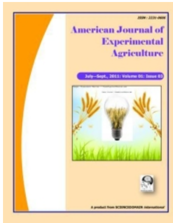

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Optimal Time of Supplemental Irrigation during Fruit Development of Rainfed Olive Tree (*Olea europaea,* cv. *Picholine marocaine*) in Morocco

Rachid Razouk[1,2*], Jamal Ibijbijen[2] and Abdellah Kajji[1]

[1]Regional Agricultural Research Center, P.O. Box 578, Meknès, Morocco.
[2]Department of Biology, Moulay Ismail University, P.O. Box 4010, Meknès, Morocco.

Authors' contributions

This work was carried out in collaboration between all authors. Author RR designed the study, performed the experiment and statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors JI and AK supervised the study and managed the literature searches. All authors read and approved the final manuscript.

Research Article

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ABSTRACT

Aims: This work was carried out to identify the optimal time of supplemental irrigation on a traditional rainfed olive orchard.
Study Design: Randomized complete block design with three replications where the variable factor was water regime.
Place and Duration of Study: Experimental station AinTaoujdate, Regional Agricultural Research Center, 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 control (T_d). Treatments were applied to thirty years old olive trees (cv. *Picholine Marocaine*) planted at a distance of 8x6 m, at experimental field of Regional Agricultural Research Center of Meknes 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 m^3/tree).
Results and Discussion: Fruit weight and shoot length were more affected by treatment T_a as compared to the rainfed regime, and hence fruit and oil yields were increased, in average, respectively by 43% and 37%. Water use efficiency for this treatment was 23

**Corresponding author: Email: razouk01@yahoo.fr;*

$kg.m^{-3}.tree^{-1}$. Treatments T_b and T_c improved only oil content and shoot growth without significant changes in yield. However, their combination with T_a (T_{abc}) increased fruit yield by an average of 106%. The effect observed under the tested irrigations was related to the importance of fruit growth kinetics during water application.

Conclusion: The production gain of supplemental irrigation, applied particularly during the first period of fruit development, is promising to promote this technique on several rainfed olive orchards.

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

1. INTRODUCTION

Olive is one of the pillars of crop production systems in the Mediterranean agriculture [1,2]. In Morocco, olive area is 790 000 ha from which 60% are planted in rainfed areas without any irrigation [3]. The importance 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]. The area of olive crop in Morocco is continuously increasing thanks to state strategy implemented since 1996 that targets the expansion of planted area to 1.22 million hectares by 2020, mostly in rainfed agro-systems [7]. Despite the importance given to the olive growing by the policy markers, the productivity of this crop remains very low and fluctuant because of drought and yield-alternation phenomenon [8] especially in rainfed orchards where fruit yield does not exceed 3t/ha [9], ensured by the low soil water reserves coming from autumn and winter rainfall and summer storms [10].

Rainfall deficit in Morocco is mostly observed for a long period from June to September [11,12] and this coincides with fruit growth and first wave of vegetative growth [13]. Therefore, rational management of available water for olive sector is imposed and application and optimization of irrigation water, whenever possible, is a promising option for increasing and sustaining olive yield and quality and water productivity.

Olive response to irrigation is obvious, especially during the period of intense growth and development that extends from floral differentiation to harvest [14] occurring from April to November under the 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 to mitigate yields alternation phenomenon [18,19]. Irrigations in spring and summer improve significantly fruit growth kinetics even during stone hardening period where fruit growth is usually slowed [20] and consequently allows fruit yield increase [21]. Shoots vigor is also higher under irrigation and this provides more support to fruiting in subsequent years [22]. However, fruit oil content is assumed to be less under irrigation [23], but this decrease is often offset by fruit-weight improvement ensuring an increase of oil yield [24].

