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*Research paper

Optimal time of supplemental irrigation during fruit development of rainfed olive tree (*Olea Europea*, cv. *Picholine Marocaine*) in Morocco

Rachid Razouk^{1*}, Jamal Ibijbjen² and Abdellah Kajji¹

¹: Regional Center of Agriculture Research, P.O. Box 578, Meknès, Morocco.

²: Department of Biology, Moulay Ismail University, P.O. Box 4010, Meknès, Morocco.

*Corresponding author: Email: razouk01@yahoo.fr

Abstract

Aims: This work was carried out to identify optimal time of supplemental irrigation on adult olive orchard, traditionally cultivated under rainfed conditions.

Study design: Randomized complete block design with three replications where the variable factor was water regime.

Place and Duration of Study: Experimental station Ain Taoujdate, Regional Center of Agriculture Research, Meknès, Morocco during 2009 and 2010.

Methodology: Seven treatments of supplemental irrigation were tested, individually during one day at beginning of stage I of fruit development (T_a); beginning of stage II (T_b); beginning of stage III (T_c) and in combination of two irrigations, T_a and T_b (T_{ab}), T_a and T_c (T_{ac}), and T_b and T_c (T_{bc}) in addition to three irrigations T_a , T_b and T_c (T_{abc}), and no irrigation used as rainfed control (T_d). Treatments were applied to thirty years old olive trees (cv. *Picholine Marocaine*) planted at a distance of 8x6m, at experimental station of INRA institute in North-center of Morocco. Amount of each watering was equivalent to the easily usable water-reserve on 70 cm of soil depth ($0.5 \text{ m}^3 \cdot \text{tree}^{-1}$).

Results and discussion: Fruit weight and shoot growth were more affected by treatment T_a , increasing fruit yield by an average of 43% and oil yields by 37%. Water use efficiency for this treatment was $23 \text{ kg} \cdot \text{m}^{-3} \cdot \text{tree}^{-1}$. Treatments T_b and T_c affected only oil content and shoot growth without significant changes in yield. However, their combination with T_a in treatment T_{abc} increased fruit yield by an average of 106%. The effect observed under the tested irrigations was related to importance of fruit growth kinetics during their application.

Conclusion: The positive effects of supplemental irrigation, particularly during the first period of fruit development, are promising to promote this technique on several rainfed olive orchards. Under conditions of the experiment, the production gain of irrigation applied in this period is able to generate substantial economic returns.

Keywords: Morocco, rainfed olive, supplemental irrigation, vegetative growth, fruit yield, oil yield.

1. Introduction

Olive is a pillar of Mediterranean agriculture [1, 2]. In Morocco, olive area occupy 790.000 ha, 60% of which is rainfed [3]. The interest given to this crop in the national agricultural policy comes from its socio-economic roles and its adaptability to different environments [4, 5], including drought [6]. Moroccan olive area is in continuous extension since 1996 due to the

new agricultural policy of promoting this crop with an objective of increasing area to 1.22 million hectares by 2020[7]. Despite this prospect, productivity remains very low and fluctuant because of yield-alternation phenomenon[8] especially in rainfed orchards where fruit yield does not exceed 3t/ha[9], ensured by the low water reserves coming from autumn and winter rainfall and summer storms[10]. Rainfall deficit is high and lasts long (June to September)[11, 12], during critical growth stages: fruit growth and first wave of vegetative growth[13]. In orchards with irrigation facilities or availability of water, olive trees are sometimes irrigated, during summer where evapotranspiration is highest. Therefore, rational management of available water for olive crops is necessary. Thus, optimization of supplemental irrigation is one way to efficiently manage this precious resource.

Olive response to irrigation is evident, especially during period of its intense activity that extends from floral differentiation to harvest[14], occurring from April to November under Moroccan conditions [15]. The application of irrigation in early spring prevents severe physiological disturbances such as low floral development[16] and pistil abortion[17]. It also helps mitigate yields alternation phenomenon[18, 19]. Irrigations in spring and summer significantly improve fruit growth kinetic even during stone hardening period where fruit growth is usually slowed [20], resulting in increased fruit yield[21]. In addition, shoots vigor is higher under irrigation, providing more fruiting-supports in subsequent years[22]. However, fruit oil content is assumed to be less under irrigation because of high water content[23], but this decrease is often offset by fruit-weight improvement ensuring an increase of oil yield[24].

