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Olive tree growth dynamics under semi-arid conditions of AlHaouz region in Morocco

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Abstract
The growth dynamics of olive-tree branch and fruit was investigated. This paper concerned the growth in length of the branch, the extension, the rate and the rhythm of appearance of leaves on its apex; we also investigated the growth of the olive fruit in terms of weight, dry matter and volume. The objective was to simulate the growth dynamics by characterizing the olive tree functioning under climatic conditions of AlHaouz region (Marrakech, Morocco). The obtained results showed that the growth of the branch, the rate and the rhythm of appearance of the leaves vary in a quasi linear way with time. The average observed rate of linear growth of the branch was 0.3 cm/d and the development of the leaves on the apex was approximately made with a plastochron of 5 to 6 days. The period of growth coincides with that of the appearance of the leaves on the apex and lasts 110 days. Measurements of the leaves surface S and dimensions (maximum width, W and length, L) carried out on 70 leaves (with variable sizes), made it possible to obtain the adjustment of an equation like Montgomery's one that was on the form $S=0.71\times W\times L$ ($R^2=0.98$). We also adjusted a relation between the volume of the fruit and its dimensions. The growth in weight or volume of the fruit and the accumulation of its dry matter vary in a linear way in two phases (fast phase which lasts 80 days followed by a relatively slow phase which lasts 120 days). This break in the growth dynamics of the fruit can be due to the high thermal gradients which undergoes by olive trees during July and August. Regarding the olive fruit, our observations show that during all the growth season, its content of dry matter and its density remain constant (34% for the dry matter and 1.05 g/cm^3 for the density).

Keywords: Olive tree, growth dynamics, leaf size, olive fruit, semi-arid climate

1. Introduction
The olive tree is a tree traditionally rooted in the Mediterranean basin (more than 98% of the world reserves). The surface that it occupies continues to grow around the world. The olive tree can grow in the range of latitudes between 30° to 40° North and South except at high altitudes. It grows on various soils, including shallow and poor soils except if they are compact. However, olive trees prefer non-stratified, moderately fine textured soils. Such soils provide aeration for root growth, are moderately permeable and have a high water holding capacity [1].
In Morocco, the olive tree cultivation covers an area of 900,000 Ha [2], it is the main source of our table olives and edible oil needs. Despite the potentials that benefit our country on the subject of olive trees culture (climate, soil and abundant workforce), the production of olives and olive oil is still very insufficient and does not yet meet the needs of the internal market. The annual average of national olive oil production reached about 140 000 t/year in 2009/2010 season [2].
We note that the demand on olive products increases linearly according to the population growth that knows Morocco. This culture occupies an important place in national arboriculture heritage. However, there is a big difference between potential and actual productions, and strong fluctuations of the latter are highly detrimental to the country's economy. Among the explanatory factors of this difference, the constraint climate appears in

first order, and then come technical and socio-economic constraints. The climate constraint is more pronounced in the South of Morocco where the drought has become more and more frequent (rainfall < 240 mm/yr) [3].
In the semi arid climate of the South of Morocco and mainly in the AlHaouz region, maintaining this tree requires a good knowledge of the various interactions taking place between the plant and the climatic, edaphic and cultivation conditions during its growth and development. In this region the soils are light, deep and exhibit high hydraulic conductivity. Another point of weakness of olive culture in Morocco is the dominance of one cultivar 'Moroccan Picholine" (more than 96%) with low planting densities. This variety is used for two purposes: oil and table olive production, but it is known to be susceptible to diseases. These conditions explain partly the low yields obtained in this region.
In this context, it appears absolutely necessary to develop tools to better manage these constraints and make the best use of water irrigation ensuring a level of an acceptable performance. In addition to the technical solutions (new varieties, modernization of processing units, etc.), the emphasis may be placed on the use of so-called complete models, which are developed within the scientific community. These new tools of simulation allow – on the one hand – studying the behavior of systems grown under various constraints, and on the other hand getting a synthetic vision at the regional level. Thus, in this work we aim to take stock of the state of growth of this tree under the usually practiced conditions. Therefore, we determined the growth rates of the various organs of the olive tree (leaf, stem and fruit). First of all we studied the appearance and the growth of leaves then we studied the growth of branch then the fruit. This is the method used to study the growth and the development of plants [3]. Indeed, the leaves are the organs responsible of plant growth while branch are the organs that will carry the fruit. Two companions of measures both in the laboratory (destructive measures) and in the field under natural conditions (non-destructive measures) were undertaken during two successive seasons (2005 and 2006).
This work is part of a broader goal to set up the olive tree in the STICS (multidisciplinary simulator for standard crops) model. Indeed, the STICS model is a model of cultures functioning designed as a tool of operational simulation under agricultural conditions. It was developed at the Avignon INRA in France [4]. This model is said to be of a generic character which means that is adaptable to many crops (cereals and trees) [5], an asset which will allow us to easily insert the olive tree.
Indeed, the stages of development of the olive tree are currently sufficiently known [6, 7]. Moreover, the accumulation of data on growth, development and measurement of leaf surface, as well as the collected literature will allow us to better parameterize this culture.

