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DESEMPENHO PRODUTIVO DO MAMOEIRO EM SOLO FRANCO-ARENOSO COM COBERTURA POR *MULCHING* E IRRIGAÇÃO POR PULSO

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1 RESUMO

Este trabalho teve como objetivo avaliar a produtividade do uso da água no mamoeiro ‘Tainung 01’, cultivado em solo franco-arenoso, em função da irrigação por pulsos, da cobertura do solo e de diferentes lâminas de irrigação. O delineamento experimental adotado foi o de blocos casualizados, em esquema de parcelas subsubdivididas (3×2×2), sendo três lâminas de irrigação somadas à precipitação (0,83 da ETc = 1.128 mm; 1 da ETc = 1.219 mm; e 1,2 da ETc = 1.330 mm), dois intervalos de pulso de irrigação (12 e 24 h) e duas condições de cobertura do solo (com e sem *mulching* plástico preto de 20 µm), com quatro repetições. Foram avaliadas variáveis morfológicas, fisiológicas e produtivas. O *mulching* aumentou o número de folhas, enquanto sua ausência favoreceu a expansão da área foliar. A irrigação com intervalo de 12h proporcionou maior desenvolvimento, produtividade e eficiência no uso da água em comparação ao intervalo de 24h. Destacou-se a lâmina de 1.330 mm com *mulching* e a de 1.128 mm sem cobertura, ambas associadas aos melhores resultados de produtividade da água no mamoeiro ‘Tainung 01’ em solo franco-arenoso.

Palavras-chaves: *Carica papaya* L., cultiva Tainung 01, cobertura do solo, estratégia de irrigação, déficit hídrico

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PRODUCTIVE PERFORMANCE OF PAPAYA IN LOAMY SANDY SOIL WITH *MULCHING* AND PULSE IRRIGATION

2 ABSTRACT

This study aimed to evaluate water use productivity in 'Tainung 01' papaya cultivated in sandy loam soil as a function of pulse irrigation, soil cover, and different irrigation depths. The experimental design was a randomized block in a split-split plot scheme (3×2×2), consisting of

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three irrigation depths combined with rainfall (0.83 ETc = 1.128 mm; 1.0 ETc = 1.219 mm; and 1.2 ETc = 1.330 mm), two irrigation intervals (12 and 24 hours), and two soil cover conditions (with and without black plastic *mulching*, 20 µm), with four replications. Morphological, physiological, and yield variables were evaluated. *Mulching* increased the number of leaves, whereas the absence of soil cover promoted the expansion of the leaf area. Compared with the 24-hour interval, the 12-hour irrigation interval promoted greater development, yield, and water use efficiency. The best water productivity results were obtained for ' Tainung 01' papaya, which was grown in sandy loam soil, at a mulching depth of 1,330 mm and 1,128 mm without mulching.

Keywords: *Carica papaya* L., Tainung 01 cultivar, soil *mulching*, irrigation strategy, water deficit.

3 INTRODUCTION

Fruit farming is among the main sectors of agribusiness in Brazil, with papaya (*Carica) being a key product. Papaya (Papaya* L.) is among the most commercially traded fruits in the country (Silva *et al.*, 2024). In 2023, Brazil produced 1,138,343 tons of papaya, with the states of Bahia (31%), Espírito Santo (30%), Rio Grande do Norte (12%), and Ceará (10%) standing out, together concentrating the majority of national production (ABRAFRUTAS, 2024). This production is strongly influenced by the use of irrigation, which, according to Coelho Filho and Coelho (2017), enhances the productivity of papaya trees compared with nonirrigated areas.

Although irrigated management in papaya orchards increases crop yield, the major challenge lies in maintaining productivity and fruit quality while minimizing the volume of water applied throughout the production cycle, given the growing concern about the scarcity of this resource. The reduction in water availability in Brazil occurs concomitantly with the expansion of anthropogenic activities, mainly in irrigated agriculture, which has increased the number of conflicts over water use in producing regions, as reported by Buainain and Garcia (2015).

