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Fruit production and quality of 'Paluma' guava with nematode-tolerant rootstock irrigated in the semi-arid region[1]

Produção e qualidade de frutos de goiaba 'Paluma' com porta-enxerto tolerante a nematoides irrigados no semiárido

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HIGHLIGHTS:

Nematode-tolerant rootstock increases the efficiency of irrigated guava cultivation in the Brazilian semi-arid region.
The use of 'BRS Guaraçá' rootstock is feasible mainly in the second half of the year for the Brazilian semi-arid region.
Irrigation depth of 120% ETc increases the production of 'Paluma' guava with 'BRS Guaraçá' rootstock.

ABSTRACT: Using nematode-resistant and/or -tolerant rootstock is a strategy that has maintained guava cultivation feasible in the irrigated perimeters of the Brazilian semi-arid region. The objective was to evaluate the production, gas exchange, and fruit quality of 'Paluma' guava with and without nematode-tolerant rootstock under different irrigation depths and production periods. The experimental design was randomized blocks, in the mixed 2 × 4 × 2 factorial scheme, corresponding to two forms of cultivation of 'Paluma' guava (without and with nematode-tolerant rootstock), four irrigation depths (60, 80, 100, and 120% of crop evapotranspiration - ETc), and two production periods, with four replicates. Guava plants were evaluated for physiological, production and post-harvest quality parameters. Gas exchange in 'Paluma' guava leaves was higher in the second production cycle, under irrigation depths above 100% ETc, not differing with the use of the rootstock. The use of the rootstock 'BRS Guaraçá' promotes a greater number of fruits and production with the increase of the irrigation depth, mainly in the second half of the year, with the increase of soluble solids and titratable acidity in the fruits.

Key words: *Psidium guajava* L., evapotranspiration, production, post-harvest, gas exchange

RESUMO: A utilização de porta enxerto resistente e ou tolerante a nematoides é uma estratégia que tem tornado viável a manutenção dos cultivos de goiabeira nos perímetros irrigados do semiárido brasileiro. Assim, o objetivo foi avaliar a produção, trocas gasosas e qualidade dos frutos da goiabeira 'Paluma' com e sem o porta enxerto tolerante a nematoide sob diferentes lâminas de irrigação e épocas de produção no Semiárido Brasileiro. O delineamento experimental foi em blocos ao acaso, no esquema fatorial misto 2 × 4 × 2, sendo duas formas de cultivo da goiabeira 'Paluma' (sem e com o porta enxerto tolerante a nematoide), quatro lâminas de irrigação (60, 80, 100 e 120% da evapotranspiração da cultura - ETc) e duas épocas de produção, com quatro repetições. Foram realizadas avaliações fisiológicas das plantas, produção e qualidade pós-colheita. As trocas gasosas nas folhas da goiabeira 'Paluma' foram maiores no segundo ciclo de produção, quando irrigada com lâminas de irrigação acima de 100% da ETc, não diferindo com o uso do porta enxerto. O uso do porta-enxerto 'BRS Guaraçá' proporciona um maior número de frutos e produção com o aumento da lâmina de irrigação, principalmente no segundo semestre do ano, bem como o aumento do teor de sólidos solúveis e acidez nos frutos.

Palavras-chave: *Psidium guajava* L., evapotranspiração, produção, pós-colheita, trocas gasosas

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Introduction

‘Paluma’ guava is one of the main crops exploited in the Sub-Middle São Francisco Valley, being mostly cultivated under localized irrigation, which, when well-managed, has promoted increments in yield (Vitti et al., 2020). However, edaphoclimatic conditions and biotic and abiotic stresses interfere with the performance of crops, affecting the production potential of each genetic material (Bhat et al., 2020; Oliveira et al., 2020; Simões et al., 2020).

In addition, one of the limiting factors for the maintenance and expansion of guava cultivation areas in the Sub-Middle São Francisco Valley is the presence of nematodes of the genus *Meloidogyne*, which are considered the key pest of guava in the region (Singh, 2020). According to Pereira et al. (2009), in 2008 this nematode affected about 5,000 ha of guava in several states of Brazil, causing a sharp decrease in yield and the death of plants.

A strategy that has shown to be feasible for coping with the nematodes and for the maintenance of guava plantations is the use of nematode-resistant and/or -tolerant rootstocks (Oliveira et al., 2019). According to Souza et al. (2018), the hybrid of *P. guajava* × *P. guineense* has good resistance to the nematode *Meloidogyne enterolobii*.

