Scientia Horticulturae 241 (2018) 275–284

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Prolonged artificial shade affects morphological, anatomical, biochemical and ecophysiological behavior of young olive trees (cv. Arbosana)

Amani Ajmi[a,*], Saúl Vázquez[b], Fermín Morales[b,c], Anissa Chaari[d], Hamdi El-Jendoubi[b], Anunciación Abadía[b], Ajmi Larbi[d]

[a] ISA Chatt Mariem B.P 47, 4042 Chott Mériem, Sousse, Tunisia
[b] Estación Experimental de Aula Dei (EEAD), CSIC, Department of Plant Nutrition, Apdo, 13034, 50080, Zaragoza, Spain
[c] Instituto de Agrobiotecnología (IdAB), Universidad Pública de Navarra-CSIC-Gobierno de Navarra, Campus de Arrosadía, 31192, Mutilva Baja, Spain
[d] Olive Tree Institute, BP 208, 1082, Tunis, Tunisia

ARTICLE INFO

Keywords:
High-density olive orchards
Shade
Leaf anatomy
Leaf phenotypic plasticity
Photosynthesis

ABSTRACT

Light requirement in olive trees is the most important factor to ensure both olive production and oil quality. However, in the intensive and hyper intensive olive cultivation, problems of shading frequently appear. The objective of this work was to study the effects of reduced irradiance on growth, morphology, anatomy, physiology and some biochemical traits of young olive plants.

Thus, an artificial shade (ca. 60%) was performed in young olive plants cv. Arbosana. Plant responses occurred to shade application may be classified as short- and long-term ones. Shoot growth was started to be affected 18 months after shading application, and after that date a total suppression of growth was observed. However, both leaf surface and leaf angle insertion were affected from the beginning of the experiment (3 months).Shaded leaves had higher area and lower thickness. Palisade and spongy parenchyma thickness were reduced in shaded plants. Stomatal density, net photosynthetic rate, stomatal conductance and transpiration rate were also reduced by shade.

Shading induced a significant decrease in the concentration of chlorophyll *a*, β-carotene, lutein and pigments within the xanthophyll cycle (VAZ). A significant decrease of fruits number was observed in shaded plants after one year of shading application, while with prolonged shade, a total absence of fruits were observed. In conclusion, the limitation of the amount of light intercepted by the olive canopy affects negatively most of studied parameters. Therefore, an adequate management of the olive canopy by applying adequate training and pruning programs or by the application of growth regulators will avoid shading problems with negative effects on vegetative growth and yield.

1. Introduction

The potential productivity of olive has increased in the last decade largely due to increases in planting density. Densities of plantation in modern olive groves range nowadays from 200 to 2000 plants ha^{-1} (De la Rosa et al., 2007).

Currently, only three cultivars (Arbequina, Arbosana and Koroneiki) dominate super-high density orchards (De La Rosa et al., 2007; Camposeo and Godini, 2009), due to their outstanding characteristics such as compact growth habits, low-medium vigor, early maturity and excellent oil quality (Tous et al., 2003). This new olive planting system was introduced in Tunisia in 2000 and cover currently more than 4500 ha (Larbi et al., 2015). Its main advantages are high early yields, the totally mechanized harvesting and low harvest costs, to maximize short-term profits (De la Rosa et al., 2007; Proietti et al., 2012).

However, the main problem related to the increase in planting density is to ensure canopy optimal illumination while controlling tree size to allow the harvesting machine passing over the hedgerow (Proietti et al., 2012; Connor et al., 2014). This inconvenience is due to the high vigor of this species (Del Río et al., 2002), especially in areas where the growing season is very long like Tunisia and Spain (Larbi et al., 2011). Yet, plant productivity is directly dependent on the photosynthetic capacity of the leaves (Boardman, 1977; Jackson, 1980). Besides the photosynthetic assimilation of the tree is affected by many factors, both plant (total leaf area, leaf orientation, leaf age, sink presence and size, anatomical structure, content of chlorophyll) and

* Corresponding author.
E-mail address: ajmiamani88@gmail.com (A. Ajmi).

https://doi.org/10.1016/j.scienta.2018.06.089
Received 9 October 2017; Received in revised form 30 April 2018; Accepted 29 June 2018

environmental (light levels that occur in different portions of the canopy, temperature, water and nutrients availability, CO_2 concentration) (Ceulemans and Saugier, 1991; Proietti and Famiani, 2002).

Photosynthetic rates in olive are reduced by shade (Gregoriou et al., 2007; Larbi et al., 2015), and also long exposure of leaves to reduced irradiance might alter releted photosynthetic parameters, such as stomatal density, stomatal conductance and chlorophyll contents (Boardman, 1977). This reduction in leaf net photosynthesis might decrease saccharide contents in leaves and consequently reduce floral bud initiation leading to a non-fruiting year for olive, which is by nature a strongly alternate bearing tree (Proietti, 2000; Cherbiy-Hoffmann et al., 2013).

Olive tree yield and product quality, similar to other fruit crops, are related to the amount of photosynthetically active radiation (PAR) intercepted by the orchard (Mariscal et al., 2000; Villalobos et al., 2006). Indeed, artificial shading (< 15% of incident PAR) induces a drastically decrease in number of inflorescences, fruit set, fruit size, and fruit oil content (Proietti et al., 1994; Tombesi et al., 1999). Shade reduces leaf thickness due to the presence of only 1–2 palisade layers and reduces the length of palisade cells and spongy parenchyma (Gregoriou et al., 2007; Larbi et al.,2015). These changes can be permanent, particularly for those leaves that have emerged under shade (Gregoriou et al., 2007).

