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# EFFECT OF WATER DEFICIT ON SAFFLOWER CULTIVATION AT DIFFERENT PHENOLOGICAL STAGES

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**KEYWORDS**

*Carthamus tinctorius* L.; yield components; agrarian scenario; irrigation; water demand.

**ABSTRACT**

Safflower stands out among oilseeds due to its oil quality and crop resilience in dry and cold regions. However, there have been limited studies on its water requirements. This study aimed to assess water stress indices and determine phenological stages with the highest water demands during safflower cultivation. The experiment was conducted in two phases: one in a greenhouse and another in the field. Treatments involved different irrigation timings during the stages of crop development. The variables analyzed included plant height, stem diameter, fresh and dry aboveground biomass, number of capitula, and number and weight of seeds. The results showed that safflower cultivation benefited from irrigation during its vegetative stage, in conjunction with irrigation during the reproductive and/or grain formation stage. It exhibited susceptibility to water deficit when irrigated only during the vegetative stage. Safflower can be cultivated in various climatic regions of Brazil and become an economically important species due to its adaptability, production, and potential.

## INTRODUCTION

Safflower (*Carthamus tinctorius* L.) is an oilseed plant belonging to the Asteraceae family (Anicésio et al., 2018). Its plants have branched, erect herbaceous stems, ranging from 0.4 to 2.0 meters in height, with a taproot system that can reach depths of up to 3.0 meters (Neto et al., 2020). The crop has been cultivated for the production of oil, primarily for use in biodiesel production, animal feed, applications in cosmetics industries, manufacturing of industrial and culinary dyes, and pharmaceutical uses (Chakradhari et al., 2020; Kim et al. 2020; Steberl et al. 2020).

Its cultivation has been expanding in Brazil due to several important characteristics, such as tolerance to elevated temperatures, saline soils, low humidity, water deficit, and strong hot winds (Sá et al., 2020). Therefore, the crop has the potential for alternative plantings during Brazilian off-seasons (Bidgoly et al., 2018; Zafari et al., 2020). Soil water stress during flowering and grain filling negatively affects safflower yield (Tabib-Loghmani et al., 2019). For this reason, defining the periods when the crop is susceptible to water shortage is essential for reducing productivity losses (Carvalho et al., 2013).

Zhang et al. (2019) conducted a case study in the city of Beijing, China, indicating that 53.1% of farmers adopted irrigation engineering technologies such as the use of automatic irrigation systems. The use of irrigation techniques optimizes water usage, aiming to provide the crop with the precise amount of water it needs (EMBRAPA, 2022).

Safflower research involving its potential, adaptation, and genetic improvement is needed since there are few studies in the literature. Therefore, this study can contribute to the establishment of safflower cultivation in the country, especially in regions with water deficits. In light of the above, the present study aimed to assess water stress indices and determine the stages with the highest water demands in safflower cultivation.

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## MATERIAL AND METHODS

The study was divided into two stages: one conducted in a greenhouse at the experimental area of the University of Western Paraná – UNIOESTE campus, with planting on April 12 and harvest on September 29, 2021. The other stage was conducted in the field at the Foundation for Scientific and Technological Development – FUNDETEC, with planting starting on March 9 and harvest on November 8, 2022. Both experiments were carried out in the city of Cascavel-PR. The soil in the region is classified as a dystroferric Red Latosol (Oxisol), with a humid subtropical climate, an average annual temperature of 19°C, and an annual rainfall of 1841 mm (Köppen-Geiger, revised by Kottek et al., 2006).

Since its phenological stages have varying durations, water conservation throughout the safflower cycle was considered, and irrigations were fractionated according to each phenological stage (Figure 1). These irrigation depths were based on the classification by Flemmer et al. (2014). Therefore, in both experiments the treatments were divided as follows: T1: Vegetative; T2: Reproductive; T3: Grain formation; T4: Vegetative and reproductive; T5: Vegetative and grain formation; T6: Reproductive and grain formation; T7: None of the stages; T8: All stages.

