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Effects of sunscreen protection and water management on the physiology and production of 'Pera' sweet orange orchards in sub-humid climate

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Abstract: The risks associated with climate events are the main factors responsible for sweet orange production losses in Brazil. For rainfed citrus cultivation, it is mainly due to soil water deficit, but also to citrus cultivation associated with extreme temperatures. The present study investigated the effects of water management in 'Pera' sweet orange orchards under sub-humid climate conditions and application of calcium carbonate-based sunscreen on the plant canopy, aiming to mitigate the effects of abiotic stresses on orchard physiology, production, and irrigation water use efficiency. The experimental design was in randomized blocks in a 3 x 2 factorial scheme. Treatments for water management factor were: full irrigation (100% ETc), irrigation with moderate deficit (65% ETc), and no irrigation; and for sunscreen protection: sunscreen use and no sunscreen. The factors have impacted gas exchange, fruit quality, and orchard yield. There was no isolated effect of soil water management on orchard productivity, but with sunscreen, citrus plants are more resilient based on gas exchange data, mitigating environmental effects (high temperatures and water deficit), resulting in improvements in fruit quality related to total fruit mass in plants grown without irrigation and with 12% increase in orchard productivity, regardless of soil water management. Productivity gains related to sunscreen indicate the need for the use of sunscreen protection regardless of soil water management in the region.

Index terms: Citrus, drip irrigation, deficit irrigation, physiological indicators, gas exchange, rainfed cultivation, irrigation water use efficiency, sunscreen.

Efeitos da proteção solar e do manejo de água na fisiologia e produção de pomar de laranja 'Pêra' em clima subúmido

Resumo: Os riscos associados aos eventos climáticos são os principais responsáveis pelas perdas de produção de laranja no Brasil. No caso da citricultura de se-

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queiro, principalmente pelos eventos de déficit hídrico no solo, mas também para citricultura em geral, quando associados aos extremos de temperatura. O presente trabalho investigou os efeitos do manejo de água em pomar de laranjeira ‘Pera’, em condições de clima subúmido, e da aplicação de protetor solar à base de carbonato de cálcio, no dossel vegetativo das plantas, visando a mitigar os efeitos dos estresses abióticos na fisiologia, produção e eficiência de uso de água de irrigação. O delineamento experimental foi em blocos casualizados, em esquema fatorial 3 x 2. Os tratamentos para o fator manejo de água: irrigação plena (100% ETc), irrigação com déficit moderado (65% ETc) e ausência de irrigação; e para proteção solar: uso de protetor solar e ausência de protetor. Houve impacto dos fatores estudados nas trocas gasosas, na qualidade de frutos e na produção do pomar. Não houve efeito isolado do manejo de água na produtividade do pomar, mas o uso do protetor solar tornou plantas de citros mais resilientes com base nas trocas gasosas, mitigando os efeitos ambientais (elevadas temperaturas e déficit hídrico), implicando em melhorias na qualidade de frutos relacionadas à massa total de frutos em plantas cultivadas sem irrigação e aumento de 12% da produtividade do pomar, independentemente do manejo de água. Os ganhos na produtividade, relacionados ao uso de protetor solar, indicam relevância da prática da proteção solar, independentemente do manejo de água do pomar na região.

Termos para indexação: citros, irrigação por gotejamento, déficit de irrigação, indicadores fisiológicos, trocas gasosas, cultivo em sequeiro, eficiência de uso de água de irrigação, proteção solar.

Introduction

The Brazilian citrus farming has orange as the main fruit produced, placing Brazil as the world’s largest orange producer, and most of production is intended for the juice processing industry (ESTER, 2014). Brazil produces 16.21 million tons of oranges per year (IBGE, 2021), accounting for 34% of world’s orange production and more than half of the juice produced, being, therefore, an activity of great economic importance for the country, which production chain is demanding in terms of labor, generating employment, impacting the economy not only of producing municipalities, but also of surrounding ones (NEVES;TROBIN, 2017).

The Northeastern region of Brazil occupies third place in national production, with emphasis on the states of Bahia and Sergipe, the fourth and fifth most productive states in the region, respectively. However, it is the region with the worst average productivity (IBGE, 2017). In general, low average productivity is linked to a set of factors, among them insufficient fertilization and water deficiency, which occur due to rainfall below requirements and/or with irregular rainfall distribution during the year (COELHO et al., 2011). Water deficiency, associated with the high temperatures that plants are subjected to for a good part of the year, is a limiting factor for orange production.

Some chemical compounds have been applied to plants with the aim of improving productive performance, acting as a protection against thermal stress and high radiation incidence. Foliar chemicals used to mitigate transpiration can act in the transpiration process through partial stomata obstruction and increased reflection of solar radiation, reducing the leaf temperature gradient (EL-KHAWAGA, 2013).

The use of a calcium carbonate-based product induces photoprotection through maintenance of physiological activity, reducing damage caused by abiotic stress, improving the initial performance of coffee seedlings (SOELA et al., 2023).

It also provided benefits in grapevines, resulting in increased sucrose biosynthesis

(CONDE et al., 2018). In "murcott" tangerine, spraying with carbonate calcium reduced leaf temperature and reduced damage caused by sunburn on fruits (TSAI et al., 2013). In this crop, the use of kaolin is very widespread in the Semiarid region of Brazil, in the region of Bom Jesus da Lapa-BA, mainly due to high temperatures and solar irradiance, in the second half of the year, mitigating damage caused by sunburn during the fruit development period.

Therefore, the aim of this study was to mitigate abiotic effects on production and increase the water use efficiency and the productive efficiency of plants, evaluating different water management strategies in interaction with sunscreen application.

Material and methods

The experiment was conducted from September 2021 to May 2023 in the municipality of Rio Real, São João farm (11°27'55.9" S and 37°57'57.5" W, altitude of 176 m a.s.l.), located in the Northern Coast region of the state of Bahia, bordering with a citrus producing area in the state of Sergipe, which together form the citrus belt of Sergipe and Bahia.

