



Impact of irrigation with saline water and drought on floral quality, vegetative growth and yield of olive trees (*Olea europaea* L.) in an arid climate

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Abstract

The Mediterranean region's agriculture is predicted to be severely impacted negatively by climate change. In the primary production region of southern Tunisia (34°43'N, 10°41'E) in olive orchard submitted to different treatments: Rain-fed, drip irrigation with saline water (FI) : EC = 7.5 dS/m at 100% of crop evapotranspiration (ETc), alternate irrigation (PRD) with saline water at 50% of ETc and switched every 30 days, regular deficit irrigation (RDI) with saline water at 50% of ETc, drip irrigation with tap water (TW) : EC=2.46 dS/m at 100% of crop evapotranspiration (ETc), with predicted temperature increases, the effects of climate change and salinity on the floral performance of olive trees were assessed from 2015 to 2017 and the vegetative growth and yield were evaluated over the period. As results, while conserving water in comparison to FI and TW, PRD produced high values for internodes length (1.68 cm) in 2016 and an annual shoot elongation (2.5 cm) in 2015. When comparing flowering (RF) and fruit-setting (RS) rates, olive trees under PRD outperformed those under RDI and FI with (RF=67.52% and RS=7.81%) in 2015. For olive trees exposed to RDI, PRD, and FI, the fruits per unit length were statistically similar in 2015. The use of the PRD technique (50% ETc) yielded good results with an average of 2.96(kg/m³) in our study both quantitatively and qualitatively.

1. INTRODUCTION

The agricultural sector is especially susceptible to climate change in North African nations. Rising temperatures and less precipitation are predicted as a result of climate change, which poses serious risks to farmers' ability to survive (Ghrab et al., 2022). The climate has a significant influence on when biological events occur. Because of variable weather, flowering is a crucial plant characteristic that varies from year to year and has a range of ecological implications (Elloumi et al., 2020). Due to changes in the precipitation regime and global climate change, significant variations in the onset and release of dormancy for fruit trees have been observed over the past century. In fact, the climate has a major impact on the productivity of trees in arid regions. Climate has a major role in the

successful production of trade fruits, according to Ghrab et al. (2022). Important seasonal cycles are governed by climate, such as winter dormancy. In actuality, fruit and nut trees need cold temperatures to break dormancy, followed by heat to produce consistent crop yields and homogenous flowering (Ruiz et al., 2007; Ghrab et al., 2022).

The Mediterranean region experiences warmer winters and fewer chills as a result of rising temperatures brought on by global warming (Ghrab et al., 2016, 2022). Fruit trees without covering experienced irregular, partial, or low bud break, a delayed bloom and longer flowering period, as well as low fruit quality and yield (Ghrab et al., 2022). Many fruit trees in Tunisia's orchards displayed aberrant physiological behavior, irregular fruit development, and low

yields, especially since the unusually warm winter of 2007 (Ghrab et al., 2022). Moreover, the Chemlali Sfax is a vigorous cultivar that is anticipated to begin yielding and exhibiting alternate and high quality early on. Farmers prefer it because of its high productivity and ability to adapt to dry conditions, such as poor soils and scarce water supplies (Chtourou et al., 2013; Trabelsi et al., 2023). Water scarcity and low productivity per unit area due to yearly variations in rainfall, alternate bearing, and improper management of cultural practices are the primary obstacles facing Tunisia's olive industry. The fact that olive trees are typically planted on the poorest, least fertile soils is astounding. Because of their exceptional resistance to drought, olive trees are growing well in arid and semi-arid regions with as little as 150-200 mm of annual precipitation (such as central and southern Tunisia), where they play a significant role in protecting the soil from wind and water erosion. Because olive farming is flexible and adaptable to the edapho-climatic conditions, it is practiced throughout the country (Trabelsi et al., 2023).

In order to ensure a permanent adjustment of olive oil policy, the development of arid regions, and the management of natural resources, Tunisia has made the cultivation of olive trees one of its national priorities and strategies in the olive sector. Barranco et al. (2000) believed that Chemlali Sfax was resistant to dry conditions in their original sites. This Chemlali Sfax performance was attained in the Sfax region in an intensive plantation density (625 trees/ha, 4 m/4 m), subjected to various treatments using fresh water, saline water, and a dry system. Nonetheless, inadequate understanding regarding olive tree adaptation and inappropriate driving mode selection, particularly in arid and semi-arid areas, can have a detrimental impact on the sector's sustainability. In the Sfax region (the Olive Tree Institute's Experimental Station), olive trees grown in an intensive mode are to have their agronomic parameters, floral quality measurements, and productive performance evaluated. They will be subjected to water irrigation treatments using both saline and fresh water (EC = 7.5 mS/cm; 2.48 mS/cm) in an arid climate during 2015 and 2017.

