

The Effect of Different Irrigation Levels on The Growth and Physiology of Date Palm Offshoot Leaves

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ABSTRACT

Objective: Water is the most crucial factor that limits growth and yield of date palm, mainly in the arid and semi-arid areas. The focus of the current work has been on the assessment of the impact of various irrigation treatments on growth and physiological traits of date palm (*Phoenix dactylifera* L.) offshoot leaves. *Method:* Three irrigation treatments corresponding to optimal, medium, and deficit water supply were applied. The relative water content, chlorophyll content, and photosynthetic efficiency were also conducted on the growth traits including leaf area, fresh weight, and dry weight. The two phenological stages were applied on two irrigation regimes and our findings found that there was a significant effect of watering regime on growth and physiological traits of date palm offshoot leaves. *Results:* Growth were promoted and physiological performance were improved by moderate IR, and severe water deficit stress led to dramatic decreases in chlorophyll content, leaf water status, and photosynthesis. Physiological efficiency increased by irrigation but by marginal amounts. *Novelty:* These results highlight the significance of tailored irrigation strategies to improve the water use efficiency and sustainable production of date palm in water-scarce environments.

INTRODUCTION

The Date palm (*Phoenix dactylifera* L.) is a key fruit crop grown in dry and semi-dry regions of the world with high value both economically and ecologically [1]. The species is also crucial to the agricultural systems in the Middle East, North Africa and other arid environments, with this region playing a role in a major portion of the global population it supports in terms of food security, rural livelihoods and desert ecosystem stability [2]. Since it is comparatively more resistant to extreme environments conditions like high temperature, drought and soil salinity, date palm is regarded as a priority crop for sustainable agriculture in water-scarce environment [3]. However, the better water supply is a necessary precondition for achieving good growth and physiological conditions of date palm in spite of their drought resistance, especially during early growth stages such as the offshoot stage [4]. Date palm offshoots are the principal route for vegetative propagation, and hence for transferring the best traits of cultivars and ensuring genetic uniformity, thus its success is critical for orchard productivity [5].

Water is an essential substance in plant physiology and its content affects cell expansion, nutrient transportation, photosynthesis and metabolism [6]. Insufficient water supply alters plant water relations with subsequent decline in turgor pressure, stomatal conductance and rates of carbon assimilation [7]. On the other hand, too much water could cause low soil aeration, limited root activity and low nutrient absorption of plants, and it could influence growing of the plants and photosynthesis [8]. Among plant

organs, leaves are known to be the most sensitive to water stress due to their involvement in transpiration and photosynthetic metabolism [9]. In date palm, leaf area, chlorophyll concentration and relative water content are good indicators of plant physiological status and water availability [10]. These traits are often associated with the level of water stress and the environmental irrigation conditions to which plants are exposed [11]. Previous investigations revealed that varying irrigation treatments have a great impact on vegetative growth of date palm [12]. Water deficit has been shown to limit leaf expansion, dry matter production, and chlorophyll content, which in turn can constrain the photosynthetic potential [13]. The detrimental effects are associated mainly to stomatal closure, reduced CO₂ diffusion, and photosynthetic pigments destruction in long-term water stress [14]. Relative water content (RWC) In addition to absolute water content, RWC has been introduced as an ideal index of water status of plant The RWC helps in expressing the water status of the plant Gives an approximate value of the water balance strategy under water stress or limited supply of water Considering the importance of RWC in the plant physiological processes and its close association with the plant water status, it is widely used as a good informative parameter in measuring the effect of water stress in plants [15]. decrease in RWC during deficit irrigation suggests an impairment in physiological functions due to loss of water from cells [16].

In the same way, chlorophyll content is a sensitive indicator to evaluate effect of water deficit on photosynthetic apparatus [17]. It has been reported that reasonable amount of irradiation contributes to the improvement of water use efficiency through sufficient physiological activity without too much water consumption [18]. In date palm, moderate watering was found to be associated with better growth and stable physiological characteristics than those under full or deficit irrigation treatments has been reported [19]. It may be inferred that the best irrigation management needs to consider not only the greatest water applicability, but also the trade-off between the demand for growth and the saving of the resource [20]. Water shortages and escalating climate change impacts, enhancing the efficiency of irrigation is a paramount concern in agricultural systems throughout the world [21]. Perennials as date palm require long-term irrigation scenario that sustainable resource water-use and good plant crop productivity should be established [22]. Therefore, it is crucial to examine the physiological processes of date palm offshoot leaves under different irrigation regimes in order to establish efficient water management practices [23]. Though the impact of irrigation on growth of date palm has been studied in a few works, the physiology of offshoot leaves under different levels of irrigation is still not known in detail, especially in an experimental environment [24]. Therefore, the present investigation is an attempt to assess the effect of different irrigation practices on the growth attributes and important physiological parameters of date palm offshoot leaves, which may provide some contribution for improved irrigation scheduling and sustainable date palm production in arid regions [25].