In Mediterranean rainfed areas, the application of supplemental irrigation on olive trees usually grown in rainfed conditions is possible in some orchards, especially for those located near of water resources such as rivers or containing wells even with low-flow. Supplemental irrigation may have considerable effect if it is applied during critical stages of olive growth [25]. Adoption of this technique is conditioned by delivery of water from available resources to olive orchards. For those located on rivers edges or containing wells, water pumping systems are to anticipate. The distant orchards from water resources require hydro-agricultural investments that are to be deducted from production gains. Therefore, it is essential to determine the optimal periods to apply supplemental irrigation having high economic efficiency and giving the satisfactory production gain. It is within this context that this study was carried out aimed to identify optimal periods of irrigation, by quantifying effects on fruit and shoot growths on adult olive orchard habitually grown under rainfed conditions.

2. Materials and methods

2.1 Experimental site and crop management

The experiment was carried out during two consecutive seasons (2009-2010) at the experimental farm of National Institute of Agricultural Research (INRA) Ain Taoujdate Station (40 km North of Meknès city, 33° 56' E, 5° 13' N; 500 m) in the plain of Sais located in North center of Morocco. Meteorological data for experimental station during the two years of study was presented in Figure 1 where it is shown that rainfall deficit is more marked during a large part of olive growth, between May and September with a peak in July and August.

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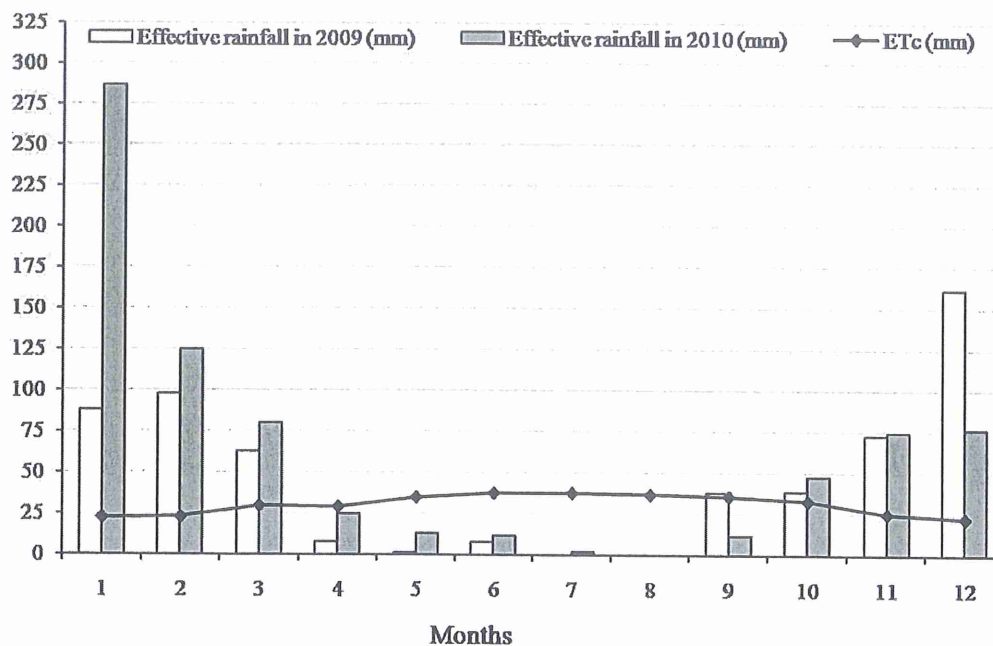


Figure 1. Effective rainfall (80% of rainfall) and average of olive evapotranspiration (ETc) obtained from the Hargreaves model, during 2009 and 2010, in experimental field.