2. MATERIAL AND METHODS

2.1. Orchard site and irrigation treatments

L'essai a été installé suivant un dispositif en parcelles divisées avec la dose d'urée et la fréquence de sarclage comme facteurs. The experiment was conducted in an orchard in central coastal Tunisia ; Sfax (34°43'N, 10°41'E). This area has deep sandy silt soils (49.7% sand, 43.3% silt, and 7% clay) and an arid Mediterranean climate. The experimental site's climate is defined by low minimum temperatures (as low as 3°C) in January and February 2016, which mark the start of the crop cycle, and high maximum temperatures (up to 39°C) in the summer, which coincides with the growth period. In this region, rainfall is low and irregular with an average accumulated annual precipitation of about 200 mm. An orchard of Chemlali olives (*Olea europaea* L.) that was 26 years old served as the site of the experiment. Chemlali Sfax was considered as resistant to dry conditions by Barranco et al. (2000) in their original sites.

The olive trees, spaced at 4 x 4m (625 trees ha⁻¹). They were drip irrigated with two pipe lines on each row of olive trees located 0.5 m from the trunk and eight pressure compensated emitters per tree having a flow rate of 8 Lh⁻¹ and an irrigation frequency of 12.88mm/tree per week, on average. No fertilization and phytosanitary treatments were used. Three years (2015-2016-2017) defined the experimental period: "On" (2015) followed by one year of "Off" (2016) and "On" (2017). In 2015, three treatments were applied and used for a three-year period (2015-2017): Irrigation treatments were applied in March 2015: DRY (Rain-fed conditions), drip irrigation with saline water (FI) with an EC of 7.5 dS/m at 100% of crop evapotranspiration (ET_c), alternate irrigation (PRD) with saline water at 50% of ET_c and switched every 30 days, and regular deficit irrigation (RDI) with saline water at 50% of ET_c, and TW 100%ET_c (Full irrigation with tap water (EC=2.46 dS/m) on 10 olive trees for each treatment during March 2015 to September 2017. Saline water (EC=7.5 dSm⁻¹) was used from a ground water source (depth 2.5 m). Its composition was logged as 1130 mg/L Na⁺, 1112.3 mg/L Cl⁻, 24 mg/L K⁺, 2.16 mg/L N-NH₄⁺, and 40.51 mg/L N-NO₃⁻ with a pH of 7.35 (Trabelsi et al., 2019). To evaluate the effect of irrigation with saline ground water, a potable tap water treatment from ground tables and dams (EC=2.46 dSm⁻¹) were added. Tap water characteristics were: 367.5 mg/L Na⁺, 592.07 mg/L Cl⁻, 13 mg/L K⁺, 0.504 mg/L N-NH₄⁺, and 2.356 mg/L N-NO₃⁻ at pH of 8.02 (Trabelsi et al., 2019).

The monthly Etc varied from 26.5 to 80 mm with frequent warm months. Effective precipitation (Ep), considered as 80% of total precipitation, ranged between 0 (July) and 41.2 mm (October) (Trabelsi et al., 2024). Crop evapotranspiration ($ET_c = K_c \cdot ET_o \cdot K_r$) of the olive trees was calculated using the Penman-Monteith equation FAO-56 (Allen et al., 1998), where ET_o is the reference evapotranspiration, K_c is the crop factor and K_r is a dimension less evaporation reduction coefficient. In the current study, we used a K_r of 1. Daily weather data was recorded at the weather station of the National Institute of Meteorology (INM), (5 km from the experimental site), and used to estimate ET_o as described by Trabelsi et al. (2019).

2.2. Experimental conditions

The meteorological drought from October 2015 to January 2017 was estimated using the Standardized Precipitation Index (SPI) (McKee et al., 1993, 1995; Trabelsi et al., 2019). Drought occurrence (start, end and severity) was achieved using SPI (McKee et al., 1993, 1995; Soro et al., 2014) and determined as described by Trabelsi et al. (2019). The drought occurred when three consecutive dry months were recorded using the SPI index (Ben Abdelmalek et al., 2016). So, while the SPI was below -1, drought conditions were acknowledged, and they were declared over when the SPI turned positive. For both dry and wet periods, the SPI index classes are separated into moderate, severe, and extreme categories. SPI indicated a long dry period from October 2015 to August 2016 (Trabelsi et al., 2019). In fact, the drought was moderate for nine months (ranging between -1 and 0), but severe for two months in 2015, such as December (-1), and March (-1.06) (Trabelsi et al., 2019). After a dry period, September 2016 was categorized as moderately wet with an SPI of 0.63, followed by 68.8 mm of rain, a moderately dry month (October 2016), a moderately wet month (November 2016), and an extremely wet month (December 2016) with an SPI of 2.79 (Trabelsi et al., 2019). Two distinct periods were identified for the assessment of olive trees under different regimes in an arid climate: a severe drought detected by the SPI from 2015 to 2016, and after-rainfall period occurring one month after the drought in 2016. These periods were utilized for nutritional records and biochemical sampling to evaluate the trees' responses under field conditions:

1. Drought (October 2015 to August 2016).

2. After raining (re-watering by 68.8 mm of rainfall in September 2016) at the end of October 2016 which corresponded to one month after the drought ended).

