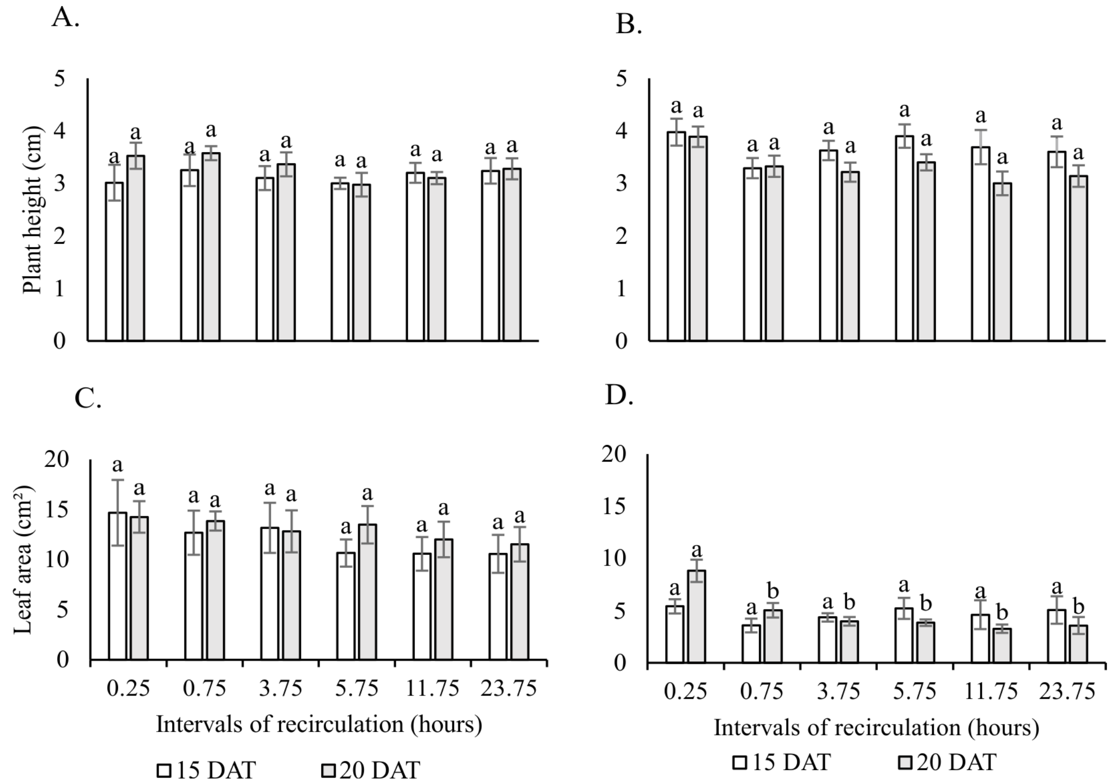
The effect of recirculation from 20 DAT onwards, mainly in the hotter period of the year, can be connected to a lower dissolved oxygen concentration in the solution, as the demand for oxygen for root respiration increases due to an increased plant growth (Morard & Silvestre, 1996).

Cellular respiration is the reverse process of photosynthesis, however, it is essential for the maintenance and development of plants, as it releases energy as adenosine triphosphate (ATP) from carbon sources for cellular use (Taiz et al., 2017).

According to the analysis of variance (Table 4), leaf area was more sensitive to the treatments.

No significant effect (p>0.05) on absolute growth rate (AGR) of plant height was found from 15 to 20 DAT, in both seasons (Table 4); similar result was found for relative growth rate (RGR). However, differences in AGR and RGR of leaf area was found, except for RGR in the winter (Figure 4C). RGR was less sensitive than AGR, showing no significant difference in leaf area between treatments in the winter; the results were significantly different for AGR.