The soil is silty clay with an average of 3.04 % CaCO_3 , rich in organic matter, with an average of 2.51% in the top soil surface layer (0-30 cm). The soil pH is almost neutral (7.3) and not saline (average EC around 0.07 ms.cm^{-1} in the top 60 cm).

Plant material used was the cultivar *Picholine Marocaine*, planted and grown in rainfed conditions since its planting in 1981 at a density of 208 tree/ha (8x6 m). This cultivar occupies 96% of olive orchards in Morocco [26] and it is highly adopted because of its availability and its good adaptation to drought conditions [27].

2.2 Irrigation treatments, experimental design and measurements

Determination of periods to test supplemental irrigation was based on fruit-growth kinetics under local conditions of the experiment (figure 2). Indeed, supplemental irrigation was tested during different stages of fruit growth. Dates of water supply were: "T_a" : irrigation in mid-June, two weeks after start of the first rapid stage of fruit growth; "T_b" : irrigation at the end of July, corresponding to mid-phase of stone hardening and "T_c" : irrigation in early September, two weeks after start of the second rapid stage of fruit growth, and all their combinations "T_{ab}", "T_{ac}", "T_{bc}" and "T_{abc}". All these seven treatments were compared to rainfed regime "T_d" with no irrigation. In each water treatment, the trees were surface irrigated, using a cistern, around the trunks by 2m with a quantity equivalent for each watering to the easily usable water-reserve of soil estimated equal to two-thirds of the useful soil reserve on 70 cm of depth. Thus, quantity for each watering was 0.5 m^3 per tree, equivalent to $104 \text{ m}^3/\text{ha}$ (Table 1).