In both experiments, irrigation was carried out daily for the first fifteen days to establish the crop. After this period, irrigation was adjusted according to the phenological stages of the crop (treatments).


Source: Flemmer et al. (2014).

FIGURE 1. Phenological stages of *Carthamus tinctorius* L., wherein D1: D1.1= emergence; D2: D2.1= vegetative; D3= middle inflorescence differentiation; D4= lateral inflorescence branching; D5= reproductive; D6: time of stem harvest; D7: full flowering; D8: grain formation; D9: dried floral stems.

Irrigations were daily based on the calculation of crop water requirement (Equation 1):

$$Et_c = Et_0 \times K_c \tag{1}$$

Where:

$Et_c$ is the daily measurement of crop evapotranspiration (mm.day$^{-1}$);

$Et_0$ stands for the reference potential evapotranspiration (mm.day$^{-1}$) estimated or measured daily, and

$K_c$ represents the crop coefficient. Considering that this information is not yet available for safflower, the Kc (Crop Coefficient) of cotton (*Gossypium hirsutum* L.), which belongs to the Malvaceae family and has similar water requirements, was used, as shown in Table 1.

TABLE 1. Water demands at different cotton cultivation stages.

| Water demand | Days after sowing |
|---|---|
| Kc 0.45 | 20 |
| Kc 0.75 | 40 |
| Kc 1.15 | 80 |
| Kc 0.85 | 100 |

Source: Barreto et al. (2003).

$Et_0$ was determined using measurements of an evaporation tank (EV), which are related to $Et_0$ through the tank coefficient ($K_p$) (Equation 2).

$$Et_0 = K_p \times EV \tag{2}$$

Where:

EV is the evaporation from the tank (mm.day$^{-1}$), and

$K_p$ represents the tank coefficient.

By applying eqs (1) and (2), the following parameters could be determined:

$$K_i = K_c \times K_p \quad (3)$$

$$Et_c = K_i \times EV \quad (4)$$

Where:

$K_i$ is the coefficient of irrigation (Santos et al., 2004).

The variables analyzed included plant height, stem diameter, fresh and dry aboveground biomass, number of capitula, number of seeds, and seed weight. Plant height, stem diameter, and fresh and dry biomass measurements were taken when the crop reached 50% of its flowering stage, with six randomly selected plants per treatment. The following materials were used for the analyses: graduated measuring tape, digital caliper, precision scale, and a continuous air circulation oven set at 65 °C.

For the variable "yield," plant harvesting was done manually in the field, followed by weighing the grains using a precision scale.

The analyses were carried out in the Seed and Plant Evaluation Laboratory (LASP) and the Multi-User Laboratory for Sustainable Technologies (LABTES). The obtained results were subjected to analysis of variance, and means were compared using the Tukey test ($p < 0.05$), with the SISVAR software (Ferreira, 2000).

**Greenhouse experiment**

The experimental design used was completely randomized (CRD), consisting of eight treatments and four replicates, randomly distributed by drawing. The plots consisted of PVC tubes with a capacity of 28.26 kg (18.84 liters), measuring 20 cm in diameter and 60 cm in height, filled with 26 kg of dystroferric Red Latosol and 1.5 kg of earthworm humus.

Sowing and cultural practices were carried out manually. The sowing depth was about three centimeters, with 4 seeds planted per tube. Later, thinning was performed, leaving only two plants per tube. The cultivar used was IPR–211, which was provided by the Rural Development Institute of Paraná (IDR-Paraná). The genotype is adapted for cultivation throughout Paraná State in April and May and has a cycle of 160 days, with a potential yield of 1.0 to 1.9 t/ha.

Irrigation was carried out manually with the assistance of a plastic graduate cylinder in mL/L, based on the crop's water requirements.

**Field experiment**

The experimental design adopted was a randomized complete block design (RCBD), with eight treatments and six replicates. Each treatment consisted of three planting rows, each three meters long, spaced 0.50 meters apart from each other, with a plant spacing of 0.10 meters within the row.

The studied cultivar was the variety CIPL – 04407 provided by Embrapa Soja. According to the same, the seeds had a vigor of approximately 80%.

