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Leaf area index and light distribution in olive tree canopies (*Olea europaea* L.)

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Key words: Olive tree, Vase form, LAI, Photosynthetically active radiation, ratio PAR_T/PAR_I.

Abstract

The leaf area index (LAI) and the spatial leaf arrangements are the main factors which influenced the radiant energy distribution within the tree. The leaf area index has been shown to be an important factor of the olive productivity. Although, the photosynthetically active radiation intercepted by leaves (PAR) is the main environmental factor that determined the dry matter production, which is the main source of energy for the photosynthesis. Therefore, a commercial sensor for LAI determination (Sun scan DELTA-T Devices Ltd), was tested for olive trees, in an olive orchard located near Sousse, central Tunisia (36N, 10E). The plants were cultivated at 7m × 7m and trained on vase system. Measurements were made at two tree's layers; on lower and upper part of the canopy and on the four cardinal directions (north, south, east and west). The results showed that the LAI was more important on the lower part of the canopy than on the upper one for all directions. LAI was also higher on South and East side of tree. The Incident Photosynthetically Active Radiation PAR_I, was quite constant for all directions. However, the transmitted fraction PAR_T decreased inside the tree canopy. The lower part of the canopy was less shaded for the vase tree form. There is a significant negative relationship between LAI and ratio PAR_T/PAR_I. These results will be the fundamental basis of the olive pruning basis and to establish new intensive olive orchards with fully developed canopies which intercepted the maximum solar radiation.

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Introduction

In all fruit orchards, the high productive planting must be pursued. Trees should express along the year high photosynthesis for using the principal assimilates on fruit production. All processes along the productive cycle must be optimised and completed without anomalies and disorders which compromise the yield and the life of planting (Tombesi, 2006). Leaves are the active interface of energy, carbon and water exchanges between tree canopies and the atmosphere. The assimilate production depends on leaf area and its light exposure expressed by the canopy volume, the leaf density, the leaf light interception. The leaf canopy component can be determined by Leaf Area Index (LAI) which regulates a number of physiological processes such as the evapotransporation and the photosynthesis (Villalobos *et al.*, 1995; Cutini *et al.*, 1998). The photosynthetic active radiation (PAR) intercepted by a crop canopy, is the main factor that determines dry matter production. This amount is determined by the incident radiation conditions. The canopy photosynthesis and thus biomass production were the result of the photosynthetic response of leaves and the distribution of radiation within the canopy (Mariscal *et al.*, 2000).

Olive orchards are the main component of numerous agricultural systems in the Mediterranean region. An olive orchard is a heterogeneous stand, since the leaves are located within an envelope that is distributed in the space according to the planting pattern and the row orientation (Mariscal *et al.*, 2000). The intensity of incident light decreases through the olive crown and this attenuation may vary according to the training system and the canopy density. Within a heterogeneous stand, the attenuation of radiation resulting from absorption and scattering by leaves creates a vertical gradient of mean irradiance. Extensive cropping systems intercept around 20-30% of the solar radiation while new intensive orchards intercept at most 70% of the solar (Villalobos *et al.*, 1995; Mariscal *et al.*, 2000).

The leaf component of a canopy may be quantified by its structural attribute LAI (projected leaf area per unit of ground area). Its distribution in field crops is more homogeneous than in arrays of trees. The leaves are not distributed homogeneously and there are large gaps within the vegetation (Villalobos *et al.*, 1995). Tombesi (2006) noted that trees with a canopy volume of 10000-12000m^3.ha^{-1}, showed a leaf area index equal to 6.I. LAI often approached to 2.5 for olive orchard with density equals to 300 trees ha^{-1} [5]. Different instruments have been developed in order to measure rapidly and reliably LAI of plant canopies like plant canopy analyzer (Villalobos *et al.*, 1995) and hemispherical photographs (Bonhomme and Chartier, 1972).

