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Production, gas and biochemical exchanges in pear cultivated in semi-arid region under different irrigation managements[1]

Produção, trocas gasosas e bioquímicas em pereira cultivada no semiárido sobre diferentes manejos de irrigação

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HIGHLIGHTS:

Pear gas and biochemical exchanges are optimized under irrigation depths between 85.64 and 98.50% crop evapotranspiration.
Pear production is optimized under drip and microsprinkler irrigation systems with a depth of 91.8% crop evapotranspiration.
Excess water with water depths over 120% ETc impairs pear performance, reducing photosynthetic rates and production.

ABSTRACT: The objective of this study was to evaluate the influence of irrigation systems and water depths on physiological, biochemical and production processes of pear trees grown in the Brazilian semi-arid region. The experimental design was randomized blocks, with 2 × 4 factorial scheme, corresponding to two irrigation systems (drip and microsprinkler) and four irrigation depths (60, 80, 100 and 120% of the crop evapotranspiration - ETc), with four replicates. Water deficit and excess applied to plants are harmful to gas exchange as well as to biosynthesis and accumulation of carbohydrates, amino acids and proteins in leaves, compromising the cultivation cycle of pear plants grown in the Sub-Middle São Francisco region. The irrigation depth of 91.8% ETc promotes the highest production of pear (18.49 kg plant^{-1}) under drip and microsprinkler irrigation systems, under the edaphoclimatic conditions of the Sub-Middle São Francisco region.

Key words: *Pyrus communis* L., localized irrigation, irrigation depths, plant science

RESUMO: O objetivo deste trabalho foi avaliar a influência de sistemas de irrigação e lâminas de irrigação sobre processos fisiológicos, bioquímicos e produtivos da pereira cultivada no Semiárido brasileiro. O delineamento experimental foi em blocos casualizados, com fatorial 2 x 4, sendo dois sistemas de irrigação (gotejamento e microaspersão) e quatro lâminas de irrigação (60; 80; 100 e 120% da evapotranspiração da cultura - ETc), com quatro repetições. A deficiência e o excesso hídrico aplicados às plantas são prejudiciais às trocas gasosas, bem como à biossíntese e acúmulo de carboidratos, aminoácidos e proteínas nas folhas, comprometendo o ciclo de cultivo de pereiras cultivadas na região do Submédio São Francisco. A lâmina de irrigação de 91,8% ETc promove a maior produção de pereira (18,49 kg planta^{-1}) sob sistemas de irrigação por gotejamento e microaspersão, nas condições edafoclimáticas do Submédio São Francisco.

Palavras-chave: *Pyrus communis* L., irrigação localizada, lâminas de irrigação, fitotecnia

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Introduction

Pear (*Pyrus communis* L.) is a species native to temperate zones of Europe and Asia (Oliveira et al., 2022) and its cultivation in Brazil is concentrated in the South and Southeast regions, producing in 2020 about 13,000 tons of fruits (IBGE, 2022).

Studies have shown that it is economically viable to grow pear trees in the Brazilian semi-arid region, with small areas of cultivation already existing (Oliveira et al., 2015; Oliveira et al., 2017c; Oliveira et al., 2022), and, according to Oliveira et al. (2015), by using varieties tolerant to the edaphoclimatic conditions of the region, associated with the use of appropriate irrigation management techniques, it is possible to promote fruiting at any time of the year.

The species cultivated in the semi-arid region usually have high transpiration rate, a phenomenon that can drastically affect the entire growth cycle until the reproduction stage of the plants, mainly due to the damage to the process of water absorption, transport and consequently compensation, thus affecting the balance of its flow in the plant. Plant species may experience several problems due to water deficit, for instance decreases in photosynthetic rates and biochemical activities such as the production of sugars, amino acids and proteins, among others (Mibei et al., 2017; Oliveira et al., 2017b).

Considering that the correct management of irrigation can promote improvement in the morphophysiological characteristics of the plant, which can promote significant increase in production, the objective of this study was to evaluate the influence of irrigation systems and water depths on physiological, biochemical and production processes of pear trees grown in the Brazilian semi-arid region.