For proper irrigation management, it must be considered that both the deficit and excess of water in the soil cause stress to the plant (Campos et al., 2021), interfering with fruit production and quality (Simões et al., 2021), so knowledge of the water demand is necessary to provide the appropriate irrigation management for the crop and guarantee its viability. Thus, the objective of this study was to evaluate the production, gas exchange, and fruit quality of ‘Paluma’ guava with and without the nematode-tolerant rootstock, under different irrigation depths and production periods in the Brazilian semi-arid region.

Material and Methods

The experiment was conducted in two cycles, the 1st from January to June and the 2nd from July to December, 2018, in the Experimental Field of Bebedouro, belonging to the Embrapa Semi-arid Region, located in the municipality of Petrolina-PE, Brazil (9° 09’ South latitude, 40° 22’ West longitude, and average altitude of 365 m), in an Argissolo Vermelho-Amarelo (Ultisol) (Bockheim et al., 2014). According to Köppen’s classification, the climate of the region is BSh type, hot semi-arid, with summer rains. The mean, minimum, and maximum monthly temperatures and daily reference evapotranspiration during the experimental period are presented in Figure 1.

The experimental design was randomized blocks, in a mixed 2 × 4 × 2 factorial scheme, corresponding to two forms of cultivation of ‘Paluma’ guava (with and without nematode-tolerant ‘BRS Guaraçá’ hybrid rootstock), whose rootstocks were obtained by rooting cuttings, that is, clones of the same plant, four irrigation depths (60, 80, 100, and 120% of crop evapotranspiration - ETc) and two production periods (first and second half of the year), with four replicates.

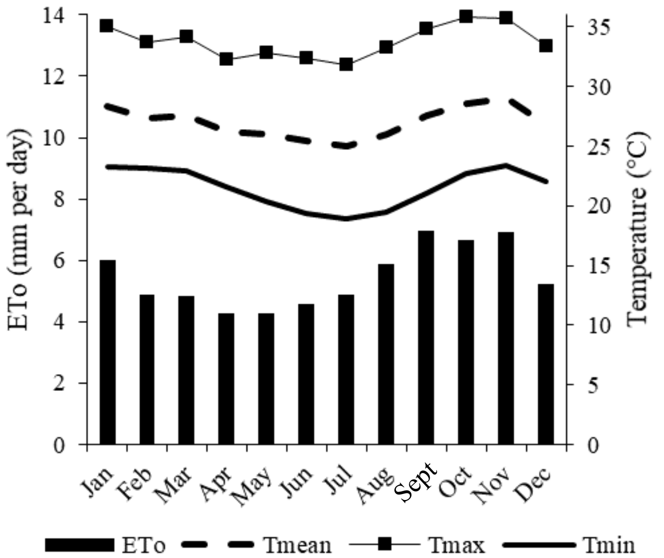


Figure 1. Average daily reference evapotranspiration (ETo) and monthly averages of minimum (Tmin), mean (Tmean), and maximum (Tmax) temperatures of the year 2018, in Petrolina-PE

ETc was obtained from the product between reference evapotranspiration (ETo) determined using the Penman-Monteith equation, with data from a weather station installed near the experimental area, and crop coefficient (0.61 to 0.84) indicated by Teixeira et al. (2003) and location coefficient (KL), according to Eq. 1. Irrigation was applied by a micro-sprinkler system, with one emitter per plant and average unit flow rate of 38 L h^{-1}, with daily irrigation interval.

$$KL = 0.1\sqrt{PM} \quad (1)$$

The crop was two years old at the beginning of the first cycle evaluated, with plants spaced 6.0 × 4.0 m apart. The experimental plots were composed of four plants, considering the two central plants as usable. During the experiment, the routine practices of a commercial guava orchard were performed, with pruning after harvest. All other cultural practices, with production pruning, fertigation, and top-dressing fertilization, and foliar and pre-harvest fertilization, were carried out according to the results of the soil analysis and following recommendations from the Agronomic Institute of Pernambuco (Cavalcanti, 2008). The nematodes are endemic to the Bebedouro Experimental Field of the present study and surrounding areas.

Harvests of the first and second cycle were carried out in the first and second half of 2018.

At 150 days after pruning (DAP), the physiological evaluations of the plants subjected to the treatments performed in the two production cycles were: photosynthesis, stomatal conductance, and transpiration, measured by the Infrared Gas Analyzer - IRGA (Model Li 6400 Licor®). The analyses were carried out in the fruiting stage of the crop, between 10:00 and 12:00 a.m. on cloud-free days, in physiologically mature leaves, in the second third of branches with fruits, exposed to the sun and free of mechanical damage, symptoms of nutritional deficiency, pests, and diseases.