AGR of leaf area between 15 and 20 days varied from 1.41 (0.25 hours) to 0.31 cm² day^{-1} (3.75 hours) in the winter (Table 5); the 0.25-hour interval did not significantly differ from the intervals of 5.75 and 23.75 hours. The use of a 0.25-hour interval in the summer-autumn promoted greater leaf expansion, differing from the other intervals. This may be



Bars with different letters denote significant difference between recirculation intervals by the Scott Knott test at $p \leq 0.05$

Figure 2. Plant height (A - winter and B. - summer-autumn season) and leaf area (C. - winter and D. - summer-autumn) of banana seedlings acclimatized using hydroponics with different intervals of recirculation of the nutrient solution

Table 4. Summary of analysis of variance for absolute (AGR) and relative growth rate (RGR) of plant height (PH) and leaf area (LA) at 15-20 and 20-25 days after transplanting (DAT) in the winter and summer-autumn seasons

Source of variation	DF	Mean squares							
		15-20 DAT				20-25 DAT			
		AGR(PH)	RGR(PH)	AGR(LA)	RGR(LA)	AGR(PH)	RGR(PH)	AGR(LA)	RGR(LA)
		Winter							
Interval	5	0.0070^{ns}	0.0009^{ns}	0.6602*	0.0043^{ns}	0.0257*	0.0014*	1.5024*	0.0018^{ns}
Block	3	0.0027^{ns}	0.0006^{ns}	0.6067^{ns}	0.0049^{ns}	0.0118^{ns}	0.0008^{ns}	1.1188^{ns}	0.0017^{ns}
Residue	15	0.0031	0.0006	0.1596	0.0037	0.0060	0.0004	0.3829	0.0011
CV (%)		94.27	121.33	53.28	95.03	50.21	46.89	57.08	56.81
		Summer-autumn							
Interval	5	0.0011^{ns}	0.00007^{ns}	0.2047**	0.0053**	0.0338*	0.0013^{ns}	3.7849**	0.0102**
Block	3	0.0015^{ns}	0.00013^{ns}	0.1821**	0.0104**	0.0297^{ns}	0.0012^{ns}	1.6030**	0.0124**
Residue	15	0.0022	0.00019	0.2010	0.0007	0.0083	0.0004	0.2693	0.0021
CV (%)		96.3	96.25	49.76	59.21	44.07	59.21	59.24	49.22

ns, *, **, - Respectively not significant, significant at $p \leq 0.05$ and $p \leq 0.01$ by F test; DF - Degrees of freedom; CV - Coefficient of variation

Table 5. Absolute growth rate and relative growth rate from 15 to 20 and 20 to 25 days after transplanting for plant height - PH (cm day^{-1}) and leaf area - LA (cm^2 day^{-1}) of banana seedlings acclimatized using hydroponics with different recirculation intervals of nutrient solution

	Variable	Season	Intervals of recirculation (hours)						
			Period	0.25	0.75	3.75	5.75	11.75	23.75
Absolute growth rate	PH	Winter	15-20	0.1075a	0.115a	0.0475a	0.03a	0.015a	0.04a
	PH	Summer-autumn	15-20	0.0725a	0.0225a	0.0525a	0.045a	0.0425a	0.0575a
	LA	Winter	15-20	1.4148a	0.5332b	0.3132b	1.0259a	0.4878b	0.7239b
	LA	Summer-autumn	15-20	0.671a	0.3366b	0.1262c	0.1996c	0.3298b	0.0362c
	PH	Winter	20-25	0.2975a	0.115b	0.1475b	0.1825b	0.1125b	0.0675b
	PH	Summer-autumn	20-25	0.3125a	0.155b	0.07b	0.1425b	0.09b	0.07b
	LA	Winter	20-25	2.0614a	1.5046a	0.861b	1.0859b	0.453b	0.5382b
	LA	Summer-autumn	20-25	2.783a	1.0156b	0.4782b	0.3964b	0.254b	0.3284b
Relative growth rate	PH	Winter	15-20	0.0406a	0.0365a	0.0148a	0.0101a	0.0047a	0.0129a
	PH	Summer-autumn	15-20	0.0196a	0.0071a	0.0157a	0.0134a	0.0133a	0.0180a
	LA	Winter	15-20	0.1166a	0.0470a	0.0255a	0.0884a	0.0479a	0.0607a
	LA	Summer-autumn	15-20	0.1006a	0.0884a	0.0273b	0.0579a	0.0875a	0.0107b
	PH	Winter	20-25	0.0721a	0.0294b	0.0391b	0.0539a	0.0334b	0.0191b
	PH	Summer-autumn	20-25	0.0650a	0.0420a	0.0180a	0.0374a	0.0253a	0.0187a
	LA	Winter	20-25	0.0847a	0.0813a	0.0565a	0.0576a	0.0316a	0.0421a
	LA	Summer-autumn	20-25	0.1834a	0.1199a	0.0728b	0.0683b	0.0453b	0.0692b

Columns with different letters indicate significant difference by the Scott Knott test at $p \leq 0.05$

because the plants still did not show clear responses at the time of the first evaluations (Toyosumi et al, 2019).