The climate is As type (hot and humid), according to the Koeppen's classification, with average annual temperature of 24 °C, reaching temperature of 18 °C in the coldest month. The average rainfall is 1000 mm, with a rainy period between the months of April to September and more concentrated rainfall between the months from May to July (SANTANA et al.,2006).

Climatic data regarding air temperature, relative humidity, wind speed and solar radiation were obtained from the automatic station of the National Institute of Meteorology (INMET), located in the municipality of Itabaianinha-SE, 42 kilometers away from the experimental site. Based on these data, the reference evapotranspiration (ETo) was estimated using the Penman-Monteith equation (ALLEN et al., 1998).

$$ET_0 = \frac{0{,}408\,\Delta\,(R_n - G) + \gamma \frac{900}{T_{med} + 273{,}16} U_2 (e_s + e_a)}{\Delta + \gamma(1 + 0{,}34\,U_2)} \quad (1)$$

being Δ the water vapor saturation curve slope (kPa °C^{-1}); Rn the radiation balance (MJ m^{-2} day^{-1}); G the soil heat flux density (MJ m^{-2} day^{-1}); γ the psychrometric factor (MJ kg^{-1}); Tmed the average air temperature (°C); U2 the wind speed 2 meters above the ground (m s^{-1}); e_s the vapor saturation pressure (kPa); and e_a the current steam pressure (kPa).

The daily reference evapotranspiration (ETo) values were multiplied by the orange crop coefficient (kc), which according to Doorenbos and Pruitt (1977), present values that vary according to vegetation cover, depending on the plant size and the presence or absence of weeds; and also multiplied by the canopy coverage percentage (Kr), thus obtaining the crop evapotranspiration value (ETc).

$$ET_c = ET_o \; x \; K_c \; x \; K_r \quad (2)$$

Precipitation data were obtained by a rain gauge installed at the experimental area. In this way, irrigation management was defined based on the crop evapotranspiration values through replacement percentages, which are carried out via drip irrigation for the different treatments under study, with two-day watering regimen.

The soil is classified as a Gray Cohesive Argisol, sandy loam texture with flat topography. Soil samples were collected undisturbed and deformed for soil characterization in the experimental area. For chemical analyses, samples were collected at two depths 0.0-0.20 m and 0.20-0.40 m and for physical analyses, samples were collected at three depths 0.0-0.20 m, 0.20-0.40 m and 0.40-0.60 m, obtaining particle size, soil density and soil water retention analyses (Tables 1, 2 and 3).

Table 1. Result of soil chemical analysis at two depths 0.0-0.20 m and 0.20-0.40 m, São João farm, Rio Real-BA.

Z m	pH	MO g kg^{-1}	P mg dm^{-3}	K	Ca	Mg	Na cmol$_c$ dm^{-3}	H+Al	SB	CTC	V %
0.0-0.2	6.04	11.5	28.9	0.08	1.02	0.41	0.035	0.309	2.62	2.93	89.4
0.2-0.4	4.48	9.04	28.9	0.06	1.02	0.27	0.033	0.672	1.38	2.05	67.3

Table 2. Soil particle size analysis and textural classification at three depths 0.0-0.20 m, 0.20-0.40 m and 0.40-0.60 m, São João farm, Rio Real-BA.

Depth (m)	Total sand	Silt (g kg^{-1})	Clay	Textural classification
0.0 – 0.20	822.9	31.7	145.4	Sandy loam
0.20 – 0.40	724.5	50.9	224.6	Sandy clay loam
0.40 – 0.60	703.7	31.7	264.6	Sandy clay loam

Table 3. Soil density (Ds), water retention and available soil water at three depths 0.0-0.20 m, 0.20-0.40 m and 0.40-0.60 m, São João farm, Rio Real-BA.

Depth (m)	Ds Kg dm^{-3}	Matrix potential (kPa) -33	-1500	Available water
		Soil humidity (%)		
0.0 – 0.20	1.17	8.05	5.16	2.89
0.20 – 0.40	1.40	10.77	6.96	3.81
0.40 – 0.60	1.42	12.23	7.99	4.24

The experiment was installed in a 5-year-old 'Pêra' sweet orange orchard, grafted onto 'Cravo' lemon, with plants spaced 6 x 3 m. The crop was irrigated by drip irrigation, using a line of drippers with flow rate of 2.4 l/h, spaced at 50cm, distributed along the planting line, 60cm away from the plant trunk.

The experimental design was in randomized blocks in a 3 x 2 factorial scheme with five replicates. Each experimental unit consisted of seven plants. Factors corresponding to three water management schemes (two water management irrigation and treatment under rainfed conditions) and phytotechnical management through sunscreen application in the vegetative canopy: (i) treatment with monthly foliar sprays and (ii) without sunscreen application. With regard to water management in the orchard, the following treatments were applied: (i) irrigation (100% of crop evapotranspiration - ETc), (ii) deficit irrigation (65% of crop evapotranspiration - ETc), (iii) without irrigation (0%). It is noteworthy that the citrus farming is predominantly rainfed in the region and on the farm under study.

Soil moisture was monitored based on soil dielectric constant values, which were obtained using RDT (Reflectometry Domain Time) probes, installed according to Coelho et al. (2006). RDT probes were installed in two plants for each treatment and at two depths (0.20 m and 0.60 m), 1.50 m away from the plant trunk, representing the plants' root system zone.

The following plant growth assessments were carried out at the end of the study on May 31, 2023: plant height and crown diameter, obtained using a graduated ruler, from a PVC tube properly graduated in meters, taking the distance from the plant stem, close to the ground, to the top of the plant. Canopy volume (V) (m^3) was also evaluated, determined based on plant height measurements (H) and the average canopy diameter (Dm), the latter being obtained in the line direction (Dl) and in the perpendicular direction (Dr), by V = 2/3 x π x Dm^2/4 x H (POMPEU JUNIOR, 1991).