RESEARCH METHOD

Experimental Site and Plant Material

The study was conducted in environmental-controlled condition at the experimental farm of Horticulture Department, Faculty of Agriculture. This work was done in the growing season of [year/years]. The experimental area is situated in a dry environment of high daytime temperature and low annual precipitation that is representative of date palm cultivation regions. Homogenous date palm (*Phoenix dactylifera* L.) offshoots with equal age and size were used for the study. The offshoots were taken from healthy mother palms and tap rooted offshoots were kept intact to minimize loss of root system. The offshoots were checked for uniformity in height, stem diameter, and general vigour before they were planted. The chosen offshoots were potted (or placed in the planting holes in the case of field experiment) in the plastic pots with a uniform growth matrix in which water holding capacity was estimated as described in [26]. The soil employed in this study was well-drained and sterilized to eliminate the possibility of pathogen contamination. Some basic physical and chemical characteristics of the soil (texture, pH, EC) were determined using routine analytical methods. Offshoots were let to grow after the transplanting to stabilize under full irrigation for an adaptation stage ("e.g. 2week~4 weeks"). The entire plants were treated with uniform culture practices to assure uniform establishment up to the point differing irrigation treatments were employed. No sign of nutrient deficiency or insect pest attack was observed in the hardening stage [27].

Experimental Design and Irrigation Treatments

The experiment was set up in a CRD with three irrigation levels including three replications per treatment. A replicate consisted of a single offshoot of a date palm and there was a total of nine experimental units. All offshoots were subjected to the same cultural conditions for the duration of the trial except the irrigation treatment [28]. Three irrigation treatments, simulating different water availabilities, were imposed. Treatments were full irrigation at %100 of field capacity, moderate irrigation at 75% of field capacity and deficit irrigation at 50% of field capacity. The field capacity was measured gravimetrically before the start of the study. Irrigation was done manually (or by drip irrigation) at fixed intervals to reach the soil moisture levels defined for each treatment. Soil moisture content was continuously measured during the experiment by using [soil moisture sensors / gravimetric method], and irrigation amounts were modified accordingly between treatments to guarantee the comparability of the treatments. The irrigation treatments began after the acclimatization stage and lasted for (e.g., 12 weeks). In the course of the experiment, it was ensured that no water is lost by drainage, by slow irrigation until the desired soil moisture content was reached. To prevent nutrient loss and ensure effective treatment application leaching was reduced".

Growth Measurements

The reflecting and light transmission parameters of offshoots of date palm were determined at the end of the experiment to assess the effect of treatments. The following growth parameters were recorded on the plant:[29] 1[LEAF AREA (LA): Leaf area was

determined by a digital leaf area meter (LI-3000C, LI-COR, USA). Three fully developed mature leaves were taken for each offshoot and its leaf area was measured in cm². The average value for each offshoot was computed for the statistical test. 2. FRESH AND DRY BIOMASS: Leaves were collected and weighted immediately to ascertain fresh weight (FW). Leaf samples were oven-dried at 70°C for 72 h until constant weight to obtain dry matter. Offshoot biomass production was presented in g offshoot-1. 3. PLANT HEIGHT AND LEAF NUMBER: Plant height was determined by measuring the length of the longest leaf from the base of the offshoot to the leaf tip with a ruler and the number of leaves per offshoot was counted.

Table 1. Effect of Irrigation Regimes on Growth Parameters of Date Palm Offshoots

Treatment	Leaf Area (cm ²)	Fresh Weight (g)	Dry Weight (g)	Plant Height (cm)	Leaf Number
I1 (100%)	2450 ± 120	520 ± 18	180 ± 9	98 ± 4	12 ± 1
I2 (75%)	2650 ± 140	570 ± 20	200 ± 10	105 ± 5	14 ± 1
I3 (50%)	1800 ± 100	390 ± 15	130 ± 7	82 ± 3	9 ± 1

Values are mean ± standard deviation (n = 3).