The objectives of this work were (a) to evaluate the use of a Sun scan DELTA-T Devices Ltd for measuring LAI in olive trees (*Olea europaea* L. cv Meski) and studying the variation of foliage density within the tree and (b) to analyze the distribution of photosynthetically active radiation over the canopy and its extinction within the tree.

Material and methods

Study site and plant material

The experiment was performed during 2008 in an olive orchard located in Central Tunisia, about 40 km from Sousse (36°.08'N, 10°.22'E). In this region, climate is semi-arid with rainfall concentrated from autumn to spring (350mm year^{-1}) and an evapotranspiration (ET_o) around 1400mm. The orchard was planted in 1985 with a 7mx7m spacing (204 trees ha^{-1}), which is the density usually used in this region for intensive plantation. The used variety was Meski (a local table olive cultivar) which was known for having a marked alternate bearing behaviour, and is used for table olive production due to its large fruit size. The olive trees were trained to vase form. The tree skeleton was formed by a single trunk of 0.7m height and 3 to 4 primary branch, oriented on different directions with an angle of 45°. This system has for advantage that is known for its uniform light distribution and is suitable for table olives. Olive trees were drip irrigated during the dry season, from April to end of September.

Measurements

Measurements were made during the last week of November when shoot growth ceased. Vegetative growth parameters like height and width trunk, tree height and canopy width were noted. Then, crown volume par tree and per hectare, fruit setting area and canopy ground index, were calculated.

The LAI and the Light interception measurements were realized by SunScan system (Eijkelkamp). The SunScan package consists of a light interception probe, data collection module and external PAR sensor. A direct relation exists between the quantity of incoming radiation absorbed (intercepted) and biomass created. The *SunScan* system suited for measurement and analysis of the PAR in the canopy of crop. Ray readings and derived functions such as light transmission and leaf area index (LAI= variation in light perforation by canopy) can be shown, collected and stored.

Measurements were carried out on eighteen trees. Measurements were noted below and inside the tree precisely in the central part of the tree, during clear days, between 9.00 and 12.00 solar time. These measurements were also realised on the four cardinal directions North, South, East and West. The incident photosynthetically active radiation (PAR_I) and the transmitted photosynthetically active radiation (PAR_T) were recorded. The relationship between the ratio PAR_T / PARI and LAI were investigated in order to study the evolution between these two parameters.

Statistical analyses

Means and standard deviation were calculated. Analysis on variance (ANOVA) was performed by using SPSS 20.0. When significant differences occurred, means were separated by the Duncan's multiple range test at (P<0.05).

Results

Tree growth

All measurements noted on trunks and canopies were reported in Table 1. The average height trunk tree was equal to 37.2cm while their width was about of 24.4cm. Tree height reached an average of 4.6 m while its width was about of 4.8 m. Final canopy volume was calculated per tree and then reported per hectare by multiplying it to number of trees. For a density of 204 trees ha^{-1} used in his orchard, the volume canopy per tree and per hectare was equal to 48.4 $m^3$and 9886.2 m3/ha, respectively. Fruit setting reached 19.1 m^2 $Tree^{-1}$. The ground cover index was estimated to 39% of total soil.

Table 1. Vegetative parameters measured on olives trees.

	Unit	Values
Trunk height	cm	37.2 ±10.9
Trunk width	cm	24.4 ± 3.1
Tree height	m	4.6 ± 0.6
Canopy height	m	4.1 ± 0.6
Canopy width	m	4.8 ±0.7
Crown volume	m3/ Tree	48.4 ± 9.4
	m3/ha	9886.2 ± 3958.2
Fruit setting surface	m2/Tree	19.1 ±5.2
Canopy ground index	%	39 ± 10.7