2. Materials and methods

2.1. Climate data for two successive seasons

During the two seasons of observations (2005 and 2006), a classic station was installed near the city of Marrakech. Data were recorded at a half hour time step and were stored on acquisition servers, before being downloaded and brought back to laboratory for process and analyze. Information on the instrumentation of the meteorological station is mentioned in Table 1.

Table 1. Instruments used for measuring weather conditions (SudMed Project 2002/04)

Parameter	Sensor
Air temperature	Thermistance HMP45C
Global solar radiation	Radiometer CNR1, Kipp&Zonen
Air humidity	Hygrometer HMP45C
Wind speed and direction	Anemometer A100R
Precipitation	Pluviometer FSS500

2.2. Experimental measurements

Among more than 100 olive trees (Moroccan Picholine variety) grown in the green space of our institution and irrigated using Gravity Flow Irrigation System according to a traditional protocol, 12 trees of different ages were chosen for this study on which we conducted the following non-destructive observations:
- Monitoring the growth of shoots in length (taken at random from each tree twig), 12 branches in total;
- Counting the number of leaves developed on the twig (all youth and adult leaves);

- Monitoring growth of the leaves of the shoot in extension by measuring their maximal length and width.

These measurements were performed periodically at a frequency of 8 to 20 days depending on the observed growing phenomenon.

Destructive measurements were also made in the laboratory to determine the relationship between the surface of a leaf to its dimensions (maximal length and width) and the growth in weight and volume of the fruit. Therefore, we collected 70 leaves of different ages upon which we measured maximal length and width. The surface of these leaves was determined by planimetry on computer using the 'ImageJ' software [8]. Concerning the monitoring of olive fruit growth, ten fruits were harvested periodically every 10 or 15 days since their juvenile age until the harvest period. The length and width of each fruit were then measured and the weight was taken on fresh and dried fruits. Drying is carried out, after crash, in a ventilated oven at 70°C for 6 days. For 20 fruits, we conducted direct measurement of the volume in a graduated tube. These measures were used to determine the relationship between the fruit volume and its dimensions.

3. Results and Discussion

3.1. Climatic conditions of the study region

Climatic data recorded during the two seasons were not very different. Table 2 summarizes the set of these variables for the year 2006 and Figures 1 and 2 show a comparison of the evolution of daily maximum and minimum temperatures during the two seasons.

