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Short communication

Vegetative structure and distribution of oil yield components and fruit characteristics within olive hedgerows (cv. Arbosana) mechanically pruned annually on alternating sides in San Juan, Argentina

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ABSTRACT

In olive hedgerows mechanical pruning is needed to control hedgerow dimensions for canopy illumination and access by harvesting machinery but yield responses to pruning strategies remain unclear. This study records the impact of annual mechanical topping with pruning on alternating sides of hedgerows on the internal distribution of fruit characteristics and oil yield. Hedging was applied in winter at 0.4 m from the trunk on West and East sides in 2015–16 and 2016–17 seasons, respectively, along with topping at 3.0 m height. Hedgerow width, height and porosity were characterized after pruning and before harvest. Oil production, fruit number and fruit characteristics were evaluated in 20 positions within the hedgerows defined by two sides (East and West), two depths per side (inner and outer) and 5 heights. West-unpruned sides in 2015–16 and East-unpruned sides in 2016–17 produced 70 and 80% of the total oil, respectively. Within each season, fruit oil and water concentration and pulp/pit ratio were similar on opposing sides. In contrast, fruit weight and maturity were similar between sides in 2015–16 but not in 2016–17 where greater fruit weight and more advanced maturity were observed on West-pruned. In both seasons, inner positions (within 0.5 m of trunk) produced 65% of total oil production and fruit numbers. Fruits showed similar characteristics between hedgerow depths. In contrast, oil production and fruit characteristics showed a marked gradient with height. Oil production and fruit number were greatest from 1.0 to 2.0 m height, decreasing to the top and to the base. Fruit weight, oil concentration and maturity decreased from hedgerow top to base, while fruit water concentration showed the opposite pattern. Mechanical pruning applied annually to alternating sides maintained both hedgerow dimensions and oil yield in successive years.

1. Introduction

In Argentina, new olive plantations are large (> 100 ha) with high tree density (> 300 trees/ha) and tall hedgerows (> 4.0 m) (Gómez-del-Campo et al., 2010). Hedgerows are important because they allow full mechanization of pruning and harvest which is required to contain costs of management and manpower, while offering additional advantages of much faster and more efficient management interventions, important in large orchards (Trentacoste et al., 2015a). Mechanical pruning is an efficient tool to maintain hedgerow dimensions and form compatible with harvesting machinery and also for the branch renewal necessary to sustain and locate shoot growth, flowering and subsequent productivity (Connor et al., 2014).

Two studies have recorded the effect of simultaneous mechanical hedging of both sides of olive hedgerows (Albarracín et al., 2017; Vivaldi et al., 2015). In the first case, oil yield was reduced in the current pruning season but recovered to that of the un-pruned control in the following season. Over three consecutive seasons, cumulative oil yield was non-significantly different between the unpruned control and hedgerows pruned on both sides. In the second case, hedging and topping reduced oil yield for three years in high- but not in low-vigor cultivars such as Arbequina and Arbosana, explicable because in these cultivars fruiting shoots were mainly located near the trunk. In contrast, few published studies have examined the productive response to hedging of alternating sides (Cherbiy-Hoffmann et al., 2012; Tombesi et al., 2014). Cherbiy-Hoffmann et al. (2012) in Northwest Argentina

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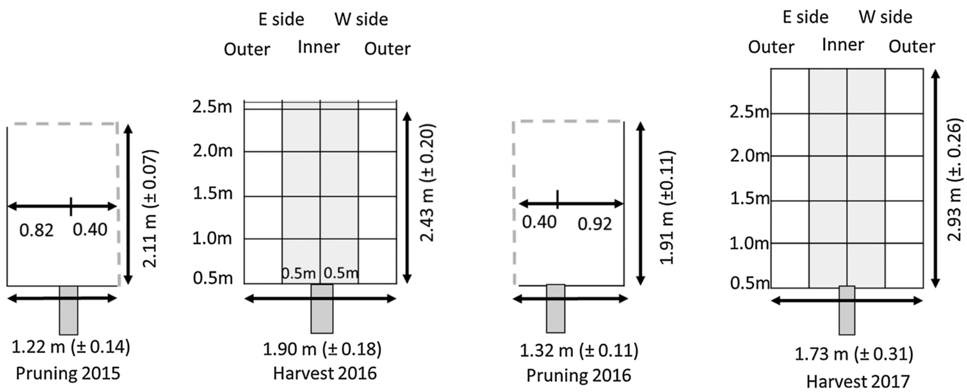