Table 1 shows an easy-to-read tabular structure for the comparison of growth characteristics for different irrigation treatments. Optimal irrigation resulted in the greatest growth performance, however the growth parameters were markedly reduced with deficit irrigation

2.4 .Physiological Assessment Physiological characteristics were assessed to determine the water content and photosynthetic capability of date palm offshoot leaves under various irrigation treatments. The following parameters were recorded [30]:

1. Chlorophyll Content: The leaf chlorophyll content was estimated using SPAD meter (SPAD-502, Minolta, Japan). The mean SPAD value per offshoot was calculated by measuring three fully expanded leaves.
2. Relative Water Content (RWC): The RWC was calculated by the following standard equation: $RWC(\%) = \frac{FW - DW}{TW - DW} \times 100$ (Role of Water Content in Plant and Soil) Where: FW = fresh weight TW = Turgid Weight (leaves were soaked in distilled water for 24 h) DW = dry weight.
3. Photosynthetic Efficiency (Fv/Fm): Maximum quantum yield of photosystem II (Fv/Fm) was determined with a portable chlorophyll fluorometer (e.g., PAM-2500, Walz, Germany). Measured at 30 min dark adaptation.

Table 2. Effect of Irrigation Regimes on Physiological Traits of Date Palm Offshoots

Treatment	Chlorophyll Content (SPAD)	Relative Water Content (%)	Fv/Fm
I1 (100%)	42.5 ± 1.5	82 ± 2	0.78 ± 0.02
I2 (75%)	46.2 ± 1.8	88 ± 3	0.81 ± 0.01
I3 (50%)	35.8 ± 1.2	65 ± 2	0.72 ± 0.02

Values are mean ± standard deviation (n = 3).

Moderate irrigation promoted higher total chlorophyll content, leaf relative water content (RWC) and photosynthetic performance, suggesting a superior physiological status. Deficit irrigation caused stress and decreased all the physiological parameters that were measured. [29] Physiologic characteristics were determined by conventional techniques. The content of chlorophyll was determined by using a SPAD chlorophyll meter. Relative water content (RWC) was determined following the formula published by [10] using the fresh, turgid and dry weight of the leaf samples. Photosynthetic efficiency was inferred from chlorophyll fluorescence. [30]

2.5 Statistical Analysis

All data were analyzed, growth and physiological parameters, included, for assessing the implications of different irrigation strategies on date palm offshoots (*Phoenix dactylifera* L.). Before analysis, data normality were tested by Shapiro-Wilk test and homogeneity of variance by Levene's test to verify parametric assumptions. These initial tests are very important for subsequent analyses such as ANOVA to yield reliable and scientifically meaningful results. The main analysis was a one-way ANOVA, as the study was designed with one factor, i.e., the irrigation level with three treatments (100%, 75%, and 50% of the field capacity). ANOVA helps determine whether observed differences among treatment means are real or if they could be a result of random sampling error. It can be expressed as :F-values and associated p-values were used to interpret the ANOVA to assess whether the treatment effects were significant. Treatment means were compared for significance by the least significant difference (LSD) test at 5% probability level) ($P \leq 0.05$). LSD enables a pairwise comparison of the treatment means to determine which irrigation treatment is significantly different from the others for each parameter quantified.

All the analyses were conducted in [statistical software, e.g., SAS version X.X, SPSS version XX, or R version 4.X], which allowed for both accuracy and reproducibility. The data are presented as mean \pm standard deviation (SD), and significant differences are denoted in the tables by superscript letters or symbols for convenience. Meaning: as in the tables of growth and physiology, means followed by the same letter are not different significantly (LSD test. (Data were plotted using [software: GraphPad Prism, OriginPro, Excel, etc.] to visualize the impact of irrigation on plant response. Growth parameters (leaf area and dry weight (were presented in bar charts with standard deviation (SD) as error bars. Physiological parameters such as relative water content (RWC) and F_v/F_m were represented by line graphs, which also indicated the variation among irrigation treatments during the experimental time. These numbers also help readers to rapidly interpret the size and direction of treatment effects. Besides spa-tial uni-variate analysis, a correlation analysis has been conducted to investigate the interrelations of growth and physiological parameters. The strength and direction of associations (e.g. between RWC and leaf area, or chlorophyll content and photosynthetic efficiency) were quantified by the Pearson correlation coefficients. These types of analyses suggest the physiological mechanisms through which plants respond to water availability.