With the use of an IRGA infrared gas analyzer model LCpro-SD from ADC Bioscientific (Hoddesdon, England), the following physiological evaluations were carried out in the orchard in the driest and hottest period of the year: stomatal conductance to water vapor (g_s, μmol·m^{-2}s^{-1}), transpiration rate (E, mmol. $m^{-2}s^{-1}$), CO_2 assimilation (A, μmol·$m^{-2}.s^{-1}$) and intercellular CO_2 concentration (*ci*, μmol·mol^{-1}) . All measurements were carried out between 8:00 and 10:30 am at 1.5 m above the ground on the second or third fully expanded leaf in branches located at the external part of the plant and fully exposed to direct solar irradiance, with 10 replicates per treatment. The physiological water use efficiency (WUE, μmol·$m^{-2}s^{-1}$.mmol. $m^{-2}s^{-1}$) was estimated by the ratio between A and E.

Productivity analyses were carried out in three harvests, during the harvest period from June 5, 2022 to May 2023, by weighing fruits using a digital platform scale (Win super crown 100). Production efficiency was calculated by the average ratio between the annual plant production and the canopy volume of the respective year, according to the following equation: EP = P/V. EP is the efficiency productive (Kg of fruit.m^{-3} of canopy); P is the total production per plant (kg); and V is the canopy volume (m^3). To determine fruit quality, ten fruits were collected per plant on the outside of the canopy, complying with the uniformity criterion of samples based on the skin color. Then, fruits were sent for the determination of the following physical parameters: height (cm), diameter (cm), and fruit mass (g).

Based on production results and irrigation water depth applied in the production cycle, the irrigation water use efficiency was determined according to the following equation: WUEi= P / I. WUEi is the irrigation water use efficiency (kg of fruit.m^{-3} of water); P is the total production per plant (kg); and I is the irrigation water depth applied per plant (m^3).

Collected data were submitted to analysis of variance (ANOVA) and when significant, interactions were analyzed and comparisons of treatment means were performed using the Tukey test ($p \leq 0.05$).

Results

Climatic conditions during the study

During the study period, the highest monthly rainfall recorded was of 234.1 mm, occurring in November 2022, a period considered dry; and the smallest of 18.4 mm, in February of that same year (Figure 1). The average air temperature reached maximum of 27.69 °C in February 2022 and minimum of 22.8 °C in July 2022 (Figure 1). The highest temperatures were recorded from November to April, decreasing in May and reaching the lowest values between June and August, starting to increase in September, the month of natural occurrence of more pronounced flowering.

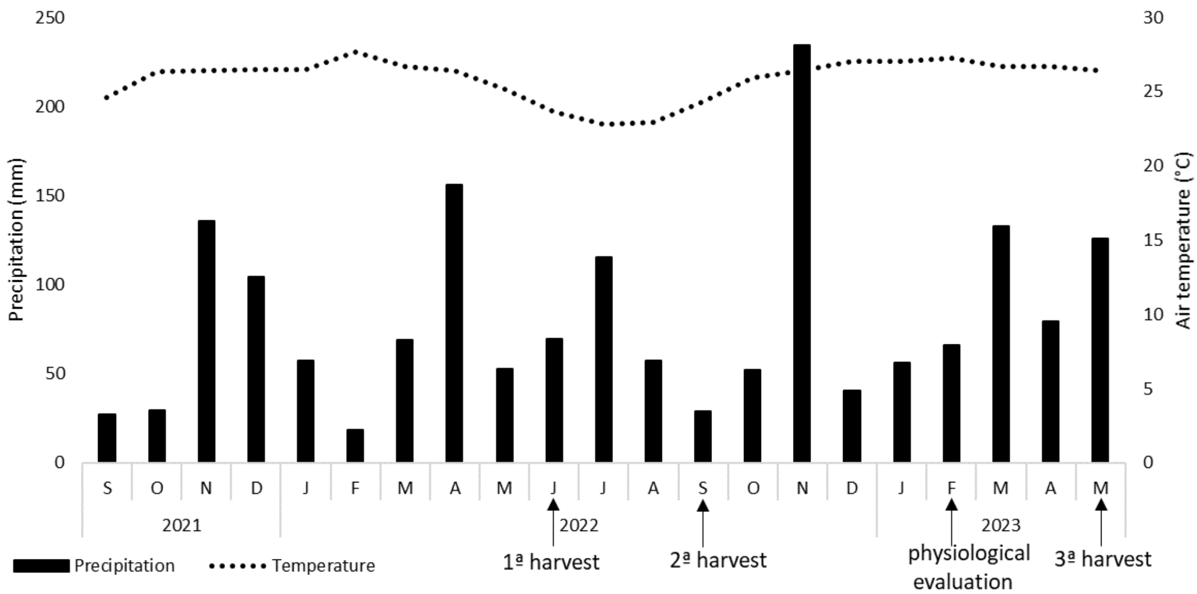

Figure 01. Precipitation and average monthly temperature during the study period, from September 21, 2021 to May 2023, São João farm, Rio Real-BA.

Gas exchange of plants in response to factors under study (sunscreen protection and water management)

There was an effect of sunscreen and water management on the gas exchange of ‘Pêra’ sweet orange plants. The differences detected in relation to the effects of the use of sunscreen for transpiration (E) and stomatal conductance (g_s), with higher average values for treated plants, which could not be statistically differentiated (Figure 2b). There was an isolated effect of the use of sunscreen on the photosynthesis rate (A), internal carbon concentration (c_i) and water use efficiency (WUE) (Figure 2b), with values indicating improvement in these physiological indicators for plants with sunscreen protection (Figures 2 and 3).

