Scientia Horticulturae 133 (2012) 31–36

Contents lists available at SciVerse ScienceDirect

Scientia Horticulturae

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

# Yield characteristics of N–S oriented olive hedgerow orchards, cv. Arbequina

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ARTICLE INFO

*Article history:*
Received 28 July 2011
Received in revised form 7 October 2011
Accepted 11 October 2011

*Keywords:*
Fruit characteristics
Hedgerows
Oil yield
Olive
Solar radiation
Yield profiles

ABSTRACT

Profiles of yield (g oil $m^{-2}$) and yield components, fruit density ($m^{-2}$), size as dry weight (DW) (g), and oil% DW were measured in 11 N–S oriented hedgerow orchards, cv. Arbequina, of various height and alley width combinations in Spain. Profiles of daily shortwave solar radiation incident vertically on the canopy walls (MJ $m^{-2}$) calculated by a canopy illumination model were weakly exponential, revealing the importance of alley width in determining the diurnal persistence of sunlit canopy wall to depth. Strong positive linear relationships were established between radiation incident on canopy walls and fruit size and oil% over the entire canopy depth in all orchards. In contrast, fruit density was closely related to incident radiation on canopy walls only in the lower profile where incident daily solar radiation was <6 MJ $m^{-2}$ during oil production in October. The consequence was a weaker relationship between yield (g oil $m^{-2}$) and incident radiation on canopy walls than between the size and oil% components. Explanation is found in the impact of pruning applied to maintain hedgerow height that removes fruit in the current year. Results emphasize the importance of alley width:height relationships in determining complete illumination of canopy walls in hedgerow orchards giving guidance to questions of optimal orchard structure for maximum yield. They also demonstrate importance and need for work on canopy management to maintain yield in upper canopies of hedgerows where fruit are large and also have high oil%.

## 1. Introduction

Hedgerows are new production systems for olive. They are estimated to occupy 1% (100,000 ha) of a worldwide area of 10 Mha planted to olive. Although currently a small percentage, hedgerows are the most common orchard design in new plantings, especially in non-traditional production zones away from the Mediterranean Region. Advantages relate to ease of disease and pest control and to minimization of costs by mechanization of harvest and pruning. Tree densities are high, ranging from 400 to 1975 $ha^{-1}$, as is also cost of establishment, but this is compensated by early production, especially in orchards planted at high density.

Design and management of canopy structure are major concerns. An important question asks, for each location and grower, what is the optimum combination of row height, width and spacing to meet productivity, water requirement, and management objectives and capabilities? A second asks, how best to maintain optimum structure once has been achieved? Early experiences (Pastor et al., 2007) demonstrated changing patterns of fruitfulness in developing hedgerows. Fruitfulness moved gradually higher as hedgerows grew taller, thus identifying the need to adjust canopy height to free alley width (i.e. row spacing minus row width), or vice versa, to provide adequate illumination of entire canopy walls. That aspect of optimum canopy structure was investigated with a light interception model (Connor, 2006) advising, as previously known for other hedgerow systems, apple (Cain, 1972) and wine grape (Smart and Robinson, 1991), that optimum structure for high productivity is found when the entire depth of canopy wall receives radiation above the threshold for fruitfulness. Applying a threshold radiation incident on canopy walls of 20% of horizontally incident radiation, as established for apple by Cain (1972), analysis revealed a solution for maximum productivity when free alley width was approximately equal to canopy depth. Observations on yield profiles in hedgerow olive orchards (Connor et al., 2009) have identified preliminary relationships between patterns of canopy illumination and yield components of various cultivars in hedgerows of various structures and orientations.

In this paper we re-analyze relationships between incident radiation and yield components in N–S oriented hedgerows of cv. Arbequina by adding new data to that previously presented in Connor et al. (2009).

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doi:10.1016/j.scienta.2011.10.008

**Table 1**
Location and structural features of 11 N–S oriented olive hedgerow orchards, cv. Arbequina, and daily clear sky shortwave radiation during October.

| Site number | Location | Shortwave radiation October (MJ m$^{-2}$ d$^{-1}$) | Canopy | | | | | Number of layers |
|---|---|---|---|---|---|---|---|---|
| | | | Height (m) | Rows at (m) | Trees at (m) | Alley (m) | Alley/height | |
| 1 | El Carpio | 16.7 | 2.0 | 3.0 | 1.35 | 2.1 | 1.1 | 5 |
| 2 | El Carpio | 16.7 | 2.4 | 3.0 | 1.35 | 2.1 | 0.88 | 6 |
| 3 | El Carpio | 16.7 | 2.8 | 3.0 | 1.35 | 2.1 | 0.75 | 7 |
| 4 | Ecija | 17.8 | 3.0 | 3.75 | 1.35 | 2.5 | 0.83 | 5 |
| 5 | Toledo | 16.7 | 2.0 | 4.0 | 1.50 | 3.3 | 1.5 | 4 |
| 6 | Toledo | 16.7 | 2.5 | 4.0 | 1.50 | 3.0 | 1.2 | 5 |
| 7 | Ermita | 16.7 | 2.8 | 3.0 | 1.35 | 2.1 | 0.75 | 4 |
| 8 | Ermita | 16.7 | 2.8 | 3.0 | 1.35 | 2.1 | 0.75 | 4 |
| 9 | Pedro Abad | 17.6 | 2.0 | 3.75 | 1.35 | 2.4 | 1.2 | 5 |
| 10 | Pedro Abad | 17.6 | 2.8 | 3.75 | 1.35 | 2.2 | 0.79 | 7 |
| 11 | Pedro Abad | 17.6 | 3.6 | 3.75 | 1.35 | 2.4 | 0.67 | 9 |