At 180 DAP, in the "semi-ripe" maturation stage, harvest was carried out for four weeks, and the fruits harvested from the observation plants were counted and weighed to determine the number of fruits per plant, average fruit weight, and yield. A sample of five fruits was placed in plastic bag and sent to the Post-harvest Laboratory of Embrapa Semi-arid Region. The fruits were peeled and the pulp was homogenized in a domestic juice processor, for analysis of soluble solids (SS) content, determined by manual refractometer (Pocket PAL model), and titratable acidity (TA), determined by titration of 1 g of homogenized pulp diluted in 50 mL of distilled water, using three drops of 1% phenolphthalein indicator, with titration carried out with a digital burette, under constant shaking, with 0.1 N NaOH solution, and the results expressed in g of citric acid per 100 g of pulp.

The collected data were subjected to analysis of variance, follow-up of interactions when significant and application of Tukey test for comparison of means at 0.05 probability level for qualitative factors (forms of cultivation and cycles) and regression analysis for quantitative factors (irrigation depths) were performed using Sisvar software.

Results and Discussion

The results of the analysis of variance of the data collected are described in Table 1.

Gas exchange (photosynthesis, stomatal conductance, and transpiration) was significantly influenced by irrigation depths and production periods, as observed by the forms of cultivation in Figure 2.

The results in Figure 2 show that both excess and scarcity of water caused partial closure of the stomata, which is an essential mechanism for plant survival under different soil moisture conditions (Simões et al., 2018; Ghafari et al., 2020; Gupta et al., 2020; Li et al., 2020). The highest levels of photosynthesis (Figures 2A and D), stomatal conductance (Figures 2B and E) and transpiration (Figures 2 C and F) in the cultivation with the rootstock were estimated for irrigation of 107.4, 108.3, and 117.3% ETc in the first half of the year and 114.4, 117.5, and 112.0% in the second half of the year, respectively. In the cultivation of 'Paluma' guava without the rootstock, the highest levels were estimated for irrigation of 125.0, 105.0, and 125.2% ETc in the first half of the year and 106.2, 125.0, and 90.8% ETc in the second half of the year, respectively.

The results of stomatal conductance and transpiration for the second half of the year were higher than those found by Bezerra et al. (2018), working with 'Paluma' guava in Campina Grande, Paraíba. This difference may have occurred because higher temperatures were observed in this experiment compared to that of Bezerra et al. (2018), since high temperatures cause greater gas exchange in plants according to Taiz & Zeiger (2017). This also explains the fact that the lowest gas exchange occurred in the first half of the year (Figures 1 and 2). The weather conditions observed in the cycle of the first half of the year, with lower evapotranspiration, possibly led to the lowest gas exchange compared to the second half of the year.

'Paluma' guava with the rootstock 'BRS Guaraçá' produced more fruits than guava cultivated without the rootstock in the two halves of the year (Figure 3), demonstrating adaptability between them to this form of cultivation.

The higher fruit yield with the rootstock 'BRS Guaraçá' is associated with its resistance to the nematode *Meloidogyne enterolobii*, which is a key pest of the crop in the region, according to Souza et al. (2018), being endemic to the Experimental Field of Bebedouro and surrounding areas. Thus, this resistance of the rootstock 'BRS Guaraçá' can improve crop yield since the occurrence of the pest causes progressive rot of the root system and leaf burn, resulting in production losses and plant death.

The number of fruits was higher in the cycle of the second half of the year (Figure 3A), the hottest season (Figure 1), for the two forms of cultivation, a result similar to that found by Ramos et al. (2011), who observed that the best time of pruning for the production of 'Paluma' guava is August. However, it is worth mentioning that, in the present study, the forms of cultivation tested led to higher number of fruits with average temperatures close to 28 °C during the fruiting stage.

