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Effect of olive hedgerow orientation on vegetative growth, fruit characteristics and productivity

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ABSTRACT

The effect of row orientation on oil production and fruit characteristics was studied, during years 3–6 after planting of the super-high density olive hedgerows (1923 tree/ha) planted at the same row spacing (4 m) in four orientations (N–S, NE–SW, NW–SE and E–W). During the last two years of observations the hedgerows were maintained by lateral pruning and topping at the same row width (1 m) and height (2.5 m). In those years, maximum fruit yield was achieved by NE–SW and NW–SE (15.7 t/ha). Of these, NE–SW achieved the highest oil yield (2.7 t/ha). There were no differences in fruit or oil yield between N–S (2.5 t oil/ha) and E–W (2.3 t oil/ha) orientations. Fruit density was the most important component to explain these differences, by previous influence on number of buds developed and fruit set. Analyses of profiles of yield components and yield on opposing sides of hedgerows revealed many differences that contributed to overall hedgerow performance. Regardless of row orientation, fruit density was highest from 1.0 to 2.0 m height, decreasing to the top and to the base. In both sides of N–S and also in N side of the E–W hedgerows, fruit weight decreased linearly from top to base, whereas on both sides of NE–SW and NW–SE and S side of E–W hedgerows, fruit weight decreased linearly from the top layer to 1.4 m height and remained stable to depth. Fruit ripening was also highest in the top layers and decreased linearly to the base in all orientations, but was more evenly distributed in the S and SW sides of E–W and NW–SE hedgerows. Fruit water content increased linearly from top to base in all orientations, more sharply in NE–SW, NW–SE and N–S hedgerows. The discussion explores the role of light relations in the determination of yield in olive hedgerows and options for future study and selection of optimal hedgerow designs.

1. Introduction

Worldwide, most olive area remains characterized by old, widely spaced trees (between 100 and 300 trees/ha), trained to vase structure, and grown under rain-fed conditions. Productivity is low and the high demand for manpower for harvest and pruning (Vieri and Sarri, 2010) compromises the international competitiveness of olive compared with alternative vegetable oils. In response, growers have recently begun to establish new olive orchards in hedgerows to allow mechanical harvesting and so reduce the costs of manual labour while also allowing more rapid and timely management interventions (Connor et al., 2014; Tous et al., 2010). Two types of hedgerow have emerged suited to available mechanized over-row, canopy-contact harvesters. The first are hedgerows planted at high tree density (1500–2000 trees/ha) that are maintained around 2.5 m high and 1.0–1.5m wide to suit the dimensions of modified grape harvesters. These orchards have expanded in environments where olive shows moderate-low vegetative vigour in Spain, Chile and Portugal (León et al., 2007; Rius and Lacarte, 2010) and are usually called "superintensive" orchards. The second are large hedgerows, planted at 250–500 trees/ha and maintained around 4.5 m high and 4 m wide. A large harvester, "the Colossus", was developed for these so-called "intensive" orchards that have expanded in production zones where olive grows vigorously in Argentina and Australia (Cherbiy-Hoffmann et al., 2012; Ravetti, 2008). The design and management of hedgerow orchards has improved mainly through trial and error by commercial growers, while adequate scientific research in olive hedgerow remains very limited (Cherbiy-Hoffmann et al., 2012; Connor et al., 2014; Pastor et al., 2007; Tombesi and Farinelli, 2014).

Row orientation is a major aspect in the design of these planting systems and yet its influence on olive oil production and fruit characteristics has not been well studied. In practice, N–S oriented

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hedgerows that largely dominate olive orchards seemingly have the appeal that either side of such hedgerows receive equal daily direct solar radiation. Deviations from N–S orientation are mostly adaptations to shape or size of terrain, where an alternative orientation allows more efficient use of land or machinery, or where planting on or off contours reduces soil erosion or frost hazard, respectively. But in absence of these environment- and terrain-limitations, the question remains if orientation could be a strategy to manage oil production and quality in olive hedgerow orchards.

Previous studies that make adequate comparisons of the productivity of hedgerow orchards of contrasting orientation, mostly the extremes of N–S *vs* E–W, are very limited and have been made mostly with the deciduous fruits, apple and pear, some in grape, but none in olive (recently reviewed by Trentacoste et al., 2015). The limited results support the generally greater productivity of N–S hedgerows. Naylor et al. (2000) and Intrieri et al. (1996) found ~20% greater yields in N–S than E–W oriented vineyards at latitude 41 °S and 44 °N, respectively. Khemira et al. (1993) obtained 21.4% greater accumulated yield across 10 years in pears grown in N–S than E–W orientations at 42 °N. Christensen (1979) found that N–S orientation yielded 17% more than E–W in apple hedgerows at 55 °N. There is, however, one exception to this general response in the study of Devyatov and Gorny (1978), which reported greater yields of apples in E–W than N–S orientated hedgerows at 53.8 °N latitude. Orientations other than N–S and E–W have been rarely compared, but Intrieri et al. (1996) reported greater accumulated grape yield over four seasons in NE–SW and NW–SE than N–S and E–W row orientations.