2.3. Plant sampling and floral quality parameters

Floral performance was monitored on three randomly selected olive trees per treatment, chosen in February for their comparable potential yield and canopy, to be used for floral quality measurements. In mid-February of three consecutive years (2015 to 2017), eight shoots of one year old per tree were identified and for each one, the number of buds was determined. In the following spring, for each year from 2015 to 2017, flowering quality indicators, were recorded as well as qualitative and quantitative namely: i) Flowering parameters: the flowering rate (RF in %), representing the proportion of buds that developed into inflorescences, and the fruit set rate (RS in %), indicating the percentage of total shoot flowers that successfully set fruit, were measured. Additionally, inflorescence parameters were recorded from a sample of 20 inflorescences at the white button stage, just before flowering: the ovary abortion rate (ROA in %) was calculated according to Lavee et al. (1997) and Sanz-Cortes et al. (2002):

Flowering rate RF (%) =

$$\left(\frac{\text{number of inflorescences}}{\text{number of buds}} \right) * 100$$

Setting rate RS (%) =

$$\left(\frac{\text{number of flowers set}}{\text{total number of flowers}} \right) * 100$$

Rate of ovarian abortion (ROA in %) =

$$\left(\frac{\text{number of aborted flowers}}{\text{total number of flowers}} \right) * 100$$

2.4. Vegetative measurements

Vegetative measurements of current-year shoots were made on 8 healthy shoots from 3 trees of each treatment facing different directions around the canopy. At the start of monitoring, the number of nodes of each shoot was determined and the initial average internodes length in cm was calculated (length of shoot / number of nodes). Annual cumulative growth was measured from bud break until the end of the growth season, just before dormancy. Shoots per plant were tagged when trees were in dormancy and shoot elongation was measured from March to October each year 2015 and 2017. The lengths of all apical and axillary shoots were measured for the cumulative growth of shoot.

2.5. Olive production

Yield per ha was measured at harvest on 10 trees per treatment. Olive fruits were harvested by hand from December 2015 and December 2017. A representative sample of olives per tree and per treatment was taken during the optimal period for harvest to determine the production. Olive yield was recorded and used to calculate both cumulative yield and average yield in kg/ha.

3. RESULTS & DISCUSSION

3.1. Vegetative growth parameters

The monitoring of olive tree growth focused on the average spring and autumn elongation of vegetative shoots (Fig. 1). Irrigated trees showed an improvement in height and number of axillary shoots compared to those of rainfed olive trees. This growth improvement was recorded for all irrigated treatments. However, the annual growth varied depending on the applied water regime. Indeed, it was higher in olive trees irrigated under FI (CE = 7.5 mS/cm), followed by RDI and PRD, with respective values of 5.33 cm, 2.55 cm, and 2.57 cm for the year 2015. In 2017, with the application of tap water irrigation, this treatment showed the best performance. The three treatments used saline water and the Rain-fed treatment exhibited the same pattern as in 2015. However, all observed differences in 2017 were not significant. It was lowest under Rain-fed conditions (0.5 cm) in both 2015 and 2017. The use of saline water did not influence growth compared to TW (CE = 2.46 mS/cm) in 2017. Additionally, deficit irrigation achieved the same growth as full irrigation while allowing a 50% reduction in water use.

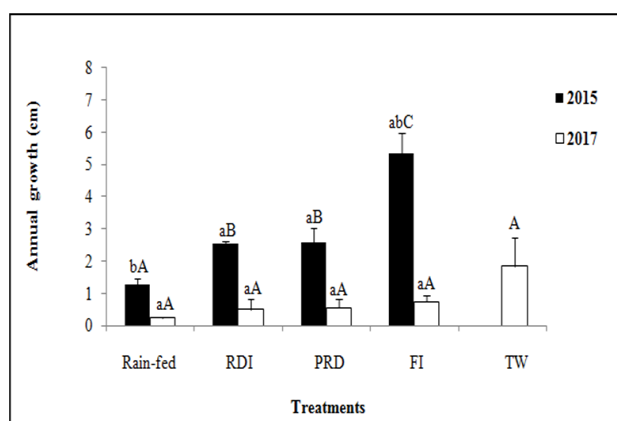


Fig. 1. Variation in the annual growth (cm) of olive trees subjected to different treatments (Rain-fed, RDI, PRD, FI and TW). The letters a, b and c indicate significant differences ($p \leq 0.05$) for the same treatment between years. The letters A, B and C indicate significant differences

($p \leq 0.05$) between treatments for the same year using Duncan's test.

The length of the internodes of olive tree shoots from the different treatments provides insight into the vigor of the year. The greater internodes length indicates the higher production (Poli, 1979; Ksantini, 2003). The history of these different water regimes in 2016 showed (Fig. 2) that they recorded the following internodes lengths: Rain-fed (1.57 cm); RDI (1.42 cm); PRD (1.68 cm); FI (1.6 cm); and TW (1.75 cm). In 2016, these shoots were characterized by low vigor (2016 "Off") with short internodes lengths not exceeding 2 cm (Fig. 2).