Material and Methods

The experiment was conducted in the irrigation district Senador Nilo Coelho - Núcleo 5 (9° 21' 27.65" South latitude and 40° 37' 56.07" West longitude, and altitude of 396 m), located in the municipality of Petrolina, PE, Brazil. The crop evaluated was pear (*Pyrus communis*), with four years of age, propagated vegetatively with the rootstock 'Pirus' (*P. calleryana* L.) and the scion 'Triunfo', at spacing of 3.5 × 1.25 m.

The climate of the region is semi-arid, with an average annual temperature of 26.5 °C, classified as BSwh by Köppen, with the highest peaks between October and December, with July being considered the coldest month. The textural classification of the soil of the experimental area is sandy, as observed in Tables 1 and 2.

During the experiment, the mean global radiation was 20.1 MJ m^{-2} per day, the relative air humidity showed an average of 57.3%, and the accumulated precipitation was 15.2 mm. Figure 1 shows the data of average air temperature and reference evapotranspiration (ETo) in the experimental period.

The experimental design used was randomized blocks, with a 2 × 4 factorial scheme, using two irrigation systems (drip and microsprinkler) and four irrigation depths (60, 80, 100 and 120% of the crop evapotranspiration - ETc), to detect the plant demand, in relation to the crop coefficient indicated so far. Each plot was composed of 10 plants, and the three central ones were considered usable.

For drip irrigation system, two lines of drip hose were installed 0.8 m apart, with spacing of 0.5 m between emitters and flow rate of 2 L h^{-1}, forming a double continuous wet strip per row of plant. In the microsprinkler irrigation system, four diffuser nozzles were used per plot, each one with flow rate of 27 L h^{-1} and spaced 3.1 m apart.

Irrigations were performed daily from the ETc data, and the ETo values were estimated by the Penman-Monteith method, as described by Allen et al. (2006), obtained by a weather station installed near the experimental area, using the crop coefficient (Kc) (Vegetative stage - 0.8; Flowering stage - 1.20; Fruiting stage - 0.85) also indicated by the same authors.

To standardize the flowering and production of the orchard, a cleaning pruning was carried out at the beginning of the experiment, by removing unwanted, poorly positioned, diseased and excessively vigorous branches. The study began in May 2017 and ended in November of the same year.

Gas exchange in the leaves of pear plants was quantified by determining CO_2 assimilation rate - A (μmol CO_2 m^{-2} s^{-1}), stomatal conductance - gs (mol H_2O m^{-2} s^{-1}), internal carbon concentration - Ci (μmol CO_2 m^{-2} s^{-1}), leaf transpiration - E (mmol H_2O m^{-2} s^{-1}), leaf temperature - LT (°C), and intrinsic water use efficiency - WUEi (μmol CO_2 $mmol^{-1}$ H_2O). WUEi was established by the ratio between photosynthesis rate and stomatal conductance - A/g_s.

Measurements related to gas exchange were made with an infrared gas analyzer (IRGA, Li 6400, Licor). Measurements were performed from 9 to 11 a.m., on two leaves per plant in

Table 1. Chemical characteristics of the soil in the experimental area

Depth (cm)	EC (dS m^{-1})	pH H_2O	P (mg dm^{-3})	K	Na	Ca	Mg	Al	H + AL	SB	CEC	V (%)
				(cmol$_c$ dm^{-3})								
0-20	0.25	6.2	13.86	0.02	0.01	2.3	0.90	0.00	0.5	3.2	3.7	87.0
20-40	0.19	6.1	12.30	0.02	0.01	1.3	0.70	0.00	0.5	2.0	2.5	80.7
40-60	1.55	6.1	16.05	0.03	0.01	1.5	0.60	0.00	0.2	2.1	2.3	89.7

EC - Electrical conductivity in the saturation extract; pH - Hydrogen potential; P - Phosphorus extracted by the Mehlich-1 method; K - Exchangeable potassium; Na - Exchangeable sodium; Ca - Exchangeable calcium; Mg - Exchangeable magnesium; Al - Exchangeable aluminum; SB - Sum of bases; CEC - Cation exchange capacity; V - Base saturation

Table 2. Physical characteristics and particle size of the soil in the experimental area

Depth (cm)	Density (g cm^{-3})		Sand	Silt	Clay	Field capacity	Permanent wilting point	Total porosity
	Bulk	Particle	(g kg^{-1})			(g g^{-1})		(%)
0-20	1.55	2.39	825	129	46	0.13	0.03	45.7
20-40	1.62	2.58	830	121	49	0.13	0.03	47.6
40-60	1.62	2.56	801	156	43	0.13	0.03	47.0

