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Scientific Article

Deficit irrigation strategies and potassium fertilization in the cultivation of banana cv. Nanicão

Estratégias de irrigação com déficit hídrico e adubação potássica no cultivo de bananeira cv. Nanicão

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ABSTRACT - This study aimed to evaluate the effects of potassium fertilization on gas exchange and production of banana under water deficit irrigation strategies. The experiment was conducted at the experimental farm belonging to the Center of Science and Agri-Food Technology of the Federal University of Campina Grande, in São Domingos - PB, Brazil. The treatments were arranged in a randomized block design, in a split-plot arrangement, with main plots consisting of four water deficit irrigation strategies based on phenological phases (without water stress – irrigation with 100% of crop evapotranspiration (ETc); water deficit (irrigation with 50% ETc) during the juvenile phase only; during the fruiting phase only; and during both the juvenile and the fruiting phases) and subplots consisting of two potassium doses (50% and 100% of the recommendation), with three replications and six plants per plot. Continuous water deficit during the juvenile and fruiting phases reduced stomatal conductance and transpiration, while deficit in the fruiting phase alone compromised the CO_2 assimilation rate. Banana plants cultivated under water deficit in the juvenile phase with 50% K_2O and in the juvenile/fruiting phases with 100% of the potassium recommendation showed the greatest physiological acclimation to water deficit conditions, although with yield losses compared to those irrigated with 100% ETc and fertilized with 100% K_2O.

Keywords: *Musa* spp.. Abiotic stress. Acclimatization. Fertilizer management.

RESUMO - Este estudo teve como objetivo avaliar os efeitos da adubação com potássio nas trocas gasosas e produção da bananeira sob estratégias de irrigação com déficit hídrico. O experimento foi realizado na fazenda experimental pertencente ao Centro de Ciências e Tecnologia Agroalimentar da Universidade Federal de Campina Grande, em São Domingos – PB, Brasil. Os tratamentos foram distribuídos em blocos casualizados, em esquema de parcelas subdivididas, cujas parcelas foram constituídas de quatro estratégias de irrigação com déficit hídrico nas fases fenológicas (sem estresse hídrico – irrigação com 100% da evapotranspiração da cultura (ETc); déficit hídrico (irrigação com 50% da ETc) apenas na fase juvenil; na fase de frutificação e, nas fases juvenil e frutificação, e as subparcelas constituídas por duas doses de potássio (50 e 100% da recomendação), com três repetições e seis plantas na parcela. O déficit hídrico nas fases juvenil e de frutificação de forma contínua reduziu a condutância estomática e a transpiração e apenas na frutificação comprometeu a taxa de assimilação de CO_2. A bananeira cultivada sob déficit hídrico na fase juvenil sob 50% de K_2O e na juvenil/frutificação, com 100% da recomendação potássica, demonstraram maior capacidade de aclimatação fisiológica às condições de déficit hídrico, embora com perdas na produtividade em relação as irrigadas com 100% da ETc e adubação com 100% de K_2O.

Palavras-chave: *Musa* spp.. Estresse abiótico. Aclimatação. Manejo de adubação.

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INTRODUCTION

Banana (*Musa* spp.) is the most produced fruit worldwide, cultivated in over 125 countries. The Asian continent stands out as the largest producer, with an output of approximately 64.73 million tons (FAO, 2025). In Brazil, this fruit is also the most consumed, and in 2023, the national production reached 6,825,724 tons, with cultivation over an area of 456.5 thousand hectares. During this season, the Northeast region was the primary producer, contributing around 35.1% of the national production, equivalent to 2.41 million tons (IBGE, 2023).

Among the obstacles to the expansion of production areas in the Brazilian semi-arid region are the irregularity of rainfall and high evapotranspiration rates, resulting in limitations in water availability during the crop cycle, leading to losses in production and fruit quality (MACIEL; MACIEL; GOMES, 2021). Water deficit impairs the synthesis of proteins and nucleic acids, photosynthesis, and respiration, thereby reducing crop yields (AHMAD et al., 2019).

Coelho et al. (2021), in a study evaluating the yield, water use efficiency, and fruit size of different banana cultivars under controlled deficit irrigation in northern Minas Gerais, concluded that a water replacement depth of 70% of ETc applied only during one period (November to February, the rainy season) resulted in higher yield and greater water use efficiency for 'Grande Naine', placing it in the same group as 'BRS Princesa' and 'Prata-Anã'. Santos et al. (2016), in a study evaluating root distribution and water extraction in 'BRS Princesa' banana, observed that partial deficit irrigation (50% of ETc) led to a tendency for greater root development.

In this context, it is necessary to adapt to the region's reality and address the problem by implementing technologies and techniques that seek to reduce the detrimental effects of water deficit on crops. For this reason, the efficient use of water resources is a precise, effective, and integrated alternative based on the premise of equitable and rational water use, which is essential for long-term sustainability, increasing the yield and competitiveness of plants during specific periods of the crop cycle (FÁTIMA et al., 2024). Thus, the strategic use of irrigation is fundamental for agricultural expansion, especially in regions with water restrictions, contributing to the socioeconomic progress of arid and semi-arid regions (SOARES et al., 2023).

Irrigation management allows for the adoption of different water application strategies. One of these options is deficit irrigation at different cultivation stages, which consists of applying the amount of water capable of fully overcoming the water deficit only during the phenological stages that are most sensitive to water restrictions, directly influencing yield (FATIMA et al., 2024). This aims to maximize water use efficiency, especially during drought periods when irrigation water is scarce. However, the efficiency of deficit irrigation depends mainly on the crop's phenology and effects related to the timing, duration, physiological state of the plant, genotype, severity of the water stress, and the region's climatic conditions (SOARES et al., 2023).