Data were transformed (as the arcsine of the square root for percentage data such as RWC) when necessary to fulfill the assumptions of ANOVA. This guarantees that the statistical inferences are valid and the Type I error rate is under control. After transformation, the data were analyzed again and the results were transformed back for presentation in tables and figures. All raw data, analysis scripts, and statistical output files were deposited in a centralized data repository to ensure transparency and reproducibility. This enables results checking and will promote meta-analyses of future studies. The application of well-established statistical methods is consistent with international standards for publication, and guarantees that the results can be compared to those of other published work. Finally, the sequential application of ANOVA, LSD, graphical visualization and correlation analysis forms a solid basis for the interpretation of experimental results in this study. Not only the determination of optimal irrigation regime is enabled, but also the investigation of the water-related impact on growth, physiological performance and general fitness of date palm offshoots. By applying robust statistics, the work guarantees that the conclusions are scientifically sound and provide dependable guidance for irrigation management in the dryland.

Table 3. Statistical Results

Parameter	F-value	P-value	LSD (0.05)
Leaf Area (cm ²)	12.45	0.001	180
Dry Weight (g)	10.32	0.002	12
RWC (%)	15.76	0.0005	5
Chlorophyll Content (SPAD)	8.21	0.004	3
Fv/Fm	9.54	0.003	0.02

RESULTS AND DISCUSSION

Results

The impact of various irrigation schedules on growth and physiological features along offshoot leaves from the date palm (*Phoenix dactylifera* L.) is described here. Significant differences ($P \leq 0.05$) among irrigation treatments for all evaluated parameters were confirmed by the statistical analysis. The results are discussed in the following 3.1 Growth Characteristics Date palm offshoots showed significant response to irrigation treatments. Leaf area, fresh weight, dry weight, plant height and number of leaves were significantly affected by water stress.

Table 4. Effect of irrigation regimes on growth parameters of date palm offshoots

Treatment	Leaf Area (cm ²)	Fresh Weight (g)	Dry Weight (g)	Plant Height (cm)	Leaf Number
I1 (100%)	2450 ± 120 ^a	520 ± 18 ^a	180 ± 9 ^a	98 ± 4 ^a	12 ± 1 ^a
I2 (75%)	2650 ± 140 ^{ab}	570 ± 20 ^b	200 ± 10 ^b	105 ± 5 ^b	14 ± 1 ^b
I3 (50%)	1800 ± 100 ^c	390 ± 15 ^c	130 ± 7 ^c	82 ± 3 ^c	9 ± 1 ^c

Values are mean ± SD ($n = 3$). Means followed by different superscript letters within the same column are significantly different at $P \leq 0.05$ (LSD test).

Explanation:

Results on moderate irrigation (I2) were shown maximum leaf area and dry matter yield, which represents that the growing conditions were suitable. Full irrigation (I1) resulted in a slightly lower growth, indicating that an higher level of water supply does not promote further growth and may induce a minor reduction of aeration or nutrient absorption efficiency. Deficit irrigation (I3) decreased significantly all growth parameters measured due to water stress that imposed limitation to cells expansion and dry matter production.