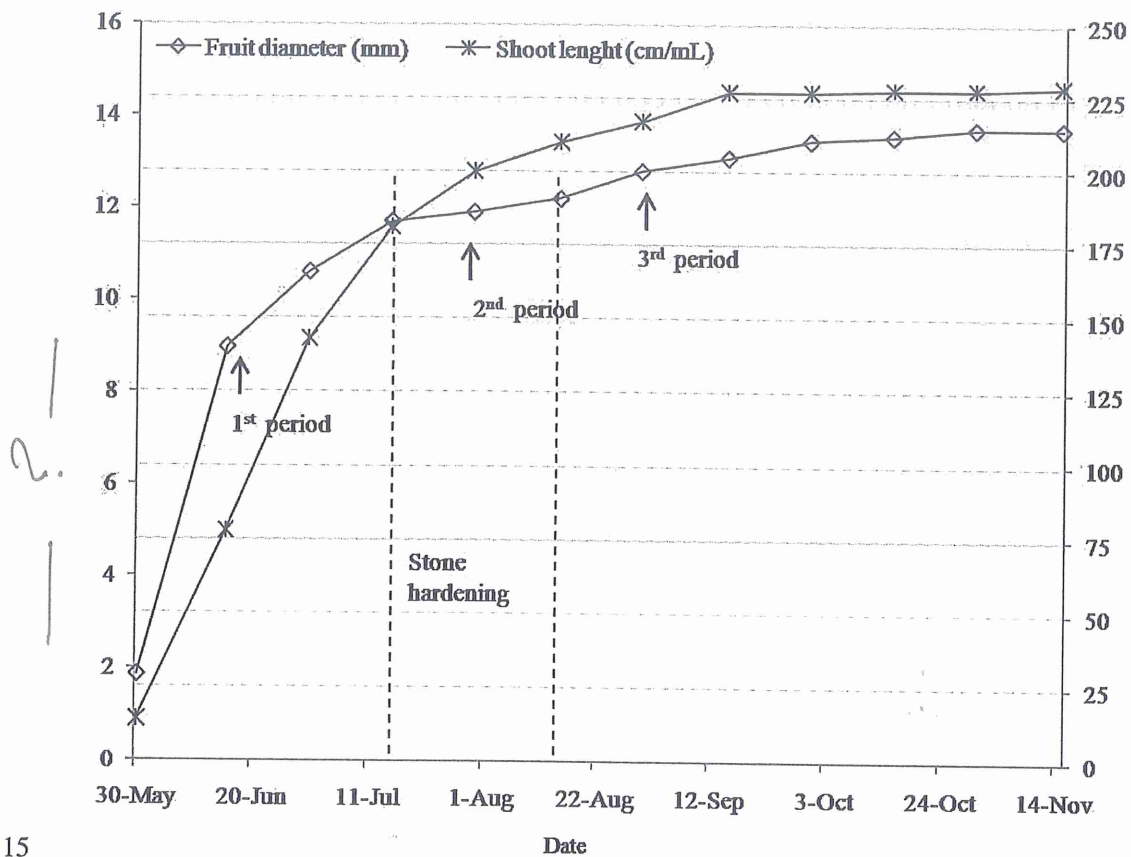


Figure 2: Growth kinetics of fruit diameter (left axis) and shoot length (right axis) of olive in experimental field under rainfed regime (average of two years: 2009 and 2010) and localization of irrigation periods.

Table 1: Treatments of supplemental irrigation tested on rainfed olive.

	Applied water (m ³ .tree ⁻¹)			
	Mid-June	End of July	Early September	Total of applied water
T _a	0.5	0	0	0.5
T _b	0	0.5	0	0.5
T _c	0	0	0.5	0.5
T _{ab}	0.5	0.5	0	1
T _{ac}	0.5	0	0.5	1
T _{bc}	0	0.5	0.5	1
T _{abc}	0.5	0.5	0.5	1.5
T _d	0	0	0	0

The experiment was conducted in randomized complete block design with three replications where the variable factor was water regime. The three blocks were selected inside of the orchard. Each block consisted of eight elementary plots where each comprised three olive trees.

The measurements relate to vegetative growth and fruit yield. Vegetative growth was observed every week throughout the season by measurement of shoots length brought by six fruiting 2-years-old branches with similar lengths per plot. The branches were selected in two exposures of trees, East and West. Total lengths of shoots (primary and secondary) were reported to linear meter of fruiting branch in order to minimize variability due to branches vigor.

At the end of November, each tree was manually harvested and the yield weighed in the field. In order to minimize variations due to trees vigor, the yield value was reported to section area of the principal carpenters, estimated by measuring their base-circumference. Samples of fruits, approximately 3 kg, were collected from randomly ten selected fruiting branches per plot to measure fruit and stone weight. Completely black olives of the samples were used for determination of fruit oil content by nuclear magnetic resonance using NMR analyzer type oxford 4000.

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143 3. Results and discussion

144 3.1 Vegetative growth

Irrigation had an immediate effect on vegetative growth of rainfed olive, with varying degree depending on time of application. Shoot growth was highly influenced by the first irrigation (T_a), applied just after start of vegetative growth, significantly higher than that obtained with the second and the third irrigation (T_b and T_c) even combined, increasing shoot length by annual average of 36% (figure 3). The irrigations T_b and T_c increased shoot length respectively by 26 and 15% comparatively with rainfed regime (T_d). Therefore, it is clear that more irrigation date is advanced more its effect on shoot elongation decreases. This is explained by the fact that the first irrigation was applied during rapid phase of shoot growth, while the two other irrigations coincided with a slowdown of shoot growth (figure 2).

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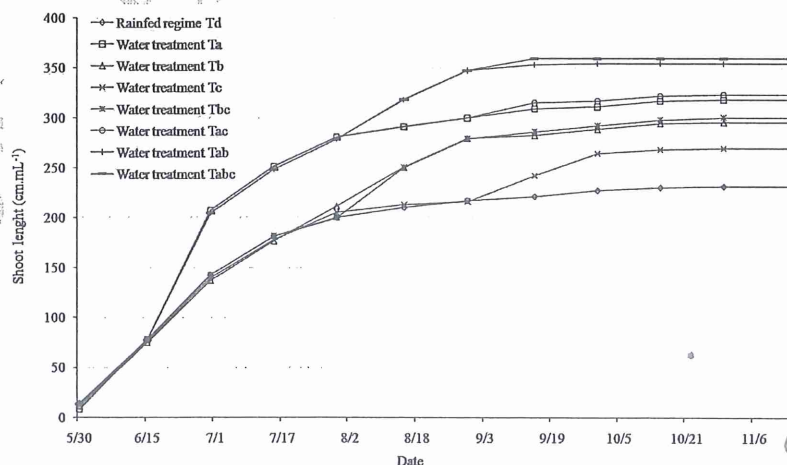


Figure 3. Olive shoots growth under different supplemental irrigations (average of two years: 2009 and 2010).