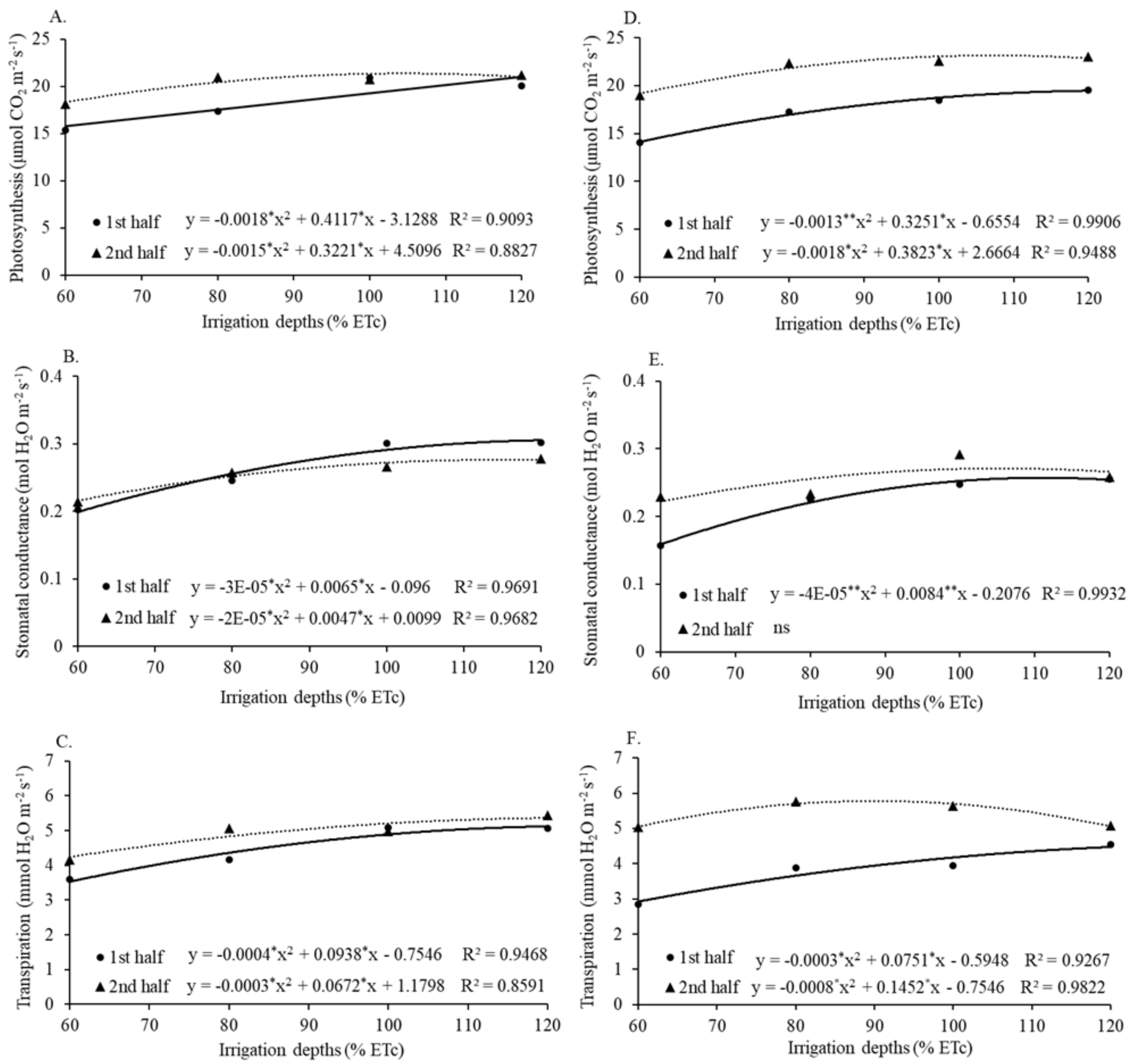
There was interaction between irrigation depths and production cycles (Figure 3B). In the cycle of the second half of the year, the increase in irrigation depth increased the number of fruits produced, with the maximum values obtained under the irrigation depth of 120% ETc for the two forms of cultivation, equal to 690 fruits per plant in 'Paluma' guava without grafting and 791 fruits per plant in 'Paluma' guava with the rootstock, which may be associated with the higher water requirement of the crop, caused by the higher temperatures in this production period.

Moreover, it is worth pointing out that this type of system can provide a microclimate conducive to the development of plants, considering that in this situation the relative humidity can become high due to the water droplets in suspension, reducing the temperature of the environment and influencing

Table 1. Summary of analysis of variance of the variables analyzed

SV	DF	Pho	SCo	Tr	MFPP	FW	Prod	SS	TA
Block (B)	3	2.856	0.000098	0.09254	200.57	4360.32	145.61	1.45	0.035
Form (F)	1	16.352*	0.003326*	2.28741*	144.26*	1530.44*	42.47*	1.59	0.014*
Depth (D)	3	0.244*	0.000482*	0.007112*	264.43*	8995.36*	205.03*	3.80	0.003
Cycle (C)	1	7.360*	0.000007*	1.54231*	50.51*	25451.87*	1080.32	21.77*	2.871
F × D	3	0.005	0.0000054	0.000058	4.14*	2109.02*	55.38*	1.23	1.690
F × C	1	2.971*	0.0000008*	0.007965*	51.67*	877.54*	54.78*	0.81*	0.881*
D × C	3	0.567	0.0000005	0.008788	188.52*	5098.23*	15.32*	0.49	0.768
F × D × C	3	0.0001	0.00000001	0.000007	42.71*	1430.01*	18.96*	0.25	0.299
Error	45	0.111	0.000005	0.005316	112.19	3037.10	32.44	0.71	0.874
CV (%)		5.40	5.14	4.95	15.77	9.13	12.07	10.33	13.74