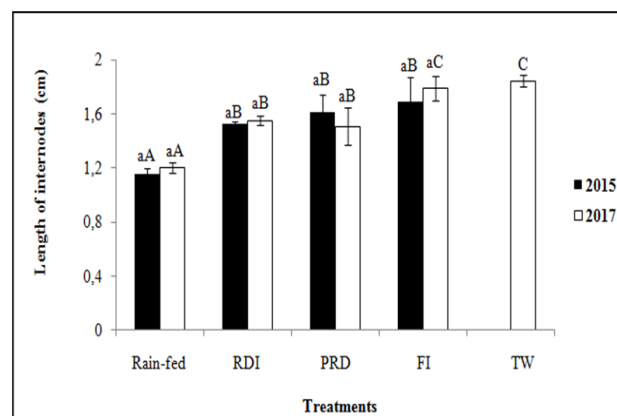


Fig. 2. Variation in the internodes length (cm) of olive trees subjected to different treatments (Rain-fed, RDI, PRD, FI and TW). The letters a, b and c indicate significant differences ($p \leq 0.05$) for the same treatment between years. The letters A, B and C indicate significant differences ($p \leq 0.05$) between treatments for the same year using Duncan's test.

3.2. Flowering parameters

Irrigation treatments resulted in a higher flowering rate compared to the Rain-fed regime (Fig. 3).

However, the flowering rate varies depending on the applied water treatments. The TW treatment recorded the highest rate (79.64%) in 2017, while in 2015; the best rates were obtained by RDI (79.06%) and FI (77.74%). Moreover, we observed variability between treatments depending on the year. Indeed, flowering in 2015 was significantly higher than in 2017. These variations could be related to the tree's physiology and climatic conditions (Poli, 1979; COI, 1997). In fact, it was cooler and there was more precipitation in March (57.4 mm) in 2015 compared to 2017. Irrigation does not seem to mitigate the alternation.

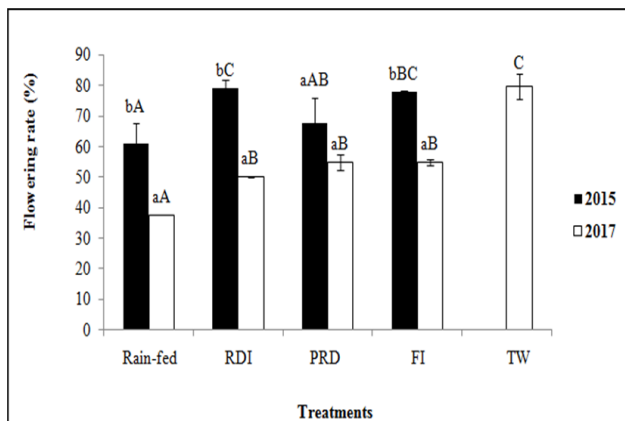


Fig. 3. Flowering rate (%) for olive trees subjected to different treatments (Rain-fed, RDI, PRD, FI and TW) for the years 2015 and 2017.

The letters a and b indicate significant differences ($p \leq 0.05$) for the same treatment between years. The letters A, B and C indicate significant differences ($p \leq 0.05$) between treatments for the same year using Duncan's test.

Olive trees subjected to different water regimes showed a statistically significant difference in the abortion rate at the 5% level between the Rain-fed treatments and the other regimes. The lowest value was recorded in trees irrigated with TW (CE = 2.46 mS/cm) in 2017 (Fig. 4). Water deficit increased the abortion rate compared to irrigated trees. The other irrigation systems RDI, PRD and FI had similar abortion rates for both years. These results suggest that irrigation with saline water (CE = 7.5 mS/cm) increased the abortion rate to a lesser extent than water deficit.

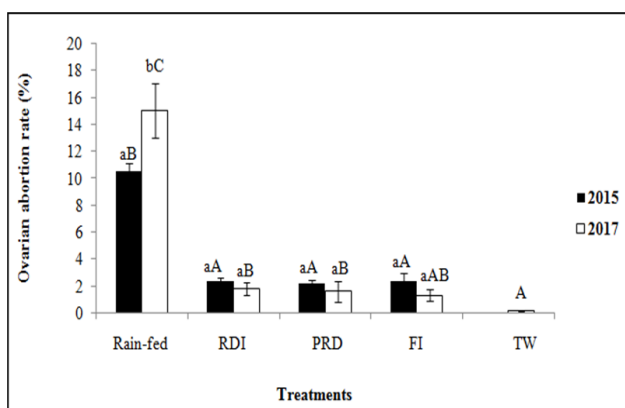


Fig. 4. Ovarian abortion rate of olive trees subjected to different treatments (Rain-fed, RDI, PRD, FI and TW) for the years 2015 and 2017.