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The positive effect of supplemental irrigation on shoot growth is in agreement with those of Girona et al. and Pérez et al. [28, 29] who found that rainfed olive responds significantly to irrigation, but with different magnitudes depending on variety used and water-application method. The activation of shoot growth under irrigation is an evident response, caused by the increase of transpiration [30]. It results from several reversible mechanisms such as increase of cell division speed [31], elasticity of cellular wall, facilitated cell growth [32] and increased cell turgor [33]. However, there is a consensus that activation of vegetative growth is not a consequence of water activity in cells, but is rather controlled by mechanical movement of water in the trees [34].

Under all water treatment, shoot growth was realized in one growth wave from May to late September. This result is in contradiction with those obtained under continuous irrigation by few authors [35, 36] who observed two periods of growth; one more intense up to summer and the other less active in autumn. This last growth wave would be mitigated under effect of water stress occurring in summer and early autumn. This hypothesis is supported by acceleration of shoot growth with irrigation applied in summer in treatment T_c (figure 3), as well as by results of Hadiddou et al. [15] who observed one wave of shoot growth in some Moroccan olive varieties under rainfed conditions.

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3.2 Yield and water use efficiency

During the two years of the experiment, yield per tree was influenced by variability of trees vigor in addition to water-treatment variation doing what their multiple comparison was not highlighted the effect of water regimes. However, consideration of carpenter's section in evaluation of water treatments allowed eliminating vigor effect. Variance analysis of yield per unit carpenter's section, under irrigation applied on one day, showed that fruit and oil yields increased only by the first irrigation T_a, applied two weeks after fruit set (table 2). Under this treatment, average of yield increase was 43% for fruits and 38% for oil. This result is in agreement with those of several authors [48, 37] who observed that olive production decrease significantly under water stress applied during the first period of fruit development.

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Table 2: Fruit and oil yields of olive under different supplemental irrigations

	2009				2010			
	Fruit yield		Oil yield	WUE	Fruit yield		Oil yield	WUE
	kg.tree ⁻¹	g.cm ⁻² . TCS ⁻¹	ml.cm ⁻² . TCS ⁻¹	kg.m ⁻³ . tree ⁻¹	kg.tree ⁻¹	g.cm ⁻² . TCS ⁻¹	ml.cm ⁻² . TCS ⁻¹	kg.m ⁻³ . tree ⁻¹
T _a	55.3 c	20.1 ab	3.6 ab	27.22 d	46.0 b	16.7 ab	2.8 ab	19.24 d
T _b	30.0 a	13.6 a	2.4 a	0.00 a	19.0 a	12.5 a	2.0 a	1.67 a
T _c	36.0 ab	16.1 a	2.6 a	10.49 b	35.0 ab	13.0 a	2.1 a	3.76 b
T _{ab}	47.6 abc	24.7 ab	4.5 ab	23.19 c	37.3 ab	18.6 ab	2.9 ab	13.59 c
T _{ac}	33.6 ab	25.0 ab	4.4 ab	23.80 c	32.0 ab	20.8 ab	2.8 ab	18.19 d
T _{bc}	32.3 ab	20.0 ab	3.2 ab	13.53 b	20.0 a	15.5 ab	2.7 ab	7.11 c
T _{abc}	50.3 bc	31.5 b	5.5 b	24.94 c	41.6 b	21.9 b	3.6 b	13.66 c
T _d	33.6 ab	13.6 a	2.5 a	-	27.6 ab	12.1 a	2.1 a	-

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TCS: total carpenter's section;
WUE was calculated for additional water only.