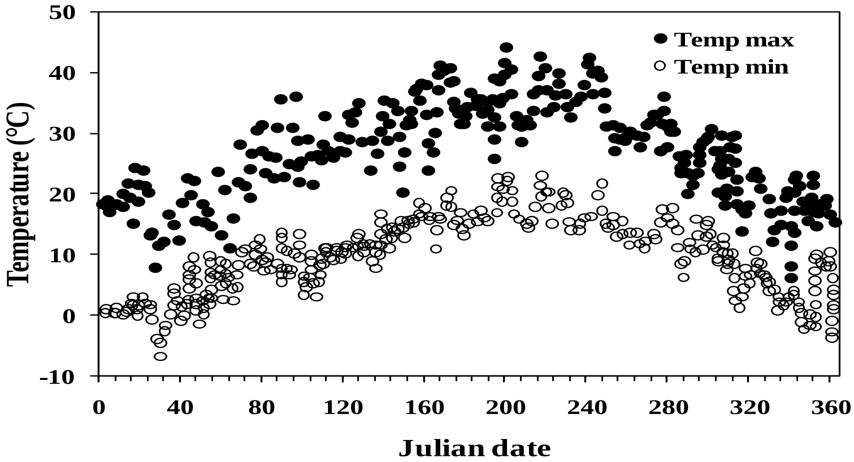

Figure1. Change of the daily maximum and minimum temperatures as function of the Julian date of the year 2006.

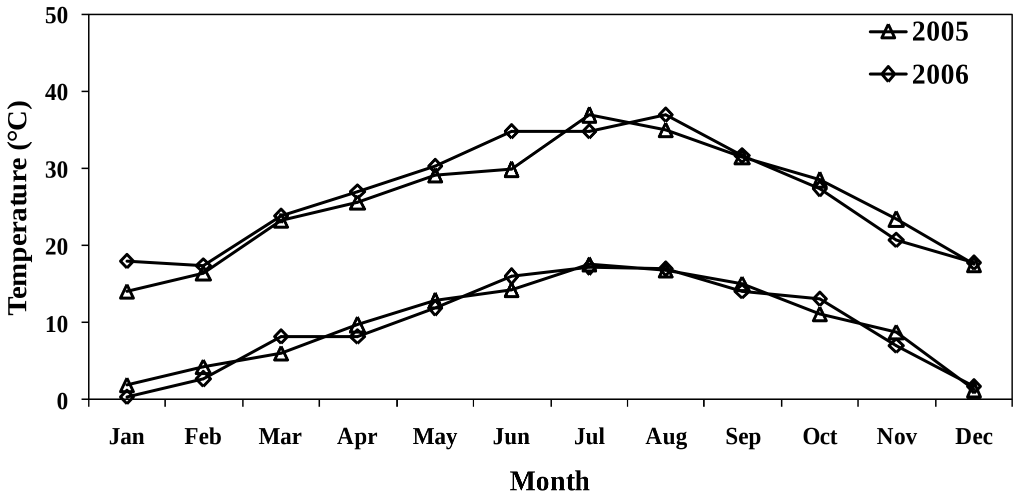

Figure2. Change of the monthly average of maximum and minimum temperatures, Δ represent the data of the season 2005 and ◊ for the data of the season 2006.

During the tree growth season (March-May) and during the two seasons of observations, the temperature known quite high maximal values. During the month of May, the average was 30°C/d. The minimal values were going up to 6°C/day during the month of March (Table 2 and Figure 1).
The comparison between temperature evolution curves on the Figure 2 shows that the values of maximal and minimal temperatures in the two seasons were not very different. In addition, these temperatures were more or less similar to that of the average climate of the region. Cumulative rainfall was low and has been in the order of 220 mm for full-year 2005 and 306 mm for the year 2006.

Table2. Monthly average of climatic variables in Al Haouz region (data recorded during 2006 season)

Month	Relative humidity (%)	Solar radiation (MJ/m²)	Wind speed (m/s)	Precipitation (mm)	T_{max} (°C)	T_{min} (°C)
January	80.5	9.8	0.8	113.4	14.7	2.2
February	78.0	11.3	1.0	36.0	16.9	4.6
March	64.0	19.5	1.1	10.6	23.7	6.3
April	59.8	22.0	1.2	41.0	26.0	1.2
May	57.5	24.9	1.1	5.4	29.9	13.4
June	59.1	24.4	1.2	3.0	30.5	14.9
July	48.5	25.1	1.1	5.2	37.3	18.0
August	55.2	24.7	1.1	0.2	35.2	17.1
September	54.5	19.9	1.1	0.4	32.1	15.3
October	63.4	17.2	0.9	30.6	28.8	11.8
November	70.3	12.6	0.7	37.0	23.8	9.1
December	71.1	12.7	0.8	23.6	18.1	1.8

Average temperatures were so low at the beginning of season (6°C in January, 10°C in February and 15°C in March) and the maximal temperatures were very high during the summer (exceeding often 35°C, Figure 1).
Knowing that low temperatures (close to zero) and high temperatures (above 34°C) cause significant damage on the bloom and according to the changes in temperatures, in some days, thermal stress could affect strongly the growth and the flowering.