To increase efficiency and promote the rational use of water in irrigation, management strategies such as regulated deficit irrigation (RDI) stand out. Deficit Irrigation) and pulse irrigation, which allow for water conservation without compromising productivity. Pulse irrigation management involves the application of water volumes lower than the full needs of the crop during phenological phases that are less sensitive to water stress (Iqbal). *et al.,* ., 2020). In turn, pulse irrigation is based on applying the required water depth in a fractionated manner over time in two or more events within the interval between irrigations (Rank; Vishnu, 2021). Both strategies can contribute to increased irrigation efficiency and water use by crops (Coelho Filho; Coelho, 2017; Almeida *et al.*, 2018; Menezes *et al.*, 2024).

The literature has demonstrated the positive effects of different irrigation management strategies on various agricultural crops. Santos *et al.* (2021) reported that in papaya cultivation, a 35% reduction in irrigation depth, associated with partial root drying at frequencies of 7 and 14 days, promoted an increase in water use productivity without compromising gas exchange performance. For sugarcane cultivation, Menezes *et al.* (2024) reported that the combination of pulse irrigation with controlled deficit irrigation (RDI) applied at 80% of crop evapotranspiration (ETc) resulted in the best productivity and fresh biomass indices. Similarly, Almeida *et al*. (2018) reported that pulse drip irrigation attenuated the negative effects of irrigation water salinity on snap bean yield, in addition to increasing water use productivity.

In this context, these irrigation strategies have the potential to be used in papaya cultivation in sandy soils and, when associated with soil cover management through *mulching*, contribute to improving water use productivity without reducing crop yield. According to Sakariya *et al*. With respect to papaya cultivation, the greatest average plant height, stem diameter, and number of leaves, flowers and fruits were observed under the condition with plastic cover, whereas the lowest values for these parameters occurred in the absence of soil cover (2018).

Coelho *et al*. (2022) reported that, in papaya cultivation, the use of plastic as soil cover contributes to maintaining water availability above 75%, even with irrigation levels equivalent to at least 75% of the ETc, in clay loam and sandy soils. Furthermore, plastic cover increased the productivity of crops such as rice (Zhang *et al*., 2020), corn (Lee *et al*., 2021), and wheat (Qin *et al*., 2022).

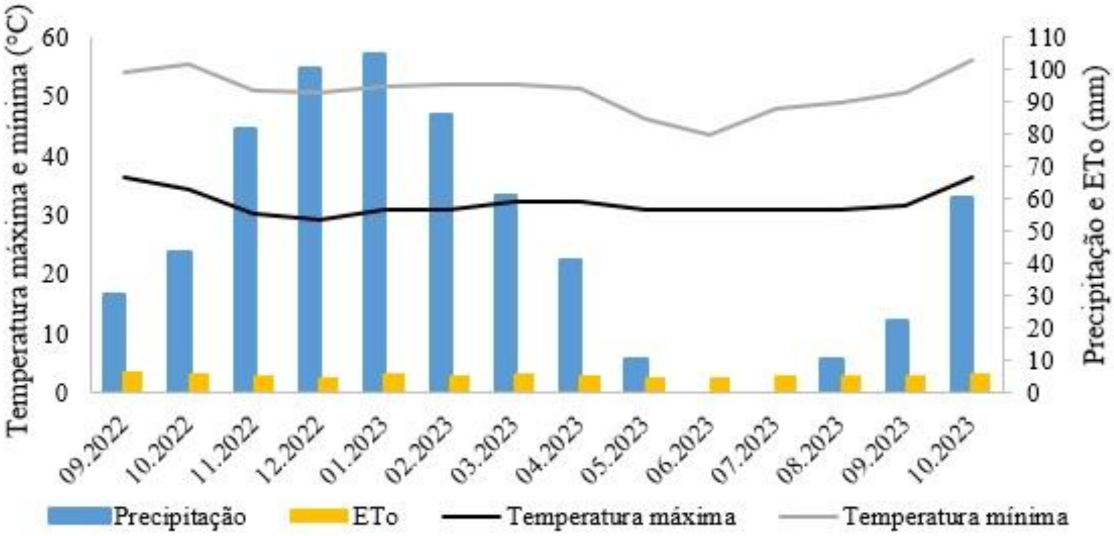
Although several studies have evaluated the individual effects of *mulching*, pulse irrigation, and controlled water deficit in agriculture, few studies have verified the efficiency of the interaction between these factors for papaya cultivation. Therefore, this study aimed to evaluate the productivity of water use in 'Tainung 01' papaya, which is grown in sandy loam soil, as a function of pulse irrigation, soil cover with *mulching*, and different irrigation depths.