The letters a and b indicate significant differences ($p \leq 0.05$) for the same treatment between years. The letters A, B and C indicate significant differences ($p \leq 0.05$) between treatments for the same year using Duncan's test.

A low fruit set rate was observed for all treatments, not exceeding 8%. The average fruit set rate varied between 1.5% and 4.2% depending on the treatments, with values of (Rain-fed = 1.46%; RDI = 3.69%; PRD = 3.89%; FI = 3.12%; TW = 4.23%) in 2017 (Fig. 5). It was higher in 2015 compared to 2017, except for the Rain-fed regime, which did not show any variation between 2015 and 2017. The PRD treatment had the highest fruit set rate, while the Rain-fed regime resulted in the lowest rate (Fig. 5). The PRD treatment induced the highest fruit set rate in 2015, despite having the lowest flowering rate. It seems that there was a compensation phenomenon where the low flowering (due to imperfect flowers) was offset by a good fruit set.

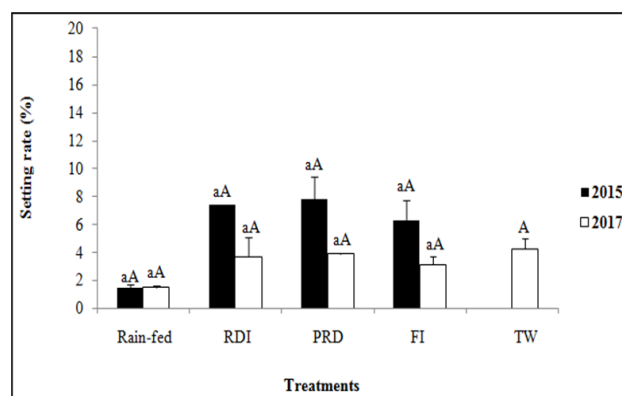


Fig. 5. Setting rate of olive trees subjected to different treatments (Rain-fed, RDI, PRD, FI and TW) for the years 2015 and 2017. The letter a indicates non-significant differences ($p \leq 0.05$) for the same treatment between years. The letter A indicates non-significant differences ($p \leq 0.05$) between treatments for the same year using Duncan's test.

The Rain-fed treatment resulted in the lowest average number of fruits, with 19 fruits per linear meter (Fig. 6).

In contrast, olive trees subjected to the RDI and PRD treatments showed the highest fruit counts in 2015. In 2017, this rate was almost similar for irrigated olive trees regardless of the irrigation technique and water quality. Indeed, the differences between deficit irrigation and full irrigation with either saline water or tap water were not significant at the 5% level. Therefore, salinity did not affect the number of fruits.

3.3. Evaluation of productive performance

The yield in 2015 showed non-significant differences between treatments, whereas significant differences were observed for the year 2017 (Table 1). The TW treatment (CE =

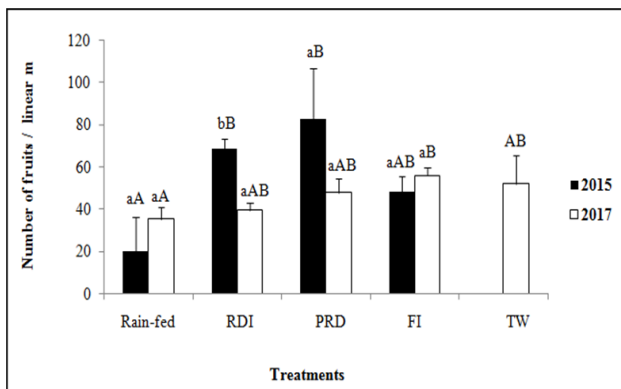


Fig. 6. Number of fruits per linear meter in olive trees subjected to different treatments (Rain-fed, RDI, PRD, FI and TW) for the years 2015 and 2017. The letters a and b indicate significant differences ($p \leq 0.05$) for the same treatment between years. The letters A and B indicate significant differences ($p \leq 0.05$) between treatments for the same year using Duncan's test.

2.46dSm⁻¹) resulted in a significant improvement in production compared to Rain-fed regime. Indeed, the average olive yield for trees under Rain-fed treatment is about 3862.5 kg per hectare between 2015 and 2017, but it is

multiplied by a factor of 2 to 3 depending on the amount and distribution of precipitation (Table 1). Irrigation has led to a substantial improvement in yield and productivity using a limited amount of water over an extended period. Consequently, there was an increase in olive production with the application of limited irrigation amounts, averaging 15703.15 kg/ha for FI and 8953.12 kg/ha for TW compared to Rain-fed conditions.