3.2. Relationship between leaf surface and its dimensions

As cultivation of olive expands outside of the traditional Mediterranean Basin, increased understanding of how the crop responds to environmental conditions is necessary. This greater understanding should prove useful for the prediction of possible changes in olive yield and quality under expected future scenarios of global warming and to explain variations in fruit and oil quality across regions.
The surfaces of plant organs are the main interfaces of plant–environment interactions, and leaf shape and surface thus constitutes a critical feature of a plant. It can be modified by growth conditions and according to ontogenetic stages. Leaf shape and surface has been widely investigated in cereals and different mathematical functions have been proposed for their description [9].
Measures of the surface S and the leaf dimensions (its maximum width, W, and its length, L) provided by adjusting a relation of Montgomery type [10] in the form of $S = 0.71 \times W \times L$ (Figure 3). The value 0.71 was obtained on a series of 70 leaves of varying sizes with a coefficient of determination of $R^2 = 0.96$.
It should be noted that in the case of leaf blades of maize, wheat leaves and fig rackets, the adjustment values are 0.75, 0.87 and 0.72, respectively [3,11]. This relationship is appropriate for leaves of pseudo-rectangular forms. The multiplicative factor which makes the necessary correction was found to be between 0.5 for the diamond shape and 1 for rectangular form [12].

3.3. Dynamics of branch growth

The dynamics of a branch is represented in this work by its growth in length and the rate of leaves appearance on its apex. Figure 4 shows that the observed changes are of sigmoidal type with 3 phases of growth [13]:

- A first phase where the growth is slow, usually known as exponential phase, this phase is short;
- in the course of the 2nd phase, the growth is almost linear, this is the main phase because it takes almost all of the growth period;
- During the third phase, growth is slowed down until zero (growth is stopped).

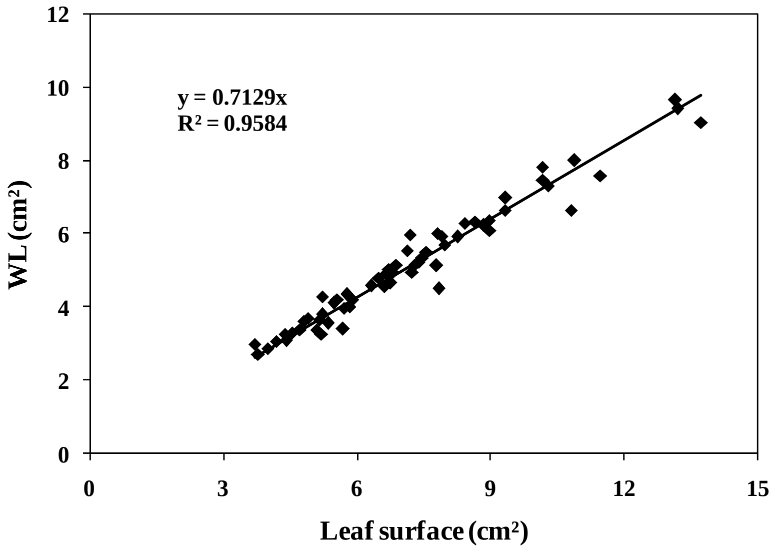

Figure3. Linear regression between olive leaf surface and the product of its dimensions (W, width and L, length).