The two last irrigations T_b and T_c have not influenced significantly yield level compared to rainfed regime T_d . It is only when these irrigations were combined in treatment T_{bc} that it ensured an effect equivalent to that observed with the first irrigation T_a . However, their whole combination with the first irrigation in treatment T_{abc} gave the highest response, with increase of fruit yield by an average of 106 % and of oil yield by 96 % in comparison to rainfed treatment T_d .

Moreover, the magnitude of the different water treatments effect was considered spectacular. This result may imply that expression of irrigation effect on rainfed olive is more pronounced under drought conditions, which occurred during a large part of the active period of olive tree (June - August) for two years of the experiment. This affirmation may be confirmed by studies of Moriana and Orgaz [49] who found the same differences between rainfed and irrigated olive during a dry year. Whereas, during a rainy year, differences found by these authors were less important, with an average of production gain of 46% under full irrigation. The variations observed in yield levels were linked in large part to fruit weight variation because the water treatments were started after fruit set. Indeed, linear regression between fruit weight and fruit yield is significant (figure 4).

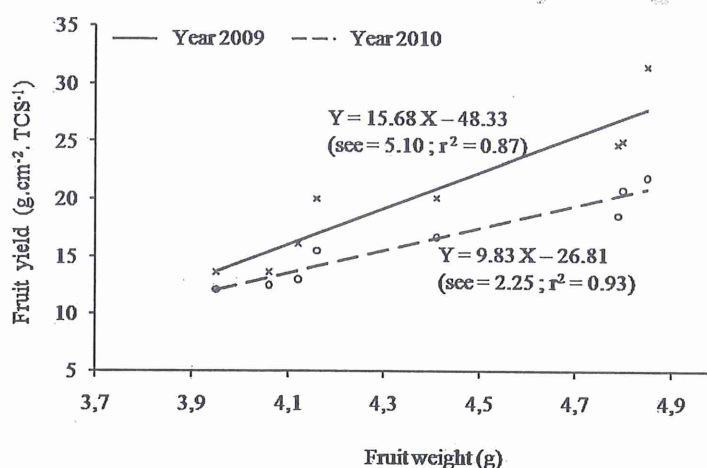


Figure 4. Relationship between fruit weight and fruit yield per total carpenter's section of olive tree (all treatments combined).

Determining water use efficiency (WUE) of olive tree under the tested water treatments is interesting for decision-making as to feasibility of supplemental irrigation on olive orchards usually conducted under rainfed conditions. The increase of WUE under supplemental irrigation is attributed to production gain induced by mitigation of rainfall deficit during active period of fruit growth, in agreement with results of several authors [50, 29]. Indeed, WUE has been improved only with irrigation T_a , applied at one day in the first period of fruit development, which increased production gain by $23 \text{ kg.m}^{-3}.\text{tree}^{-1}$. Addition of another irrigation T_b , T_c , or both combined, induced a significant decrease in WUE value by an average of 20%.

3.3 Fruit weight

Fruit weight was highly affected by water treatments. The classification of fruit weight averages and the follow of its diameter during the cycle showed that fruit weight was more influenced by irrigation T_a applied during the first rapid stage of fruit growth. This irrigation increased fruit weight by 13% compared to rainfed regime T_d (Table 3). This is explained by the coincidence of this irrigation with active multiplication of fruit cells, which seems the more crucial parameter affecting fruit weight [37].

Table 3: Olive fruit characteristics and oil content under different supplemental irrigations

	2009				2010			
	Fruit weight (g)	Stone weight (g)	Stone/fruit	Oil content (%.DW)	Fruit weight (g)	Stone weight (g)	Stone/fruit	Oil content (%.DW)
T_a	4.41 c	0.88 c	0.19	37,83 d	3,96 c	0.79 c	0.19	34.5 d
T_b	4.06 ab	0.85 ab	0.20	36,56 c	3,61 ab	0.76 ab	0.20	33.6 c
T_c	4.12 b	0.95 b	0.22	33,77 a	3,67 b	0.84 b	0.22	32.5 c
T_{ab}	4.79 d	1.10 d	0.22	37,53 d	4,34 d	1.00 d	0.22	34.4 d
T_{ac}	4.80 d	0.96 d	0.19	36,83 c	4,35 d	0.87 d	0.19	32.3 c
T_{bc}	4.16 b	0.83 b	0.19	33,36 a	3,71 b	0.74 b	0.19	30.2 a
T_{abc}	4.85 d	1.11 d	0.22	35,96 b	4,40 d	1.01 d	0.22	31.4 b
T_d	3.95 a	0.79 a	0.19	37,46 d	3,50 a	0.70 a	0.19	36.0 d