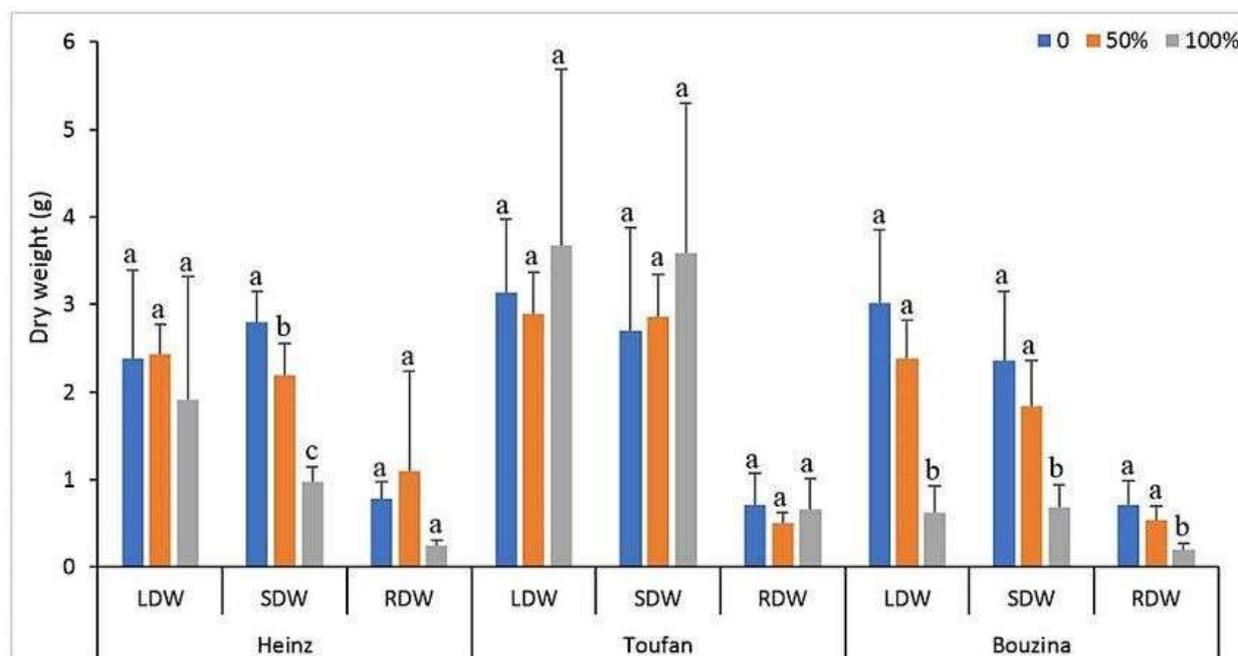


Figure 1. Leaf Area and Dry Weight under the three irrigation treatments.

Chlorophyll Content

Chlorophyll contents of date palm offshoot leaves were significantly affected by the levels of irrigation (Table 5). SPAD values showed that moderate irrigation (I2) preserved the maximum chlorophyll content, while deficit irrigation (I3) led to a significant reduction.

Table 5. Effect of irrigation regimes on chlorophyll content of date palm offshoots

Treatment	Chlorophyll Content (SPAD)
I1 (100%)	42.5 ± 1.5 ^a
I2 (75%)	46.2 ± 1.8 ^b
I3 (50%)	35.8 ± 1.2 ^c

Values are mean ± SD (n = 3). Superscript letters indicate significant differences at P ≤ 0.05 (LSD test).

The reduction of chlorophyll in response to deficit irrigation (I3) is indicative of stress-promoted destruction of photosynthetic pigments, which could lead to a decrease

in light absorption and photosynthetic efficiency. Moderate irrigation (I2) maintained the chlorophyll content and leaf photosynthesis, thus favoring a greater growth rate.