Irrigation (100% ETc) with TW and FI, using 467.95 mm of water, increased yield by an average of 131.8% for olive trees under the TW treatment (CE = 2.46 mS/cm) and by 306.5% for olive trees under the FI regime (CE= 7.5 mS/cm), compared to those grown under Rain-fed conditions, which received annual precipitation of 226.4 mm and 104.7 mm respectively for the years 2015 and 2017. Applied irrigation (IA) also stabilized olive production year after year. The impact of irrigation went beyond just increasing yield to significantly improve water productivity. Water productivity for irrigation and rainfall is enhanced when both are used together (Oweis et al., 1998 and 2000; Oweis and Hachum, 2004). Rainwater productivity (RWP) increased during

Table 1. Variations in Rainwater Productivity (RWP), Ep and IA water productivity (TWP) and irrigation water productivity (GIWP) of olive tree in different treatments (Rain-fed conditions, FI: irrigated with 100% ETc with saline water (CE= 7.5 mS/cm), RDI: Regularly deficit irrigation that supplied 50% of the irrigation water applied in FI, PRD: Alternate irrigation switched every 30 days that supplied 50% of the irrigation water applied in FI and TW: irrigated with 100% ETc with tap water (CE= CE= 2.46 mS/cm) during the experimental period.

Year	Ep (mm)	Rain-fed yield (kg/ha)	RWP (kg/m ³)	IA (mm)		Ep + IA(mm)	
				100%ETc	50%ETc	100%ETc	50%ETc
2015	226.4	4125	1.82	430.9	215.5	657.3	441.9
2017	104.7	3600	3.44	505	252.5	609.7	357.2
Mean	165.5	3862.5	2.63	467.95	234	633.5	399.5

Year	Irrigated yield (kg/ha)				TWP (kg/m ³)				GIWP (kg/m ³)			
	FI	TW	PRD	RDI	FI	TW	PRD	RDI	FI	TW	PRD	RDI
2015	20937.5	9687.5	18750	18437.5	3.2	1.47	4.24	4.17	4.86	2.25	8.7	8.55
2017	10468.8	8218.75	6043.75	7937.5	1.72	1.35	1.69	2.22	2.07	1.63	2.39	3.14
Mean	15703.1	8953.12	12396.9	13187.5	2.46	1.41	2.96	3.19	3.46	1.94	5.54	5.84

RWP (kg/m³ of water) is taken as the ratio of Rain-fed yield to rainwater. TWP (kg/m³ of water) is taken as the ratio of irrigated yield to total water supply (Ep + IA). GIWP (kg/m³ of water) is taken as the ratio of increase in yield to the gross depth of water applied IA.

these two years, particularly during the driest period (2015), but on average, it ranged from 1.82 to 3.44 kg/m³ for 2015 and 2017, respectively. Irrigation water productivity (GIWP) ranged from 1.94 to 5.84 kg/m³. Thus, olive trees responded positively to the application of irrigation.

Therefore, the use of irrigation combined with rainfall produced more olives per unit of water than using irrigation alone in fully irrigated areas where precipitation is negligible. Productivity varied from 1.35 kg/m³ for the TW regime (CE = 2.46 mS/cm) to about 4.24 kg/m³ for the PRD regime. This difference suggests that the allocation of limited water resources should be shifted towards a more efficient practice (Oweis, 1997).

In fact, the use of the PRD technique (50% ETc) yielded good results in our study both quantitatively and qualitatively. However, our results suggest that unstable climatic conditions can directly affect bud differentiation, flowering, fruit set, and consequently tree production. These climatic conditions are notably observed in regions where winter temperatures vary significantly from year to year, as is the case in our study. Darnell et al. (2003), Elloumi (2013), Elloumi et al. (2016) and Elloumi et al. (2020) have shown that insufficient cold can affect trees' ability to produce through its impact on flowering and vegetative growth. Indeed, in our study, the lack of cold and high temperatures (mild winter 2015-2016) delayed the vegetative and floral bud burst, decreased the percentage of floral bud burst, and disrupted the progression of various flowering stages and vegetative growth. These results contradict the observations made by Elloumi et al. (2016, 2020). On the other hand, Trigui (1987) notes that olive production is always characterized by the interaction of factors such as technique (management practice) and external factors (edapho-climatic conditions). While there is significant variation within each treatment across years, this phenomenon is also present within the same year. Indeed, the relatively high coefficients of variation for most of the monitored parameters indicate variability in performance among trees of the same treatment. In other words, we found some trees in production while others were in vegetative growth at the same time. We can speak of an intra-treatment alternate bearing phenomenon as opposed to an inter-annual one. These two alternation phenomena indicate that we can

ensure a minimum acceptable production regardless of annual conditions by applying deficit irrigation (50% ETc). This result could allow for better utilization of water resources and an increase in national olive production, especially during challenging years.

4. CONCLUSIONS

The study of vegetative and reproductive potential allowed us to deduce the influence of different water regimes applied to twenty-six-year-old Chemlali Sfax olive trees grown intensively in an arid climate. It is based on the assessment of vegetative growth, floral biology, and production in relation to edaphic conditions.