Fig. 1. Representative scheme of hedgerow structure and dimensions (width and height) after mechanical lateral pruning of West side in winter 2015 and on East side in winter 2016. In 2016 and 2017, hedgerows were harvested in 20 canopy positions, as shown. The vertical scale (column) on the right indicates the boundary heights (m above ground).

observed that fruit load retained on unpruned sides in large olive hedgerows (cv. Arbequina) prevented vigorous and nonproductive regrowth on pruned sides that can result from severe pruning. In walnut hedgerows, Ramos et al. (1992) found greater cumulative fruit yield during five years in hedgerows that were hedged annually on alternating sides compared with others hedged simultaneously on both-sides in alternating years.

In mechanized olive hedgerows the distribution of oil yield, its components and fruit characteristics are also important to establishing hedgerow design, harvest time, mechanical efficiency and modeling hedgerow performance and yield (Connor and Gómez-del-Campo, 2013; Trentacoste et al., 2015b). The distribution of oil yield components within hedgerows has been evaluated in narrow, porous (20%) olive hedgerows cv. Arbequina (width 1.20 m × height 2.5 m) under low vigor growing conditions of central Spain. There, fruits were concentrated towards the canopy periphery (Trentacoste et al., 2015b) in contrast to the central zones of lower irradiance in wider (~5.0 m) hedgerows in Argentina (Cherbiy-Hoffmann et al., 2012). Hedging alternating sides of hedgerows causes the development of asymmetric canopies with potential for different fruit load, shoot growth and irradiance environment between canopy sides (Wood and Stahmann, 2004) and opportunities for management to control production and its components at whole hedgerow level.

This work was undertaken to determine the impact of annual lateral pruning of alternating sides of hedgerows, cv. Arbosana, on canopy dimensions (width, height and porosity) and distribution of oil yield, its components and fruit characteristics within hedgerows.

2. Material and methods

2.1. Site and orchard

The experiment was carried out during the 2015–2016 and 2016–2017 seasons in a commercial olive (cv. Arbosana) orchard at Cañada Honda Valley (31° 58´S, 68° 32´ W, 614 m.a.s.l.), San Juan, Argentina. The hedgerows were established in 2011 with rows oriented N-S and trees spaced 1.75 m x 3.5 m (1632 trees/ha). The climate of the region is arid with annual rainfall of 195 mm concentrated during summer months, and average annual temperature of 18.5 °C. The soil is sandy-loam with high content of gravel below 0.8 m of depth. Daily meteorological data, recorded at an automated weather station located near to the experimental site, included maximum and minimum temperatures, relative humidity and rainfall.

Trees were irrigated with emitters of 2.0 L/h spaced at 0.8 m intervals along a single drip line per hedgerow. Irrigation, corrected for rainfall, was applied to restore 70% of crop evapotranspiration over the whole growing season. Crop evapotranspiration was calculated as:

$$ETc = ETo \times Kc \times Kr \tag{1}$$

where ETo is reference evapotranspiration calculated with Penman-Monteith modified by FAO (Allen et al., 1998), Kc is a seasonally constant crop coefficient = 0.70 estimated for olive trees by Girona et al. (2002) and Kr is an empirical coefficient to account for changing crop cover. It was calculated as 2 x crop cover %/100 with a limit of Kr = 1 for cover fraction > 50% (Fereres et al., 1981) at the beginning (September) and mid growth season (January). Fertilizer was applied with irrigation water to supply 58.2 kg/ha of N, 10.4 kg/ha of P, 22.0 kg/ha of K, and 8.7 kg/ha of Mg in both growing seasons.