4 MATERIALS AND METHODS

The experiment was conducted at the Mocambinho Experimental Field of the Minas Gerais Agricultural Research Company (EPAMIG-Norte), which is located at latitude S 15°07'47", longitude W 43°57'02" and altitude 551 m, within the Jaíba Irrigated Perimeter, in the state of Minas Gerais. The region’s climate is classified as hot semiarid (BSh), according to the Köppen–Geiger classification (Arruda *et al*., 2013), with variable annual rainfall and minimum indices below 800 mm (Veloso; Ferreira; Silva, 2017).

During the experimental period, meteorological data were monitored using an automatic weather station installed on site (Figure 1).

Figure 1. Monthly averages of maximum and minimum temperature, precipitation, and reference evapotranspiration ETo (Hagreaves - Samani) recorded between 2021 and 2022 in Jaíba, Minas Gerais, MG.



Sources: The corresponding authors.

Tainung 01', were used, spaced 1.5 × 2.5 m apart, with a density of 2,666 plants per hectare (ha $^{-1}$). Before the experiments were performed, soil samples were collected for physical and chemical analyses. The soil in the experimental area presented a sandy-loam texture, a density of 1.70 g cm^{-3}, and water retention characteristics (Table 1). Chemical analysis of the soil indicated the need for nitrogen (N), phosphorus (P), and potassium (K) fertilization (Table 1). Subsequently, planting and topdressing fertilizers were applied, the latter via fertigation, following the recommendations for papaya cultivation by Coelho *et al.* (2011).

Table 1. Chemical attributes and water retention properties of the soil in the experimental area cultivated with papaya ' Tainung N°1'

Chemical attributes of the soil											
Ref.	**pH**	**P**	**K**	**Her e**	**Mg**	**Al**	**In**	**SB**	**CTC**	**V**	**MO**
cm	**H2 O**	**mg dm $^{-3}$**	**--------------------- cmol $_c$ dm $^{-3}$**							**%**	**g kg $^{-1}$**
0 -20	6.2	5	0.72	3.39	1.46	0.0	0.01	5.58	6.46	86	14.0
20 - 40	5.4	1	0.79	1.49	0.56	0.2	0.01	2.85	4.50	63	5.0

Soil water retention characteristics							
Ref.	**0.06**	**0.1**	**0.33**	**1**	**3**	**15**	**AD**
cm -- atm -------------------------------							**cm ^{3} cm $^{-3}$**
0 - 20	7.88	7.30	6.20	5.40	4.44	3.92	3.38
20 - 40	8.24	7.56	6.84	6.27	5.36	4.02	3.54

Ref. P – Sampling depth reference; pH – Hydrogen potential; P – Phosphorus; K – Potassium; Ca – Calcium; Mg – Magnesium; Na – Sodium; SB – Sum of bases; CEC – Cation exchange capacity; V – Base saturation; OM – Organic matter; atm – Atmosphere; AD – Available water in cm^{3} ^{of} water per cm^{3} ^{of} soil. **Sources:** The corresponding authors.

The orchard was irrigated by a drip irrigation system with two lateral lines per row of plants, using emitter tubes spaced 0.50 m apart with a flow rate of 4.2 L h^{-1}. Irrigation management was based on replenishing water to the crop in the interval between two irrigations and was carried out on the basis of crop evapotranspiration (ETc), which was calculated as the product of reference evapotranspiration (ETo), as estimated by the Hargreaves and Samani method (1985), and the crop coefficient (Kc), according to Posse *et al*. (2008) and the reduction coefficient (Kr), determined by the Keller and Bliesner method (1992).

The experiment was conducted in a randomized complete block design (RCBD) in a split-split-plot arrangement (3 × 2 × 2). In the main plots, three irrigation depths were evaluated plus the accumulated precipitation (0.83 of ETc = 1,128 mm; 1.0 of ETc = 1,219 mm; and 1.2 of ETc = 1,330 mm) between irrigations. In the subplots, two intervals between irrigation pulses (12 and 24 hours) were allocated, and in the subsubplots, the two soil cover conditions (with and without 20 µm black plastic *mulch*) were considered. The accumulated precipitation during this period was 672 mm.