In the 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 water resources such as rivers or wells even with low water flows. 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 the olive groves located on rivers edges or containing wells, water pumping systems are to anticipate. The irrigation of orchards located far from water resources require hydro-agricultural investments that have to be deducted from production gains. Therefore, to minimize the costs of these investments and increase the economic water productivity and production gains of the crop, it is essential to determine the optimal periods of irrigation water application. Within this context, this study is carried out to evaluate the effects of seven types of supplemental irrigation regimes applied during different periods of fruit growth on adult olive orchard normally grown under rainfed conditions without any irrigation supply.

2. MATERIALS AND METHODS

2.1 Experimental Site and Crop Management

The experiment was carried out during two consecutive seasons (2009-2010) in the AinTaoujdate experimental station of the National Agricultural Research Institute (INRA), located at 40 km North of Meknes city (33º 56' E, 5º 13' N; 500 m) in the North center of Morocco. Meteorological data, collected from the experimental field station, during the two years of study are presented in Fig. 1 where it is shown that there was insufficient rainfall between May and September, imposing a supplemental irrigation of 25 to 40 mm/month to satisfy water requirements of olive tree under local climatic conditions. The soil, in this site, is silty clay with an average of 3.04 % $CaCO_3$ and 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).

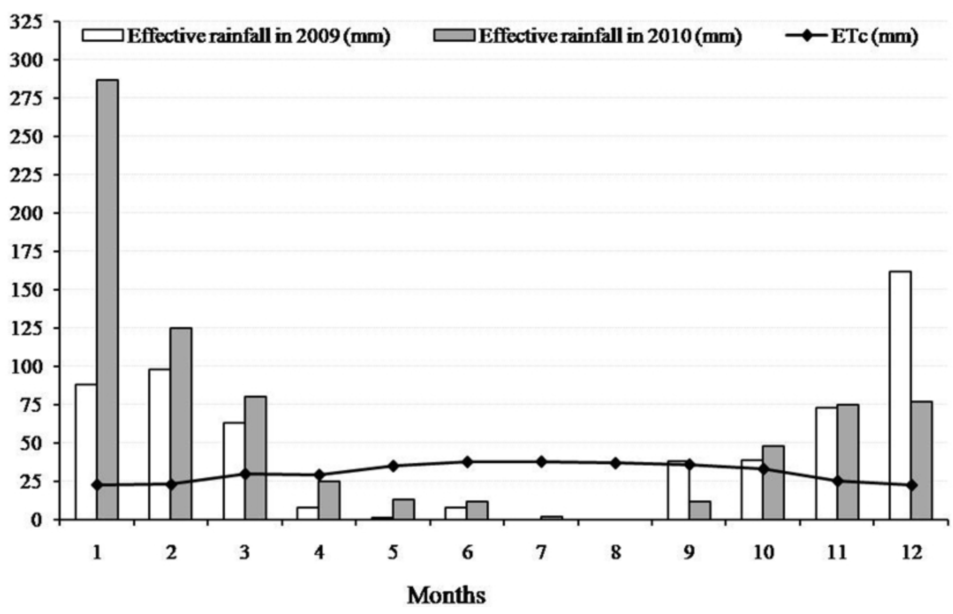

Fig. 1. Effective rainfall (80% of rainfall) and average of olive water requirements (ETc) obtained from the Hargreaves model, during 2009 and 2010, in experimental field.

Plant material used was the cultivar *PicholineMarocaine*, planted and grown in rainfed conditions since its planting in 1981 at a density of 208 trees/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 during four consecutive years, from 2007 to 2010. Indeed, supplemental irrigation was tested during different stages of fruit growth (Fig. 2). 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 2 m 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, the irrigation amount for each watering was 0.5 m^3 per tree, equivalent to 104 m^3/ha.