Among the strategies used to reduce the negative effects of water deficit on crops, potassium fertilization stands out. Potassium (K) acts as an enzymatic activator, aiding in the translocation of carotenoids, starch synthesis and degradation, and the maintenance of ionic balance and cell turgor, thereby providing greater plant tolerance to water deficit (HASANUZZAMAN et al., 2018). In bananas, potassium is the most important nutrient, influencing bunch and hand production, as well as fruit quality (BORGES et al., 2021).

Martins et al. (2011), evaluating the effects of potassium fertilization and irrigation on bananas, observed that potassium applied via fertigation acts positively on both the production and the quality of the cv. Williams. The hypothesis of this study is that potassium aids in stomatal regulation, favors sugar synthesis, and improves the plant's water status by increasing water and nutrient absorption, thereby inducing tolerance to water deficit in bananas under semi-arid conditions. In this context, the objective of present study was to evaluate the effects of potassium fertilization on the gas exchange and production of banana cv. Nanicão cultivated under different deficit irrigation strategies in a semi -arid area.

MATERIALS AND METHODS

The experiment was conducted from January 5 to December 12, 2024, at the 'Rolando Enrique Rivas Castellón' Experimental Farm, belonging to the Center of Science and Agri-Food Technology (CCTA) of the Federal University of Campina Grande (UFCG). The experimental farm is located in the municipality of São Domingos, Paraíba, Brazil, at the geographic coordinates 6°48'37.9" S latitude and 38°08'20.6" W longitude, at an altitude of 199 m. According to Köppen's classification, adapted to Brazil, the region's climate is classified as BSh, hot and dry semi-arid with summer and autumn rains (ALVARES et al., 2013). Data collected at the São Gonçalo - PB meteorological station during the experimental period are presented in Figure 1.

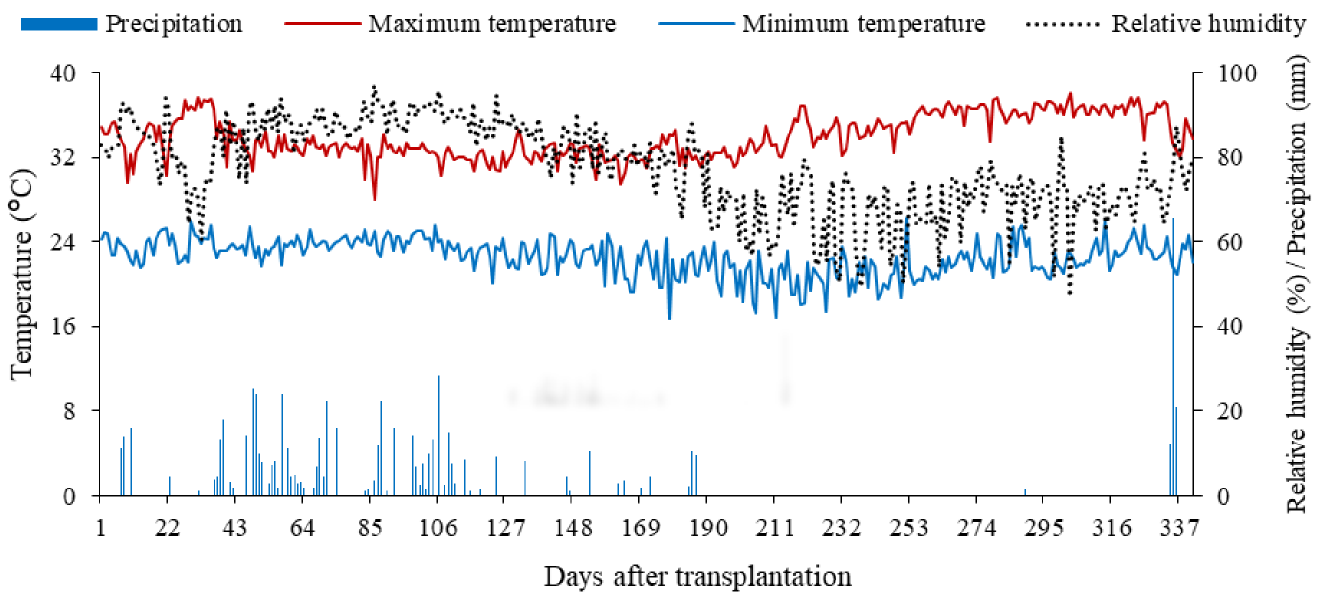


Figure 1. Maximum and minimum temperature, relative air humidity, and precipitation data during the experimental period (January 5 to December 12, 2024).

The experiment was conducted in a randomized block design with a split-plot arrangement. The main plots consisted of four irrigation strategies (IS) based on crop evapotranspiration (ETc): irrigation with 100% ETc throughout the entire growing cycle (SE); and 50% ETc irrigation applied during the juvenile (JU), fruiting (FR), and juvenile/fruiting (JU/FR) phases. The subplots consisted of two potassium doses (KD) (50% and 100% of the recommended potassium dose), with three replications and six plants per experimental plot. The 100% potassium dose corresponded to 400 g of K_2O plant^{-1} year^{-1}, as recommended by Cavalcanti et al. (2008).

Prior to planting, soil samples were collected from the 0-40 cm depth, and their physical and chemical characteristics were subsequently determined according to the methodology of Teixeira et al. (2017), with the results presented in Table 1.

Table 1. Chemical and physical characteristics of the soil (0–40 cm) of the experimental area, before the application of treatments.