DW: dry weight;

The Irrigation applied during the second rapid stage of fruit growth (T_c) has the lesser effect, increased fruit weight by an average of 5%. This rise originates from the low increase of cell volume trained by accumulation of water, oil and other reserves in vacuoles [38] whose number is previously determined at the end of the first rapid stage of fruit growth[39]. The irrigation applied during stone hardening stage (T_b) had the lowest effect, increased fruit weight by 3%. This irrigation coincides with low activity of pulp cells associated to lignification of stone cells [40], weakening effect of irrigation at this period.

The effects of irrigation applied at the different tested periods are additives but not in a linear manner. Adding another water irrigation to treatment T_a applied in the first stage of fruit development, during stone hardening stage (T_{ab}), or during the second phase of fruit growth (T_{ac}), or during these two periods (T_{abc}), increased final fruit weight by the same magnitude with an average of 23% compared to rainfed regime T_d , where the large part is determined by irrigation T_a .

The increases of fruit weight observed under all tested treatments result from simultaneous growth of pulp and stone, as indicated by non-significance of differences between the averages of weights ratio "stone/fruit". This result seems in contradiction with those of Wahbi *et al.* [41] who found that water stress induced a significant reduction of this ratio, due to simultaneous changes in fruit weight and stone weight. The contradictory results may be related to differences in water stress intensity which was severe in the present experiment.

3.4 Fruit oil content

Generally, olive oil content decreased with irrigation. This finding is generally accepted by several authors [42, 43]. It originates from the competition between oil and water in cellular spaces, because of their opposite polarity [44, 45]. Indeed, oil content was highly decreased by the last irrigation T_c , followed by the second irrigation T_b (table 3), having reduced oil content, over the two years of the experiment, respectively by an average of 3.6 and 1.6% compared to rainfed treatment T_d . Therefore, it appears clear that more the irrigation coincide with the intense activity of oil accumulation, which is more active during stone hardening stage and the second rapid stage of fruit growth [46, 38], more its effect is prominent on oil content. The combination of these two irrigations (treatment T_{bc}) had the highest effect, decreased oil content by an average of 5% compared to rainfed treatment T_d .

However, treatment T_a did not significantly cause change in oil content. This is explained by the fact that this irrigation was applied outside of active period of oil accumulation in fruit. During the first period of fruit growth, water absorbed by the trees is valorized in fruits mainly by cellular mitosis [47], may make water less competitive for oil accumulation, and even may foster it. This last hypothesis is reinforced by elimination of treatment T_c effect and mitigation of treatment T_{bc} effect on oil content, when it have been associated to treatment T_a .

4. Conclusion

The application of a supplemental irrigation on adult olive orchards, traditionally cultivated under rainfed conditions, is a promising technique to improve olive production in several Mediterranean regions. The present experiment revealed that supplemental irrigation, even applied in one day during fruit development, has an immediate effect on vegetative growth and yield.

Olive production and vegetative growth improved significantly under supplemental irrigation applied at one day during the first period of fruit development, in mid-June. The yield increase was related to acceleration of fruit growth kinetics during this period. The irrigations applied at one day during stone hardening stage (end of July) and at startup of the second period of fruit development (early September), did not affect olive production although it increased significantly fruit weight. However, application of irrigation during the three tested periods has doubled olive production, with a significant decrease of WUE in comparison with that obtained under the first irrigation applied alone. The effect of supplemental irrigation, observed on rainfed olive, is considered spectacular. This observation was related to drought conditions that have characterized two years of the experiment, under which effect magnitude of supplemental irrigation proved more pronounced.

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