2.2. Mechanical pruning and plot selection

At the beginning of the experiment, tree canopies formed continuous hedgerow walls that exceeded the target dimensions compatible to harvesters. Pruning, comprising topping and single-side hedging, was applied by machine with four rotating disks assembled on two rotating booms (see graphical abstract) in winter. Topping was set at 3.0 m height and hedging at 0.4 m from the trunk in single passes on 5 July 2015 and 25 June 2016 for West and East sides, respectively (Fig. 1). Both, hedging distance from the trunk and topping height were selected in relation to dimensions of the intended harvesters.

Trees for measurement were selected from a section of 6 adjacent rows with 50 trees per row following measurements of trunk perimeter and crown volume of all trees (300 trees). From these, nine subplots (replicates) each consisting of two contiguous trees were chosen with similar trunk perimeter and crown volume. The same 18 trees (i.e. 9 subplots per two trees) were evaluated in both seasons.

2.3. Hedgerow vegetative structure

Hedgerow structure was described on both trees per subplot immediately after pruning and before harvest in 2015–16 and 2016–17 growing seasons. For this, height of top and bottom foliage was measured in 3 positions per tree, near the trunk and at 0.5 m on each side. Hedgerow width was measured at 0.5, 1.0 and 1.5 m height at 3 positions of the same trees. Canopy porosity (%) was estimated according Trentacoste et al. (2015b).

2.4. Definition of canopy positions

At harvest, the canopies of the two contiguous trees per replicate were divided into 20 positions based on two vertical layers of canopy depth (inner and outer) on both sides (East and West) divided into 5 horizontal height intervals (see Fig. 1). The inner layer was the first 0.5 m measured outwards from the trunk while the outer layer was the remainder of the external canopy. The five height intervals above ground were 0.5–1.0 m, 1.0–1.5 m, 1.5–2.0 m, 2.0–2.5 m, and > 2.5 m aboveground.

Table 1
Average fruit and oil yield and its components, fruit number and fruit weight per linear meter of hedgerow, according to height, side and depth in olive hedgerow pruned on West side in 2016 and on East side in 2017.

Canopy position		Fruit yield (kg/m linear)		Oil yield (kg/m linear)		Fruit number /m linear		Fruit dry weight (g)	
		2016	2017	2016	2017	2016	2017	2016	2017
Height (m)	+2.5	0.13c	0.04c	0.02bc	0.01c	70c	24b	0.68a	0.80a
	2.0-2.5	0.63a	0.32ab	0.10a	0.05a	363a	181a	0.64a	0.72a
	1.5-2.0	0.57a	0.36a	0.08a	0.05ab	362a	222a	0.55b	0.61b
	1.0-1.5	0.30b	0.25ab	0.04b	0.04ab	214b	157a	0.46c	0.56b
	0.5-1.0	0.05c	0.23b	0.01c	0.03b	37c	151a	0.46c	0.55b
Side	East	4.63a	1.18b	0.68a	0.18b	2939a	642b	0.53	0.69a
	West	2.11b	3.67a	0.31b	0.55a	1245b	2297a	0.59	0.58b
Depth	Outer	2.77b	1.28b	0.42b	0.19b	1719b	762b	0.59	0.62
	Inner	3.97a	3.56a	0.58a	0.54a	2466a	2176a	0.54	0.63
Total/average		6.74	4.85	1.00	0.73	4185	2938	0.57	0.63
P-value	Height	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
	Side	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.095	< 0.001
	Depth	0.005	< 0.001	0.010	< 0.001	0.032	< 0.001	0.087	0.800

Values with the same letter are not significantly different within each year, height, sides and depths canopy positions of the hedgerows by LSD's test at $P \leq 0.05$. Letters only presented when ANOVA indicated significant effect.