Chemical characteristics									
pH (H_2O) (1:2.5)	OM dag kg^{-1}	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	$H^+ + Al^{3+}$	ESP	EC_{se} (dS m^{-1})
			(cmol$_c$ kg^{-1})					%	
6.95	0.96	13.75	0.35	0.83	3.74	2.30	0.00	11.43	0.32
Physical characteristics									
Particle-size fraction (g kg^{-1})			Textural class	Moisture (kPA)		AW	Total porosity (%)	Bd	Pd
Sand	Silt	Clay		33.42	1519.5 dag kg^{-1}			(kg dm^{-3})	
719.20	241.60	39.20	SL	12.24	4.58	7.66	47.76	1.40	2.68

OM – Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with 1 M KCl at pH 7.0; Na^+ and K^+ extracted using 1 M NH_4OAc at pH 7.0; $H^+ + Al^{3+}$ extracted using 0.5 M CaOAc at pH 7.0; ESP - exchangeable sodium percentage; EC_{se} – electrical conductivity of the soil saturation extract; SL – Sandy Loam; AW – Available Water; Bd – Bulk density; Pd – Particle density.

The spacing used between plants and rows was 2.5 × 2.5 m, with planting holes measuring 0.40 × 0.40 × 0.40 m. After opening the holes, basal fertilization was performed with 20 L of cured bovine manure and 166.66 g of single superphosphate, as a source of phosphorus (P_2O_5), following the recommendation of Cavalcanti et al. (2008). Before transplanting the seedlings (15 days after the basal fertilization) to the area, the soil moisture content was raised to a level near field capacity, and planting was carried out. Subsequently, the soil moisture content was monitored using a Time-Domain Reflectometer (TDR), through the emission of high-frequency electromagnetic pulses by the sensor, in which reflections occurring over time were recorded and read as distance, according to their relationship with the dielectric constant.

A micro-sprinkler irrigation system was used, with 32 mm PVC tubes for the main line and 16 mm low-density polyethylene tubes for the lateral lines. Each plant was equipped with one 'Bailarina Rotativa' model micro-sprinkler, with a flow rate of 52 L h^{-1}, installed on a 35-cm-tall stake at a distance of 15 cm from the pseudostem. Irrigations were performed daily according to the plant's water demand. The water used for irrigation was sourced from an artesian well located in the experimental area. The irrigation strategies were applied during the distinct phenological phases, based on the reference evapotranspiration (ETo) estimated by the Hargreaves and Samani (1985) method, according to Equation 1.

$$ETo = 0.0023 \times Qo \times (tmax - tmin)^{0.5} \times (tmean + 17.8) \quad (1)$$

Where:
ETo = reference evapotranspiration, mm day^{-1};
tmax = maximum air temperature (°C);
tmin = minimum air temperature (°C);
tmean = mean air temperature (°C); and,
Qo = extraterrestrial solar irradiance of equivalent evaporation (MJ m^{-2} day^{-1}).

The extraterrestrial solar irradiance for equivalent evaporation was calculated according to Allen et al. (1998). From the ETo data and the crop coefficient (Kc), the crop evapotranspiration (ETc) was estimated according to Bernardo et al. (2019), using Equation 2.

$$ETc = ETo \times Kc \quad (2)$$

Where:
ETc = crop evapotranspiration, mm day^{-1};
ETo = reference evapotranspiration, mm day^{-1}; and,
Kc = crop coefficient, dimensionless.

For the ETc calculations, the crop coefficients (Kc) adopted were 1.35 (juvenile phase, 90–240 days after transplanting - DAT) and 1.0 (fruiting phase, 241–335 DAT), according to Coelho et al. (2012). During the first 75 DAT, corresponding to the banana's establishment phase, the plants were irrigated with 100% ETc for crop acclimation. After this period, the differentiation of irrigation depths began, according to the crop's phenological phases.

Potassium chloride (KCl, 60% K_2O) was used as the potassium source, with the fertilization split into five applications according to the pre-established treatments. The applications began at 60 DAT, applied manually by diluting the fertilizer in irrigation water and distributing it in a circle under the plant's crown projection.

Nitrogen fertilization also followed the recommendation of Cavalcanti et al. (2008), using 20, 30, 50, 100, and 60 g of nitrogen (N) per mat (composed of two plants) at 60, 120, 180, 240, and 300 DAT, respectively. Urea (45% N) was used as the nitrogen source. Micronutrient fertilization was carried out with the commercial product

Dripsol micro® (Mg^{2+} = 1.1%; B = 0.85%; Cu = 0.5%; Fe = 3.4%; Mn = 3.2%; Mo = 0.05%; Zn = 4.2%; 70% EDTA chelation) at a concentration of 1.0 g L^{-1}, supplied during the juvenile phase and at the beginning of flowering. For the micronutrient application, a non-ionic agricultural adhesive spreader was added at 50 mL L^{-1}, according to the manufacturer's recommendation.

During the experiment, three desuckering (thinning) events were carried out, consisting of the removal of the youngest suckers, at 95, 120, and 170 DAT. Each mat was composed of two plants: one mother plant and one daughter plant, in order to reduce competition for light, water, and nutrients. Desuckering was performed up to the beginning of the fruiting phase to prevent damage to the rhizome, which could cause the mother plant with the bunch to topple.

Phytosanitary control was performed as necessary, including defoliation to manage *Mycosphaerella musicola* and improve air circulation and luminosity within the experimental area. For the control of mites and aphids, four applications of a neutral detergent solution (200 mL in 20 L of water) were carried out at 100, 106, 112, and 118 DAT. Weed control was performed by applying the herbicide Glyphosate® at 35 DAT and supplemented with manual weeding at 30, 90, and 120 DAT. During the fruiting phase, staking was implemented to prevent plant lodging and toppling. Fifteen days after the opening of the last hand, the male flower bud (heart) was removed to improve fruit quality, increase bunch weight, and accelerate ripening.