The 0.25-hour interval resulted in a greater plant height growth per day between 20 and 25 DAT. The absolute growth rate for plant height in the winter was 0.297 cm day^{-1} in the treatment with 0.25-hour interval, whereas the other treatments did not differ from each other, presenting a mean of 0.125 cm day^{-1} and representing a decrease of 58.0%. A 66.2% decrease was found in the summer-autumn, with means of 0.312 and 0.105 cm day^{-1} in the treatment with 0.25-hour interval and in the other treatments, respectively.

Considering the winter season, AGR was significant only for plant height between 20 and 25 DAT. However, AGR was significant for plant height between 20 and 25 DAT in the summer-autumn, and for leaf area in both periods.

Using 0.25-hour interval in the summer-autumn season resulted in greater daily growth for leaf area from 15 to 20 DAT. The 0.75-hour and 11.75-hour intervals presented intermediate results. The results showed a variation from 0.68 (0.25 hour) to 0.03 cm^2 day^{-1} (23.75 hours), representing a decrease of 94.7%.

The absolute growth rate for leaf area from 20 to 25 DAT in the winter did not statistically differ between the treatments at intervals of 0.25, 0.75, and 5.75 hours. A higher mean (2.78 cm^2 day^{-1}) was found for the 0.25-hour interval in the summer-autumn, statistically differing from the others.

Considering the both variables, the first evaluations showed no clear effects of the treatments. Leaf area is the most affected, presenting higher percentage differences between treatments (approximately 120%) in the acclimatization process when comparing hydroponics with the conventional system; fresh and dry weights, height, and total length the root system presented a mean difference of 45% (Toyosumi et al., 2017).

The decrease in banana seedling growth as the interval between the nutrient solution recirculation was increased can be attributed to decreases in the dissolved oxygen concentration in the solution (hypoxia), as the substrate moisture was high even after 24 hours after irrigation (Table 2), not limiting the availability of nutrients to plants. No visual symptoms of water deficit (chlorosis or necrosis) were observed. In addition, the absence of oxygen reduces water and nutrient absorption by roots (Lenzi et al., 2011). Longer intervals also have caused negative effects on plant growth in hydroponic systems with deep flow technique (DFT) (Silva et al., 2020).

Table 6 presents the summary of the analysis of variance for the variables analyzed at the end of the experiment, i.e., at 25 DAT. Plant height in the winter presented no significant differences.