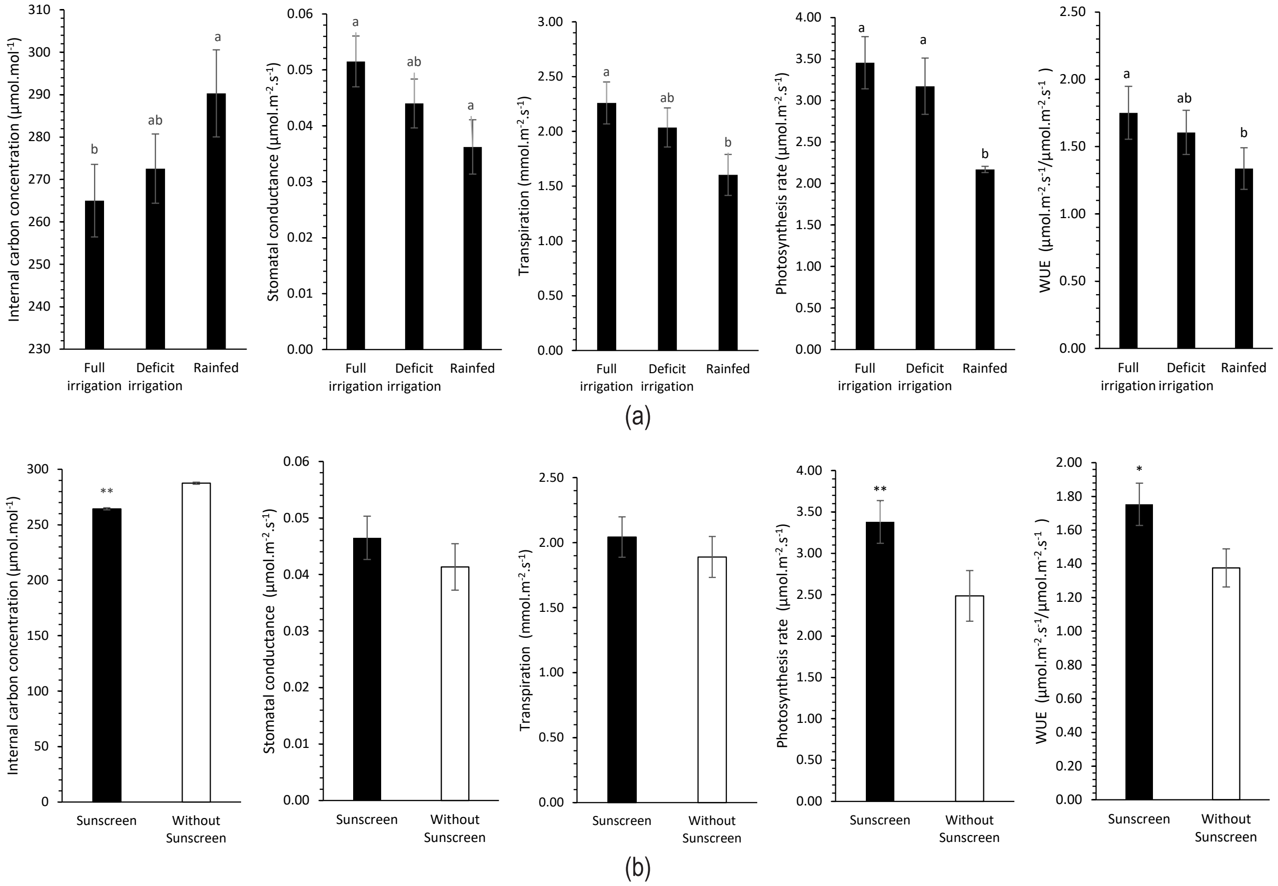

Figure 02. Isolated effects of irrigation management factors (a, full irrigation, water deficit irrigation and rainfed plants) and sunscreen protection (b, with and without the use of sunscreen) on stomatal conductance, leaf transpiration, internal carbon concentration, photosynthesis rate and water use efficiency in ‘Pêra’ sweet orange plants grafted on ‘Cravo’ lemon. Measurements carried out between 9:00 and 10:30 am. Capital letters refer to the effects of water management within each sunscreen protection treatment; lowercase letters represent the effects of sunscreen protection for each water management: 100% ETc replacement, 65% ETc and treatment without irrigation, São João farm, Rio Real-BA. Means followed by the same letter do not differ statistically by the Tukey test *(p<0.05); ** p<0.01).

As expected, $\mathbf{c}_i$ increased in plants submitted to water deficit, but sunscreen protection mitigated the effects of abiotic stresses, maintaining ci at lower levels, with average reduction of 8%, regardless of water management (Figure 2ab). Similarly, the highest A values were observed for irrigated plants without any associated deficit, reducing as the water deficit increased, and this was more pronounced for plants not sprayed with sunscreen. This explains the 36% increase in photosynthesis rate, regardless of soil water management for plants with sunscreen protection (Figure 2b).

Taking into account the effects of orchard water management on gas exchange on plants, in general, all variables responded to treatments applied, always with a linear tendency of variation depending on the soil water availability (Figure 2a), with interaction between factors under study (water management and sunscreen protection) for variables stomatal conductance and leaf transpiration (Figure 3).