## 2. Materials and methods

### 2.1. Data collection

Measurements of fruit density, size and oil%, the latter two according to dry weight (DW), were made from fruit harvested manually by layers, mostly of 0.4 m depth but up to 0.7 m, in 11 N–S oriented orchards of varying height, width, and row spacing. All sites were in Spain, ranging from 37.5 (Ecija) to 39.9°N (Toledo). Values were analyzed as means of observations for individual layers taken from both sides of the central axes of the hedgerows, for which no differences were established.

Structural features of the orchards are summarized in Table 1. All were planted a high density with intra-row tree spacing of either 1.35 or 1.5 m. At the time of measurements all orchards formed continuous, essentially rectangular, hedgerows. Key comparators of orchard structure are height and alley width. Height ranges from 2.0 to 3.6 m and alley width from 2.1 to 3.3 m. The ratio alley width:height was from 0.67 to 1.65.

### 2.2. Analytical methods

#### 2.2.1. Profiles of incident radiation on canopy walls

Incident radiation ($Rad_{ij}$) on canopy walls was estimated at the mid-point of each layer ($j$) of each orchard ($i$) according to horizontally incident daily shortwave radiation at each site ($Rad_i$) and corresponding alley width (see Table 1) using the canopy illumination model of Connor (2006) that accounts for penetration of direct beam solar radiation and diffuse sky radiation into alley spaces. A validation of the model has been presented in Connor et al. (2009). Vertical profiles of incident radiation on canopy walls for each orchard were then expressed as exponential functions according to Eq. (1). By that analysis, each orchard is distinguished by an extinction coefficient ($k_i$) that depends on alley width.

$$Rad_{ij} = Rad_i \quad e^{-k_i \ \mathrm{Depth}_{ij}} \tag{1}$$

#### 2.2.2. Profiles of yield and yield components

Linear regressions of yield or yield components ($Y_{ij}$) on radiation incident on canopy walls ($Rad_{ij}$) were performed to calculate overall relationships with the site effect ($S_i$) introduced as an additive site specific factor and treated as a block in linear regression analysis (Eq. (2)). The slope $b$ defines responses of yield or yield components to incident radiation by layers on canopy walls.

$$\mathrm{Yield}_{ij} = S_i + bRad_{ij} \tag{2}$$

#### 2.2.3. Effect of site on yield and yield components

A principal component analysis was made of values of the additive site specific factor ($S_i$) in regressions of yield and yield components on radiation incident on canopy walls (Eq. (2)). The result is presented as a biplot that allows visual representation of differences between sites. On the one hand it reveals correlations between components of yield, and on the other, their association with sites.

#### 2.2.4. Components as determinants of yield

Linear models were also used to determine individual effects of yield components on yield. First, simple linear regressions were applied in which site effects were introduced as blocks (Eq. (3)). The slope $c$ defines responses of yield to yield components.

$$\mathrm{Yield}_{ij} = S_i + c\mathrm{Yield\ comp}_{ij} \tag{3}$$

Second, a multiple linear regression of yield vs. yield components was applied in order to identify the component with greatest impact on yield variation. For this, yield components were included progressively, if statistically significant, with a forward selection criterion.

All statistical analyses were carried out using R (R Development Core Team, 2008).

## 3. Results

### 3.1. Profiles of radiation incident on canopy walls

Results are presented for October that is an important month in fruit growth and oil production. Profiles of radiation incident on canopy walls of individual orchards, as presented together in Fig. 1. They are exponential in form with individual extinction

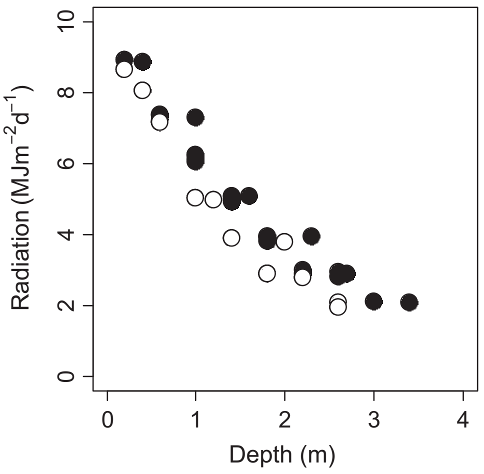

**Fig. 1.** Vertical profiles of daily shortwave radiation incident on canopy walls of various N–S olive hedgerow orchards on clear sky days during October at *ca.* 39°N. Open circles distinguish observations with larger extinction coefficients at sites 1, 2, 3, 7 and 8.