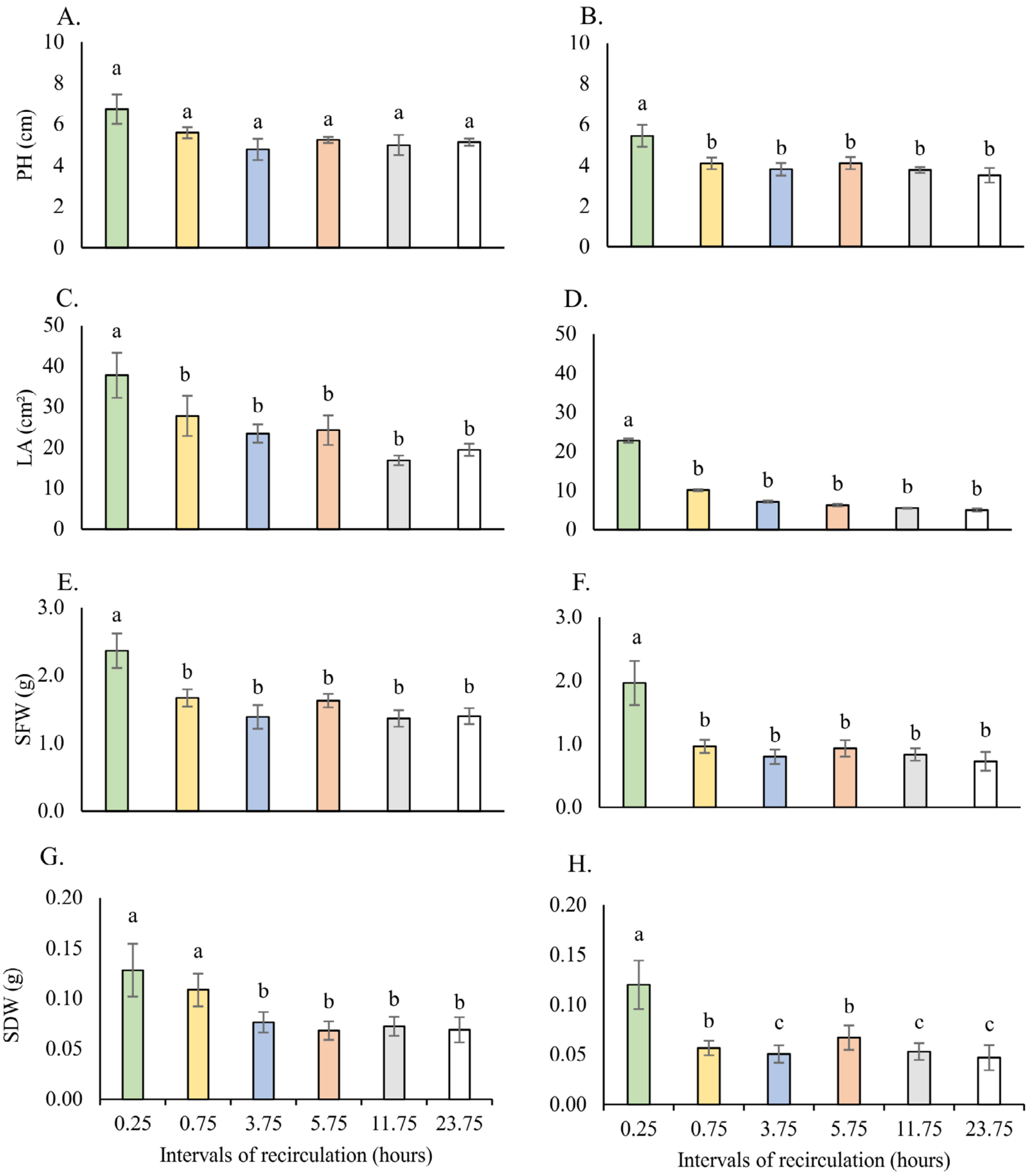
The effect of the treatments on plant height at 25 DAT was significant only in the summer-autumn; the treatment with 0.25-hour interval resulted in a higher mean (5.45 cm), as shown in

Table 6. Shoot fresh (SFW) and shoot dry weight (SDW), plant height (PH), leaf area (LA), total root length (TRL), total root volume (TRV), and mean root diameter (MRD) of banana seedlings at 25 days after transplanting in the winter and summer-autumn seasons

Source of variation	DF	Mean squares						
		SFW	SDW	PH	LA	TRL	TRV	MRD
					Winter			
Interval	5	0.5790**	0.0025**	1.9892ns	215.817**	3203.5*	0.0071*	0.0072*
Block	3	0.2035ns	0.0045**	1.0469ns	141.075*	12.9ns	0.0013	0.0023ns
Residue	15	0.0784	0.0002	0.7001	33.713	796.4	0.0021	0.0020
CV (%)		17.12	16.11	15.47	23.28	23.96	22.5	9.43
					Summer-autumn			
Interval	5	0.8551**	0.0030**	1.8813**	182.691**	3849.3**	0.0052**	0.5334*
Block	3	0.4748**	0.0029**	2.3537**	79.374**	2129.4**	0.0034*	0.0234ns
Residue	15	0.0601	0.0003	0.0965	9.663	325.8	0.0008	0.0155
CV (%)		23.68	26.22	7.53	32.91	48.55	47.88	24.01

ns, *, **, - Respectively not significant, significant at $p \leq 0.05$ and $p \leq 0.01$ by F test; DF - Degrees of freedom; CV - Coefficient of variation

Figure 3B. Leaf area was significantly affected in both seasons (Figure 3C and Figure 3D). The use of a 0.75-hour interval resulted in a decrease in the means, compared to the 0.25-hour interval, and did not differ from the other treatments.