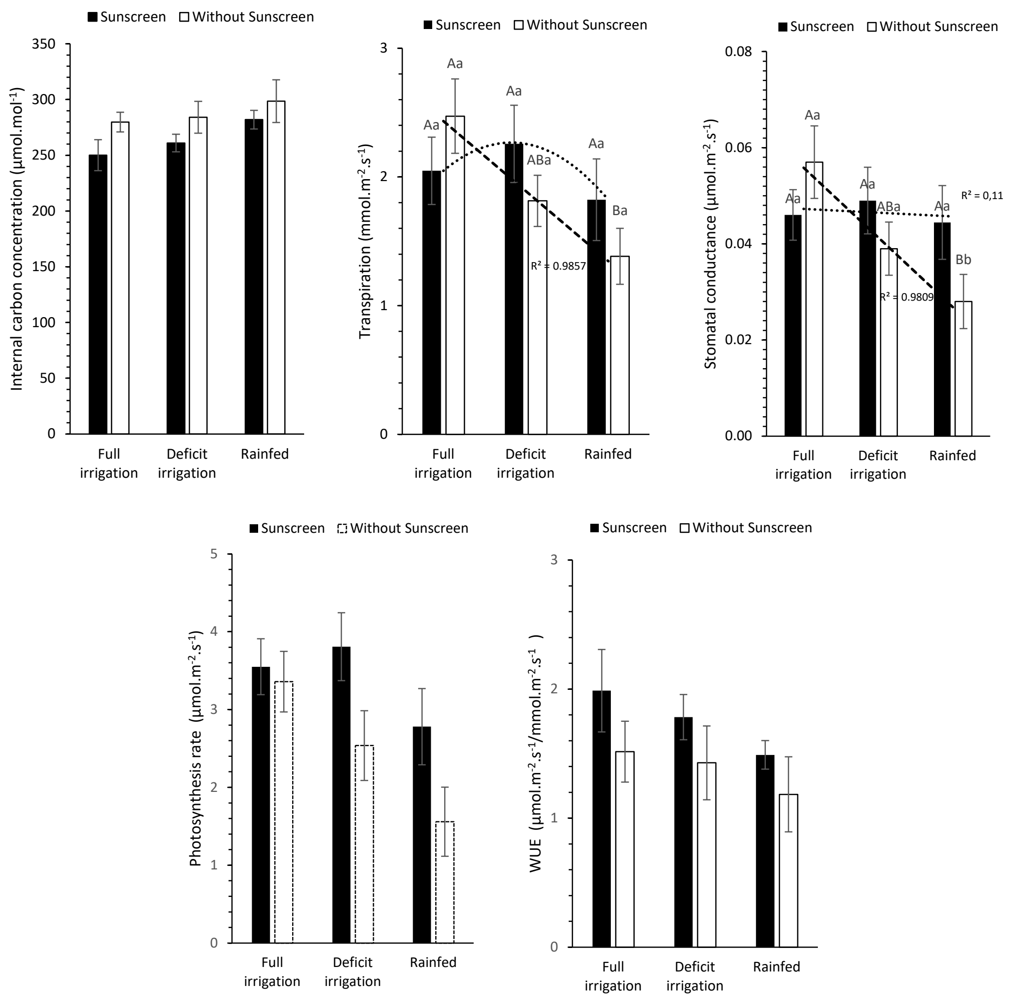

Figure 03. Interactions between irrigation management factors (full irrigation, deficit irrigation and rainfed plants) and sunscreen protection (with and without the use of sunscreen) for stomatal conductance and leaf transpiration of ‘Pêra’ sweet orange plants grafted onto ‘Cravo’ lemon. Observations taken between 8:00 and 10:30 am. Capital letters refer to the effects of water management within each sunscreen protection treatment; lowercase letters represent the effects of sunscreen protection for each water management: 100% ETc replacement, 65% ETc and treatment without irrigation, São João farm, Rio Real-BA. Means followed by the same letter do not differ statistically by the Tukey test ($p<0.05$).

Interactions are explained by the tendency towards stability in the values of these variables, regardless of orchard water management, when plants were treated with sunscreen. This plant resilience to soil water deficit is exemplified by the stomatal conductance results (Figure 3). It could be observed that in the case of plants not protected, the reduction in $\mathbf{g_s}$ is even more significant, especially in the rainfed treatment, with significantly lower values (-40%) compared to protected plants (Figure 3). Similar behavior was observed for **E**.

Combining the previously presented results related to **A** and **E**, the effects of sunscreen on WUE were clear, with values decreasing linearly with the applied deficit, regardless of the effects of sunscreen protection (Figure

2a). When analyzing the simple effects of sunscreen protection, gains in WUE were significant (+27%) compared to plants without protection (Figure 2b). This result, as observed for the other variables analyzed, are explained by the clear upward trend in WUE when plants are protected, considering different irrigation management adopted (Figure 2).

Vegetative growth, production and fruit quality

There was an effect of water management on plant height, with full irrigation providing greater plant growth (Table 4). There was no statistical difference on canopy volume, but it is possible to verify that full irrigation also contributed to greater canopy volumes, as shown in Table 4. Analyzing the results related to fruit production in the orchard of the three harvests carried out separately and the total values for each treatment, the isolated effect of sunscreen on total fruit production were statistically evidenced. This can be explained by the positive responses when plants were protected, considering each harvest event and each water management. The use of sunscreen increased orchard productivity by 12% (Figure 4).

Interestingly, in relation to the water management factor, no direct effects on orchard production and no interaction between factors were observed. Note that it was in the rainfed treatment, a condition of greater water stress, that the use of sunscreen contributed to greater production gains, with increase of 17% in production when compared to treatment without the use of sunscreen. This behavior may explain why statistically there was no effect of water management on plant productivity. As there was no effect of treatments on canopy volume, productive efficiency was not affected by water management (EP, kg of fruits.m^{-3} of canopy) and not even due to the use of sunscreen protection during the period analyzed.

Irrigation management strategy with water deficit (65% ETc) provided a 53% gain in irrigation water use efficiency (WUEi). There was no isolated effect from sunscreen protection in the increase in WUEi, as observed for other variables under study. Despite the benefits of using sunscreen both under full irrigation conditions as in irrigation deficit, the differences can be attributed to the variability (Figure 04 def).

Table 4. Production of ‘Pêra’ sweet orange grafted onto ‘Cravo’ lemon, canopy volume (VC), plant height (A), productive efficiency (EP) and water use efficiency (WUE), during the period from June 2022 to May 2023, São João farm, Rio Real-BA.