2.5. Oil yield and its components

Olives were harvested separately from all canopy positions combining fruits of two contiguous trees per replicate, on 17 and 23 May in 2016 and 2017, respectively. Fruit from each position, both total and a sample of 50 fruits, was weighed immediately at harvest. Maturity index was determined by classifying 50 fruits on a scale from 0 to 7 according to skin and pulp colour. The total number of fruits from each position was estimated from the weight of 50 fruits and the total harvest weight. Later, 30 fruits were used to determine fruit oil concentration and 20 to determine the pulp/pit ratio in the laboratory. A subsample of 50 fruits was weighted and dried at 60 °C to constant weight in order to estimate fruit dry weight and water content as 100 × (fresh wt - dry wt)/fresh wt. Oil concentration was measured in duplicate using the method of Avidan et al. (1999). Fruit oil concentration was estimated as the quotient, in percentage, of oil weight and pulp weight on fresh (OCFW) and dry weight (OCDW). Oil yield was calculated as the product of fruit yield and fruit oil concentration on the fresh weight.

Fruit yield, oil yield and fruit number in each position were expressed per linear metre of hedgerow. Average fruit weight, pulp/pit ratio, fruit oil concentration, fruit water content, and maturity index of each side, or depth, were calculated as averages weighted by fruit number.

2.6. Statistical analysis

Data for each year were subjected to analysis of variance individually using Infostat version 1.5. The effects of height, depth and side on distribution of measured parameters were compared using a split-plot model. The means were separated using the LSD-test for a level of significance $\alpha = 0.05$.

3. Results and discussion

3.1. Hedgerow structure

The hedging depth of 0.4 m from the trunk restricted the distribution of thick inelastic branches in these hedgerows to the inner 0.8 m width after two successive seasons. The outer canopy width had 0.90 m (2016) and 0.73 m (2017) (hedgerow width minus inner canopy width) and was formed exclusively of flexible young shoots (< 1 year old) (Fig. 1), with the resultant reduced potential to damage tree structure during passage of the harvester (~ 1.2 m shaking chamber width) (Connor et al., 2014).

Hedgerow width was similar at both harvests, 2016 and 2017, reaching 1.90 m (0.68 m increase from pruning 2015) and 1.73 m (0.41 m increase from pruning 2016) in 2016 and 2017, respectively. Lateral pruning on one hedgerow side maintained high production on the unpruned-side. Castillo-Llanque and Rapoport (2011) report that this response can contribute to controlling shoot growth on the pruned-side through vegetative and reproductive competition, offering consequent advantage to hedgerow management.

Hedgerow height reached 2.4 m and 2.9 m by growth increments of 0.30 m and 1.0 m during 2015–16 and 2016–17, respectively. Many new shoots that formed there in response to topping were flexible with capacity to bend within the harvester. They contributed little fruit, however, and further their vigor reduced irradiance within inner canopy positions. More studies on adequate topping management (height, timing and frequency) are required to understand the mechanisms of yield response with the objective to improve hedgerow productivity.

Horizontal porosity of hedgerow was 9.2% ± 3.5 and 4.7% ± 1.9 at harvest in 2016 and 2017, respectively, smaller than observed in narrow hedgerows in Central Spain (range 20–30%) (Trentacoste et al., 2015b; Gómez-del-Campo et al., 2017). The low porosity reduced radiation transmission towards inner canopy positions at harvest. Lateral pruning of one side, however, favored higher irradiance inside the hedgerows during the early growing season until the growth of new lateral- and top-growth shoots reduced transmission. After pruning, inner canopy positions were better illuminated by increased transmission from pruned sides. High canopy illumination during spring has been related to increase of flowering sites and improvement of fruit set within hedgerow canopies (Cherbiy-Hoffmann et al., 2012; Trentacoste et al., 2017).

3.2. Distribution of oil-yield components and fruit characteristics on either side of the hedgerows

The distributions of oil production, its components and fruit characteristics on either side of the hedgerows in 2016 and 2017 are presented in Tables 1 and 2. The hedgerows achieved oil production of 2.9

Table 2
Average fruit characteristics according to height, side and depth within olive hedgerows pruned on West sides in 2016 and East sides in 2017.