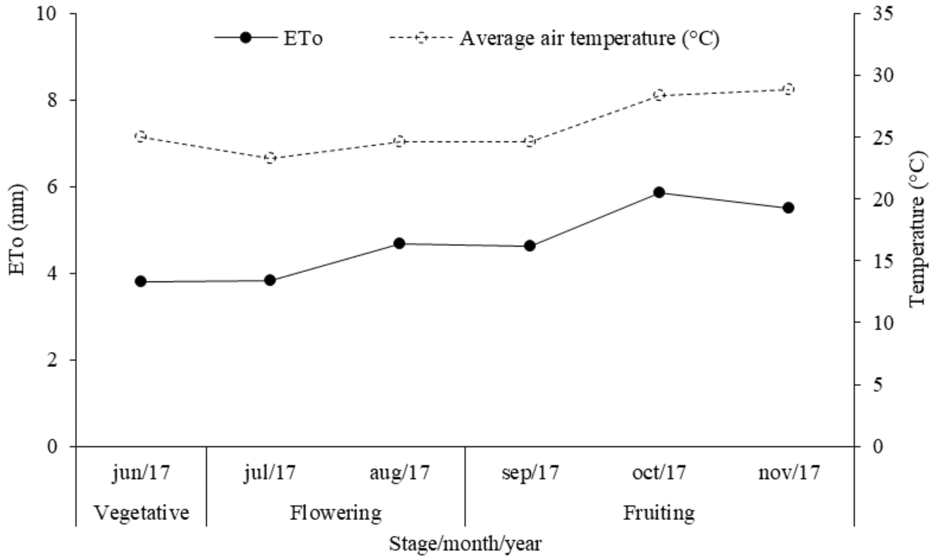


Figure 1. Average daily air temperature and reference evapotranspiration (ETo) in the irrigation district Senador Nilo Coelho - Núcleo 5, municipality of Petrolina, PE, Brazil, during the experimental period

each plot, which were selected for being healthy, with uniform green color and having similar sun exposure.

To determine the contents of carbohydrates and proteins, leaves exposed to sunlight, fully expanded, with no signs of senescence and healthy were selected and collected. These leaves were dipped in liquid nitrogen at -180 °C, then put into identified plastic bags, which were placed in ice and then stored in a freezer at -20 °C, until biochemical analyses.

Leaf contents of the following variables were evaluated: reducing sugars, quantified by the Dinitrosalicylic acid (DNS) method; amino acids, which quantifies glucose, fructose and mannose in plant tissues; total and non-reducing sugars, according to the methodology described by Yemm & Willis (1954); and total soluble proteins, using bovine serum albumin protein (BSA, Sigma, USA) as standard. In addition, fruit production per plant was evaluated, measured on a precision scale. Harvest was carried out when the fruits were at the maturity stage, characterized by the epidermis without roughness and shiny.

The results were subjected to analysis of variance to assess the interaction between the factors irrigation systems and water depths, with means compared by Tukey test for qualitative variables and regression analysis for quantitative variables, at $p \leq 0.05$, using Sisvar software.