Treatments	P (kg plant^{-1})	VC (m^3)	A (m)	EP (kg m^{-3})	WUE (kg m^{-3} $_{water}$)
IT CP	60.43	8.62	2.32	7.17	33.31
IT SP	54.31	7.75	2.18	7.23	29.93
ID CP	55.64	7.48	2.14	7.45	49.86
ID SP	52.04	6.80	2.18	7.66	46.63
S CP	57.98	7.55	2.12	7.66	
S SP	49.24	7.02	2.15	7.03	
CV (%)	**18.79**	**14.45**	**3.66**	**19.61**	**15.09**
Fatores					
IT*	57.37	8.18	**2.25** a	7.20	**31.62** a
ID	53.84	7.14	**2.16** b	7.55	**39.90** b
S	53.61	7.29	**2.13** b	7.34	
CP	**58.02**	**7.88**	**2.19**	**7.43**	**41.58**
SP	**51.86**	**7.19**	**2.17**	**7.31**	**38.28**

IT – Total irrigation; ID – Deficit irrigation; S – Rainfed; CP – with sunscreen protection; SP – no protection.
Means followed by different letters differ statistically by the Tukey test (p<0.05).

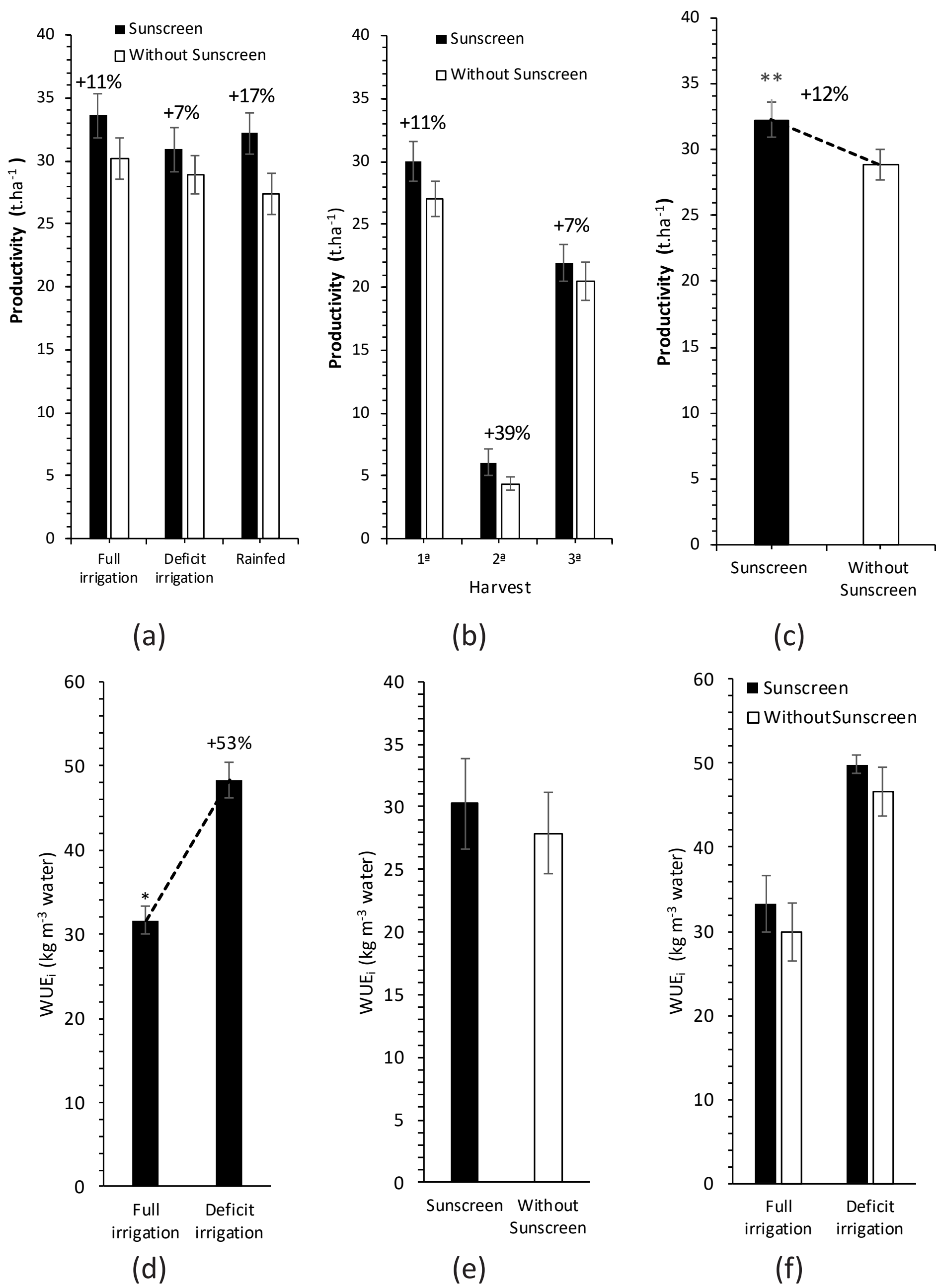

Figure 04. Orchard productivity as a function of factors under study (a), productivity as a function of sunscreen protection in different harvests (b) and total productivity as a function of sunscreen protection alone (c); and irrigation water use efficiency (WUEi) as a function of water management (d), WUEi as a function of sunscreen protection (e) and WUEi as a function of the two factors (f). The results refer to harvests carried out between the months of June 2022 and May 2023 in a 'Pêra' sweet orange orchard grafted onto 'Cravo' lemon. Water management treatments consisted of 100% ETc replacement, 65% ETc and no irrigation, São João farm, Rio Real-BA. Means followed by the same letter do not differ statistically by the Tukey test: *(p<0.05); ** (p<0.01).