The performance of olive trees subjected to different water regimes showed significant differences in vegetative potential (internodes length, annual growth). Indeed, olive trees under rain-fed conditions consistently exhibited the lowest parameters, with significantly different annual growth. In contrast, PRD provided high values for annual shoot elongation and internodes length while saving water compared to FI and TW. Olive trees under PRD exhibited the highest flowering and fruit-setting rates compared to RDI and FI. The number of fruits per unit length for olive trees subjected to RDI, PRD and FI were statistically similar. The various agronomic characteristics studied revealed significant variability between treatments and some heterogeneity within each treatment, as well as several similarities. According to our results, irrigation with saline water FI (CE=7.5 mS/cm) affects lightly agronomic parameters, but we observed that deficit irrigation (PRD) produced optimal results. We can affirm that olive trees subjected to these different regimes with saline water were able to adapt to the induced saline stress.

Yield is positively influenced by irrigation. Providing 50% ETc is necessary to achieve good production. Thus, deficit irrigation can be an optimization strategy where trees can maintain a certain level of water deficit without a significant reduction in yield. Higher volumes with the use of full irrigation (100% ETc) do not further increase yields. Consequently, the deficit irrigation technique PRD, which involves irrigating half of the root system while allowing the other half to dry, can significantly improve vegetative growth without affecting yield.

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REFERENCES

- Agnachich, B., El Antari, A., Wahbi, S., Tahy, H., Wakrim, R., Serraj, R. (2008). Fruit and oil quality of mature olive trees under partial rootzone drying in field conditions. *Grasaa y Aceites*, 59, 225-233.
- Barronco, D., Cimato, A., Fiorino, P., Rallo, L., Touzani, A., Castaneda, C., Serafini, F., Trijillo, I. (2000). Catalogue mondial des variétés d'olivier. Ed. Conseil Oléicole International 360 p illustrées.
- Ben Abdelmalek, M., Nouiri, I., Tarhouni, J. (2016). Spatio-temporal variation of standardized precipitation index (SPI) in Tunisia and mapping of degree of drought severity for the period 1973-2015. 2nd ICIEM 2016. International Conference on Integrated Environmental Management for Sustainable Development.
- Chtourou, M., Gargouri, B., Jaber, H., Abdelhedi, R., Bouaziz, M. (2013). Comparative study of olive oil quality from Chemlali Sfax versus Arbequina cultivated in Tunisia. *Eur. J. Lipid Sci. Technol.* 115, 631-640.
- COI.(1997). Méthodologie pour la caractérisation primaire et secondaire des variétés d'olivier. Encyclopédie mondiale de l'olivier. Edition Conseil Oléicole International, Projet RESGEN-CT (96 /97). Union européenne- COI. 479p.
- Darnell, R.L., Cantliffe, D.J., Kirschbaum, D.S., Chandler, C.K. (2003). The physiology of flowering in strawberry. *J. Amer. Soc. Hort. Sci.* 28:325-349.
- Dbara, S., Ben Mimoun, M., Hellali, R. (2011). Réponse de l'olivier à la technique de dessèchement partiel des racines durant trois années consécutives d'essai. *Tropicultura* 29, 70-74.
- Elloumi, O. (2013). Thèse de doctorat en sciences agronomiques : sciences de la production végétale. Alternance de production chez le pistachier (*Pistacia vera* L.) : Contribution de quelques facteurs exogènes et endogènes dans la variabilité de la production et de la croissance des arbres. INAT, 136 pp.
- Elloumi, O., Chaari, A., Ayadi, M. (2016). Comportements agronomiques de l'olivier (*Olea europaea* L.) sous climat semi-aride tunisien. *Revue des Régions Arides* n°43(3/2017) -Numéro spécial-Actes du 5^{ème} Meeting International sur l'Aridoculture et les Cultures Oasiciennes : Biotechnologie végétale en zones arides et oasiciennes Zarzis (Tunisie), 19-21.
- Elloumi, O., Ghrab, M., Chatti, A., Chaari, A., Ben Mimoun, M. (2020). Phenological performance of olive tree in a warm production area of central Tunisia. *Scientia Horticulturae* 259 (2020) 108759
- Ghrab, M., Ayadi, M., Gargouri, K., Chartzoulakis, K., Gharsallaoui, M., Bentaher, H., Psarras, G., Ben Mimoun, M., Masmoudi, M.M., Ben Mechlia, N. (2014). Long-term effects of partial root-zone drying (PRD) on yield, oil composition and quality of olive tree (cv. Chemlali) irrigated with saline water in arid land. *Journal of Food Composition and Analysis* 36 (2014) 90-97.
- Ghrab, M., Ben Mimoun, M., Masmoudi, M.M., Ben Mechlia, N. (2016). Climate change and vulnerability of the pistachio and almond crops in the Mediterranean arid areas. *Options Méditerranéennes* 119, 247-251.
- Ghrab, M., Elloumi, O., Benmoussa, H., Trabelsi, L., Borgini, N., Ben Mimoun, M. (2022). Climate change and viability of fruit tree orchards in arid area. *Journal of Oasis Agriculture and Sustainable Development* 1-5. www.joasdjournals.com.DOI:https://doi.org/10.56027/JOASD.spiss012022.
- Ksantini, M. (2003). Contribution à l'étude de la dynamique des populations du psylle de l'olivier *Euphyllura olivina* (COSTA) (Homoptera-Sternorhyncha-Aphalaridae) et de sa nuisibilité dans la région de Sfax. Thèse de Doctorat en Sciences Biologiques. Faculté des Sciences de Sfax. 305p.
- Lavee, S. (1997). Biologie et physiologie de l'olivier. In Encyclopédie Mondiale de l'olivier. Eds COI 1997, p 61-110.
- McKee, T.B., Doesken, N.J., Kleist, J. (1993). The relationship of drought frequency and duration at time scales. *Proceedings of the 8th Conference on Applied Climatology*, American Meteorological Society 179-186.
- McKee, T.B., Doesken, N.J., Kleist, J. (1995). Drought monitoring with multiple time scales. *Proceedings of the Ninth Conference on Applied Climatology* 233-236.
- Melgar, J.C., Mohamed, Y., Navarro, C., Parra, M.A., Benlloch, M., Fernandez-Escobar, R., (2008). Long-Term Growth and Yield