At the full fruiting stage (272 DAT), gas exchange was measured, including stomatal conductance (*gs*, mmol H_2O m^{-2} s^{-1}), transpiration (*E*, mmol H_2O m^{-2} s^{-1}), internal CO_2 concentration (*Ci*, μmol CO_2 m^{-2} s^{-1}), and CO_2 assimilation rate (*A*, μmol CO_2 m^{-2} s^{-1}). Gas exchange was evaluated on two plants per plot between 8:00 and 10:00 a.m., with measurements taken on the third fully expanded leaf from the plant apex. A portable infrared gas analyzer (IRGA), model "LCPro+" (ADC BioScientific Ltda), was used under natural air temperature and CO_2 concentration, utilizing an artificial radiation source of 1200 μmol m^{-2} s^{-1} established by the photosynthetic light saturation curve.

The harvest began at 286 DAT and extended to 344 DAT, evaluating the number of fruits (units per plant), number of hands (units per plant), fruit weight (g per plant), hand weight (g per plant), and bunch weight (kg per plant). Additionally, fruit length and diameter were measured. Finally, total yield was determined based on bunch weight and spacing, considering a planting density of 1600 plants per hectare.

The obtained data were evaluated for normality (Shapiro-Wilk test) and homogeneity of variances (Bartlett's test) and, subsequently, subjected to analysis of variance by the F-test ($p \leq 0.05$). In cases of significance, Tukey's test ($p \leq 0.05$) was applied for the irrigation strategies, and the F-test was used for the potassium doses, using the statistical software SISVAR - ESAL version 5.7 (FERREIRA, 2019).

RESULTS AND DISCUSSION

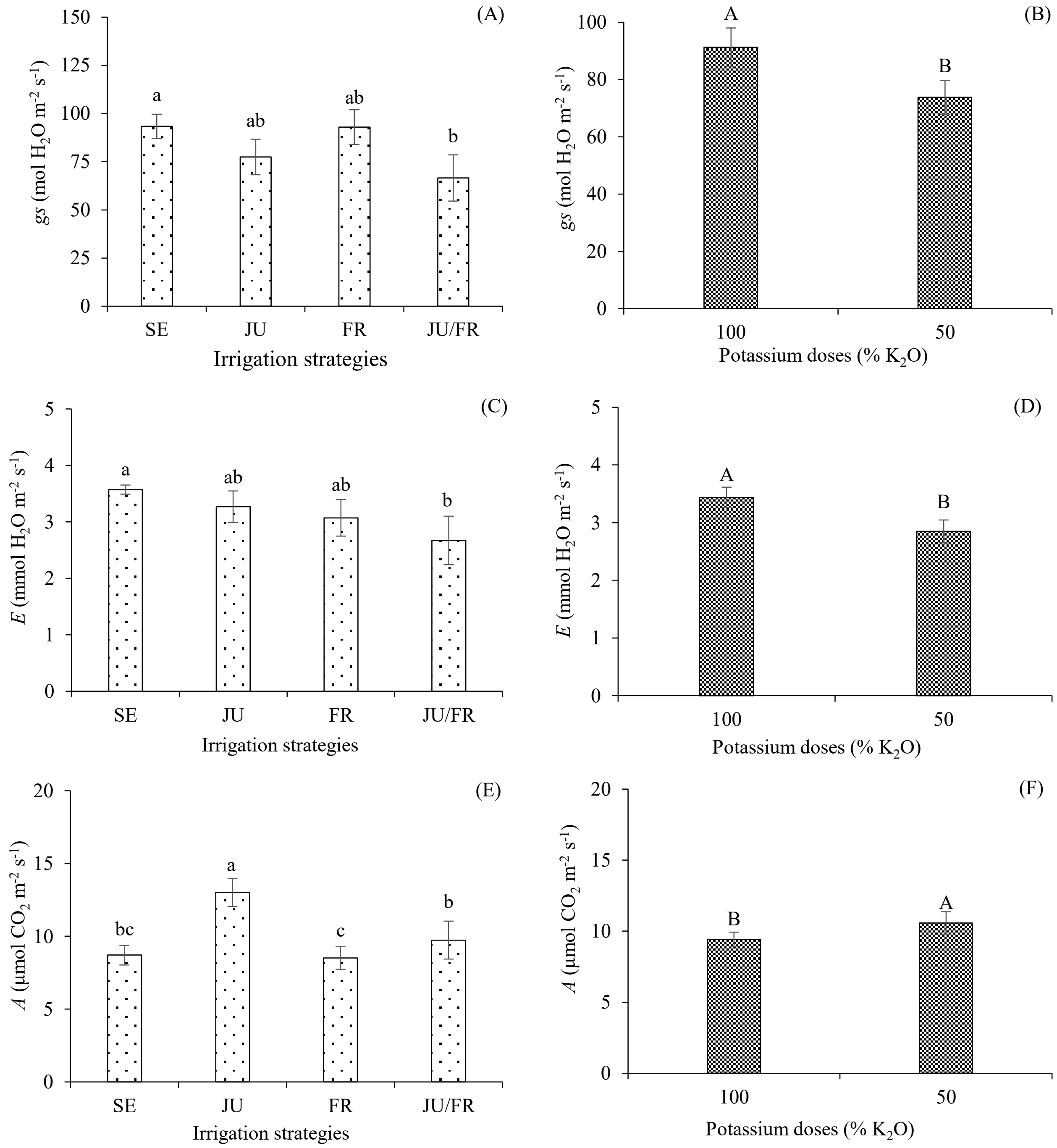
A significant interaction effect between the factors (IS × KD) was observed only for the internal CO_2 concentration (*Ci*) (Table 2). As main effects, both the irrigation strategies (IS) and potassium doses (KD) significantly influenced all analyzed variables of banana cv. Nanicão at 272 days after planting.