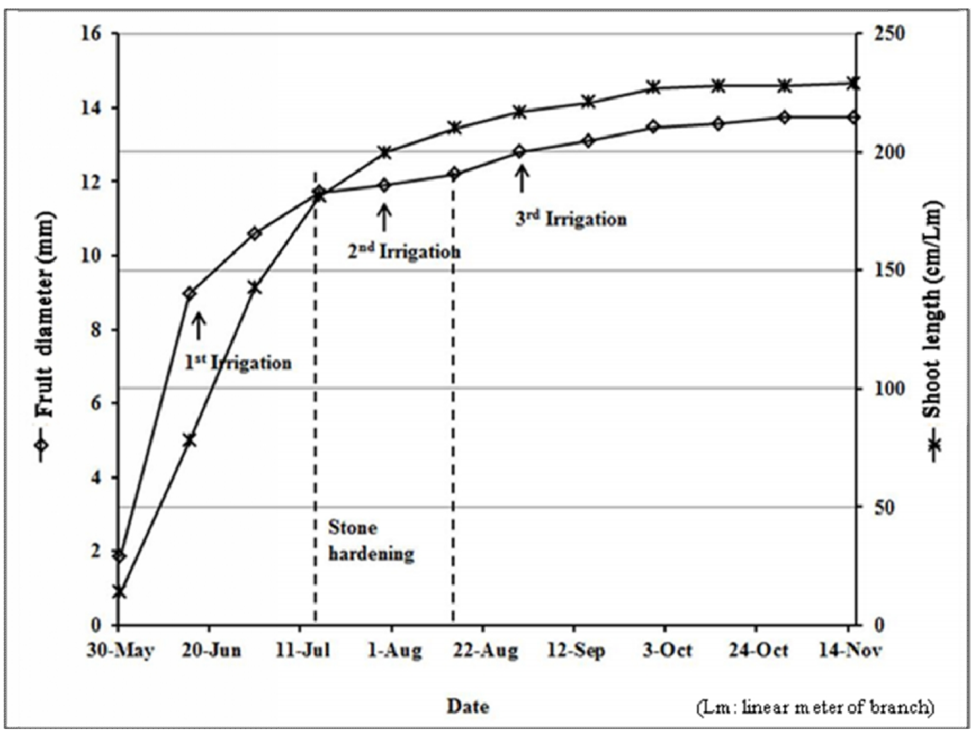

Fig. 2. Growth kinetics of fruit diameter and shoot length of olive in experimental field under rainfed regime (average of two years: 2009 and 2010) and localization of irrigation periods

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 of which was composed of eight elementary plots (treatments). Each plot contained three olive trees surrounded by untreated trees.

The measurements were related to vegetative growth and fruit yield. Vegetative growth was observed every week throughout the season by measurement of length of all the shoots (primary and secondary) growing on eighteen fruiting 2-years-old branches having similar lengths per treatment (six branches 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 divided by transversal section of the principal branches (TSPB) 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. This method of fruits sampling has been based on the fact that each fruiting branch contains all sizes of fruits existing on the tree. Completely black olives of the samples were used for determination of fruit oil content in dry matter using nuclear magnetic resonance analyzer type oxford 4000.

3. RESULTS AND DISCUSSION

3.1 Vegetative Growth

Irrigation had an immediate effect on vegetative growth of rainfed olive, with avarying degree depending on time of application. Shoot growth was highly influenced by the first irrigation (T_a), applied just after the early 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%, compared to the rainfed regime T_d (Fig. 3). The irrigations T_b and $T_c$increased shoot length respectively by 26 and 15%. 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 (Fig. 2).

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].