Analyzing the parameters associated with fruit quality, orchard water management significantly influenced fruit diameter and length, with no isolated effects of sunscreen protection on fruit size. In the case of the average fruit mass, interaction between factors under study was observed (Figure 5).

The effects of water management on dimensions (length and diameter) indicated a decrease in variables with the increase in water deficit, being more pronounced for fruit diameter, when there were differences among treatments applied. In the case of length, fruits from rainfed plants were smaller than those from irrigated plants without water deficit (Figure 5a and b). These results reflected in the total fruit mass, showing that the effects of sunscreen protection occurred only for plants grown under rainfed conditions (Figure 5c), where protected fruits presented higher mass (8.3%) compared to those without protection. It is interesting to note that, when evaluating the effects of management in relation to each treatment involving sunscreen protection, as well as the effects of gas exchange, interactions are explained by significant variations in the mass of fruits from unprotected plants, and in this case, fruits from rainfed plants presented lower mass compared to those from irrigated plants (Figure 5c).

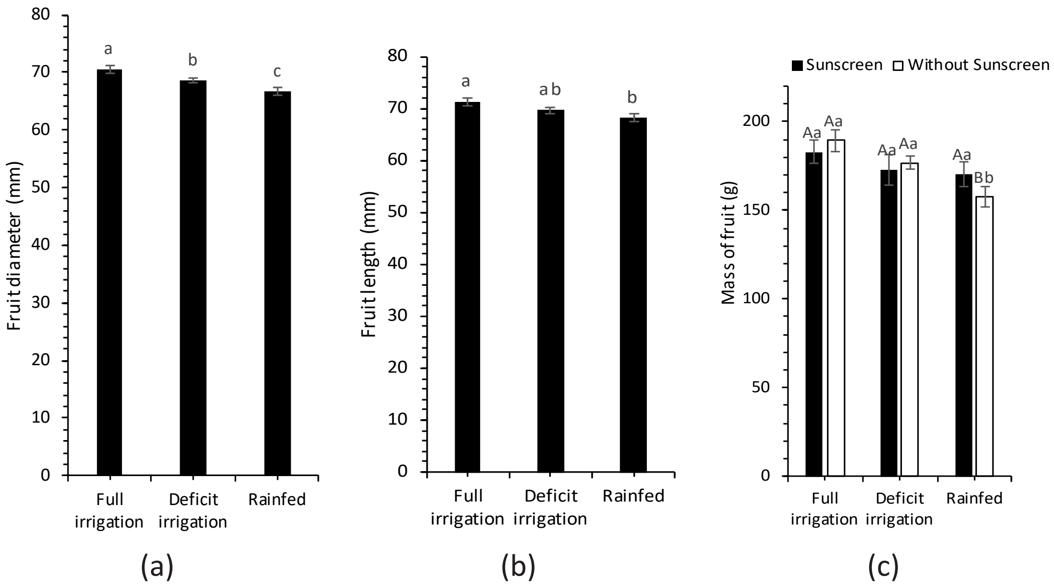

Figure 05. Diameter (a) and length (b) of 'Pêra' sweet orange fruits grafted onto 'Cravo' lemon for different orchard water management strategies. Mass of orange fruits (c) as a function of sunscreen protection for each water management strategy. Measurements were taken during the months from June 2022 to May 2023. In relation to fruit mass (c), capital letters refer to the effects of water management within each sunscreen protection treatment; and lowercase letters represent the effects of sunscreen protection for each water management: 100% ETc replacement, 65% ETc and treatment without irrigation, São João farm, Rio Real-BA. Averages followed by the same letters do not differ statistically by the Tukey test: *(p<0.05); ** (p<0.01).

Discussion

The present study evaluated the combined effect of orchard water management with different water deficit levels and the use of sunscreen protection as a stress mitigating agent. It was possible to verify that the factors under study, whether referring to water management and sunscreen protection of leaves through spraying with a calcium carbonate-based product, affected alone or through interactions plant gas exchange, plant vigor, fruit quality, productivity and water use efficiency (Figures 2 to 5). Interestingly, these responses occurred during periods with precipitation in all months, maintaining the annual average in the municipality, but with regular distribution, favoring the soil water balance for plants (Figure 1). Typically, in relation to water requirements, the greatest water demand for citrus in the region occurs in the periods of budding, flowering, fruiting and beginning of fruit development, and becomes smaller during the maturation, harvest and rest periods (PIRES, et al., 2021). Considering that two characteristic flowering periods occurred in the region, one of which occurred in the month of September, coinciding with the decrease in rainfall and the beginning of an increase in air temperature, which causes non-irrigated plants to begin to suffer water deficit, even in wetter years, as observed in the present study.

Therefore, even during a period with weather conditions more favorable than usual, the use of sunscreen protection contributed to a better water regulation of plants, maintaining more stable **gs** and **E** levels, regardless of water management, mitigating water deficit, especially for rainfed plants. On the other hand, when sunscreen was not applied to the plant canopy, plants responded directly to the effects of soil water deficit, with linear reduction in leaf transpiration and stomatal conductance (Figure 03). This response may be related to the photoprotection effects of plants, similar to that observed with the foliar application of calcium carbonate in conilon coffee seedlings, improving the photosynthetic activity performance and reducing damage caused by light intensity and high temperatures (SOELA et al., 2023).

Internal carbon concentration increased with water deficit, but remained at lower levels when sunscreen was applied. This is a clear indication of the mitigation of environmental stresses through the leaf protection system against abiotic stresses, and a possible reduction in the efficiency of the photosynthetic apparatus and CO_2 assimilation, resulting in decrease in carboxylation efficiency (EVERARD et al., 1994; MACHADO et al., 1999). Furthermore, there was a contribution from sunscreen in increasing CO_2 assimilation. The photosynthesis rate decreased with deficit irrigation management in non-irrigated plants. Reductions in photosynthetic activity and CO_2 assimilation are indicative of water deficit in citrus plants (SANTOS et al., 2016; FAVER et al., 1996; MACHADO et al., 1999). The physiological response to reduce water loss, reducing transpiration and consequently carbon dioxide absorption (CO_2), causes reduction in the photosynthetic rate and accumulation of photoassimilates (TAIZ et al., 2017).