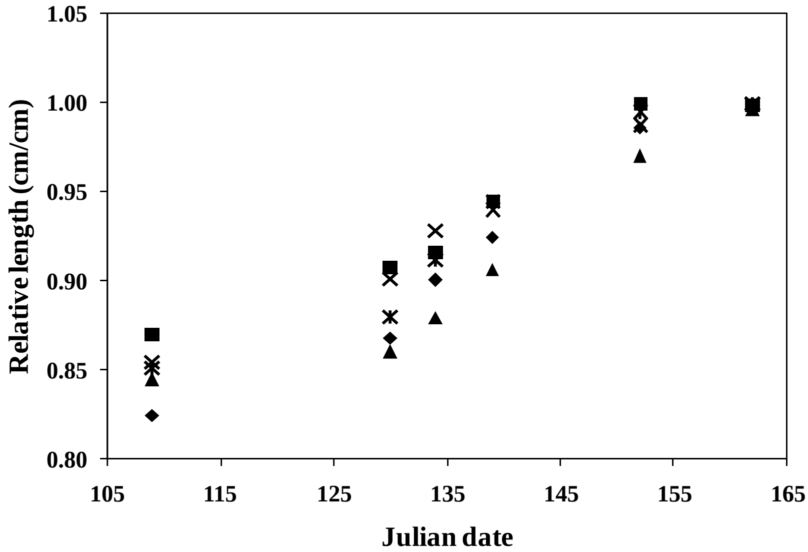

Figure4. Evolution of the relative length of 5 olive branches from different trees growing under the climatic conditions of AlHaouz region; data collected during the season 2005.

Linear growth of each of these processes has been adjusted by a straight regression line which have correlation coefficients higher than 0.93 in each case (Tables 3 and 4).
In olive tree, the linear growth of the branches and the leaves emergence starts at the same time. But the growth of the branches was rather early during the season 2006 (9th Julian day against 33rd Julian day for the season 2005). This observed delay during the season 2005 can be explained by the low temperatures observed during the months of January and February.
During the two seasons, rates of linear growth of the shoots were very variable from one branch to another. The average value is 0.3 ± 0.2 cm/d (centimeter in length per day) (Table 3, Figure 4). Similarly, the emergence of leaves at the apex was done with a variable plastochron; it was between 3 and 8 days (period between the emergences of two successive leave doublets) (Table 4). The period of leaves emergence at the apex lasts 110

days under the observed conditions. Furthermore, the leaf development lasts from 33 to 95 days depending on the initiation date (emergence) showing thus different growth rates (Table 4). Leaf surface largely determines light interception and transpiration of plants [14]. Its increase with time depends on environmental conditions, such as water deficit [15], temperature and evaporative demand [16]. Previous studies reported that the active growth occurs basically in April, July and September. However, important variations in growth dynamic were observed according to the year and variety. Temperature, pruning, water conditions, fruit load and the variety potentialities seem to be the driving factors controlling this growth [17].

Table3. Coefficients describing the linear regressions of the growth of 5 branches during the season 2005 and 4 branches during 2006

	Branch	Growth rate, a (cm/d)	Intercept, b (cm)	Coefficient of determination, R^2
Season 2005	B1	0.32	56.5	0.93
	B2	0.28	32.3	0.98
	B3	0.71	46	0.99
	B4	0.42	15	0.99
	B5	0.23	17.9	0.99
Season 2006	B6	0.05	20.1	0.99
	B7	0.14	5.9	0.98
	B8	0.44	4.3	0.98
	B9	0.11	9.1	0.97

3.4. Evolution of the leaf surface

The leaves on the olive tree branches grow by doublets. We found that the dimensions (and therefore the surfaces) of two leaves of a doublet are rarely equal. For this reason we have decided to follow the evolution of the surface of a doublet and not an isolated leaf. Figure 5 shows the evolution of the surface of four doublets. The curves of the figure show that the growth rate, the growth period and the surface depend on the stage of the tree.

Table4. Coefficients of the linear regressions of leaf emergence on 5 branches during the season 2005 and 4 branches during the season 2006 (1/a represents the duration in days separating the emergence of two successive leaves)

	Branch	Leaf emergence rate, a (leaf/d)	Intercept, b	Coefficient of determination, R^2	Plastochron, 1/a
Season 2005	B1	0.36	16.26	0.99	2.82
	B2	0.12	39.50	0.91	8.64
	B3	0.24	40.10	0.94	4.09
	B4	0.19	25.33	0.91	5.17
	B5	0.14	35.39	0.95	7.06
Season 2006	B6	0.12	16.41	0.99	8.06
	B7	0.18	9.01	0.96	5.61
	B8	0.27	6.39	0.99	3.74
	B9	0.17	10.84	0.96	5.78

The leaves at the end of the season have their growth speed reduced and develop a short surface. Table 5 summarizes the obtained results in this regard.