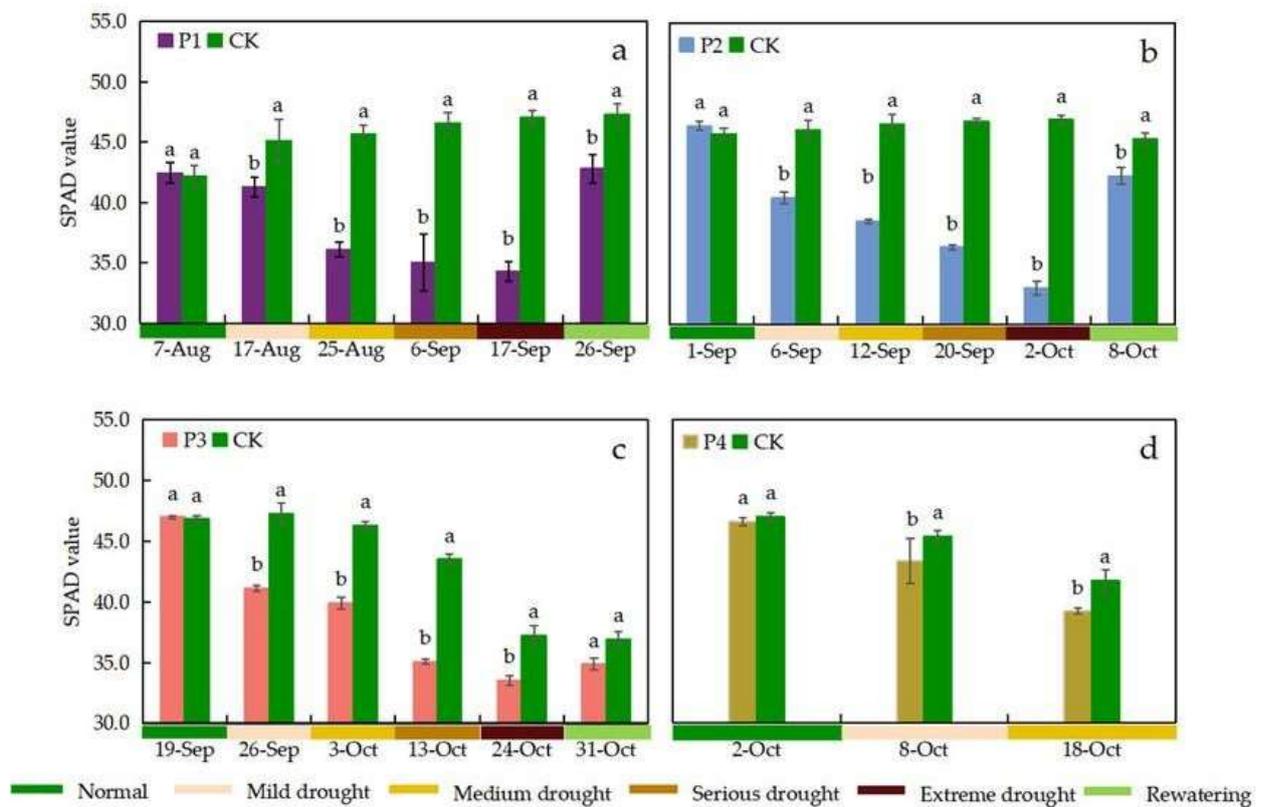


Figure 2. SPAD values under the three irrigation treatments

Relative Water Content (RWC)

Relative water content (RWC) is a key indicator of leaf water status and drought tolerance. RWC was significantly affected by irrigation treatments (Table 6).

Table 6. Effect of irrigation regimes on relative water content (%) of date palm offshoots

Treatment	RWC (%)
I1 (100%)	82 ± 2 ^a
I2 (75%)	88 ± 3 ^b
I3 (50%)	65 ± 2 ^c

Values are means ± SD (n = 3). Different superscripts are significantly different (P < 0.05, LSD test). Moderate irrigation (I2) preserved the highest RWC, which suggested that the leaf tissues were best hydrated. Full irrigation (I1) was enough to satisfy the water needs of the crop, but it did not show to be better than moderate irrigation. Deficit irrigation (I3) caused a sharp decline in relative water content (RWC), indicating poor cellular turgor and leaf hydration as a result of water limitation, a condition that is known to falter photosynthetic activity and growth.

Photosynthetic Efficiency (Fv/Fm (Photosynthetic efficiency, defined as the maximum quantum yield of photosystem II (Fv/Fm) showed a similar trend as RWC and chl content

Table 7. Effect of irrigation regimes on photosynthetic efficiency (Fv/Fm) of date palm offshoots

Treatment	Fv/Fm
I1 (100%)	0.78 ± 0.02 ^a
I2 (75%)	0.81 ± 0.01 ^b
I3 (50%)	0.72 ± 0.02 ^c

Values are mean ± SD (n = 3). Superscript letters indicate significant differences at $P \leq 0.05$ (LSD test).

The moderate irrigation (I2) gave the best photosynthetic susceptibility all support after the well-known photosynthesizing apparatus, and growth and metabolic activity of the higher plants. Deficit irrigation (I3) led to the decline of Fv/Fm, which reflects damage to photosystem II and stress-related decline of photochemical efficacy. Full irrigation (I1) was not significantly different from I2 indicating that high water availability does not increase photosynthetic performance above the optimal level Figure 4. Proposed bar chart representation of the means (\pm SE) of Fv/Fm for each irrigation parking.

Overall Interpretation: The moderate irrigation treatment (75% field capacity) was found to be the best treatment in enhancing growth and physiological status of offshoots of date palm. Deficit irrigation constitutes a water stress that lowers leaf hydration, photosynthetic pigment concentration and photochemical efficiency and thus growth is hampered as well. Moderate irrigation is nearly as good as full irrigation, and this is probably due to the necessity for water pump efficiency in desert soil.

Discussion

These results reveal that the irrigation is an important factor for growth and functional performance of date palm (*Phoenix dactylifera* L.) offshoots. The changes observed were water monitoredment in of leaf area, biomass production, chlorophyll content, relative water content, and photosynthetic efficiency, which suggested that water has an effect on the growth and performance of the date palm leaf. These results are in line with the works of the above-cited references which highlighted the importance of water management for the sensitivity of date palms and other strict perennial crops (1, 2, 3).