* - Significant at $p \leq 0.05$ by F test; Pho - Photosynthesis; SCo - Stomatal conductance; Tr - Transpiration; MFPP - Marketable Fruits per plant; FW - Fruit weight; Prod - Production per plant; SS - Soluble solids; TA - Titratable acidity; CV - coefficient of variation



* - Significant at 0.05 probability level; ** - Significant at 0.01 probability level

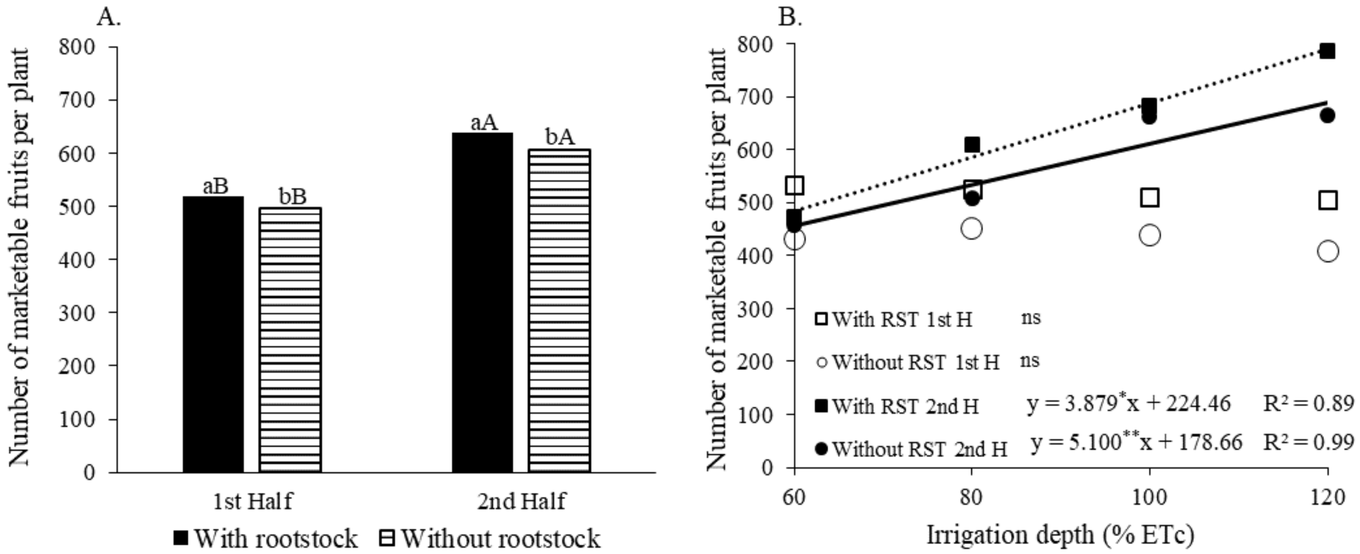
Figure 2. Photosynthesis (μmol CO_2 m^{-2} s^{-1}), stomatal conductance (mol H_2O m^{-2} s^{-1}) and transpiration (mmol H_2O m^{-2} s^{-1}) of leaves of 'Paluma' guava with 'BRS Guaraçá' rootstock (A, B and C) and without the rootstock (D, E and F), in two production periods (1st and 2nd half of the year), subjected to different irrigation depths

the processes of photosynthesis and transpiration, which affects the production of photoassimilates (Taiz & Zeiger, 2017). In the cycle of the first half of the year, there was no difference in the number of fruits per plant as a function of the applied irrigation depth, with means of 519.90 and 432.75 fruits per plant, with and without the rootstock, respectively.

In the cycle of the first half of the year, the fruits harvested had higher average weight in the two forms of cultivation, when compared to the cycle of the second half of the year (Figure 4A). This result was possibly a consequence of the lower number of fruits per plant, resulting in fewer fruits acting as a sink of photosynthetic production. The results, however, were higher than those found by Lima et al. (2002), who reported an average fruit weight of 0.104 kg for 'Paluma' guava in the Sub-Middle São Francisco Valley.