Soil chemical analysis of the cultivation area was conducted by collecting samples one day before sowing (March 08, 2022) across the entire experimental area, at a depth of 0-20 cm, as described in Table 2.

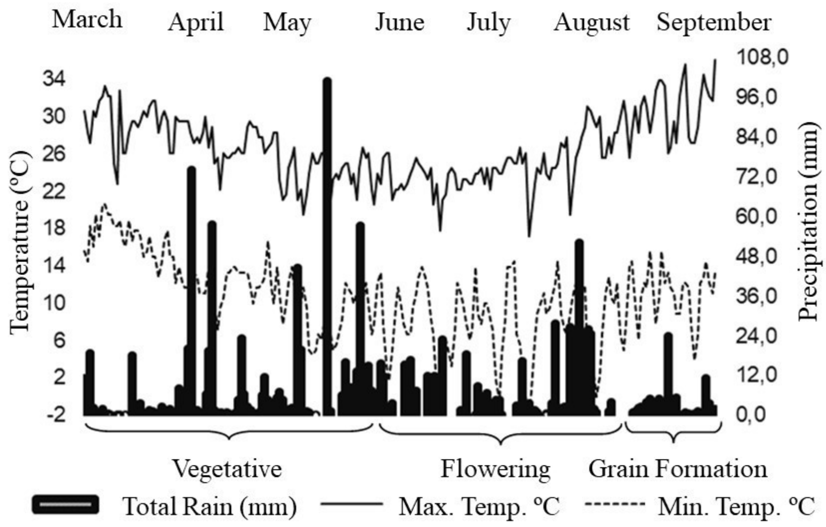
Fertilization was applied as a topdressing, with the following quantities of N, P, and K: 10, 15, and 15. Due to the lack of specific recommendations for the crop in Brazil, the recommendation for corn cultivation was followed: 400 kg/ha.

TABLE 2. Chemical characterization of the soil in the study area.

| Element | $cmol_c\ dm^{-3}$ |
|---|---|
| Calcium (Ca) | 4.57 |
| Magnesium (Mg) | 2.8 |
| Potassium (K) | 0.84 |
| Aluminum (Al) | 0 |
| H + Aluminum (H + Al) | 5.22 |
| Sum of bases (SB) | 8.21 |
| CEC (T) | 13.43 |
| | |
| Base saturation (V%) | 61.13 mg $dm^{-3}$ |
| | mg $dm^{-3}$ |
| Phosphorus (P) | 19.42 |
| pH $CaCl_2$ | 5.48 |

Source: SOLANALISE (2022).

The daily climatic parameters were measured at a meteorological station located near the experimental area (Zucchetto station), obtained from daily climate data provided by WeatherLink (Figure 2).




Source: The autor, 2022.

FIGURE 2. Rainfall (mm), maximum and minimum temperatures (ºC) at different phenological stages of safflower in 2022. V: Vegetative; F: Flowering; FG: Grain formation.

Irrigation was carried out through a drip irrigation system, with one dripper per plant. In each studied plot, the piping of this system ran parallel to the row that received irrigation. The selected model for the irrigation project was the Arduino UNO R3, which is a microcontroller board based on the ATMega 380 chip. In automatic mode, every 24 hours, the ultrasonic sensor measured the height of the evaporator's water level. If there was a difference between one day and the next, the solenoid valve was opened, and by gravity, water was directed to the drip tubes, irrigating the selected plots. Irrigations were always performed at sunset because, at other times of the day, higher temperatures lead to rapid water evaporation.

## RESULTS AND DISCUSSION

### Greenhouse experiment

The ANOVA conducted for plant height and stem diameter showed that safflower was significantly affected by water availability at different phenological stages (Table 3). The treatment that had water availability only during the vegetative stage had the lowest mean plant height (58.50 cm). Bassegio et al. (2018) also observed more pronounced decreases in this variable with water management, where safflower did not receive irrigation during the vegetative stage (V), resulting in a reduction in aboveground growth.