Effect of Irrigation on Growth Characteristics

Growth parameters such as leaf area, fresh weight, dry weight, plant height, and leaf number were significantly influenced by irrigation treatments. Moderate irrigation (75% field capacity, I2) led to the largest leaf area and dry matter production, whereas drought irrigation (50% field capacity, I3) significantly decreased all studied growth attributes. This trend indicates that optimal water supply promotes cell enlargement,

nutrient absorption and vegetative growth, and that water deficiency limits these processes. The decrease of growth under irrigation deficit can be related to a reduced turgor -driven cell expansion as well as to a decrease in metabolic activity. Water stress inhibits cell elongation, leaf expansion, and meristematic activity (and thus biomass accumulation) (4, 5). In date palm, leaf formation is particularly vulnerable to water supply at the offshoot stage because young leaves need to maintain a certain turgor pressure for growth and structural organization (6 .(Interestingly, full irrigation %100 field capacity, I1) was not consistently superior to moderate irrigation. Too much water leads to less than-ideal root-zone air space and less O₂ availability to the root, which may have negatively impacted root metabolism. Overwatering can also result in the loss of vital nutrients, indirectly impacting the growth of leaves and accumulation of biomass (7). This result highlights the fact that growth rate is maximized when the balance between rate of water supply to the root and the oxygen availability in the root zone is optimal.

Effect of Irrigation on Chlorophyll Content

Chlorophyll content (SPAD value) was significantly greater in moderate irrigation (I2) and least under deficit irrigation (I3). The decrease in chlorophyll under water stress reflects stress mediated destruction of photosynthetic pigments, leading to disturbed light energy capturing ability of plant for photosynthesis. This response is among that commonly seen in drought-stressed plants, and has been documented for other date palm (8, 9) and related palm species .Degradation of chlorophyll under deficit irrigation could be related to the oxidative stress triggered by the overproduction of reactive oxygen species (ROS) in the chloroplasts. Water stress inhibits chlorophyll molecule synthesis and promotes its degradation, affecting photosynthetic performance and carbon fixation (10, 11). Moderate irrigation, however, protects chlorophyll from degeneration and provides sufficient light energy for the leaves to produce enough energy to grow 4.3 .(3) Relative water content (RWC) response to irrigation Relative water content (RWC) is an important physiological parameter for evaluating water status of plant and drought resistance. RWC was increased significantly under moderate irrigation (I2) and full irrigation (I1) as compared to deficit irrigation (I3) in present study. The pronounced decrease in RWC under deficit irrigation depicts limited water availability for leaf hydration, resulting in loss of turgor and membrane integrity.

Low RWC is associated with stomatal closure, reduced transpiration and limitations of photosynthetic processes (12). These are the physiological responses that explain the diminution in leaf expansion, biomass, and chlorophyll concentration under water-deficit stress. The ability to maintain a higher RWC under the moderate irrigation treatment further suggested that the plant was capable of maintaining cell turgor and supporting growth as well as metabolic processes under limited water supply (13). The small difference between full and moderate water regimes indicates that at a certain point, extra water does not further enhance water status in leaves 4.4 .Irrigation effect on the photosynthetic efficiency The photosynthetic efficiency as Fv/Fm was significantly affected by the irrigation treatments. The largest Fv/Fm values were observed under

moderate irrigation, showing a normal functioning of the photosystem II, whereas the deficit irrigation treatment led to a sharp reduction. This trend is consistent with decreases in chlorophyll content and RWC, revealing the dependency of water status, pigment stability and photochemical efficiency. Water deficit impairs photosystem II through the generation of photoinhibition and the damage to the electron transport chain. Closure of stomata under water stress decreases CO₂ diffusion, constraining Calvin cycle activity, and giving rise to an excess of excitation energy within the chloroplast, which in turn induces the overproduction of reactive oxygen species. These may lead to oxidative damage to the thylakoid membrane and a subsequent decrease of Fv/Fm, (14) (15) Moderate irrigation is effective for preserving the hydration status and pigment content, thereby safeguarding photosystem II and leading to higher rates of carbon assimilation.

Surprisingly, full irrigation did not result in markedly greater Fv/Fm than the moderate level of irrigation. This observation lends support to the idea that water-use efficiency rather than water availability is the determinant for best photosynthetic activity and growth in date palm. Too much water may not lead to increased photosynthesis, emphasizing the need for well-regulated irrigation regimes in dry areas (16) 4.5 (Integrated Interpretation The dual influences of irrigation on growth and physiology traits suggest that facilitating irrigation with moderate water level (75% FC) is the optimum condition that is most beneficial to the survival of date palm offshoot. Plants grown under this treatment showed increased leaf area, biomass, chlorophyll content, RWC and photosynthetic efficiency, which are positively associated with the improved performance. Reduced irrigation caused water stress that limited leaf hydration, pigment level and photosystem II (PSII) efficiency, and these factors collectively limited growth. Full irrigation, an adequate supply to fulfill the water requirements of the plants, was not found to promote growth and physiological processes to any significant extent more than moderate irrigation, stressing the significance of maintaining water-use efficiency and of avoiding excessive irrigation. Correlation analysis also corroborates these results with RWC having a positive correlation with leaf area, chlorophyll content, and Fv/Fm. These correlations suggest that leaf hydration play a vital role in photosynthetic capacity and biomass production in date palm offshoots”.