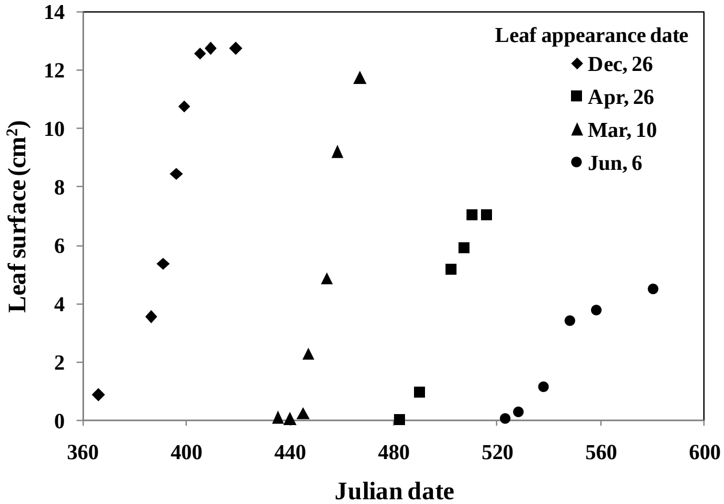

Figure 5. Evolution of the surface of the pair leaves appeared in different dates.

Table5. Surface and growth duration of olive tree leaves emerged at different dates

Leaf doublet	Emergence date	Growth duration (day)	Developed surface (cm^2)
(a)	December 26, 2004	95	12.647
(b)	March 10, 2005	28	7.058
(c)	April 26, 2005	33	11.577
(d)	June 6, 2005	67	4.563

3.5. Dynamics of fruit growth

*Relationship between the fruit size and its volume.*The olive fruit that we studied has a cylindrical shape. The estimation of its volume, V, was modeled by the equation:

$$V = kh\left(\frac{d}{2}\right)^2 \pi \quad (3)$$

where 'h' is the length of the fruit and 'd' its maximum diameter, π = 3.14 and 'k' being a shape factor between 0 and 1. This relationship has been adjusted on a series of 20 fruits of different sizes. Figure 6 shows the results of this adjustment. The value of the resulting shape coefficient is k = 0.68 (R^2 = 0.96).

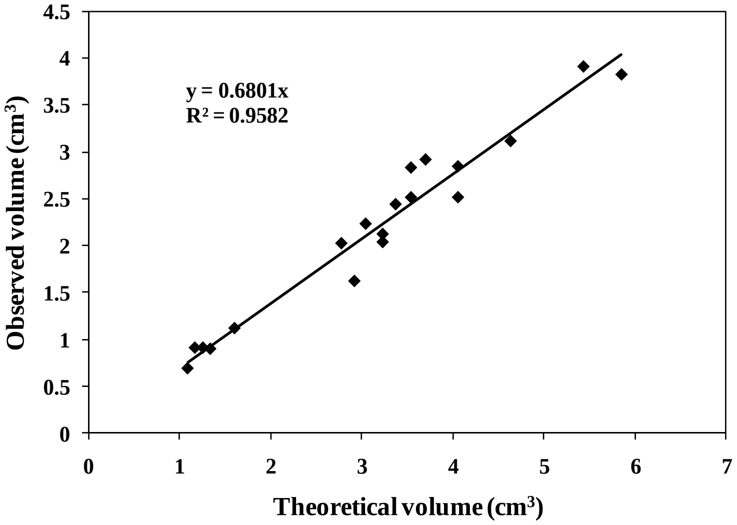

Figure 6. Relation between the observed volume of olive fruit and its calculated volume by supposing that its shape is cylindrical (theoretical volume = $\pi(d/2)^2h$), the data are those measured during the season 2005.

Evolution of water content and dry matter of the fruit.

The results obtained during two growth seasons on the evolution of the water content and dry matter of the fruit show that the fruit remains constant these two parameters throughout the growth cycle (Figure 7).