Morphological variables were determined in papaya plants at 90 and 240 days after planting (DAP), after which the number of leaves per plant and the LA growth rate were measured. To estimate the leaf area, the length of the midrib of the leaves was measured. To calculate the growth rate, the leaf areas obtained at 90 and 240 DAP were considered, according to Equation 1 described by Campostrini and Yamanishi (2001).

$$\mathrm{LogAF} = (0{,}315 + 1{,}85 * \mathrm{LogNCF})(1)$$

where AF is the leaf area ($m^{2)}$ and NCF is the length of the midrib of the leaf (m).

$$\mathrm{TAF} = \frac{(\mathrm{AF2}-\mathrm{AF1})}{(\mathrm{T2}-\mathrm{T1})} \qquad (2)$$

where TAF is the leaf area growth rate (cm ^{2} day $^{-1}$), AF2 is the leaf area at 240 DAP (cm ^{2}), AF1 is the leaf area at 90 DAP (cm ^{2}), T2 is 90 DAP, and T2 is 240 DAP.

Leaf temperature was evaluated during the fruiting period at 222 days after planting (DAP). Measurements were taken using a portable porometer (model AP4, Delta-T Devices), with readings taken between 9 am and 11 am on fully expanded, mature leaves exposed to solar radiation located on the upper part of the plants (Fernandes *et al*., 2021). Stomatal conductance (gs; mol of H_2O $m^{-2\ s^{-1}}$) and leaf temperature (Tf; °C) were measured. The chlorophyll content was determined during the same period using a nondestructive method with a ClorofiLOG portable chlorophyll meter (model CFL 1030, Falker®).

To determine productivity, fruits were harvested manually, counting only those with commercial potential per plant (NC), with a mass greater than 0.80 kg and free from deformities or physiological disorders. The average fruit mass (MF, in kg) was determined on the basis of the ratio between the total mass of fruits and the total number of fruits harvested in the useful area of the plot. Productivity (P, in t ha^{-1}) was calculated by multiplying the MF by the estimated number of plants per hectare, according to Equation 3.

$$\mathrm{P} = \frac{(\mathrm{PM}*\mathrm{NF}*\mathrm{NP})}{1000} \qquad (3)$$

where P is the productivity (t ha $^{-1}$), PM is the average fruit weight (kg), NF is the average number of fruits per plant, and NP is the number of plants ha $^{-1}$.

The productivity of water use (PWU) in papaya cultivation under different treatments was determined using Equation 5, which calculates the ratio between fruit productivity (kg ha $^{-1}$) and the total volume of water used in the cycle. This volume considers the sum of gross irrigation depths and effective precipitation from planting to harvest, as described by Santos *et al*. (2021).

$$PUA = \frac{P}{VA} \tag{4}$$

where PUA is the water use productivity (kg ha $^{-1}$ mm $^{-1}$), P is the productivity (kg fruit ha $^{-1}$), and VA is the irrigation depth plus the precipitation used in the cycle (mm ha $^{-1}$).

The data were initially assessed for normality using the Shapiro–Wilk test and for homogeneity of variance using Bartlett's test. Once these assumptions were met, analysis of variance was performed using the F test ($p < 0.05$). For variables that significantly affected the studied factors (irrigation depth, irrigation pulses, and soil cover), the means were compared using Tukey's test at the 5% probability level. The analyses were performed according to the proposed experimental design and statistical model using the SISVAR software (Ferreira, 2017).

5. RESULTS AND DISCUSSION

According to the summary of the analysis of variance, no triple interaction was observed between the factors studied (irrigation depth, irrigation pulse, and soil cover) according to the F test ($p > 0.05$). However, the morphological variables of the papaya, such as the rate of change in the number of leaves per plant and the rate of increase in leaf area during the period from 90 to 240 days after planting (DAP), were influenced by the interactions between the irrigation pulse and depth, between the irrigation pulse and soil cover, and between the depth and soil cover.

An analysis of the interaction between irrigation pulses and irrigation depth (Table 2) revealed that the number of leaves per plant (NTF) and the leaf area growth rate (TAF) exhibited similar responses. The irrigation depths of 1,128 and 1,219 associated with the 12-hour pulse resulted in the highest values for both variables, according to Tukey's test at the 5% probability level. These results indicate that papaya leaf growth is influenced by more frequent pulses at lower volumes in sandy loam soils.