Table 2. Summary of the analysis of variance for internal CO_2 concentration (Ci), stomatal conductance (*gs*), transpiration (*E*), and CO_2 assimilation rate (*A*) of banana plants cv. Nanicão grown under water deficit irrigation strategies and potassium doses, at 272 days after planting.

Sources of Variation	DF	Mean squares			
		Ci	*gs*	*E*	*A*
Irrigation Strategies (IS)	3	7061.45^{**}	1015.33^{*}	0.84^{*}	26.02^{**}
Blocks	2	652.57^{ns}	59.70^{ns}	0.12^{ns}	0.26^{ns}
Error 1	6	44.26	177.05	0.10	0.37
Potassium Doses (KD)	1	988.42^{*}	1837.67^{**}	2.10^{**}	7.85^{**}
Interaction (IS x KD)	3	8028.78^{**}	97.28^{ns}	0.13^{ns}	1.43^{ns}
Error 2	8	125.15	61.79	0.04	0.52
CV1	-	3.98	16.12	10.32	6.10
CV 2	-	6.70	9.52	7.06	7.27

DF - Degrees of freedom; CV (%) - Coefficient of variation; * significant at $p \leq 0.05$; ** significant at $p \leq 0.01$ probability; ^{ns} not significant by the F-test ($p > 0.05$).

The stomatal conductance (*gs*) of plants cultivated under water deficit in the successive JU/FR phases (Figure 2A) differed significantly from the value of those subjected to full irrigation (SE). However, no significant differences were observed among the JU, FR, and JU/FR strategies. This finding highlights the efficiency of stomatal activity in plants that received the deficit in only one phase, likely by inducing a greater balance in soil solute absorption, either through osmolyte regulation or root growth induction (PEIXOTO et al. 2020). This behavior tends to be limited in plants under prolonged water deficit due to the lack of recovery time for metabolic regulation (LACERDA et al., 2025), a situation aggravated by the semi-arid conditions where the research was conducted.



SE - without water stress; JU - water deficit in the juvenile phase; FR - water deficit in the fruiting phase; JU/FR - water deficit in the juvenile and fruiting phases. Means followed by the same letter do not differ significantly between treatments ($p > 0.05$). Vertical bars represent the standard error of the mean for water deficit irrigation strategies ($n = 6$) and potassium doses ($n = 12$).

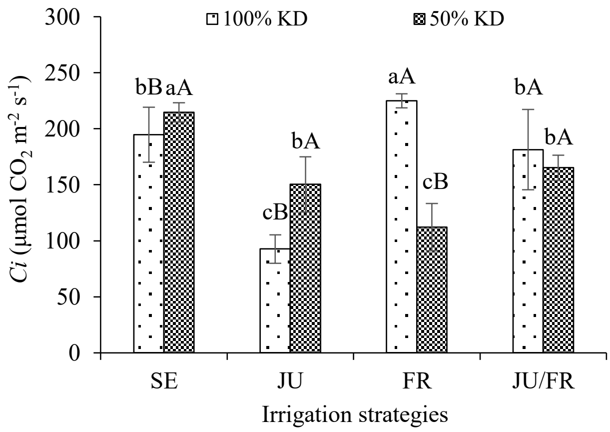
Figure 2. Stomatal conductance – *gs*, transpiration – *E*, and CO_2 assimilation rate – *A* in banana plants cv. Nanicão, as a function of irrigation strategies (A, C, and E) and as a function of potassium doses (B, D, and F), at 272 days after planting.

Regarding transpiration (*E*) (Figure 2C), plants irrigated with 100% ETc throughout the cycle (SE) were statistically superior to those cultivated under water deficit in the JU/FR phases. However, no significant difference was found among the SE, JU, and FR strategies, nor among the JU, FR, and JU/FR strategies. This corroborates recent literature, which associates the transpiration stream with stomatal opening as a strategy to reduce water loss to the atmosphere and maintain cell turgor (DANTAS et al., 2023). In banana cv. Prata-Anã, similar behavior was observed by Arantes et al. (2016), who reported a 78.57% loss in *E* in response to low relative air humidity and reduced soil moisture.

Deficit irrigation in the juvenile phase (JU) resulted in a CO_2 assimilation rate (*A*) superior to that of plants cultivated under the SE, FR, and JU/FR strategies (Figure 2E). However, plants subjected to water deficit in the JU/FR phases showed significant differences in *A* compared to those that received deficit irrigation in the fruiting phase (FR). In this case, the balance in the Calvin cycle is associated with the regulation of carbon influx and photochemical activity. This demonstrates that alterations resulting from reduced stomatal opening under adverse conditions can serve as an alternative to reduce water loss, which is compensated for by photochemical maintenance and probable antioxidant activity, thereby avoiding non-stomatal damage (FATIMA et al., 2024).

Potassium fertilization with 50% of the recommendation of Cavalcanti et al. (2008) resulted in alterations in the physiological activity of banana plants, causing a 19.17% decrease in stomatal conductance (*gs*) (Figure 2B) and a 17.15% decrease in transpiration (*E*) (Figure 2D) compared to plants under 100% K_2O fertilization. However, this contrasted with the CO_2 assimilation rate (*A*) (Figure 2F), which showed a 12.21% increase when fertilization was reduced to 50% of the K_2O recommendation. Thus, while the reduction in K fertilization affected stomatal opening a process where this nutrient is involved in guard cell signaling and osmoregulation (PACHECO; LAZZARINI; ALVARENGA, 2021) the 50% potassium supplementation may have helped maintain the absorption of other cations, such as Ca^{2+} and Mg^{2+}, which are impaired at absorption sites by the 100% K application. Alterations in the osmotic content of guard cells change the water potential and osmotic pressure, causing an efflux of water, a behavior based on guard cell osmoregulation (MORETTI et al., 2021; PACHECO; LAZZARINI; ALVARENGA, 2021).