Bars with different letters denote significant difference by the Scott Knott test at $p \leq 0.05$

Figure 3. Plant height (cm) - PH (A - winter and B - summer-autumn), leaf area (cm^2) - LA (C - winter and D - summer-autumn), shoot fresh weight (g) - SFW (E - winter and F - summer-autumn) and shoot dry weight (g) - SDW (G - winter and H - summer-autumn) of banana seedlings acclimatized using hydroponics with different intervals of recirculation of the nutrient solution, evaluated at 25 days after transplanting

Considering plant growth under the systems with recirculation intervals of 0.25 and 23.75 hours, plant height, leaf area, and shoot fresh and dry weights decreased 23.9, 48.5, 40.8, and 46.2%, respectively, in the period with milder temperatures (Figure 3A, 3C, 3E, and 3G).

Higher decreases were found in the summer-autumn season: 35.5, 78.1, 63.1, and 61.0%, respectively (Figure 3B, 3D, 3F, and 3H). Niñirola et al. (2014), Sakamoto et al. (2016), and Al-Rawahy et al. (2019) attribute this higher effect in the summer-autumn to a reduced availability of dissolved oxygen in the rhizosphere of plants under high temperature conditions, as the dissolved oxygen concentration is inversely proportional to the temperature.

Contrastingly, Pilau (2002), Luz et al. (2008), and Luz et al. (2017) used intervals ranging from 0.25 to 1.0 hour and found no growth impairments for lettuce. However, only phenolic foam is used for most hydroponic crops, and the solution remains in the roots for a short time (Karagoz et al., 2022).

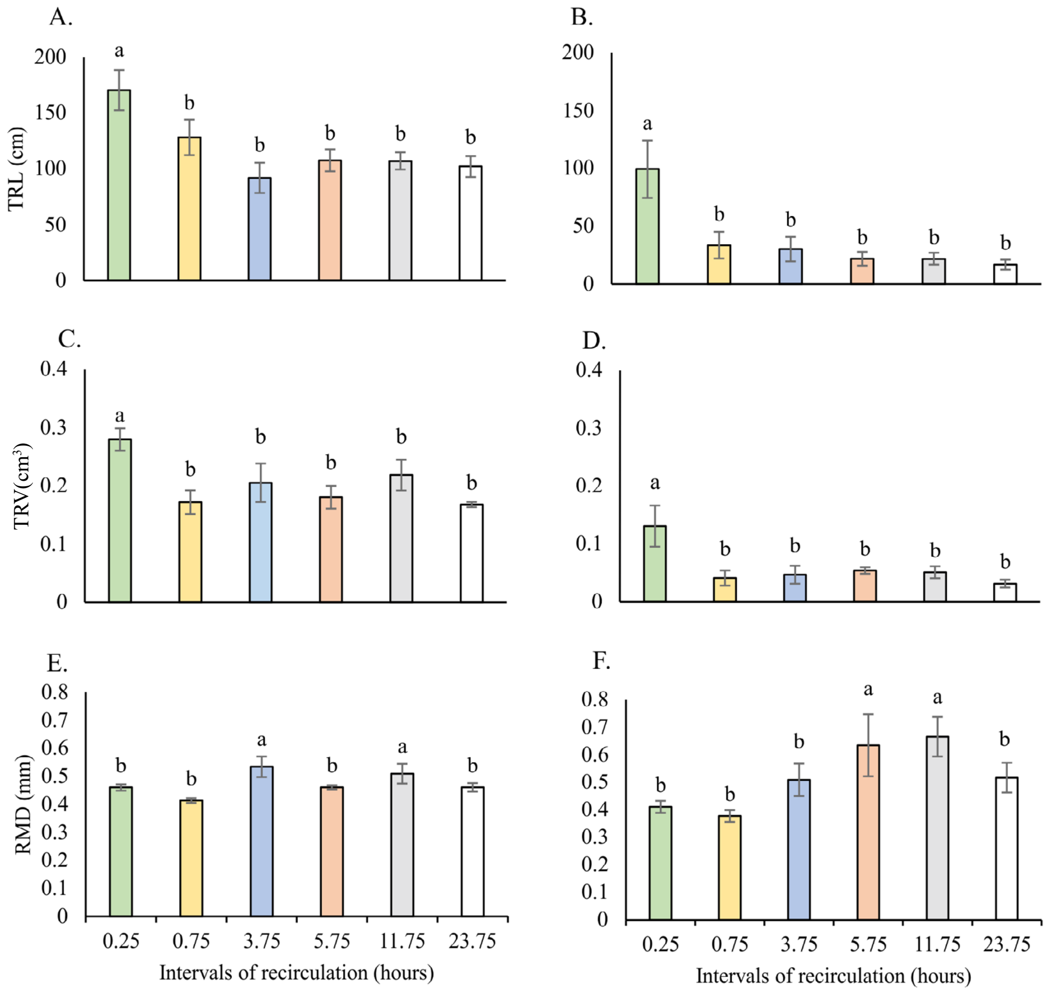
According to Luz et al. (2017), plant responses may not be generalized, as they depend on local weather conditions, since growth decreases were found when using a 0.5-hour interval for the same crop (Zanella et al., 2008).