Although they are different crops, similar responses were observed in cucumber and sugarcane crops. Rezende *et al*. (2016) concluded that, for Japanese cucumber, irrigation depths lower than those recommended for the crop can be applied through pulse irrigation without harming vegetative growth. Complementarily, Menezes *et al*. For sugarcane, (2024) verified that the combination of pulse irrigation with controlled water deficit (RDI - Regulated Irrigation) Deficit Irrigation) applied at 80% of crop evapotranspiration (ETc) resulted in the best productivity and fresh biomass indices.

Table 2. Average number of leaves per plant (NTF) and leaf area growth rate (TAF) of papaya ' Tainung 01' under different water depths combined with precipitation, soil cover, and irrigation pulses in sandy loam soil.

Pulses	**Blades plus precipitation (mm)**			**Ground Cover**	
	1.128	**1.219**	**1.330**	**With *mulching***	**No *mulching***
	Number of leaves per plant (NTF)				
12	0.08310 aA	0.0510 bA	0.0860 aA	0.0966 aA	0.0734 aB
24	0.05336 bB	0.08383 aAB	0.0938 aA	0.0805 aA	0.0507 bB
	Leaf area growth rate (cm^{2} day^{-1}) (LAR)				
12	0.0302aA	0.0228aA	0.0262 aA	0.0217 aB	0.0311 aA
24	0.0215 bB	0.0229 aAB	0.0375 aA	0.0261 aB	0.0327 aA
CV	------------------------ 20.7 ----------------------			---------------- 18.6 ----------------	

For the separate effects of pulses versus blade and pulses versus ground cover, identical lowercase letters do not differ from each other in the column, and identical uppercase letters do not differ from each other in the row, according to Tukey's test at the 5% level. **Sources:** The corresponding authors.

The interaction between irrigation pulses and soil cover significantly influenced the growth of the 'Tainung 01' papaya, according to Tukey’s test at the 5% probability level (Table 2). The 12- and 24-hour pulses, in the presence of *mulching*, resulted in the best results for the number of leaves per plant (NTF), with values of 0.0966 and 0.0805 leaves per plant, respectively, with the 12-hour pulse being superior to the 24-hour pulse in the condition without *mulching*. However, the opposite was observed for the leaf area growth rate (LAR); in the absence of *mulching*, both pulses yielded the best results. In fact, soil cover resulted in a greater increase in the number of leaves, which may have influenced their development, explaining the smaller expansion of the leaf area in the presence of *mulching* under sandy loam soil conditions.

The increase in net total fertilizer (NTF) with the use of *mulching* can be attributed to improved water retention in the soil, which promotes plant development. This is in accordance with observations by Sakariya. *et al.* . With respect to papaya cultivation (2018), the average plant height, stem diameter, and numbers of leaves, flowers, and fruits were greater under conditions with plastic *mulching* than in the absence of soil cover. Similar responses were also observed for maize (Lee *et al.*, 2021) and wheat (Qin *et al.*, 2022). These findings confirm that plastic soil cover enhances the physiological and productive performance of crops in water-limited environments.

The use of plastic mulch obscured the effect of the applied water depth, as there was no difference between the averages of the three water depths with the soil cover (Table 3). In a study with the same cultivar 'Tainung 01' and under similar sandy loam soil conditions, Coelho *et al.* (2022) reported that soil cover with plastic contributes to maintaining water availability above 75%, even when irrigation depths corresponding to only 75% of ETc are applied. These results are consistent with those observed in the present study for the 1,128 mm water depth with the use of *mulch* (Table 3). This behavior highlights the ability of plastic to reduce soil water evaporation, which, under covered conditions, results in a smaller difference in the increase in the number of leaves, regardless of the irrigation depth.

Melo *et al.* (2020), when evaluating the growth and productivity of the ' Tainung 01' cultivar in sandy loam soil under irrigation depths ranging from 1,000 to 3,500 mm, a linear increase in leaf area was observed at 320 DAP with increasing irrigation depth, indicating that greater water availability favors an increase in the leaf area of the ' Tainung 01' cultivar. This behavior was also verified in the present study, especially under bare soil conditions, where the 1,330 mm irrigation depth resulted in the greatest average rate of change in leaf area at 240 DAP (Table 3).