Improvements in the physiological characteristics of conilon coffee plants through the application of calcium particle films were also observed by Silva et al., (2019), resulting in increase in the photosynthesis rate (A), better control in stomatal conductance and leaf transpiration (E), and improvement in water use efficiency (WUE). Under natural conditions, stresses combined with high air temperatures and high solar irradiance limit the potential production of citrus plants, especially when they occur concomitantly with soil water deficit (CAMARGO et al., 1999; MARTINS; ORTOLONI, 2006) and must be taken into account in agrometeorological models for production estimates (PAULINO et al., 2007; MOREIRA et al., 2023; COELHO FILHO et al., 2021). Working under simulated conditions of controlled environment, Terán et al., (2024) evaluated the effects of combined stresses and their damage to the physiology and biochemical responses of plants. In this study, the use of kaolin diluted in water (1%) and sprayed on citrus plants to possibly mitigate the negative impacts of high temperatures and light intensity, showed deleterious effects of abiotic stresses in different forms by plants, with gains in resilience due to the reduction of damage and leaf abscission, preserving the chlorophyll content and the degradation of carotenoids; increasing quantum and photosynthetic efficiency (ΦPSII, A) and gas exchanges (E, gas). Regarding biochemical indicators, such as reduction in proline concentration and phytohormone content in leaves: reduction in cinnamic acid concentration, increased ABA and reduced jasmonic acid concentration.

Considering plants in the field and based on leaf-atmosphere gas exchanges, the physiological indicators also showed an increase in plant resilience (Figures 02 and 03) using calcium carbonate-based sunscreen. This physiological resilience influenced fruit growth when plants were submitted to soil water deficit, compensating for losses in growth rates with sunscreen application, especially for rainfed plants (Figure 5c). Non-irrigated plants have smaller and lighter fruits, but the use of sunscreen protection contributed to gains in relation to fruit quality, especially in in relation to size, which significantly increased fruit mass by 8% under rainfed conditions (Figure 5c).

Positive effects of sunscreen protection were also observed for mandarin by El-Tanany et al., (2019), with an 11% increase in fruit mass compared to plants not treated with kaolin, even in the case of an orchard irrigated by surface. These indicators are important in classifying fruits for fresh consumption, where they are marketed at better prices compared to prices practiced by juice industries (CEPEA, 2024).

The results of this study are of great interest to citrus growers, as they demonstrate significant improvements in fruit quality, both in terms of size and mass, especially with irrigation treatments (Figure 5ab). This clearly indicates that the practice of irrigation can benefit local citrus farming.

Furthermore, controlled deficit irrigation emerges as a viable alternative to be adopted, considering gains in WUEi (Kg of fruit.m^{-3} of water), when comparing the irrigation with controlled soil water deficit (ID) with irrigation carried out without deficit planning (IT) (Figure 4d). The results corroborate studies of Amorin et al., (2021), who demonstrated benefits in the quality of orange fruits, in addition to greater efficiency in the use of irrigation water (+56%), when adopting deficit irrigation in 'Pera' sweet orange orchards in the same region. Therefore, for citrus growers who depend on production systems under rainfed conditions, additional precautions are necessary, and the use of sunscreen can be a valuable tool to mitigate the impacts of climate events during the critical growth period.

The results found by Tsai et al., (2019) in an orchard located in a wet region did not show significant gains in fruit weight, volume and juice content of "Murcott" mandarin with foliar calcium carbonate sprays, but application reduced the damage caused by sunburn to fruits. Responses will greatly depend on the region's climate, the season evaluated and the orchard's water management. A good example is the planting of 'Ponkan' tangerine in the municipality of Bom Jesus da Lapa, Bahia, a region with semi-arid and very hot climate, especially between August and November, where the practice of spraying with kaolin is advocated mainly to avoid sunburn due to the high air temperature and solar irradiance in the region. El-Tanany et al., (2019) also found that the application of up to 4% kaolin during the summer on plantations in Egypt resulted in 12% reductions in the occurrence of fruits with sunburn damage compared to control plants in two harvests.

Although water management strategies affect fruit quality, there was no isolated effect on orchard productivity (Figure 4a). These results may be related to climatic conditions during the evaluated period, which were atypical, with improved rainfall distribution, a characteristic not very frequent in the study region, especially during the hottest period of the year, as previously mentioned (Figure 1). This can also be attributed to the productivity gains of plants irrigated with a water deficit or under rainfed conditions, associated with the use of sunscreen, which reduced the mean differences between water management treatments. The tendency to improve productivity regardless of water management using sunscreen was observed, but it was not sufficient to promote an interaction between factors. However, these results led to a 12% increase in production, regardless of water management, reflecting the positive effects across different harvests (Figure 4a).

This result allows improvements in harvests, both in quality and quantity, mainly in a region that presents high climate risks, whether due to variability or occurrence of deficit events in the hottest periods of the year, further aggravated by the cohesion of typical soils in the region (MENESES et al., 2020; CINTRA, 2011).

Conclusions

Deficit irrigation promoted significant gains in irrigation water use efficiency (WUEi), being a recommended practice, ensuring harvest predictability in the face of climate risks and fruit quality.

The use of sunscreen protection makes citrus plants more resilient, resulting in improvements in physiological indicators and gas exchange, with significant increases in the photosynthesis rate and physiological water use efficiency of plants under field conditions, implying positive responses in orchard production, regardless of water management and gains in fruit quality, especially for rainfed plants.

The practice of using sunscreen protection, regardless of water management in the orchards, is recommended.

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