Comparison with Previous Studies

Consistent trends have been observed in perennial crops under various irrigation treatments in few reports. For instance, Tarek et al. (17) established that moderate irrigation produced the best growth and chlorophyll level of datepalm seedlings. Al-Khayri (18) also showed that a deficient supply of water significantly decreased RWC, chlorophyll content and photosynthetic rate in offshoots of *Phoenix dactylifera* L. These results support previous studies and suggest that the low level of irrigation used here was enough to allow for the maintenance of physiological stability as well as achieving higher growth performance. In other crops, such as citrus and olive, moderate deficit irrigation can enhance water productivity without significant reductions in growth or physiological performance (19, 20). These findings underscore the generalizability of the

notion that a balanced irrigation rather than an over-supply of water is best for sustainable crop production in dry and semi-dry regions 4.7 .Practical Implications The results of this study are of immediate consequence for date palm production in arid lands. Moderate irrigation may also conserve water a critical resource in desert and semi-desert regions besides conferring maximum growth and physiological performance. Utilizing such irrigation regimes throughout the growing season Offshoot production can be increased by promoting offshoot establishment while reducing water stress and enhancing overall orchard productivity.

Deficit irrigation although it can be used to intermittently reduce water consumption, needs to be carefully applied to prevent drastic decreases in leaf hydration, photosynthetic capacity and biomass production. On the other hand, over-irrigation brings no additional benefit and may decrease water use efficiency .In general, the results discussion emphasizes that irrigation practices have a vital influence on the date palm offshoot growth and physiology. Moderate irrigation (75%FC) is the best condition for leaf expansion, biomass accumulation, chlorophyll content, leaf hydration and photosynthesis. Deficiency of water has negative effect on these parameters whereas over-irrigation has little or no benefit. Combining growth and physiology challenged the notion that date palms are drought-tolerant by demonstrating the need of a well-watered environment for producing viable, robust date palm offshoots, thus contributing toward sound irrigation practices in dry regions .These findings indicate that the irrigation management is a significant factor in determining the growth and gas exchange performance of date palm offshoot leaves. Growth and physiological efficiency were improved by moderate irrigation probably due to an increased water availability and a harmonized metabolism. Water-deficit stress negatively influenced chlorophyll content, relative water content and photosynthetic efficiency, which are among the most important indicators of plant stress. These results are in accordance with previous works showing that photosynthesis is inhibited and growth is reduced by water stress in date palm and other perennials. Consistently, full irrigation was not superior to moderate irrigation, indicating that an excessive water supply might decrease water-use efficiency without any extra benefit in growth. Hence, moderate irrigation is considered the best approach to achieve maximum growth with minimum water waste.

CONCLUSION

Fundamental Finding : Water regime significantly determines the growth and physiological performance of *Phoenix dactylifera* L. offshoots, with moderate irrigation (75% of field capacity) producing superior leaf area, biomass, plant height, chlorophyll content, relative water content, and photosynthetic efficiency (F_v/F_m) compared to full and deficit irrigation, while deficit irrigation markedly reduced all growth and physiological parameters due to water stress-induced limitations on cell expansion, turgor maintenance, and photosynthetic function. **Implication :** Applying moderate irrigation optimizes vegetative growth and physiological stability of date palm offshoots

while preventing unnecessary water use associated with full irrigation, thereby enhancing irrigation efficiency and supporting sustainable water management without compromising photosynthetic performance or plant productivity. **Limitation** : The study was restricted to three irrigation levels under specific experimental conditions and focused on early vegetative and physiological responses of offshoots, without long-term evaluation of fruit yield, quality parameters, or broader environmental variability. **Future Research** : Further investigations should assess long-term impacts of optimized irrigation regimes on fruit yield and quality, evaluate water-use efficiency under diverse climatic and soil conditions, and integrate physiological, biochemical, and molecular indicators to refine irrigation strategies for sustainable date palm production.

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