- Responses of Olive Trees to Different Irrigation Regimes. *Agricultural Water Management*, 95, 968-972.
- Moriana, A., Perez-Lopez, D., Prieto, M.H., Ramirez-Santa-Pau, M., Perez-Rodriguez, J.M. (2012). Midday stem water potential as a useful tool for estimating irrigation requirements in olive trees. *Agricultural Water Management* 112, 43-54.
- Oweis, T. (1997). Supplemental Irrigation: a highly Efficient Water-Use Practice. ICARDA, Aleppo, Syria, 16pp.
- Oweis, T., Pala, M., Ryan, J. (1998). Stabilization rain fed wheat yields with supplemental Irrigation and nitrogen in a Mediterranean climate. *Agron. J.* 90, 672-681.
- Poli, M. (1979). Etude bibliographique de la physiologie de l'alternance de production chez l'olivier (*Olea europaea* L.). *Fruits*, vol. 34, N° 11, p. 687-695.
- Ruiz, D., Campoy, J.A., Egea, J. (2007). Chilling and heat requirements of apricot cultivars for flowering. *Environmental and Experimental Botany* 61, 254-263.
- Sanz-Cortés, F., Martínez-Calvo, J., Badenes, M.L., Bleiholder, H., Hack, H., Llacer, G., Meir, U. (2002). Phenological growth stages of olive tree (*Olea europaea* L.). *Annals of Applied Biology* 140, 151-157.
- Soro, G.E., Anouman, D.L., Goula, B.I. T.A., Srohorou, B., Savane, I. (2014). Caractérisation des séquences de sécheresse météorologique à diverses échelles de temps en climat de type Soudanais : cas de l'extrême Nord-Ouest de la Côte d'Ivoire. *Larhyss Journal* 18, 107-124
- Trabelsi, L., Gargouri, K., Ben Hassena, A., Mbadra, C., Ghrab, M., Ncube, B., Van Staden, J., Gargouri, R. (2019). Impact of drought and salinity on olive water status and physiological performance in an arid climate. *Agric. Water Manag.* 213, 749-759.
- Trabelsi, L. (2020). Adaptation des stratégies nutritionnelles de l'olivier (*Olea europaea* L.) aux différents régimes hydriques en milieu aride. Thèse de Doctorat en Génie Biologique. École Nationale d'Ingénieurs de Sfax. 291 p + annexes.
- Trabelsi, L., Ncube, B., Ben Hassena, A., Zouairi, M., Ben Amar, F., Gargouri, K. (2023). Comparative study of productive performance of two olive oil cultivars Chemlali Sfax and Koroneiki under arid conditions. *South African Journal of Botany* 154 (2023) 356-364.
- Trabelsi, L., Gargouri, K., Ghrab, M., Mbadra, C., Ben Hassena, A., Ncube, B., Soua, N., Maktouf, S., Khelifi, M., Van Staden, J., Gargouri, R. (2024). The effect of drought and saline water on the nutritional behavior of the olive tree (*Olea europaea* L.) in an arid climate. *South African Journal of Botany* 165(2024)126-135.
- Trigui, A. (1987). Relations entre le climat, le sol et la production de la variété d'olivier Chemlali (*Olea europaea* L.) dans la région de Sfax (Tunisie). Contribution à l'étude bioclimatique de l'espèce par l'analyse des propriétés biophysiques, structurales et spectrales des feuilles et des arbres. Thèse de Doctorat d'Etat. Université des sciences et techniques du Languedoc (Montpellier, France). 433 p + annexes.
- Wahbi, S., Wakrim, R., Aganchich, B., Tahi, H., Serraj, R. (2005). Effects of partial root zone drying (PRD) on adult olive tree (*Olea europaea* L.) in field conditions under arid climate. I. Physiological and agronomic response. *Agric. Ecosyst. Environ.* 106, 289-301.