For the internal CO_2 concentration (*Ci*) (Figure 3), the 50% K_2O dose contributed to increasing the *Ci* in plants under the JU strategy, similar to the plants under full irrigation (SE). However, when comparing plants cultivated under water deficit in the fruiting phase (FR), an increase of 15.58% in Ci was observed relative to those irrigated with 100% ETc throughout the cycle under the dose of 100% K_2O. In contrast, plants subjected to water deficit in the juvenile phase (JU) had a 52.40% reduction in *Ci* compared to the SE treatment. This differed from plants under 50% K_2O fertilization, as the control plants (SE) resulted in the highest *Ci* value (214.66 μmol CO_2 m^{-2} s^{-1}), which was 10.27% higher than that observed with the 100% K_2O application. Gains were also established in the JU strategy, amounting to 62.22%, while for the FR strategy, the lowest value was obtained with 50% K_2O fertilization, establishing a 50.17% reduction. No differences between K_2O doses were observed only in the JU/FR strategy. This behavior is associated with the consumption of carbon for the Calvin cycle (PAN et al., 2021), given that carbon assimilation was not affected by the strategies in this research, but was notably elevated in the JU phase, which explains the variations in carbon concentration.



SE - without water stress; JU - water deficit in the juvenile phase; FR - water deficit in the fruiting phase; JU/FR - water deficit in the juvenile and fruiting phases. Means followed by the same lowercase letter do not differ significantly (Tukey, $p > 0.05$) among irrigation strategies for the same potassium dose; means followed by the same uppercase letter do not differ significantly (F-test, $p > 0.05$) between potassium doses within the same irrigation strategy. Vertical bars represent the standard error of the mean (n=3).

Figure 3. Internal CO_2 concentration (*Ci*) of banana plants cv. Nanicão, as a function of the interaction between irrigation strategies (IS) and potassium doses (KD), at 272 days after planting.

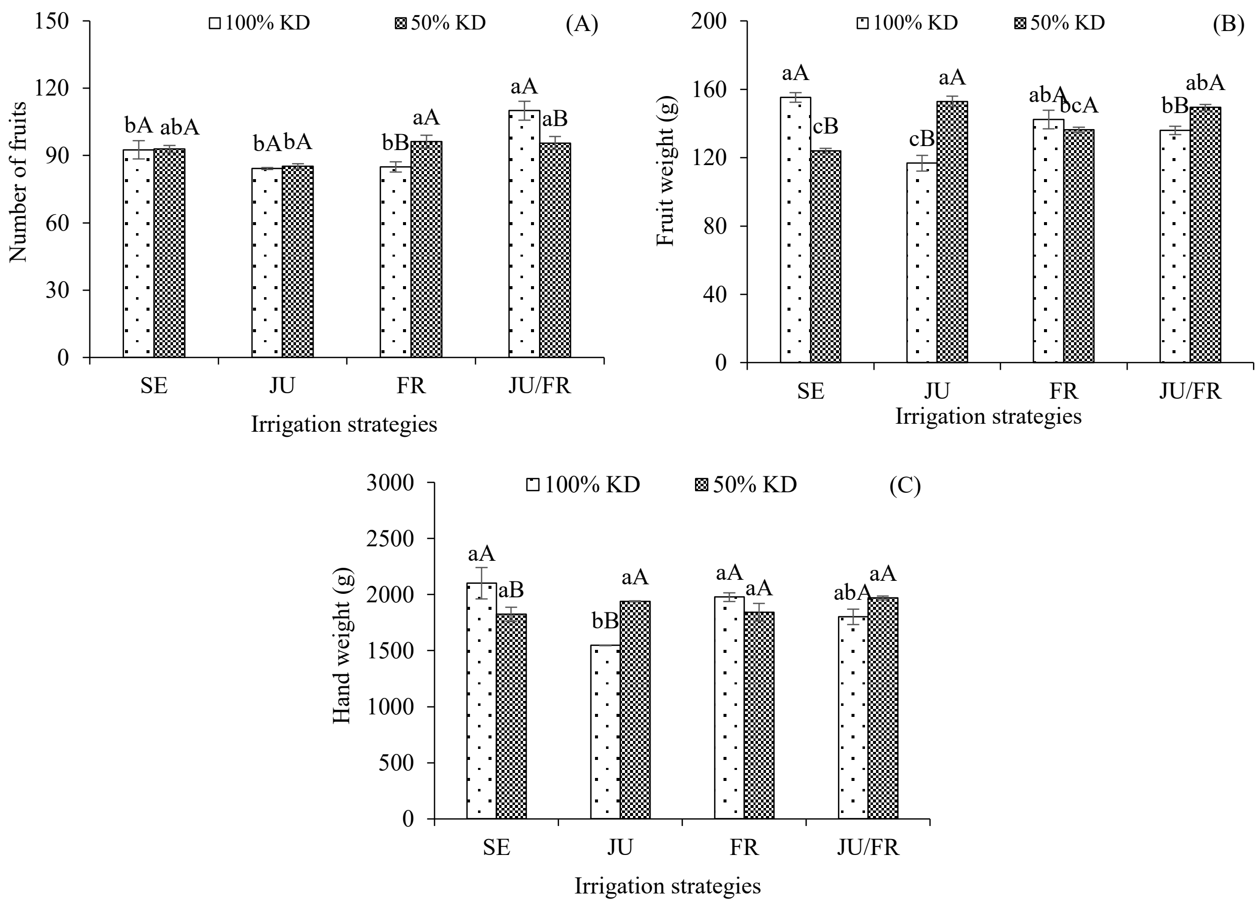
A significant interaction effect between the factors (IS × KD) was found for the number of fruits (NFRU), fruit weight (FW), and hand weight (HW) of banana plants cv. Nanicão, at 344 days after planting (Table 3). The number of hands (NH) was not significantly affected by any source of variation.