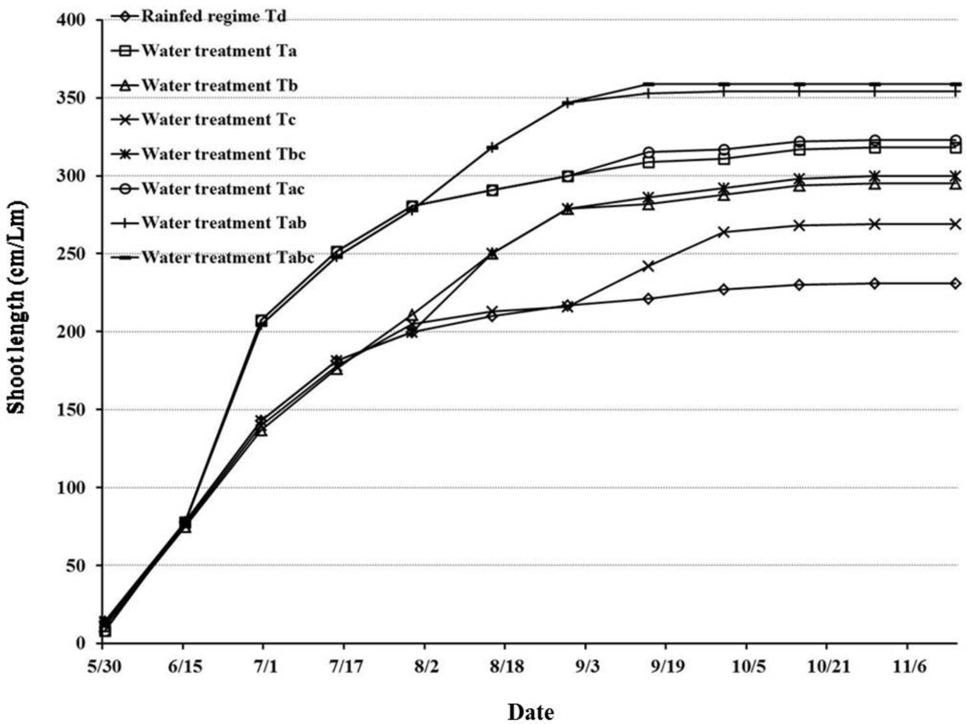

Fig. 3. Olive shoots growth under different supplemental irrigations (average of two years: 2009 and 2010)

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 (Fig. 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.

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 the transversal section of the principal branches (TSPB) in evaluation of water treatments allowed eliminating vigor effect. Variance analysis of yield, per unit of TSPB, 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 1). Under this treatment, average of yield increase was 43% for fruits and 38% for oil in comparison with rainfed treatment T_d, based on values of yield per unit of TSPB. This result is in agreement with those of several authors [37] who observed that olive production decrease significantly under water stress applied during the first period of fruit development.

Table1.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} TSPB^{-1}	ml cm^{-2} TSPB^{-1}	kg m^{-3} tree^{-1}	kg tree^{-1}	g cm^{-2} TSPB^{-1}	ml cm^{-2}TSPB^{-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	-

The values followed by the same letters are significantly equals.
TSPB: transversal section of the principal branches of tree.
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, per unit of TSPB, by an average of 106 % and of oil yield by 96 %, in comparison with 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 [38] 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 (Fig. 4).

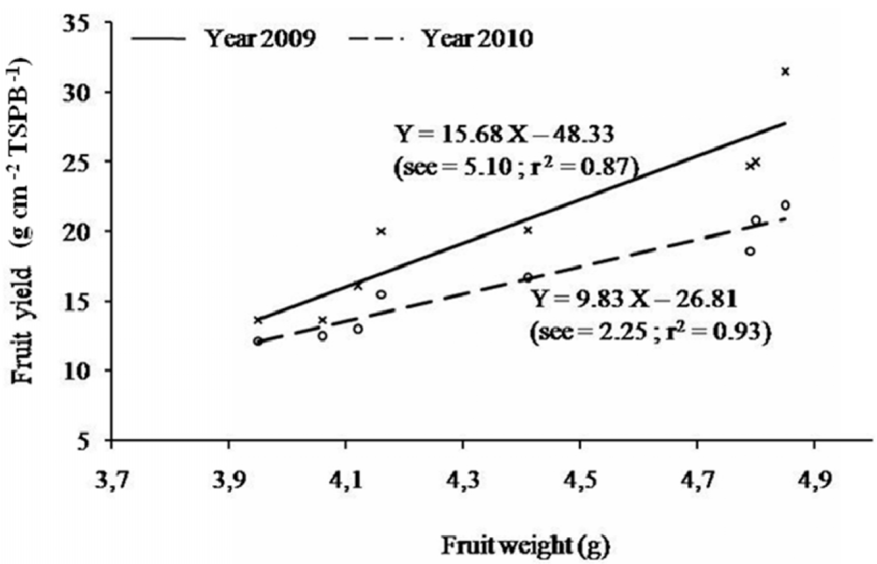

Fig. 4. Relationship between fruit weight and fruit yield per unit of transversal section of the principal branches of olive tree (all treatments combined)