Table 3. Average number of leaves per plant (NTF) of papaya ' Tainung 01' under different irrigation depths added to precipitation and soil cover in a sandy loam area.

Number of leaves per plant (NTF)		
Blades plus precipitation (mm)	**With *mulching***	**No *mulching***
1.128	0.0623 aA	0.0748 bA
1.219	0.0556 aB	0.0795 bA
1.330	0.0683 aB	0.1115 aA
CV	---------------------------- 15.4 ------------------------	

Identical lowercase letters do not differ from each other in a column, and identical uppercase letters do not differ from each other in a row according to Tukey's test at the 5% level. **Sources:** The corresponding authors.

With respect to the physiological variables, although no statistically significant differences were found between the sources of variation or their interactions according to the F test ($p > 0.05$), it is worth noting that the 1,219 mm layer presented the highest absolute mean value of stomatal conductance (710.7 mmol m^{-2} s^{-1}). On the other hand, the 1,128 mm layer resulted in the lowest absolute value (647.9 mmol m^{-2} s^{-1}). The pulse frequency (12 and 24 h) had little influence, with absolute values close to 676.2 and 685.5 mmol m^{-2} s^{-1}, respectively. The absence of mulching slightly increased the stomatal conductance to 686.2 mmol m^{-2} s^{-1} compared with that in covered soil (675.6 mmol m^{-2} s^{-1}), possibly because of greater evaporation and the consequent compensatory stomatal opening (Table 4).

Table 4. Average stomatal conductance (gs) and leaf temperature (Tf) in ' Tainung 01' papaya under different water depths combined with precipitation, soil cover, and irrigation pulses in sandy loam soil.

Blades (mm)	**gs (mmol m^{-2} s^{-1})**	**Tf (°C)**
1.128	647.9	34.5
1.219	710.7	37.6
1.330	684.1	37.6
Pulses (h)	**gs (mmol m^{-2} s^{-1})**	**Tf (°C)**
12	676.2	37.6
24	685.5	35.5
Ground Cover	**gs (mmol m^{-2} s^{-1})**	**Tf (°C)**
With *mulching*	675.6	35.5
No *mulching*	686.2	37.6
CV (%)	8.8	17.2

Sources: The corresponding authors.

With respect to the leaf temperature (Tf), as shown in Table 4, although no statistically significant differences were observed, the absolute average values indicate that the lowest leaf temperature was recorded at the lowest irrigation depth, at 34.5°C. On the other hand, the irrigation depths of 1,219 and 1,330 mm presented higher absolute average values, both at 37.6°C, which may be related to the greater volume of water in the soil. While this reduces water stress, it may have promoted microclimatic changes that altered the transpiration rate, contributing to the increase in Tf. Compared with bare soil, which was 37.6°C, the use of *mulching* reduced the leaf temperature, with an absolute average value of 35.5°C. This highlights the role of *mulching* in thermal buffering and regulating the temperature of the plant's aerial parts.

With respect to the chlorophyll content (Table 5), the results revealed that the 1,330 mm irrigation depth resulted in the highest leaf chlorophyll content in papaya, regardless of the presence of irrigation pulses, indicating that greater water availability favored the physiological state of the plants. Soil cover also contributed positively, especially under the 12-hour pulse, whose average value was 50.0, which was significantly greater than that of bare soil (47.58), highlighting the benefits of *mulching* in terms of moisture conservation and water stress reduction.

Table 5. Average leaf chlorophyll content in papaya ' Tainung 01' under different irrigation depths combined with rainfall, soil cover, and irrigation pulses in sandy loam soil.

Chlorophyll content					
Pulses (h)	**Blades (mm)**			**Ground Cover**	
	1.128	**1.219**	**1.330**	**With *mulching***	**No *mulching***
12	40.9 aA	47.5 aA	52.2 aA	50.0 aA	43.78 AB
24	38.3 aB	40.5 AB	55.4 aA	43.3 bA	46.17 aA
CV		**27.5**		**26.5**	

For the effects of pulses versus blade and pulses versus ground cover, identical lowercase letters do not differ from each other in the column, and identical uppercase letters do not differ from each other in the row, according to Tukey's test at the 5% level. **Sources:** The corresponding authors.