During the two seasons, the water content of the fruit was about 64.5% ± 2.4% for 2005 and 63.2% ± 3.0% for 2006. These two values are not significantly different and this may represent a constant of the studied olive variety in a given locality.

*Evolution of dry matter and growths in fresh weight and volume of the fruit.*Figure 8 shows that the growth of fresh weight over time is linear in two phases: an initial phase during which the growth is accelerated with a high rate 0.0387 g/day, and a second phase during which the growth is relatively slow with a rate of 0.022 g/day. The rapid growth of the fruit has begun, in both seasons, in the 124th day of the year (May the 4th) and she ended on the 19th day of July where the growth slowed until the end of the season. It should be noted that the growth of the fruit during the season 2005 was taken with one month late compared to the season 2006 where the measures have been frequent. It is possible that this rate of growth in dual regime could be related in a part to thermal stress which is accentuated during the two months of July and August. A similar behavior as shown in Figure 8 was obtained for the fruit growth in terms of volume and dry mater. Table 6 summarizes the different linearizations performed on these data.

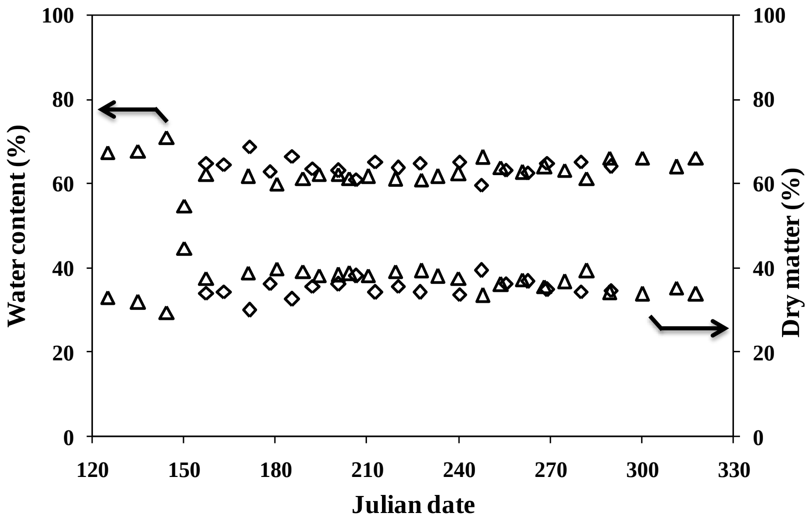

Figure 7. Evolution of the water content and the dry matter of the olive fruit against time as Julian date; Δ represent the data of the season 2005 and ◊ for the data of the season 2006.

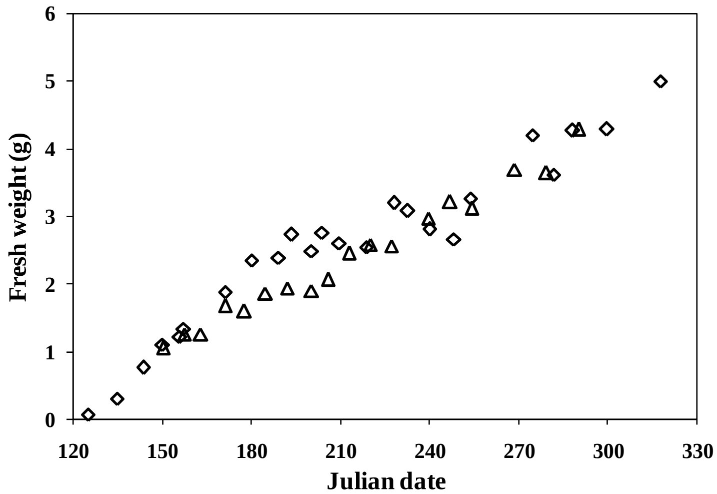

Figure8. Evolution of the fresh weight of the olive fruit as function of time in Julian date, Δ represent the data of the season 2005 and ◊ for the data of the season 2006

Table6. Coefficients of linear regressions of dry matter, fresh weight and volume of olive fruit during the two growth phases (Figure 8)