Results and Discussion

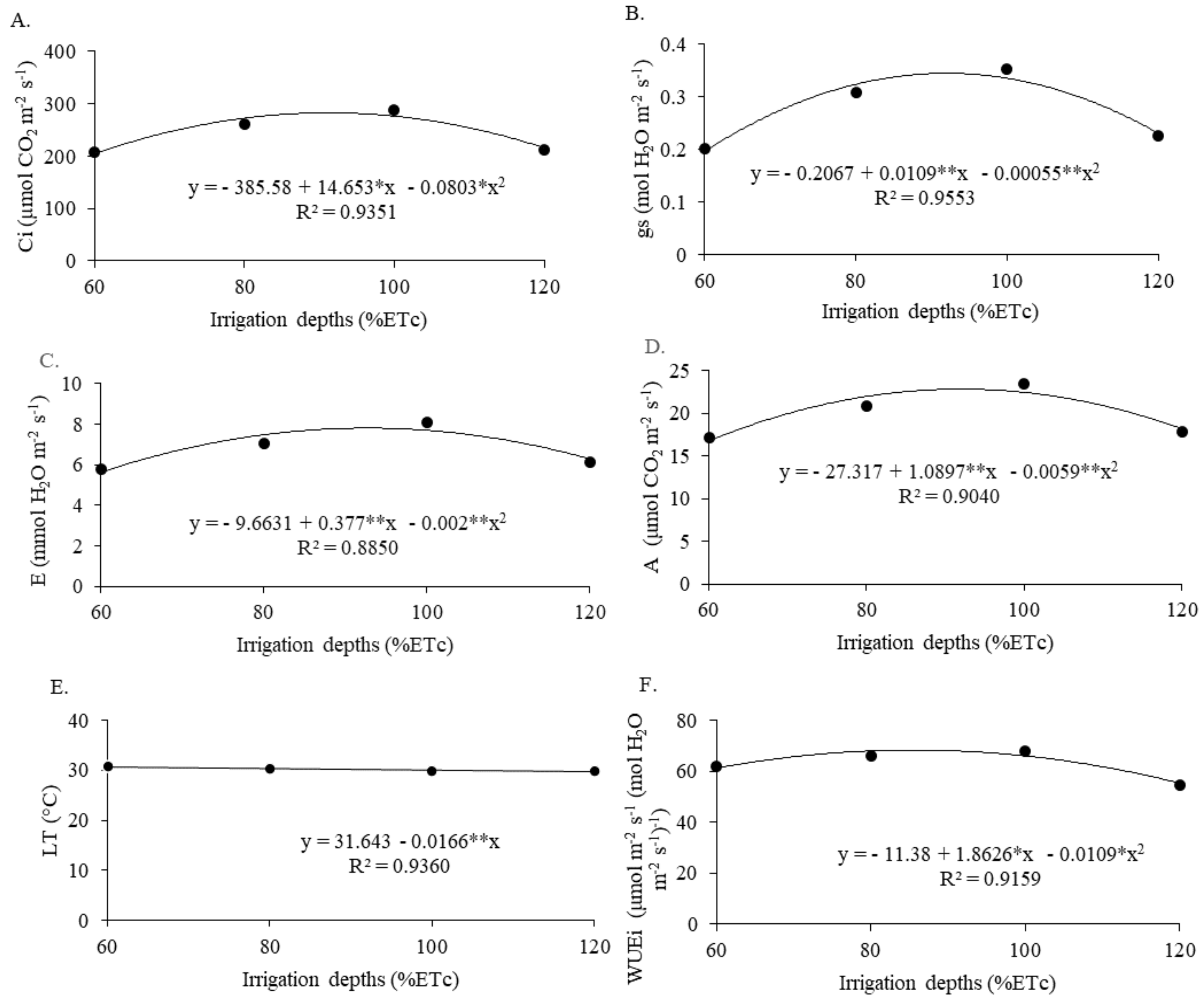
According to the analysis of variance, there was no significant interaction between the irrigation systems and irrigation depths for the evaluated variables. In addition, there was no individual effect between irrigation systems (Table 3). However, there was a significant effect of irrigation depths ($p \leq 0.05$) on the physiological variables internal carbon concentration (Ci), stomatal conductance (g_s), transpiration (E), CO_2 assimilation rate (A), leaf temperature (LT) and intrinsic water use efficiency (WUEi), and on production per plant.

Figure 2A shows that, for Ci, the fitted equation is a second-degree polynomial. For Ci, the irrigation depth of 91.2% ETc promoted the maximum value of 282.5 μmol CO_2 m^{-2} s^{-1} (Figure 2A), with the lowest mean observed for the depth of 60% ETc (208.2 μmol CO_2 m^{-2} s^{-1}). On the other hand, it was found that excess of water also caused reduction in Ci of approximately 25%, when compared to the percentage index of maximum Ci in leaf tissues. Therefore, both water restriction and water excess hampered the CO_2 concentration in the substomatal chamber and consequently between the cells that form leaf tissues, which may have directly interfered in the photosynthetic process. Excess water can also cause factors that inhibit the physiology of a plant and consequently

Table 3. Summary of the F-test mean values for net internal carbon concentration (Ci), stomatal conductance (g_s), transpiration (E), CO_2 assimilation rate (A), leaf temperature (LT) and intrinsic water use efficiency (WUEi), reducing sugars (RS), non-reducing sugars (NRS), total soluble proteins (TSP), total amino acids (TAA), and on production per plant in pear trees cv. Triunfo cultivated in the Sub-Middle São Francisco region, Brazil