Stem diameter data showed a different trend from that obtained for plant height, with no significant differences between treatments (Table 3). Neto et al. (2020), evaluating safflower accessions adaptable to water deficit conditions and their potential for breeding programs, observed significant differences. Varieties NOVO343, IMA340, NOVO338, and IMA211 stood out with a larger stem diameter (9.43, 9.53, 10.54, and 8.88 mm, respectively), which differs from the results found in this study, where stem diameter did not show significant differences.

Emongor & Oagile (2017) pointed out that safflower plants tolerate a temperature range between -7 to 40°C, depending on their developmental stage. In our study, average temperatures ranged from -2°C to 34°C (Figure 2), which may not have interfered with stem development.

TABLE 3. Effect of water stress at different phenological stages on safflower morphological components in a greenhouse.

| Source of variation | Morphological component | |
|---|---|---|
| | Plant height (m) | Stem diameter (cm) |
| Vegetative | 58.50 a | 5.45 a |
| Reproductive | 82.25 ab | 4.60 a |
| Grain formation | 80.00 ab | 5.62 a |
| Vegetative and reproductive | 88.75 ab | 5.82 a |
| Vegetative and grain formation | 78.25 ab | 6.20 a |
| Reproductive and grain formation | 74.25 ab | 6.07 a |
| None of the stages | 63.25 ab | 5.02 a |
| All stages | 104.25 b | 6.20 a |
| CV (%) | 23.5 | 18.88 |
| F | <0.05** | $0.34^{ns}$ |

Means followed by the same letter in the column do not differ from each other using the Tukey test at 5% significance | ** Significant at 5% probability | ns non-significant at 5% probability by the F-test (comparison of means).

Fresh and dry stem weights were significantly affected by water stress at different phenological stages (Table 4). The treatment that received no irrigation had the lowest mean (2.69 g), which was expected. Next, the treatment that had irrigation suspended after the vegetative stage (T1) showed a lower average compared to the other treatments (3.17 g), likely due to the underdevelopment of plants during the reproductive and grain formation stages. Joshi et al. (2021), while analyzing different cultivars and drought resistance at various phenological stages, also observed that fresh mass was not lost until the onset of water stress during flowering, highlighting the importance of irrigation availability during the vegetative stage.

The data for safflower plant dry mass showed related results to those previously demonstrated for fresh mass. The treatment that received irrigation during the vegetative and reproductive stages (T4) had the highest mean (6.95 g), while treatment eight (no irrigation) had a lower mean compared to the other treatments (1.94 g). Engroff et al. (2020), working with rice cultivation, obtained results different from the present study. In their research, the dry mass variable under different irrigation levels during the vegetative and reproductive stages of the crop did not show significant differences and did not influence dry mass production.

TABLE 4. Effect of water stress at different phenological stages on safflower biomass components in a greenhouse.

| Source of variation | Biomass component | |
|---|---|---|
| | Fresh mass (g) | Dry mass (g) |
| Vegetative | 3.17 a | 3.17 ab |
| Reproductive | 5.80 ab | 2.55 a |
| Grain formation | 5.82 ab | 3.82 ab |
| Vegetative and reproductive | 9.20 b | 6.95 b |
| Vegetative and grain formation | 3.88 ab | 2.63 a |
| Reproductive and grain formation | 6.60 ab | 4.82 ab |
| None of the stages | 2.69 a | 1.94 a |
| All stages | 6.54 a | 3.54 ab |
| CV (%) | 45.88 | 50.02 |
| F | <0.05** | <0.05** |

Means followed by the same letter in the column do not differ from each other using the Tukey test at 5% significance | ** Significant at 5% probability | ns non-significant at 5% probability by the F-test (comparison of means).

The number of capitula showed significant differences among the analyzed treatments, with the treatment that received irrigation only during its reproductive stage having the highest mean (5.00) compared to the others (Table 5). Baseri et al. (2022), in their work on safflower with different sowing times and irrigation regimes applied during phenological growth stages, also demonstrated better results for the number of capitula in treatments with supplementary irrigation during the reproductive stage.