Hedgerow orientation has a major effect on the distribution of irradiance on canopy walls according to row height and spacing. Recently, Trentacoste et al. (2015) compared irradiance distributions on four hedgerow orientations and established that seasonal interception is greater in N–S and NE–SW/NW–SE oriented hedgerows than in E–W hedgerows, and that the difference decreases with increasing latitude in the range 25–45°. Interception by N–S and NE–SW or NW–SE hedgerows is minimum and maximum in winter and summer, respectively, but the pattern is reversed in E–W hedgerows. Irradiance on opposing canopy sides also changes seasonally with hedgerow orientation. In N–S hedgerows, the pattern is similar between E and W sides. In contrast, in E–W hedgerows the S side (N hemisphere) intercepts direct irradiance throughout the year but the N side only for short periods in the early morning and late afternoon during summer (between the Spring and Autumn equinoxes) but, during the rest of the year, relies on diffuse and reflected radiation in the alleys and that transmitted through the hedgerow from the opposing (S) side. For NE–SW and NW–SE hedgerows, irradiance on SE and SW (N hemisphere) is markedly greater than on NW and NE sides, respectively, during Winter, Spring and Autumn but is similar in Summer. Additionally, the vertical distribution of irradiance down canopy walls is also modified by hedgerow orientation (Connor et al., 2014; Olesen et al., 2007). Thus variables including latitude, hedgerow dimensions and crop-specific characteristics such as timing of critical periods, canopy architecture, the physiology of the crop, and cultural practices such as pruning, could all affect the response of productivity to hedgerow orientation, emphasizing the long-standing call that experimental comparisons in actual hedgerow systems are needed (Palmer, 1989), and this now includes olive also.

The aims of this work were to determine the impact of hedgerow orientation and canopy structure on the overall oil production by the measurement of profiles of the determining processes of shoot growth, flowering, fruit set, fruit yield components (number, size and oil content) and fruit characteristics (fruit water content and ripening) on opposing sides of hedgerows in an experimental orchard with four hedgerow orientations.

2. Material and methods

2.1. Site and orchard

The experiment was maintained during the four growing seasons of 2010–2013 in an olive (cv. Arbequina) hedgerow orchard planted in spring 2008 near El Carpio del Tajo (39°53′N, 4°27′W, 479 masl), Toledo, central Spain. Four hedgerow orientations, viz. N–S, NE–SW, NW–SE and E–W were established in two plots per orientation separated by approximately 20 m, then each plot was divided into two subplots (i.e., 4 replicates per orientation) of 4 rows of 11 trees spaced at 4.0 × 1.3m (1923 trees/ha), in which the two central rows were used for the study.

The climate of the region is semi-arid with annual rainfall of 359 mm concentrated during Autumn–Spring, and average annual temperature of 16.0 °C. The soil is clay–loam comprising two layers each 0.20–0.25 m deep with contents of gravel and organic matter of approximately 10 and 1.35%, respectively, in the top 0.3 m of depth. A hard carbonaceous layer, which impedes penetration of roots to depth, was observed from 0.5 to 0.6 m. Daily meteorological data, recorded at an automated weather station located near to the experimental site, included maximum and minimum temperatures, relative humidity, rainfall, solar radiation, vapour pressure deficit and wind speed.

The orchard was managed using standard commercial practice. Hedgerows received supplementary irrigation (429 mm from 6 March to 15 October 2012, and 330 mm from 4 June to 15 October 2013), using single drip lines per row with emitters discharging 3.0 L/h at 0.5m spacing. Fertigation was used with the applied nutrient amounts determined by prior leaf analysis. In 2012 and 2013 plots were supplied with 150 kg/ha of N and K, and 90 kg/ha of P. Pruning, during winters 2012–2013 and 2013–2014, consisted of removing branches extending into the alleys and mechanical topping to 2.5 m height. Phenological development was recorded during 2012 and 2013 as occurrence of the stages: budburst, bloom, end of fruit drop and pit hardening.

2.2. Hedgerow vegetative structure

Tree height was measured yearly from 2008 to 2011 on 3 trees per subplot, in order to determine when tree crowns achieved target height (i.e., 2.5 m). Hedgerow structure was described in detail on 2 trees per subplot immediately after harvest in 2012 and 2013, when shoot growth had ceased. For this, height of top and bottom foliage was measured in 3 positions per tree, near the trunk and at 0.5m on each side. Hedgerow width was measured at 0.5, 1.0 and 1.5 m height at 3 positions of the same trees. Hedgerow external surface area and canopy volume were calculated for a rectangular shape, from average values of height and width measured in each tree.

The transmission of solar radiation through the canopy is determined by the size, distribution and orientation of foliage elements that comprise it and is an important feature of models of radiation capture and distribution in foliage (Connor et al., 2009; Connor and Gomez-del-Campo, 2013; Guiuliani et al., 2000). Here we characterized this feature of vegetative structure, leaves and stems together, by measuring the horizontal porosity as the proportion of gap seen horizontally through the hedgerow. For this, we used a hand-held laser (maximum output power <300 mW; wavelength 532 nm ± 10) as a point quadrat. In each hedgerow orientation, 150 replicates were taken randomly at mid of canopy height (1.0–1.7 m) where more than 80% of total oil production occurs. Horizontal porosity (%) was estimated as the proportion of laser points penetrating the hedgerow directly onto a white panel at the measuring