For the number of fruits (NFRU), it was observed that when plants were fertilized with 100% of the K_2O recommendation, the highest value obtained was 110 fruits, occurring under water deficit during the juvenile/fruiting phases (JU/FR). This was statistically superior to the other strategies (SE, JU, and FR), which had an average of 92.50, 84.22, and 84.88 fruits, representing reductions of 15.90%, 23.46%, and 22.83%, respectively (Figure 4A). However, when fertilization was reduced to 50% of the recommendation, plants cultivated under water deficit in the FR and JU/FR phases obtained the highest values (96.22 and 95.55 fruits), differing statistically from those under the JU strategy. It is noteworthy that the high translocation of potassium to the banana bunch directly influences fruit formation (OLIVEIRA et al., 2024).

Table 3. Summary of the analysis of variance for number of fruits (NFRU), number of hands (NH), fruit weight (FW), and hand weight (HW) of banana cv. Nanicão grown under water deficit irrigation strategies and potassium doses, at 344 days after planting.

Sources of Variation	DF	Mean squares			
		NFRU	NH	FW	HW
Irrigation Strategies (IS)	3	339.60**	0.04^{ns}	63.00^{ns}	52771.41*
Blocks	2	49.59^{ns}	1.45^{ns}	16.31^{ns}	7246.40^{ns}
Error 1	6	23.47	0.33	31.64	10232.26
Potassium Doses (KD)	1	1.11^{ns}	0.14^{ns}	55.82^{ns}	8068.73^{ns}
Interaction (IS × KD)	3	168.74**	0.15^{ns}	1233.35**	136876.93**
Error 2	8	14.85	0.27	32.78	17681.20
CV1	-	5.23	8.34	4.04	5.39
CV 2	-	4.16	7.53	4.12	7.09

DF - Degrees of freedom; CV (%) - Coefficient of variation; * significant at $p \leq 0.05$; ** significant at $p \leq 0.01$ probability; ^{ns} not significant by the F-test ($p > 0.05$).



SE - without water stress; JU - water deficit in the juvenile phase; FR - water deficit in the fruiting phase; JU/FR - water deficit in the juvenile and fruiting phases. Means followed by the same lowercase letter do not differ significantly (Tukey, $p > 0.05$) among irrigation strategies for the same potassium dose; means followed by the same uppercase letter do not differ significantly (F-test, $p > 0.05$) between potassium doses within the same irrigation strategy. Vertical bars represent the standard error of the mean (n=3).

Figure 4. Number of fruits (A), fruit weight (B), and hand weight (C) of banana plants cv. Nanicão, as a function of the interaction between water deficit irrigation strategies (IS) and potassium doses (KD), at 344 days after planting.

Regarding fruit weight (FW) (Figure 4B), it was observed that plants fertilized with 100% of the K_2O recommendation obtained the highest values under full irrigation (SE) and under water deficit in the fruiting phase (FR), differing significantly from those cultivated under deficit irrigation in the juvenile phase (JU). However, there were no significant differences in FW between plants subjected to deficit irrigation in the FR and JU/FR phases.

When fertilization was reduced to 50% of the recommendation, it was observed that the control plants (SE) showed the lowest fruit weight (123.97 g), a value that was increased by 23.31% and 20.53% in the deficit irrigation strategies during the JU and JU/FR phases, respectively. In plants under deficit irrigation in the JU and JU/FR phases, the 50% K_2O fertilization resulted in a FW superior to that obtained in those cultivated under 100% ETc (SE). This demonstrates that the solute flux in plants under water restriction can be maintained even with restricted potassium fertilization, likely due to absorption selectivity, coupled with root growth favoring the absorption of potassium already present in the soil, as reported in recent research (OLIVEIRA et al., 2024).

Regarding hand weight (Figure 4C), it was observed that under fertilization with 100% of the K_2O recommendation, the highest value obtained was 2,102 g, in plants under full irrigation throughout the cycle (SE); this was statistically superior only to the value of plants under water deficit during the juvenile phase (JU). When fertilization was reduced to 50% of the K_2O recommendation of Cavalcanti et al. (2008), there was no statistical difference among the irrigation strategies. Nevertheless, the pattern of loss in the control plants was maintained, as they showed a 13.25% reduction in hand weight under 50% fertilization compared to those that received 100% of the K_2O recommendation. This highlights that plants under full irrigation did not show acclimation to the nutritional reduction, likely due to maintaining a more frequent transpiration stream, which facilitates nutrient absorption. Consequently, the potassium restriction may have led to damage in phytomass accumulation in the fruits (ALCÂNTARA et al. 2021).

A significant interaction effect between the factors (IS × KD) was observed for bunch weight (BW) and yield (Y) of banana cv. Nanicão, at 344 days after planting (Table 4). It was observed that fruit length (FL) and fruit diameter (FD) were not affected by any of the sources of variation.