Our findings show that safflower cultivation had negative results for four out of the eight treatments. In other words, there was no seed production in the treatments that received water only during the vegetative stage (T1), vegetative and grain formation (T5), reproductive and grain formation (T6), and in those that received no irrigation (T7).

When analyzing the weight of safflower seeds, it was observed that the results were the same as the number of seeds. This suggests that the lack of productivity in the plants resulted in zero-weight averages, with productivity observed in only four treatments.

TABLE 5. Effect of water stress at different phenological stages on safflower yield components in a greenhouse.

| Source of variation | Yield component | | |
|---|---|---|---|
| | Number of capitula | Number of seeds | Seed weight (g) |
| Vegetative | 0.75 a | 0.00 a | 0.00 a |
| Reproductive | 5.00 b | 50.50 ab | 2.77 ab |
| Grain formation | 1.00 a | 2.00 a | 0.05 a |
| Vegetative and reproductive | 3.25 ab | 99.00 b | 4.39 b |
| Vegetative and grain formation | 1.00 a | 0.00 a | 0.00 a |
| Reproductive and grain formation | 3.00 ab | 0.00 a | 0.00 a |
| None of the stages | 1.75 ab | 0.00 a | 0.00 a |
| All stages | 3.50 ab | 24.50 a | 0.84 a |
| CV (%) | 65.3 | 114.35 | 128.11 |
| F | <0.05** | <0.05** | <0.05** |

Means followed by the same letter in the column do not differ from each other using the Tukey test at 5% significance | ** Significant at 5% probability | ns non-significant at 5% probability by the F-test (comparison of means)

By the results obtained in our study, Santos et al. (2018b) assessed the effect of irrigation on crop yield and observed that the treatments that received irrigation during the vegetative stage and vegetative and grain formation stages were the ones that responded the least to water application. At these stages, there were small increases in grain yield.

**Field experiment**

When analyzed based on irrigation at each phenological stage, plant height and stem diameter showed lower averages for the treatment that received no irrigation at any of its stages (Table 6). This is attributed to the stress caused by water deficiency, a significant limiting factor for plant growth and development, resulting in adverse effects on various plant attributes, including morphology, nutrition, and production (Anicésio et al., 2018).

The analysis of different irrigation availability levels revealed that treatments T4 (vegetative and reproductive) and T5 (vegetative and grain formation) had significantly larger stem diameter and plant height compared to the other treatments, indicating that water unavailability during these stages can lead to damage to the crop (Table 6). However, a study by Jhosi (2021) suggested that water stress during critical stages of flowering and grain filling has little effect on growth parameters.

Santos et al. (2018b), when suspending irrigation during the vegetative stage, also observed more pronounced decreases in stem diameter and plant height. The combination of irrigation during the vegetative stage with reproductive or grain formation stages may have favored the morphological components.

TABLE 6. Effect of water stress at different phenological stages on safflower morphological components in the field.

| Treatment | Morphological component | |
|---|---|---|
| | Plant height (m) | Stem diameter (cm) |
| Vegetative | 1.25 ab | 8.00 ab |
| Reproductive | 1.26 ab | 9.33 ab |
| Grain formation | 1.35 bc | 10.33 ab |
| Vegetative and reproductive | 1.62 e | 10.66 b |
| Vegetative and grain formation | 1.53 de | 10.66 b |
| Reproductive and grain formation | 1.48 d | 9.50 ab |
| None of the stages | 1.38 c | 8.66 ab |
| All stages | 1.23 a | 7.00 a |
| CV (%) | 4.4 | 19.61 |
| F | < 0.05** | < 0.05** |

Means followed by the same letter in the column do not differ from each other using the Tukey test at 5% significance | ** Significant at 5% probability | ns non-significant at 5% probability by the F-test (comparison of means).

The analysis of treatments for fresh and dry masses indicated significant differences ($F < 0.05$). The treatment that received irrigation only during the vegetative stage showed lower means compared to the other treatments (Table 7). Santos et al. (2018b) found equivalent results and demonstrated that fresh and dry stem masses were more sensitive to water deficit during the vegetative period.