When the influence of the sources of variation on the leaf chlorophyll content was evaluated, it was found that at depths of 1,128 mm and 1,219 mm, the presence of *mulch* resulted in a lower chlorophyll content than that in the uncovered soil. At the 1,330 mm depth, there was no significant difference between the soil cover conditions for the aforementioned levels (Table 6).

Table 6. Average leaf chlorophyll content in papaya ' Tainung 01' under different water depths combined with precipitation and soil cover in a sandy loam area.

Chlorophyll content			
Ground cover	**Blades (mm)**		
	1.128	**1.219**	**1.330**

With *mulching*	44.6 aB	41.9 aB	53.4 aA
No *mulching*	34.6 BC	46.1 aB	54.2 aA
CV	24.8		

Identical lowercase letters do not differ from each other in a column; identical uppercase letters do not differ from each other in a row according to Tukey's test at the 5% level. **Sources:** The corresponding authors.

Tainung 01' papaya was significantly influenced by the interaction between the irrigation depth and soil cover (Table 7). The highest productivity was observed with the use of *mulching* at a depth of 1,330 mm, reaching 53.88 t ha$^{-1.}$ In contrast, at the same depth, in the absence of *mulching*, productivity was lower, reaching 44.8 t ha$^{-1.}$ These results indicate that adequate water management, combined with the soil moisture conservation provided by *mulching*, can contribute to increased papaya productivity.

According to Sakariya *et al*. (2018), the average productivities of **the yields of 'Taiwan' and 'Madhu'** papaya trees **in** Bindu were influenced by the use of *mulching*, reaching 84 and 78.4 t ha $^{-1,}$ **respectively**, in contrast to 61.6 and 56 t ha $^{-1}$, respectively, for plants without cover, which highlights the influence of soil cover on crop yield. Furthermore, plastic soil cover has been reported to increase the productivity of crops such as rice (Zhang *et al*., 2020), maize (Lee *et al*., 2021), and wheat (Qin *et al*., 2022).

The interaction effect between the irrigation depth and irrigation pulse significantly affected productivity (Table 7). The 1,330 mm depth provided better performance than the 1,128 and 1,219 mm depths did during the 24-hour pulse. However, no statistically significant differences were observed between the pulses according to Tukey's test at the 5% probability level. With respect to the pulse **with** a 12-hour interval, the best results were obtained with the 1,128 and 1,219 mm blades, which provided the highest **yields—44**.30 and 54.21 t ha $^{-1}$, respectively.

These findings suggest that more frequent irrigation helps maintain soil moisture at more stable levels, which is reflected positively in productivity, as observed for other crops. In terms of eggplant cultivation, Arriero *et al*. (2020) reported that pulsed drip irrigation promoted increased productivity of marketable fruits. In the case of cucumber, Ramadan *et al*. (2022) reported that the adoption of three daily irrigation pulses, with eight pulses per fertigation season, resulted in gains in productivity and water use efficiency.

Table 7. Average productivity of ' Tainung 01' papaya under different water depths combined with precipitation, soil cover, and irrigation pulses in sandy loam soil.

Productivity - P (t ha $^{-1}$)			
Ground Cover	**Blades (mm)**		
	1.128	**1.219**	**1.330**
With *mulching*	48.98 AB	42.99 bB	53.88 aA
Without *mulching*	38.79 bB	50.78 aA	44.82 bB
CV	13.9		
Pulses (h)	**Blades (mm)**		

	1.128	**1.219**	**1.330**
12	44.30 aA	54.21 aA	46.89 aA
24	38.48 AB	39.57 bB	51.81 aA
CV	**-----------------------------------** 22.8 **----------------------------**		

For the effects of ground cover versus blades and pulses versus blades, identical lowercase letters do not differ from each other in the column; identical uppercase letters do not differ from each other in the row according to Tukey's test at the 5% level. **Sources:** The corresponding authors.