The use of an interval of up to 23.75 hours during the first days of acclimatization in the present study was only possible due to the use of a substrate with high water retention capacity, which has been used in conventional acclimatization processes. Using substrates in hydroponics is especially recommended for regions with high evapotranspiration rates, as it promotes a buffering effect that can prevent or limit water, nutritional, and temperature stresses (Massa et al., 2020).

Total root length (Figure 4A and 4B) and root volume (Figure 4C and 4D) were affected by the treatments ($p < 0.05$). Intervals equal to or longer than 0.75 hour negatively affected root growth, causing decreases of 36.99 and 75.05% in total root length and 32.50 and 65.91% in total root volume when compared to the means of the other treatments using the 0.25-hour interval in the winter and summer-autumn seasons, respectively.

The evaluations in the hotter period denoted that increases in the recirculation frequency were responsible for producing roots with smaller diameters, as found when using the 0.25- and 0.75- hour intervals. Root diameters increased up to the 11.75-hour interval and decreased up to the 23.75-hour interval (Figure 4F). A clear trend was not found in the period with milder temperatures (Figure 4E).

The use of managements that reduce production costs, including those related to electric power consumption, is essential to ensure food production sustainability (Roy et al.,



Bars with different letters denote significant difference by the Scott Knott test at $p \leq 0.05$

Figure 4. Total root length (cm)- TRL (A - winter and B - summer-autumn), total root volume (cm^3) - TRV (C - winter and D - summer-autumn), and mean root diameter (mm)- MRD (E - winter and F - summer-autumn) of banana seedlings acclimatized using hydroponics with different intervals of recirculation of nutrient solution

2018). Thus, the use of a longer interval of recirculation of nutrient solution in the first days of acclimatization of seedlings can be a viable strategy, because no significant difference in plant height and leaf area was found at 15 and 20 DAT.

Toyosumi et al. (2020) found significant differences between conventional and hydroponic systems for the acclimatization process of banana seedlings only after 20 days, with evaluations carried out every 5 days.

In this sense, the use of a 23.75-hour interval up to 15 DAT is recommended; it represents an electric pump operating time of only 0.25 hour per day, whereas the treatment with 0.25-hour interval totalizes an operating time of 6.5 hours per day (Table 1), considering that a reasonable range should be found for the use of electricity to minimize operational costs (Baiyin et al., 2021).

In addition to the recirculation frequency of nutrient solution, the oxygenation of the solution through aeration techniques (Suyantohadi et al, 2010; Tsutsumi et al., 2020) should be carried out to assess the effects on plant growth and production even under conditions with longer intervals.

Conclusions

1. The use of intervals of recirculation of nutrient solution higher than 0.25-hour for hydroponic acclimatization of banana seedlings results in a decreased plant growth at 20 and 25 DAT.

2. A 24-hour interval can be used for recirculation of nutrient solution in hydroponic system until 15 days after transplanting, with a subsequent more frequent interval (0.25 hour), as it reduces the energy consume.

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