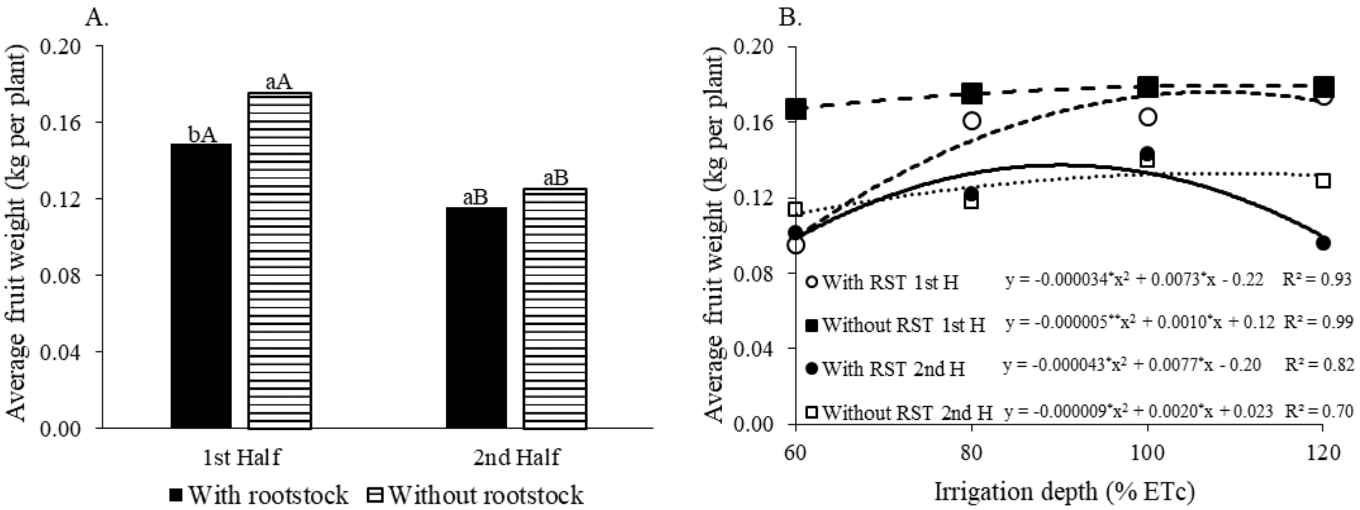
Irrigation depths also influenced the average fruit weight (Figure 4B). In the first cycle, the highest average fruit weight was estimated for irrigation depths of 107.4 and 100.0% ETc, for cultivation with and without the rootstock, respectively. In the second cycle, the maximum average fruit weight was estimated with 107.5 and 111.1% ETc for cultivation with and without the rootstock, respectively.

Considering that guava has more than 80% of water in its fresh mass, the water potential of the plant has a direct influence on the growth and cell division of fruits (Naing & Kim, 2021). Insufficient as well as excessive water supply induces stomatal closure, thus avoiding the reduction in the water potential. However, this response negatively affects various physiological processes such as transpiration and photosynthesis, causing a reduction in fruit weight (Simões et al., 2018).



* - Significant at 0.05 probability level; ** - Significant at 0.01 probability level; ns – non-significant at 0.05 probability level. Different lowercase letters indicate difference between forms of cultivation. Different uppercase letters indicate difference between production cycles. 1[st] H - 1[st] half, 2[nd] H - 2[nd] half. RST - rootstock

Figure 3. Number of marketable fruits per plant of 'Paluma' guava with the rootstock 'BRS Guaraçá' and without the rootstock, in two production periods (1[st] and 2[nd] half of the year) (A) and as a function of different irrigation depths (B)



* - Significant at 0.05 probability level. ** - Significant at 0.01 probability level. Different lowercase letters indicate difference between forms of cultivation. Different uppercase letters indicate difference between production cycles. 1[st] H - 1[st] half, 2[nd] H - 2[nd] half. RST - rootstock