Leaf area index

The leaf area index varied between 1.6 and 3.1 m^2 m^{-2}considering the entire tree and the different directions. Although, the average value of LAI calculated for the different directions, was equal to 2.8 ± 0.55 m^2 m^{-2} and 2.0 ± 0.11 m^2 m^{-2}, respectively on the lower and the upper part of the canopy (Fig. 1). The difference between the two data was significant ($P< 0.05$). Our results showed that LAI was more important on the lower part of the tree and this result was verified for all directions. Differences between LAI measured on the two level height of the tree, were statistically different for the north and the east direction and not significant for the south and west one. LAI was higher on the south direction and east direction. LAI was equal to 2.92 ± 0.61m^2 m^{-2}(South) and 3.10 ± 0.43 m^2 m^{-2} (east) and 2.37± 0.35 m^2 m^{-2} (South) and 2.20± 0.44 m^2 m^{-2} (east) respectively for the lower and the upper tree part, respectively. These results showed a tendency of the tree to be more developed on these directions and on the lower part.

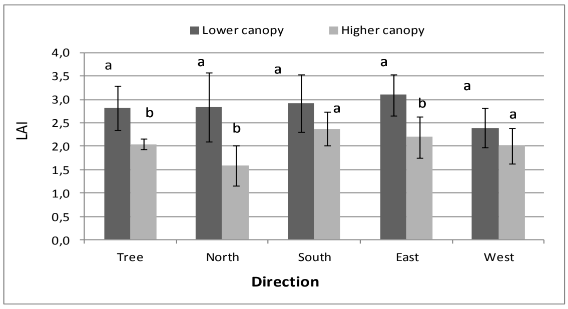

Fig. 1. LAI measured on the two parts of the tree and for the four directions. Each value is the average of eighteen trees. Values are means ± standard errors which is represented as vertical bars. Data with different letters indicate significant differences among the two levels part of the tree (Duncan tests, *P*<0.05).

Photosynthetically active radiation

The incident photosynthetically active radiation PAR_I was more or less constant on the different part of the tree and for the different directions (Fig.2A). It varied from 1353 to 1383 µmol/m²/s on the lower part of the tree and between 922-1425 µmol/m²/s on upper one. The differences between the data measured on the two levels of the tree were not significant for all directions. The transmitted Photosynthetically active radiation PAR_T was higher at the upper part of the canopy. The PAR_T tree value (average value recorded between the four directions) was equal to 178.8 ± 63.2µmol/m2/s on the lower part of the tree and 327.2 ± 102.3µmol/m2/s on the upper one. It seems that the transmitted PAR_T decreased on the tree because the density of foliage was more important on the upper part of the tree. For the lower part of the tree, values varied between a minimum of 141.1 ± 37.5 µmol/m2/s (East direction) and 239.9 ±84.43 (West one). For the higher part, it ranged until 271.2 ± 79.9 µmol/m2/s (south direction) to 441.1± 169.4 µmol/m2/s (North). The differences between the two layers of tree were significantly different only for north and east directions (Fig. 2B).

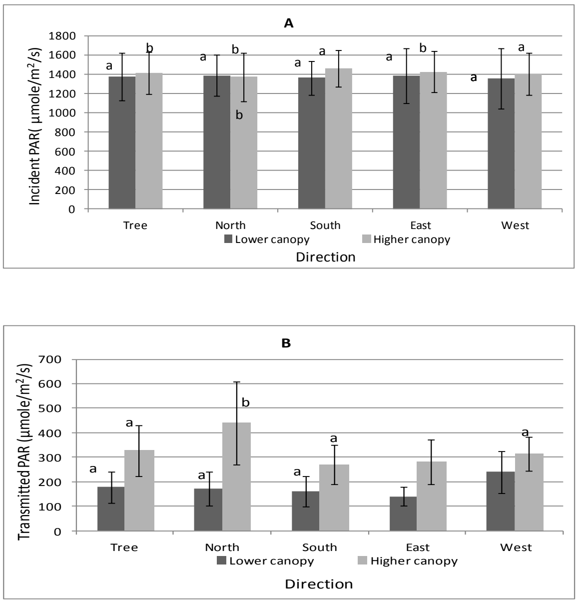

Fig. 2. PAR_I (a) and PAR_T(b) estimated on the tree and on the different directions for the two part of the canopy. Values are means ± standard errors which is represented as vertical bars. Data with different letters indicate significant differences among the two levels part of the tree (Duncan tests, *P*<0.05). NS: no significant

Exponential relation between all measured values of LAI and the ratio between transmitted photosynthetically active radiation and incident photosynthetically active radiation PAR_I was found with R^2 equals to 0.97. The coefficient was significant at p = 0.001. ($y = 0,8831e^{-0,704x}$, x was LAI and y was the ratio value). When LAI increased, the ratio value recorded between transmitted photosynthetically active radiation and incident photosynthetically active reduced (Fig. 3).