SV	DF	F test										
		Ci	g_s	E	A	LT	WUEi	RS	NRS	TSP	TAA	Production of pear
Block	3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
System	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
ID	3	*	**	**	**	**	*	*	*	*	*	*
System × ID	3	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Residue	21	-	-	-	-	-	-	-	-	-	-	-
CV (%)		8.81	14.97	9.75	9.29	1.07	16.63	8.41	23.64	27.85	8.97	20.23

SV - Sources of variation; DF - Degrees of freedom; CV - Coefficient of variation; *, **, ns - Significant at $p \leq 0.05$ and $p \leq 0.01$, and not significant by F test, respectively ; ID - Irrigation depths; Ci - mol CO_2 m^{-2} s^{-1}; g_s - mol CO_2 m^{-2} s^{-1}; E - mmol H_2O m^{-2} s^{-1}; A - μmol CO_2 m^{-2} s^{-1}; LT - °C; WUEi - μmol m^{-2} $s^{-1}$$CO_2$ $mmol^{-1}$ H_2O; RS - mg g^{-1}; NRS - mg g^{-1}; TSP - mg g^{-1}; TAA - mg g^{-1}; Production per plant - kg



*, ** - Significant at $p \leq 0.05$ and $p \leq 0.05$ by F test

Figure 2. Effect of irrigation depths (% crop evapotranspiration – ETc) on internal carbon concentration - Ci (A), stomatal conductance - gs (B), transpiration - E (C), assimilation rate of CO_2 - A (D), leaf temperature - LT (E) and intrinsic water use efficiency -WUEi (F) in pear trees cv. Triunfo cultivated in the Sub-Middle São Francisco region, Brazil, in the fourth year of cultivation

its production. These causes include the reduction in oxygen concentration, hindering root respiration, and reduction in stomatal conductance (Simões et al., 2021).

The results obtained here corroborate those of other studies conducted with fruit crops cultivated in the Sub-Middle São Francisco region, for instance with irrigated apple cultivars in the Brazilian semi-arid region, in which Oliveira et al. (2017b) observed that the increase in water regime resulted in the increase of Ci.

Figure 2B shows that, for gs, the fitted equation is a second-degree polynomial. In this case, it was estimated that the water availability for the water depth of 92.1% ETc promoted a greater stomatal opening (0.35 mol H_2O m^{-2} s^{-1}). Water restriction and excess also caused reductions in g_s values (Figure 2B), and the highest water depth (120% ETc) led to a decrease of 34.29% compared to the maximum estimated value. This result was expected, because there is a relationship of dependence between the flow of CO_2 through the stomata and its concentration within the leaf.

The stomatal regulation found in the leaves of pear plants is intrinsically linked to the establishment of adequate levels of water transpired by the leaves. This occurs because the leaves, through various physiological and biochemical defense mechanisms, can control the loss of water to the atmosphere, using mechanisms of activation of stomatal closure and opening (Zhao et al., 2015; Nascimento et al., 2019; Ghafari et al., 2020; Wu et al., 2020; Abdel-Sattar & Kotb, 2021).

In general, the means of g_s found in the present study are higher than those reported by Zhao et al. (2015), who observed g_s values below 0.18 mol H_2O m^{-2} s^{-1} and photosynthetic rates that did not exceed 14.00 µmol CO_2 m^{-2} s^{-1} of CO_2 in pear leaves in a semi-arid region of China.

Regarding E, Figure 2C shows that the fitted equation was second-degree polynomial model, and its maximum value was estimated with water depth of 94.3% ETc (8.1 mmol H_2O m^{-2} s^{-1}), a phenomenon similar to that observed for g_s. It is observed that irrigation depth higher than 94.3% ETc causes reduction in the values of E, with a decrease of approximately 31% up to the treatment of 120% ETc (6.2 mmol H_2O m^{-2} s^{-1}).

For the A variable, the fitted equation was a quadratic polynomial model (Figure 2D), and its maximum value of 23.0 μmol CO_2 m^{-2} s^{-1} of CO_2 was obtained with the water depth of 93.3% ETc. In addition, the water depth of 120% ETc led to a reduction of 29.2% compared to the highest value.