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 [39, 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 23kg.m^{-3}.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 2).

Table 2.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

Values followed by the same letters are significantly equals
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 [40] whose number is previously determined at the end of the first rapid stage of fruit growth [41].The irrigation applied during stone hardening stage (T_b) had the lowest effect, increased fruit weight by 3%.

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 Wahbiet al. [42] 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 2), 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 coincides 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.

4. CONCLUSION

The olive tree is a plant traditionally grown under rainfed conditions. The application of supplemental irrigation on adult olive orchards is a promising technique to improve olive production in several Mediterranean regions.

The experiments conducted over two years show the benefits of a major supplemental irrigation (about 70% of the water reserve in the soil) during the early phase of fruit growth in the climatic conditions of Morocco. This irrigation improves vegetative growth and increases yield without significant loss of olive oil content with a good efficiency of water use. Late irrigation does not compensate for a lack of irrigation during the critical early phase of fruit growth and may even have a negative effect on the oil content.

According to these results, we recommend to undertake at least one major irrigation during the early phase of fruit growth (June) in orchards that are mainly rainfed. This irrigation may be supplemented by a second irrigation during stone hardening stage (end of July).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sofo A, Manfreda S, Fiorentino M, Dichio B, Xiloyannis C. The olive tree: a paradigm for drought tolerance in Mediterranean climates. Hydrology and Earth System Sciences. 2008;12:293-01.
2. Artemios M, Bosabalidis M, Kofidis G. Comparative effects of drought stress on leaf anatomy of two olive cultivars. Plant Science. 2002;163:375-79.
3. Anonymous. Les aides financières de l'état pour l'encouragement des investissements agricoles. Rabat, Morocco: Ministry of Agriculture and Maritime Fisheries. 2011. French.
4. Connor DJ. Adaptation of olive (*Oleaeuropaea L.*) to water-limited environments. Australian Journal of Agricultural Research. 2005;56:1181–89.