TABLE 7. Effect of water stress at different phenological stages on safflower morphological components in the field.

| Treatment | Biomass component | |
|---|---|---|
| | Fresh mass (g) | Dry mass (g) |
| Vegetative | 27.53 a | 16.17 a |
| Reproductive | 38.83 a | 20.16 a |
| Grain formation | 36.36 a | 21.65 a |
| Vegetative and reproductive | 52.24 a | 30.23 a |
| Vegetative and grain formation | 53.9 a | 29.94 a |
| Reproductive and grain formation | 48.36 a | 27.16 a |
| None of the stages | 36.7 a | 21.87 a |
| All stages | 44.85 a | 26.33 a |
| CV (%) | 34.45 | 32.2 |
| F | < 0.05** | <0.05** |

Means followed by the same letter in the column do not differ from each other using the Tukey test at 5% significance | ** Significant at 5% probability | ns non-significant at 5% probability by the F-test (comparison of means).

As shown in Table 8, considering yield parameters (number and weight of seeds), safflower displayed better results for the treatments irrigated during the vegetative and reproductive/grain formation stages (T4 and T5). The number of seeds significantly decreased ($p < 0.05$) in the treatment that received no irrigation (T7) and the treatment irrigated only during the vegetative stage (T1). Consistent with our study, Santos et al. (2018a) observed a 37% difference in one-thousand-seed mass between safflower plants irrigated only during the vegetative period (2.81 g) and those managed with irrigation during flowering and grain filling (3.85 g), highlighting the importance of irrigation for grain filling.

However, for the parameter number of capitula, no significant differences were observed among the treatments. The number of capitula can be influenced by several factors, such as genotype, environmental conditions, and cultural practices (Koutroubas et al., 2008).

TABLE 8. Effect of water stress at different phenological stages on safflower yield components in the field.

| Treatment | Yield component | | |
|---|---|---|---|
| | Number of capitula | Number of seeds | Seed weight (g) |
| Vegetative | 6.00 a | 64.16 a | 3.33 a |
| Reproductive | 7.83 a | 82.66 ab | 4.21 ab |
| Grain formation | 9.66 a | 91.33 ab | 4.84 ab |
| Vegetative and reproductive | 14.83 a | 271.33 c | 13.83 c |
| Vegetative and grain formation | 13.33 a | 273.00 c | 13.92 c |
| Reproductive and grain formation | 9.50 a | 86.83 ab | 4.42 ab |
| None of the stages | 7.50 a | 70.50 a | 3.66 a |
| All stages | 11.50 a | 232.66 bc | 12.33bc |
| CV (%) | 51.15 | 59.39 | 58.9 |
| F | 0.06 ns | < 0.05** | < 0.05** |

Means followed by the same letter in the column do not differ from each other using the Tukey test at 5% significance | ** Significant at 5% probability | ns non-significant at 5% probability by the F-test (comparison of means).

Overall, the damage caused by water deficiency depends on the frequency, duration, and intensity of plant exposure to the stressing factor. In the study at hand, the exposure time varied with the duration of each growth stage (Santaniello et al., 2017; Van-Oosten et al., 2017).

## CONCLUSIONS

Both in a greenhouse or the field, safflower cultivation benefits from irrigation during the vegetative stage in conjunction with irrigation during reproductive and/or grain formation stages, showing susceptibility to water deficit when irrigated only during the vegetative stage.

Regarding morphological components, safflower plants receiving excess water during all phenological stages have their plant height and stem diameter compromised, indicating that the crop does not tolerate excessive water.

The availability of water in T1 (vegetative) and T2 (reproductive) favored the fresh and dry mass components of the plants.

Safflower yield components (number of capitula, number of seeds, and seed weight) increase when plants receive irrigation during the vegetative and reproductive stages, as well as vegetative and grain formation stages. Conversely, water availability only during the vegetative stage results in decreases in such yield components

In conclusion, safflower can be introduced into different climatic regions and become a species of economic importance due to its adaptability, production capacity, and potential.

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