The reduction in water application implies a lower water availability for plant uptake, which normally promotes a reduction in stomatal opening, reducing the leaf transpiration process with a consequent decrease in CO_2 input and its availability to the mesophyll cells, affecting the photochemical and biochemical phases, which implies the reduction of photosynthetic activity (Figure 2). Thus, it is observed that both water excess and water restriction hamper the CO_2 concentration in the substomatal chamber and consequently between the cells that form leaf tissues, directly interfering in the photosynthetic process (Andrade et al., 2017; Taiz & Zeiger, 2017; Oliveira et al., 2020).

In this context, given the results obtained for gas exchange in pear leaves, it was found that for the conditions of the São Francisco Valley region, the variation in water supply can significantly affect the photosynthetic activity and may interfere in its efficiency. This must have caused changes in the production and metabolism of sugars, reducing their concentrations in tissues and directly interfering in various metabolic pathways in cells, for instance the production of various types of compounds, such as carbohydrates, proteins, lipids, among others.

Regarding LT (Figure 2E), it was possible to verify that the fitted equation was a linear model, with a reduction in LT as the water volume applied increased. Lower leaf temperatures due to a higher water availability is directly correlated with higher water flow through the plant stem and consequently through the leaves. The results corroborate those reported by Oliveira et al. (2017b), who found that water restriction causes increased leaf temperature, limiting photosynthesis among other physiological events.

Sezen et al. (2019) also found results similar to those of this study and observed that the photosynthetic process can be compromised when leaf temperature increases, mainly due to high transpiration and stomatal conductance, caused by the reduction of relative air humidity, which can result in stomatal closure, thus leading to a decrease in activities during the steps of the photochemical and biochemical phases of photosynthesis.

When photosynthetic activity is reduced, several biochemical and physiological events are affected, such as respiration, cell division, protein synthesis, solute accumulation, ion absorption among others (Ghafari et al., 2020).

The irrigation depths caused changes in the intrinsic water use efficiency (WUEi), and the fitted equation was a quadratic polynomial model (significant at $p \leq 0.01$) (Figure 3F), with a maximum estimated value of 68.47 μmol CO_2 $mmol^{-1}$ H_2O for the water depth of 85.64% ETc. Thus, it was verified that the stomatal opening and closing dynamics due to the variation of irrigation depths contributed to the intrinsic water use efficiency.

According to the variables that contribute to the determination of gas exchange, the lower the water availability, the lower the flow from the root to the shoot, the lower the volume of water that reaches the leaves, and consequently the lower the stomatal opening, transpiration and photosynthesis, leading to the decrease of WUEi, so plants suffer from water stress (Oliveira et al., 2020; Vélez-Sánchez et al., 2021).

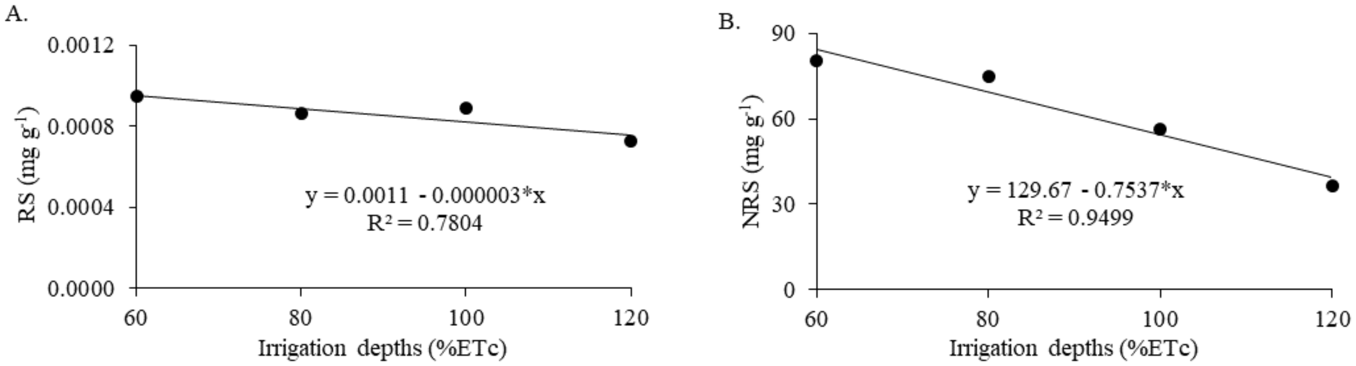
Except for leaf temperature, all determinant variables of gas exchange showed a significant reduction when the highest irrigation depth was applied, probably due to excess water, which may have caused an anaerobic stress.