5. Lavini A, d'Andria R, Patumi M, Morelli G, Tognetti R, Sebastiani L. Water management of olive trees (*OleaeuropaeaL.*) in hilly environment of central-south Italy. Options méditerranéennes. 2008;84:169-76.
6. d'Andria R, Lavini A. Irrigation. In: Sbitri MO, Serafini F, editors. Techniques de production en oléiculture. 1st ed. Madrid, Spain: International Olive Council; 2007. French.
7. Anonymous. Situation de l'agriculture marocaine. Rabat, Morocco: Ministry of Agriculture and Maritime Fisheries; 2011.French.
8. Mahhou A, Taiebi Z, Hadiddou A, Oukabli A, Mamouni A. Performance et qualité de production des variétés d'olivier (cvs. *Arbéquine*, *Koroneiki* et *Picholine marocaine*) conduites en irrigué dans la région de Settat (Maroc). Olivae. 2011;116:44-59. French.
9. Oukabli A, Mamouni A, Badraoui M. Diagnostic de la conduite technique du verger oléicole dans les périmètres du projet Millenium Challenge Corporation et propositions d'amélioration. Rabat, Morocco: National Agricultural Research Institute; 2011. French.
10. Agoumi A. Vulnérabilité des pays du Maghreb face aux changements climatiques. Manitoba, Canada: International Institute for Sustainable Development. French; 2003.
11. Bamouh A. Gestion de la contrainte pluviométrique pour l'amélioration de la production végétale et de l'efficience d'utilisation de l'eau. Bulletin Mensuel de Liaison du Programme National de Transfert de Technologie en Agriculture. 1998;50:1-4. French.
12. Benassi M. Drought and climate change in Morocco: Analysis of precipitation field and water supply. Options méditerranéennes. 2008;80:83-87.
13. Tombesi S, Tombesi A. Conception et installation de l'oliveraie. In Sbitri M.O, Serafini F, editors. Techniques de production en oléiculture. Madrid, Spain: International Olive Council; 2007. French.
14. Inglese P, Gullo G, Pace L.S, Ronzello G. Fruit growth, oil accumulation and ripening of the olive cultivar '*carolea'* in relation to fruit density. Acta Horticulturae. 1999;474:265-68.
15. Hadiddou A, Bencheqroun KO, Mekaoui A. Performances des obtentions d'olivier et des variétés étrangères sous les conditions pluviales. In: Anonymous, editor. Recueil des communications du séminaire: la recherche agronomique et al profession, ensemble pour un développement durable de l'oléiculture nationale. Rabat, Morocco: National Agricultural Research Institute; 2006. French.
16. Crous J. Efficient olive harvesting. South Africa: University of Stellenbosch; 2009.
17. Cuevas J, Pinney K, Polito VS. Flower differentiation, pistil development and pistil abortion in olive (*Oleaeuropaea* L. *manzanillo*). Acta Horticulturae. 1999;474:293-96.
18. Michelakis N, Vouyoucalou E, Clapaki G. Plant growth and yield response of the olive tree cv. *kalamon*, to different levels of soil water potential and methods of irrigation. Acta Horticulturae. 1994;356:205-09.
19. Pastor M, Castro J, Mariscal M.J, Vega V, Orgaz F, Fereres E, Hidalgo J. Respuesta del olivartradicional a diferentes estrategias y dosis de agua de riego, Investigación Agraria. 1999;14:393-04. Spanish.
20. Manrique T, Rapoport H.F, Castro J, Pastor M. Mesocarp cell division and expansion in the growth of olive fruits. Acta Horticulturae. 1999;474:301-04.
21. Moriana A, Orgaz F. Yield response of a mature olive orchard to water deficits. Journal of the American Society for Horticultural Science. 2003;128:425-31.
22. Tognetti R, d'Andria R, Lavinib A, Morellib G. The effect of deficit irrigation on crop yield and vegetative development of *Oleaeuropaea L.* (cvs. *Frantoio* and *Leccino*). European Journal of Agronomy. 2006;25:356–64.