Olive tree has a morphological and physiological plasticity that allows it to adapt to low light intensity (Granado-Yela et al., 2011; Larbi et al., 2015), but it is of great importance to know to what extent olive can tolerate the shade conditions, being productive (or not) even with low irradiance.

Contrary to ‘Arbequina’, little is known about the behavior of ‘Arbosana’ variety under super high density planting and under low irradiance conditions (Larbi et al., 2015). The adaptation of Arbosana to shading conditions will influence pruning management and hedgerow dimensions.

Within the above-mentioned context, the main objective of the present work was to study the effects of prolonged limiting irradiances by artificial shade on the behavior of young olive plants (cv. Arbosana). Effects of shading on growth, some anatomical, morphological, ecophysiological and biochemical aspects were studied, as well as olive yield.

2. Materials and methods

2.1. Plant material

Two-years-old olive plants (cv. ‘Arbosana’, I 43) with similar vegetative behavior were used in this work.

The experiment was conducted outdoors, in the Olive Tree Institute of Sfax, located in the south east of Tunisia on the Mediterranean Sea (34°43′N; 10°46′ E, area of 7086 km^2). It is characterized by an arid Mediterranean climate largely influenced by its mild and gentle topography, and its maritime exposure. The region is well ventilated with low to moderate wind velocities rarely exceeding 5 m s^{-1} (Bahloul et al., 2015). Over a 52 year period, the average total year rainfall is 210 mm, the average minimum air temperature of the coldest month (January) is 6.5 °C and the average maximum air temperature of the hottest month (August) is 31 °C, with a yearly mean of 23 °C. Most of the total annual rainfall is mostly occurring from October to December; the dry period is during June to September (data provided by the Meteorological Station of Sfax city). During the experimental period, the average minimum and maximum air temperature, were respectively 15 and 25 °C.The minimum air temperature of the coldest month (January) is 6.9 and 5,9 °C respectively for 2014 and 2015, and the maximum air temperature of the hottest month (August) is 32 and 32.3 °C respectively for 2014 and 2015 (Fig. 1A).

Total year rainfall is 228 mm and 179.5 mm for 2014 and 2015. The dry period is during May to September (Fig. 1B).

At the beginning of the experiment, plants were divided into two groups (8 plants per group) and subjected to two light regimes: sun-exposed plants under a mean photosynthetically active radiation (PAR) of 1500 μmol m^{-2} s^{-1} and shaded plants under a mean PAR of 650 μmol m^{-2} s^{-1}. Shading was performed using a plastic green mesh net. The plastic green mesh net (High density polyethylene), used in this work is 2.5 mm × 2.5 mm hole diameter size. It is provided by a Tunisian company (Agroplast, Tunisia). The height between ground and net was around 2.5 m. Olive plants were grown into pots of 20 l containing sand–perlite mixture (1:1, in volume). Plants were irrigated once a week with half-strength Hoagland nutrient solution with the following composition: (in mM) 2.5 KNO_3, 1 $MgSO_4$, 1 KH_2PO_4, 2.5 Ca $(NO_3)·4H_2O$, and 0.5 mM NaCl, and (in μM) 4.6 $MnCl_2$, 23.1 H_3BO_3, 0.06 Na_2MoO_4, 1.2 $ZnSO_4$ and 0.19 $CuSO_4$and 4 times per week with tap water (1.75 mS cm^{-1}). During fall and winter, irrigation was limited to twice a week (once with half-strength Hoagland nutrient solution and the other with tap water).

The experimental period started in March 2014 and ended in March 2016.

2.2. Light interception

PAR interception in each experimental condition was determined monthly. Readings were taken four times a day at 9, 10, 11 and 12 h solar time during the first year of the experiment.

Intercepted PAR, temperature and humidity for each experimental condition were monitored using Spectrum Watch Dog micro-station connected to quantum light 6 sensor bar (Spectrum Technology, Inc, USA). Measurements were taken on marked shoot (4 shoots per plant) each month, under clear sky conditions. The average of twelve readings on each shoot was recorded. Indeed, for each shoot, twelve readings were taken with the sensor placed horizontally at the base, the middle and the tip of each marked shoot taking into account the cardinal directions (North, South, East and West). The estimated daily intercepted PAR for each plant was calculated as the average of the daily four measurements.

2.3. Growth parameters

The length of stem plant leader (cm) and axillary shoots (cm) were measured just before application of shade and monthly after shade application until the end of the trial. Plants are carry on laterals shoots. The distance between plants, was approximately about 50–70 cm. Table 1 represents the initial dimension of plants.

Internodes extension (cm) was determined at the end of the experiment.

2.4. Leaf area

During the experiment, leaf area was determined using the Eq. (1) established by Tattini et al. (1995) and tested by Kchaou et al. (2010) for five olive varieties included Arbosana-I43. The length and width of three marked leaves per plant were measured monthly. The area of leaves was calculated according to the following regression Eq. (1):

$$Y = 0.735X + 0.125\ (R^2 = 0.987),$$

where Y is leaf area and X is the product length × width.

2.5. Leaf angle

Leaf angle was determined manually using an angle-hook by measuring the insertion angle of leaves on marked branches at each plant of the two conditions (shaded plants, and sun-exposed plants). The angle refers to the position of the leaf with respect to the branch. Measurements were made between 8 and 11 h solar time and were