According to Simões et al. (2021), plants under water excess conditions have a limitation in the photosynthetic process due to stomatal closure. The low availability of oxygen can interfere in the entire cellular metabolism, with the first site of occurrence in the cells that form the root system tissues, later propagating to the other tissues until reaching the leaf, thus affecting stomatal conductance and other variables.

With regard to biochemical characteristics, there were significant effects only of irrigation depths on the characteristics related to reducing sugars (RS) and non-reducing sugars (NRS), total soluble proteins (TSP), and total amino acids (TAA).

Figures 3A and B show the models of polynomial equations for the characteristics RS and NRS, respectively.

For the concentration of sugars in the leaf of pear plants, it was possible to observe linear reductions in the values of



* - Significant at $p \leq 0.05$ by F test

Figure 3. Effect of irrigation depths (% crop evapotranspiration - ETc) on reducing sugars (RS) (A) and non-reducing sugars (NRS) (B) in leaves of pear trees cv. Triunfo in the Sub-Middle São Francisco region, Brazil

RS and NRS as a function of the increase of irrigation depths (Figures 3A and B). However, reduction in the amount of water applied to the soil promotes increased concentrations in the leaf. This phenomenon can be explained by the fact that accumulation of free sugars in leaves and root system must have occurred due to inhibition and synthesis of proteins and hydrolysis of starch reserves by the action of the amylase enzyme (Santos et al., 2010).

The results of the present study corroborate those obtained by Oliveira et al. (2017b), who evaluated the effects of different irrigation depths on two varieties of apple in the Sub-Middle São Francisco region and reported the same reduction in the sugar content in the leaves due to the increase in irrigation depths.

In general, plants adjust osmotically in order to accumulate organic solutes in tissues and thus reduce damage, which can be caused by the reduction in the availability of water for absorption, transport, use and loss to the atmosphere through the stomata.

Santos et al. (2010), studying bean genotypes, proposed that the increase in the concentration of sugars in leaves in a situation of water stress is due to the induction of osmotic adjustment probably caused by the decline in hydrolytic activity of sucrose synthetase, associated or not with the degradation of starch due to increased activities of amylase and acid invertase. According to the same authors, due to the effect of drought, starch is degraded in the tissues that accumulate it by the action of amylase activity, thus promoting an increase in the amount of soluble reducing sugars.

Figures 4A and B show the models of polynomial equations for TSP and TAA, respectively. The maximum value reached for TSP corresponded to 2.85 mg g^{-1} with the irrigation depth of 92.64% ETc. In relation to TAA, the estimate was 0.0052 mg g^{-1} for the water depth corresponding to 98.5% ETc. Monitoring these adjustments with the availability of water is extremely important since amino acids and proteins are fundamental for the process of functional and structural formation of plants, because their growth and development depend strictly on these two chemical components. Their biosynthesis processes originate from carbon compounds produced by photosynthetic activity.

The reduction of the irrigation depth caused a reduction of photosynthetic activity, and this fact must have led to the reduction in the production of trioses, which is essential for the production of several organic compounds in plant cells, including the biosynthesis of amino acids and proteins (Figure 4). Under these conditions, plants can trigger various molecular, biochemical and physiological mechanisms, among others, in the attempt to overcome this adverse situation. According to Mibei et al. (2017), water restriction can cause the destruction of pigment-protein complexes, which protect the photosynthetic apparatus, causing oxidative stress of lipids, proteins and chloroplasts, which leads to the stomatal reduction in plants.

The contents of proteins showed variations, and their production and availability in the leaves were hampered by the extreme levels of irrigation depths. Similar results were found by Kala & Godora (2011), who reported decreases in TSP concentrations resulting from water restriction, mainly due to the action of the protease enzyme.