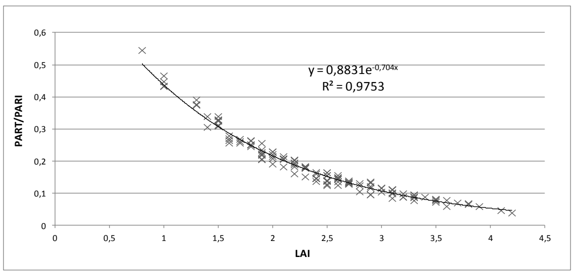

Fig. 3. Relationship between LAI and ratio of transmitted photosynthetically active radiation by Incident photosynthetically active radiation PAR_I. Measurements were taken in the different parts of the tree.

Discussion

According to our experiment conditions, the trees showed a crown volume equal to 48 m^3/tree and 9886.2m^3/ha, respectively. These results are in accordance with those reported by Pastor (1983) and Pastor and Humanes (1990) which indicated the same value for canopy size observed in intensive plantation in Andalucia. Pastor and Humanes (1990), Pastor Munõz-Cobo *et al.* (2006) and Aïachi (2014) indicated that optimum olive orchard volume ranged between 6000-8000 m^3/ha in rain-fed conditions and between 10000-12000 m^3/ha in irrigated one. When total crown volume was higher than 12000 m^3/ha, it was observed competition between trees for the light distribution.

In our experiment, LAI measurements on isolated trees in the field were accurately determined using the Sun scan DELTA-T Devices Ltd. The leaf area index LAI is ranging between 1.6 m^2m^{-2} and 3.16 m^2m^{-2}. These values seem to be similar to those observed by Bongi and Pallioti (1994) which noted a value equal to 2.5. Our results showed that LAI was more important on the lower part of the tree and this result was verified for all directions. The results showed a tendency of the tree to be more developed on the east and south directions for the lower part of the tree. These result confirmed the fact that the olive orchard is heterogeneous stand, since the leaves are located within an envelope that is distributed in the space according to planting and row orientation (Mariscal *et al.*, 2000). For these types of canopy, interactions between stand structure and radiation are complicated to deal with in field trials. Foliage is the central and basic descriptor of vegetation condition in a wide variety of physiological, climatological and biochemical studies (Asner *et al.*, 2003).

The transmitted Photosynthetically active radiation (PAR_T) decreased through the olive canopy and light extinction may vary according to the shape of the tree and the density of the leaves explained by a higher LAI on lower part of the canopy, like suggested by Bongi and Pallioti (1994). Most radiative transfer researches realized on homogeneous canopy are no suitable for forest tree and fruit tree. Two and three – dimensional characterization have been used and the tree grown has been described using ellipsoids , cones and cylinders forms (Cutini *et al.*, 1998; Ganis, 1997; Arias *et al.*, 2007). Olive orchards are complex system in which the main difficulties in modelling the flow-field and light interception are linked to the spatial non-homogeneity of foliage tree.

Conclusion

These results will be the fundamental basis of olive pruning and to establish new intensive olive orchards with fully developed canopies which intercepted the maximum solar radiation. In Order to completely characterize the light distribution within the crows of trees trained to different systems (vase system, central leader, free form), more extensive studies must be conducted. However, further research should be carried out to study light interception in the whole crown form from sunrise to sunset according different varieties and tree density in the field because of the different combinations (site, cultivar, density, season…)

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