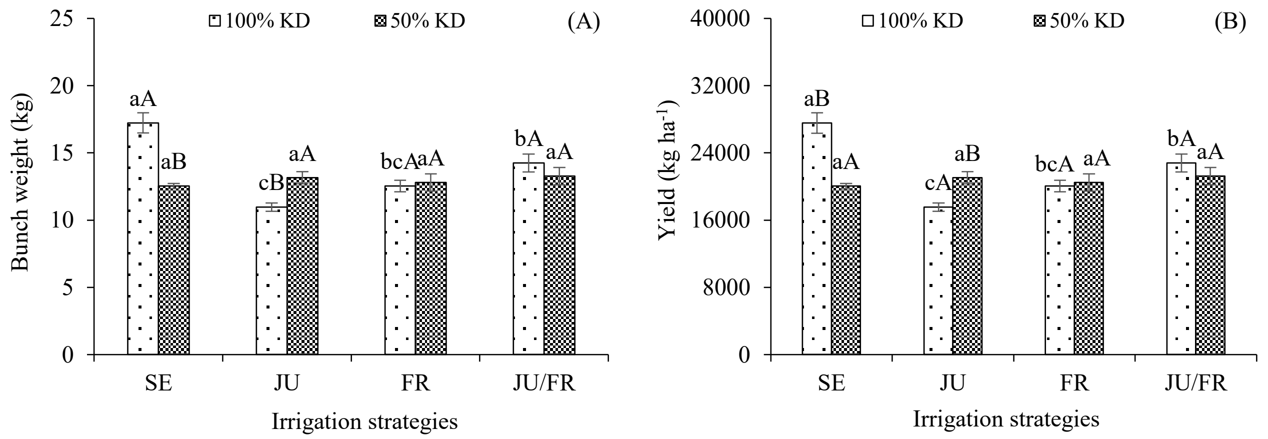
Table 4. Summary of the analysis of variance for bunch weight (BW), fruit length (FL), fruit diameter (FD), and yield (Y) of banana cv. Nanicão under irrigation strategies and potassium doses, at 344 days after planting.

Sources of Variation	DF	Mean squares			
		BW	FL	FD	Y
Irrigation Strategies (IS)	3	9.25**	4.85^{ns}	4.18^{ns}	23691584.10**
Blocks	2	0.49^{ns}	0.29^{ns}	0.96^{ns}	1262781.28^{ns}
Error 1	6	0.51	2.46	0.97	13.255519.33
Potassium Doses (KD)	1	3.97^{ns}	0.12^{ns}	0.39^{ns}	10171571.11^{ns}
Interaction (IS × KD)	3	12.56**	1.24^{ns}	1.93^{ns}	32168026.64**
Error 2	8	1.24	1.67	0.69	3178055.21
CV1	-	5.39	6.16	2.91	5.39
CV 2	-	8.35	5.09	2.46	8.35

DF - Degrees of freedom; CV (%) - Coefficient of variation; * significant at $p \leq 0.05$; ** significant at $p \leq 0.01$ probability; ^{ns} not significant by the F-test ($p > 0.05$).

For bunch weight (Figure 5A), when plants were subjected to 100% K_2O fertilization, the highest value obtained was 17.22 kg, occurring under full irrigation (SE), which was statistically superior to the other strategies (JU, FR, and JU/FR). When potassium fertilization was reduced to 50% of the recommendation, no statistical difference was verified among the adopted management strategies. Comparing the doses within each irrigation strategy, the 100% K_2O recommendation promoted a higher bunch weight (17.22 kg) in the full irrigation (SE) strategy compared to those fertilized with 50% K_2O. However, an inverse behavior was observed when analyzing the results from plants subjected to water restriction in the juvenile phase (JU), where the 50% K_2O dose was 19.78% superior compared to those that received 100% of the potassium fertilization recommendation (Figure 5A). In general, in the present study, the rehydration of plants that were under water restriction during the juvenile phase with 100% potassium fertilization was negatively affected, whereas plants that remained under water deficit throughout the cycle with 100% K_2O recommendation showed better responses to thermal stress (Figure 1).

Regarding yield (Figure 5B), under 100% K_2O fertilization, the highest value obtained was 27,558.04 kg ha^{-1}, when plants did not experience water deficit (SE), which was statistically superior to all other strategies (JU, FR, and JU/FR). When fertilization was reduced to 50% of the recommendation, no significant difference was found among the irrigation management strategies. Furthermore, it is noteworthy that statistical differences between the K doses were only established when the plants did not undergo water deficit (SE), where the 100% K_2O dose promoted higher yield (27,558.04 kg ha^{-1}). However, an inverse behavior can be observed when analyzing the results from plants subjected to water restriction in the juvenile phase, where the 50% K_2O dose resulted in a value superior to that obtained when 100% of the potassium supplementation was applied (Figure 5B).



SE - without water stress; JU - water deficit in the juvenile phase; FR - water deficit in the fruiting phase; JU/FR - water deficit in the juvenile and fruiting phases. Means followed by the same lowercase letter do not differ significantly (Tukey, $p > 0.05$) among irrigation strategies for the same potassium dose; means followed by the same uppercase letter do not differ significantly (F-test, $p > 0.05$) between potassium doses within the same irrigation strategy. Vertical bars represent the standard error of the mean (n=3).

Figure 5. Bunch weight (A) and yield (B) of banana plants cv. Nanicão, as a function of the interaction between irrigation strategies (IS) and potassium doses (KD), at 344 days after planting.

CONCLUSIONS

Water deficit applied continuously during the juvenile and fruiting phases reduces stomatal conductance and transpiration, while water deficit during the fruiting phase alone compromises the CO_2 assimilation rate. Banana plants exposed to water deficit during the juvenile phase combined with 50% of the K_2O recommendation, and those exposed during the juvenile/fruiting phases with 100% of the potassium recommendation, exhibited the greatest physiological acclimation to water deficit conditions. This acclimation occurred, however, despite yield losses relative to plants irrigated with 100% of the crop evapotranspiration and fertilized with 100% K_2O.

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