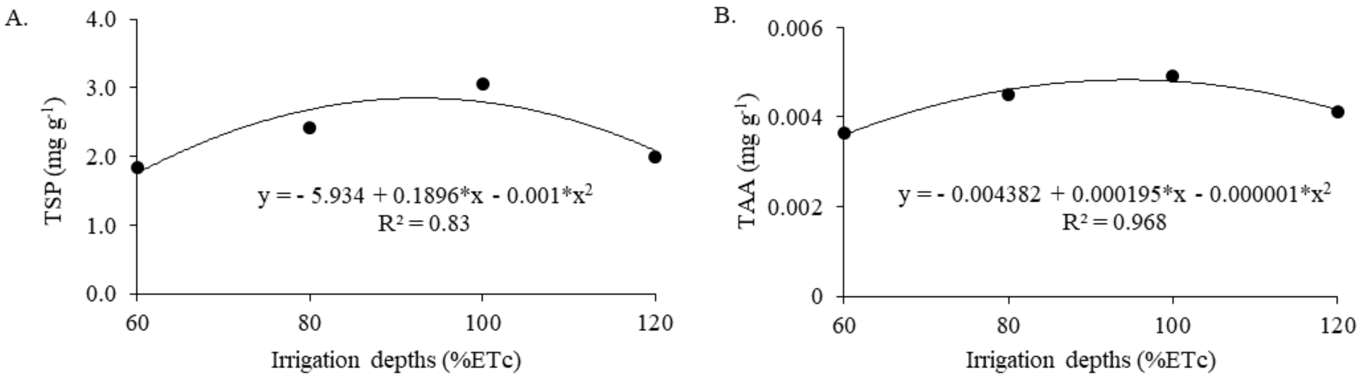
Probably, the irrigation depths of 120% ETc led to excess water volume applied to the soil, which must have promoted changes in the metabolism of amino acids and proteins, because as already reported excess water can also cause reduction in stomatal conductance, which can reduce the production of amino acids and proteins and/or activate mechanisms that act in the degradation process, negatively affecting plant growth and development (Taiz & Zeiger, 2017).

For the production per plant (Figure 5), there was also a significant effect only of the water depth, in which the fitted equation is a second-degree polynomial and the maximum value for this characteristic was estimated at 18.40 kg per plant for the irrigation depth of 91.8% ETc.

The higher fruit production in this water regime for pear may be related to the increase in carbohydrate, amino acid and protein contents per plant, which depend on photosynthetic activity, a similar condition to that found by Ghafari et al. (2020) and Simões et al. (2021).

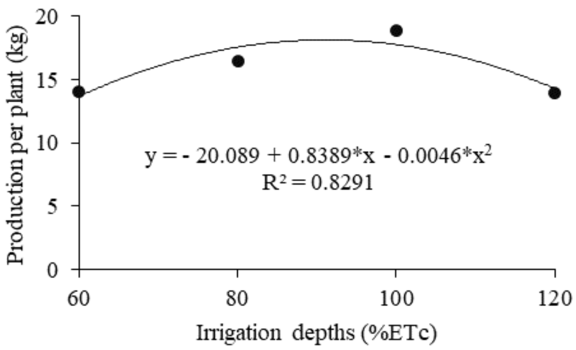
As found in other studies evaluating the production of crops from temperate climate, Oliveira et al. (2017a) observed an increase in the average weight of apple fruits due to the increment in irrigation depth in the Brazilian semi-arid region.

It was found in this study that both restriction and excess of water can compromise the performance of several events in the plant, including the reduction of photosynthetic rates, which result in the decline of production.



* - Significant at $p \leq 0.05$ by F test

Figure 4. Effect of irrigation depths (% crop evapotranspiration - ETc) on the contents of total soluble proteins - TSP (A) and total amino acids - TAA (B) in leaves of pear trees cv. Triunfo in the Sub-Middle São Francisco region, Brazil



* - Significant at p ≤0.05 by F test

Figure 5. Effect of irrigation depths (% crop evapotranspiration - ETc) on the production of pear trees cv. Triunfo in the Sub-Middle São Francisco region, Brazil

Conclusions

1. Water deficit and excess applied to plants are harmful to gas exchange as well as biosynthesis and accumulation of carbohydrates, amino acids and proteins in leaves, compromising the cultivation cycle of pear plants grown in the Sub-Middle São Francisco region, Brazil.

2. Irrigation depth of 91.8% ETc promotes the highest production of pear (18.49 kg per plant) under drip and microsprinkler irrigation systems, under the edaphoclimatic conditions of the Sub-Middle São Francisco region, Brazil.

3. Increasing irrigation depths decrease reducing and non-reducing sugars, under the edaphoclimatic conditions of the Sub-Middle São Francisco region, Brazil.

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