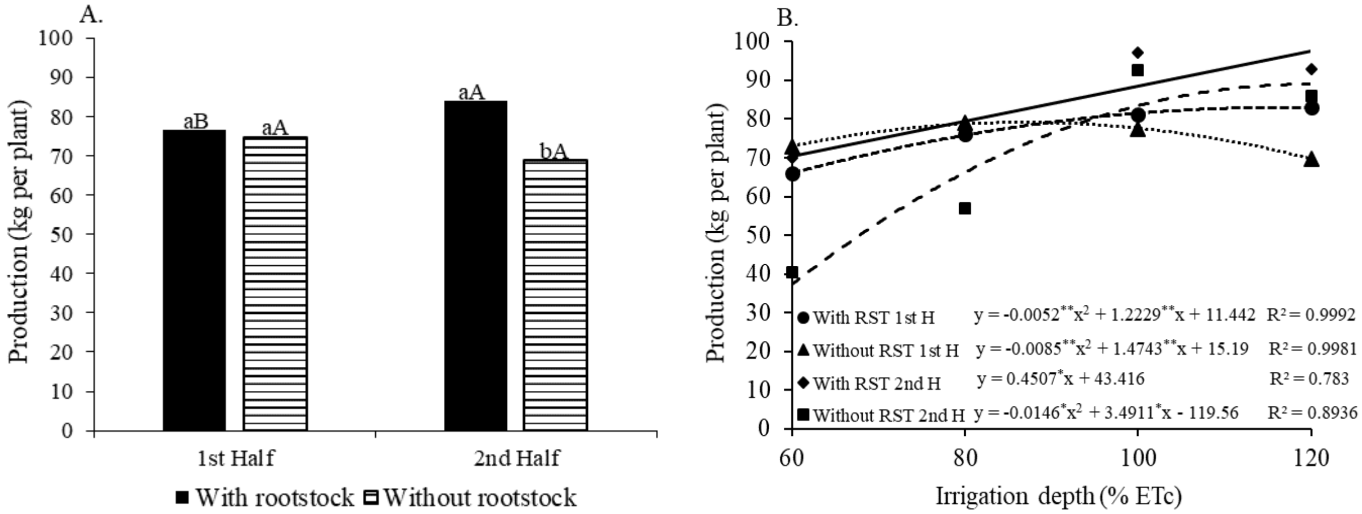
Figure 4. Average fruit weight of 'Paluma' guava with and without 'BRS Guaraçá' rootstock in two production periods (1[st] and 2[nd] half of the year) (A) and as a function of different irrigation depths (B)

Regarding production, there was interaction between the forms of cultivation and the production cycles (Figure 5). In the first cycle, there was no difference between the values of production per plant with the two forms of cultivation, because while the cultivation with the rootstock led to more fruits, without the use of rootstock there was higher average fruit weight. In the second cycle, there was no difference between the values of fruit weight, and the cultivation with the rootstock resulted in more fruits, leading to higher production (Figure 5A).

The greatest difference in the number of fruits and yield, as a function of the use or not of the rootstock in the second cycle, may be associated with increased infestation of *M. enterolobii* over time, which has become a limiting factor in the production of 'Paluma' guava (Pereira et al., 2009). This result corroborates that reported by Souza et al. (2018), who found that the rootstock 'BRS Guaraçá' is resistant to the nematode *Meloidogyne enterolobii*, so the production potential of the plant can be maintained despite the infestations, which did not occur in the treatment without the use of rootstock in the second cycle.

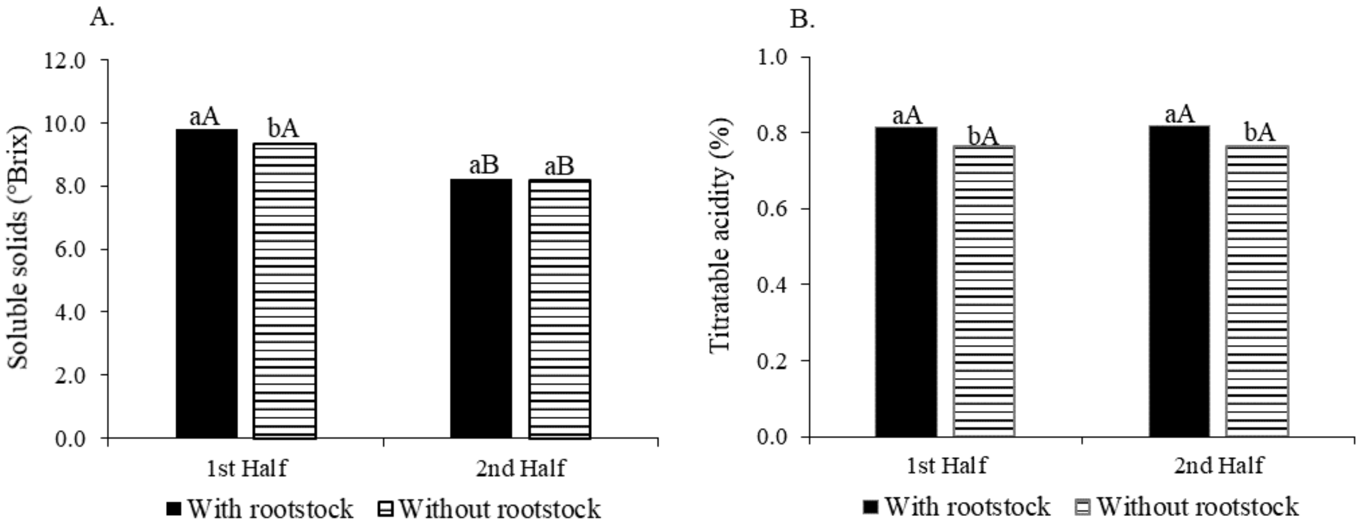
Irrigation depths also influenced production (Figure 5B). The estimates of the maximum production values in the first cycle were 83.34 and 79.11 kg per plant with irrigation depths of 117.6 and 86.7% ETc, for cultivation with and without the rootstock, respectively. In the second cycle, the estimates of the maximum production were 97.50 and 89.13 kg per plant with irrigation depths of 120.0 and 119.6% ETc, for cultivation with and without the rootstock, respectively.