The presence of *mulching*, which is associated with irrigation depth, significantly influenced the productivity of water use (PWU) of the ' Tainung 01' papaya in sandy loam soil (Table 8). The 1,330 mm irrigation depth, associated with *mulching*, resulted in the highest observed PUA of 61.92 kg ha^{-1} mm^{-1}. This positive effect of *mulching* was also observed by Sakariya *et al.* . (2018), who reported greater water use productivity in the 'Madhu ' papaya varieties. Bindu', with 29 kg ha^{-1} mm^{-1}, and 'Taiwan', with 32 kg ha^{-1} mm^{-1}, with the use of silver/black plastic, while the lowest values were recorded in treatments without cover, with 16 and 17 kg ha^{-1} mm^{-1}, respectively.

With respect to the bare soil condition, the 1,219 and 1,330 mm irrigation depths provided the highest PUA values, which were 47.87 and 51.87 kg ha^{-1} mm^{-1}, respectively. These values can be attributed to replenishing the irrigation depths equivalent to 1.0 and 1.2 times the ETc, ensuring greater water availability for the crop. This positive effect of the irrigation depth was also reported by Melo *et al.* (2020), who **reported** higher PUA in the ' Tainung 01' cultivar in sandy loam soil under an irrigation depth of 1,103 mm, which resulted in the highest productivity of water use (61 kg ha^{-1} mm^{-1}) at 320 DAP.

Table 8. Averages for water use productivity (WUP) for papaya ' Tainung 01' under different water depths added to precipitation, soil cover and irrigation pulses in sandy loam soil.

Water use productivity - WUP (kg ha $^{-1}$ mm $^{-1}$)			
Ground Cover	**Blades (mm)**		
	1.128	**1.219**	**1.330**
With *mulching*	36.76 AB	48.76 bB	61.92 aA
Without *mulching*	31.77 bB	56.87 aA	51.87 bA
CV	-------------------------------- 13.3 --------------------------------		
Pulses	**Blades (mm)**		
	1.128	**1.219**	**1.330**
12	36.28 AB	53.32 aA	54.15 aB
24	32.25 aB	38.30 bB	59.63 aA
CV	-------------------------------- 13.5 --------------------------------		

For the effects of ground cover versus blades and pulses versus blades, identical lowercase letters do not differ from each other in the column; identical uppercase letters do not differ from each other in the row according to Tukey's test at the 5% level. **Sources:** The corresponding authors.

The interaction between irrigation pulses and applied water depth significantly influenced the water use productivity (WUP) of 'Tainung 01' papaya under sandy loam soil conditions. As shown in Table 8, compared with the other water depths, the 12-hour pulse, associated with a water depth of 1,219 mm, provided the highest value (53.32 kg ha^{-1} $^{mm^{-1}}$) according to Tukey's test at a **5%** probability. These results are in agreement with those observed by Deshmukh. *et al.* . (2017) for papaya cultivation, who reported a PUA of 49 kg ha^{-1} mm^{-1} ^{in} sandy loam soil, and this was confirmed by Melo *et al.* (2020), who reported a higher PUA in the 'Tainung 01' cultivar, ^{with} an irrigation depth of 1,219 mm (55.30 kg ha^{-1} $^{mm^{-1}}$) at 320 DAP.

Although it is difficult to correlate the effects of irrigation depth with the pulses studied, the superior response of the 1,219 mm depth to the 12-hour pulse compared with that to the 24-hour pulse may be associated with the greater water distribution within the pores of the sandy loam soil studied. In this sense, Rank and Vishnu (2024) reported that under different combinations of pulses and drip rates, the remaining intervals during pulse irrigation cycles favor the redistribution of water in the macropores, reducing losses and promoting greater efficiency. Furthermore, Rank and Vishnu (2024) reported that the increase in wetted bulb was less pronounced under pulse irrigation than under continuous drip irrigation, which contributed to a more controlled and efficient moisture distribution in the soil profile.

6 CONCLUSION

The use of *mulching* resulted in an increase in the number of leaves in the 12- and 24-hour pulses, whereas an increase in leaf area was observed in the absence of soil cover in both irrigation pulses for the ' Tainung 01' papaya in sandy loam soil. Water depths of 1,128 and 1,219 mm resulted in an increase in the number of leaves and in leaf area growth when associated with a 12-hour pulse frequency.

The highest productivity and water use efficiency values were obtained with a 1,330 mm water depth with *mulching* and with a 1,219 mm water depth without plastic cover, with the 12-hour pulse being superior to the 24-hour pulse in the latter water condition.

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