23. Wahbi S, Aganchich B, El Antari A, Tahi H, Wakrim R, Serraj R. Fruit and oil quality of mature olive trees under partial rootzone drying in field conditions. Grasas y Aceites. 2006;59:225-33.
24. Serraj R, Wahbi S, Wakrim R, Aganchich B, Tahi H. Effects of partial rootzone drying (PRD) on adult olive tree (*Oleaeuropaea L*) in field conditions under arid climate: Physiological and agronomic responses. Agriculture, Ecosystems and Environment. 2005;106:289–01.
25. Cortés SF, Calvo MJ, Badenes ML, Bleiholder H, Hack H, Lacer U, Meier G. Phenological growth stages of olive trees (*Oleaeuropaea L*). Annals of Applied Biology. 2002;140:151–57.
26. Berrichi M. Oléiculture marocaine: orientations et perspectives d'avenir. Revue Hommes, Terre et Eaux. 2002;122;32-37. French.
27. Boulouha M. Les acquis de la recherche agronomique en matière d'amélioration variétale de l'olivier au Maroc. In: Anonymous, editor. Recueil des communications du séminaire: la recherche agronomique et la profession, ensemble pour un développement durable de l'oléiculture nationale. Rabat, Morocco: National Agricultural Research Institute; 2006. French.
28. Girona J, Marsal J, Alegre S, Mata M, Arbonés A. Olive tree responses to water deficit of different severity during peak evaporative demand. In: Anonymous, editor. Biosensors for tree irrigation. Madrid, Spain: Research Institute for Food Technology; 2000.
29. Pérez D, Ribas F, Olmedilla JN. Influence of irrigation on a traditional rainfed olive orchard (cv. *Cornicabra*). Options méditerranéennes. 2004;60:85-89.
30. Mahhou A, Dejong TM, Cao T, Shackel K.S. Water stress and crop load effects on vegetative and fruit growth of *'ElegantLady'* peach trees (*Prunuspersica L.*). Fruits. 2005;60:55-68.
31. Granier C, Inzé D, Tardieu F. Spatial distribution cell division rate can be deduced from that of P34 kinase activity in maize leaves grown in contrasting conditions of temperature and water status. Plant Physiology.2000;124:1393-1402.
32. Coscrove DJ. Growth of the cell wall. Molecular Cell Biology. 2005;6:850-61.
33. Bouchabke O, Tardieu F, Simounno T. Leaf growth and turgor in growing cells of maize (*Zea mays L*) respond to evaporative demand in well-watered but not in water saturated soil. Plant, Cell and Environment. 2006;29:1138-48.
34. Tardieu F, Cruiziat P, Durand J.L, Triboi E, Zivy M. Perception de la sécheresse par la plante, conséquences sur la productivité et sur la qualité des produits récoltés. In: Anonymous, editor. Sécheresseet Agriculture. Paris, France: National Agricultural Research Institute; 2006. French.
35. Mezghani M, Aïachia S.A, Jebari A. Analyse et modélisation de la croissance végétative chez l'olivier (*Oleaeuropaea L.*) en conditions pluviales. Fruits. 2007;62:45-56. French.
36. Michelakis N, Vouyoucalou E, Clapaki G. Plant growth and yield response of the olive tree *cv. Kalamon*, to different levels of soil water potential and methods of irrigation. ActaHorticulturae. 1994;356:205-09.
37. Goldhamer DA, Dunai J, Ferguson LF. Irrigation requirements of olive trees and response to sustained deficit irrigation. Acta Horticulturae. 1994;356:172-75.
38. Moriana A, Orgaz F, Yield response of mature olive orchard to water deficit. Journal of the American Society for Horticultural Science. 2003;128:425-31.
39. Eunice AB, Pereira JMM, Gonçalves BC, Fereirra HF, Correia CM. Changes in growth, gas exchange, xylem hydraulic properties and water use efficiency of three olive cultivars under contrasting water availability regimes. Environmental and Experimental Botany. 2006;60:183–92.

40. Breton C, Souyris I, Villemur P, Berville A. Oil accumulation kinetic along ripening in four olive cultivars varying for fruit size. Oléagineux Corps gras Lipides. 2009;16:58-64.
41. Inglese P, Gullo G, Pace L.S, Ronzello G. Fruit growth, oil accumulation and ripening of the olive cultivar '*carolea'* in relation to fruit density. Acta Horticulturae. 1999;474:265-68.
42. Wahbi S, Aganchich B, El Antari A, Tahi H, Wakrim R, Serraj R. Fruit and oil quality of mature olive trees under partial rootzone drying in field conditions. Grasas Y Aceites. 2008;59(3):225-33.
43. Grattan SR, Berenguer MJ, Connell JH, Polito VS, Vossen PM. Olive oil production as influenced by different quantities of applied water. Agricultural Water Management. 2006;85:133-40.
44. Gianfranco M. Huile: variétés et technologies influencent la qualité. Olivae. 1989;29:28-30. French.
45. Mazliak P. Le métabolisme des lipides dans les plantes supérieurs. 1st ed. Paris, France : Masson and Cie; 1968. French.
46. Hartmann HT. Growth of the olive fruit. Proceeding of the American Society for Horticultural Science. 1949;54:86–94.

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