The values of production were high when compared to those obtained by Alencar et al. (2016), who reported production of 30 kg per plant for irrigated 'Paluma' guava in the semi-arid region of Rio Grande do Norte state. Considering the average quantity of 416.66 plants per hectare, the fruit yield presented was above the national average, which is 24.9 t ha^{-1} (IBGE, 2021), with the exception of cultivation without rootstock when



* - Significant at 0.05 probability level. ** - Significant at 0.01 probability level. Different lowercase letters indicate difference between forms of cultivation. Different uppercase letters indicate difference between production cycles. 1st H - 1st half, 2nd H - 2nd half. RST - rootstock

Figure 5. Production per plant of ‘Paluma’ guava with and without the rootstock ‘BRS Guaraçá’ in two production periods (1st and 2nd half of the year) (A) and as a function of different irrigation depths (B)



Different lowercase letters indicate difference between forms of cultivation. Different uppercase letters indicate difference between production cycles

Figure 6. Soluble solids content and titratable acidity in fruits of ‘Paluma’ guava with and without the rootstock ‘BRS Guaraçá’, in two production periods (1st and 2nd half of the year)

irrigated with 40 and 60% ETc, which resulted in fruit yield of 16.83 and 23.71 t ha^{-1}, respectively.

Regarding soluble solids content and titratable acidity, there was interaction between the forms of cultivation and the production cycles (Figure 6).

The soluble solids content was higher for the two forms of cultivation in the first production cycle (Figure 6A), which can be explained by the lower fruit production and the source-sink ratio, as also observed by Lins et al. (2013). Cultivation with the rootstock promoted fruits with higher soluble solids content in the first cycle and higher titratable acidity in both cycles, possibly due to its tolerance to *M. enterolobii*, with less damage to the roots and leaves and with no reduction in its photosynthetic production. In the second cycle, cultivation with the rootstock led to a considerably higher production, which possibly explains the reduction in soluble solids content.

According to Cavalini et al. (2015), the adequate content of soluble solids for the harvest of ‘Paluma’ guava is 7.6 °Brix, and the titratable acidity is 0.7%, parameters that were achieved in all treatments of the present study (Figures 6A and B).

Martins et al. (2020), when evaluating the performance of guava cultivars in irrigated and rainfed environments, found that supplemental irrigation interfered in the total soluble solids content of guava fruits, differing from the present study. Both deficit and excess of water cause stomatal closure as they became stressful factors, thus reducing the absorption of CO_2, substrate of photosynthesis and, consequently, the production of photoassimilates such as sugars and organic acids (Taiz & Zeiger, 2017). However, as it reduces the soluble solids content and acidity, water stress also causes a reduction in yield, maintaining the source-sink ratio, which possibly explains the fact that these variables remain constant with the different irrigation depths tested.

Conclusions

1. ‘Paluma’ guava cultivation with the rootstock ‘BRS Guaraçá’ promotes a greater number of fruits and production

with the increase in irrigation depth, especially in the second half of the year;

2. The highest gas exchange rates for 'Paluma' guava, with and without the rootstock 'BRS Guaraçá', were obtained in the production cycle of the second half of the year, in the Sub-Middle São Francisco Valley, with irrigation requirement above 100% ETc;

3. Cultivation with the rootstock 'BRS Guaraçá' promotes fruits with higher soluble solids and titratable acidity.

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