	1st growth phase			2nd growth phase		
Coefficient	A	b	R²	a	b	R²
Dry matter	0.0153	-1.914	0.96	0.0066	-0.433	0.73
Fresh weight	0.0360	-4.410	0.97	0.0200	-1.740	0.85
Fruit volume	0.0376	-4.680	0.99	0.0222	-2.300	0.80

We also noted that the average volume of the fruit expressed in cm^3 values were close to that obtained for fresh weight expressed in grams, which means that the mass density, ρ (g/cm^3), of the fruit is almost constant during growth (Figure 9). The average value obtained is $\rho = 1.05 \pm 0.05$ g/cm^3 for the fruits of the season 2005 and $\rho = 1.03 \pm 0.04$ g/cm^3 for the fruits of the season 2006.

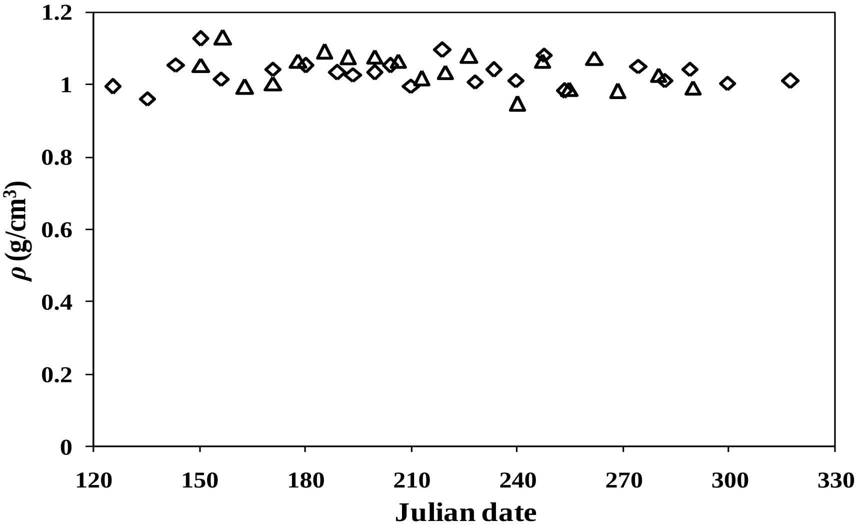

Figure9. Evolution of the density (ρ) of the olive fruit in function of Julian date, Δ represent the data of the season 2005 and ◊ for the data of the season 2006.

Proietti and Antognozzi [18] reported that the irrigation did not influence fruit shape, but increased fruit weight and volume. Larger fruit size was primarily the result of a larger number of cells and the positive effect of water availability on cell division rather than cell expansion [18]. The difference in weight was mostly because of the fruit water content. Evidently water stress, besides decreasing plant activity, causes a drop in fruit water content and fruit growth, which is only partially reversible after removing the stress. In a relatively recent study, Rapoport and Costagli [19] demonstrated that water deficit affects negatively the olive fruit morphogenesis and consequently reduces its weight and volume. The potential of fruit growth recovery after stress and the morphogenetic processes determining the final size of the olive fruit are not yet well understood [19].
Ezzahar et al. [20] reported that one of the criteria for assessing irrigation efficiency is that the ratio between crop water requirement and actual evapotranspiration (ET) should be as close to 1 as possible. Therefore, estimates of large scale ET is of great importance for improving irrigation management, which will favorably impact the sustainability of water management in semi-arid regions [20].

Conclusion

This work shows that the growth of olive tree branch and leaves can be assumed to be linear. Similarly for the rate of leaf emergence that occurs with a period of 5 to 6 days in average. The surface of a leaf and the volume of the fruit can be calculate using the following relationships $S=0.71\times W\times L$ ($R^2 = 0.98$) and $V = 0.68\ h(d/2)^2\pi$, respectively.
Concerning the phenomena linked to the fruit growth, we showed two linear phases (rapid phase which lasted 80 days followed by a relatively slow phase which lasted 120 days) while the fruit dry matter and density

remains constant throughout the growth cycle (34% for D.M. and 1.05 g/cm^3 for density). Growth dynamics of olive fruit, leaves and branches are directly affected by water and temperature conditions of the semi-arid climate. Adequate watering may also reduce the negative effects of temperatures exceeding 35°C in summer.

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