Canopy position		Pulp/pit		OCDW (%)[a]		FWC (%)[b]		Maturity index	
		2016	2017	2016	2017	2016	2017	2016	2017
Height	+2.5	7.0 a	7.4 a	58.7 a	53.0 a	63.6 c	58.6 b	1.4 a	2.3 a
	2.0-2.5	7.0 a	6.9 ab	57.0 ab	55.4 a	65.1 b	61.3 b	1.3 a	1.9 b
	1.5-2.0	6.3 b	6.4 c	55.6 b	52.3 bc	66.1 b	64.5 a	1.1 b	1.4 c
	1.0-1.5	5.9 c	6.5 c	52.4 c	50.9 c	68.7 a	65.8 a	0.1 b	1.2 c
	0.5-1.0	6.2 bc	6.5 bc	50.8 c	53.2 ab	69.1 a	65.3 a	1.1 b	1.2 c
Side	East	6.2	6.6	53.8	52.3	64.3	63.4	1.1	1.5 a
	West	6.7	6.1	55.8	51.0	65.7	61.7	1.2	1.3 b
Depth	Outer	6.4	6.6	55.5	52.6	66.6	63.1	1.2	1.5
	Inner	6.5	6.7	54.5	53.3	67.0	64.8	1.2	1.5
P-value	Height	< 0.001	0.014	< 0.001	< 0.001	< 0.001	0.003	< 0.001	< 0.001
	Side	0.081	0.122	0.317	0.467	0.606	0.308	0.117	0.002
	Depth	0.655	0.676	0.107	0.461	0.146	0.284	0.888	0.818

Values with the same letter are not significantly different within each year, height, sides and depths canopy positions of the hedgerows by LSD's test at $P \leq 0.05$. Letters only presented when ANOVA indicated significant effect.

[a] OCDW: Oil concentration in dry weight.

[b] FWC: Fruit water content.

and 2.1 t/ha in those seasons, respectively, markedly greater than the productive potential of Cañada Honda valley (1.3–1.5 t oil/ha) recently established by Tous and Romero (2017). In the 2015–16 season, fruit and oil production on West-pruned sides was 55% less than on the East-unpruned sides in response to less fruits (mean 58%) while other fruit characteristics remained similar. In the 2016–17 season, fruit and oil production on East-pruned sides was 68% smaller than on the West-unpruned sides, again in response to less fruit (mean 72%). In this season, however, there were evident fruit load difference between sides leading to greater fruit dry weight and earlier maturity on East than West sides, but similar water content (mean 61%), oil concentration (mean 54%) and pulp/pit ratio (mean 6.4).

Thus, production on pruned sides showed partial compensation between fruit weight and number. Since the hedgerows studied here were oriented N–S similar irradiance was available to either side, daily, seasonally, and annually (Trentacoste et al., 2015a). This effect on irradiance presumably contributed to reduce inter-annual differences in fruit characteristics, regardless of the pruned side. It could be expected that alternating lateral pruning in hedgerows with different orientations, especially E–W, would have different inter-annual responses to lateral pruning.

3.3. Distribution of oil-yield components and fruit characteristics in inner and outer locations of hedgerows

The distributions of oil production, its components and fruit characteristics on side and depth of the hedgerows in 2016 and 2017 are presented in Tables 1 and 2. In both seasons, fruit and oil production were distributed throughout the hedgerows but with greater concentration in the inner layer (0.5 m on each side of trunk). At 2016 harvest, 60 and 40% of total hedgerow production was present in inner and outer positions, respectively. In the following season oil production was concentrated 70% in inner positions.

Production in outer positions only occurred on unpruned-sides from remaining shoots that were more than 1 year-old. Inner positions recorded high and sustained production in both seasons. These results reveal that pruning of alternating sides allowed sufficient flower development in the inner canopy to maintain hedgerow production. Similarly, in a previous study Vivaldi et al. (2015) also showed a high proportion of fruiting shoots located near the trunk in cv. Arbosana. By contrast, the same authors also recorded low productivity in inner canopy near to trunks in vigorous cultivars such as Frantoio, Coratina and Leccino where lateral pruning could result in reduced production.

In either season, there were no differences in fruit characteristics between inner and outer positions despite the significant difference in fruit number. This is in contrast to observations in isolated vase-shaped olive trees (285 trees/ha) by Castillo-Ruiz et al. (2015). The finding in this study may be attributed to the short distances between outer and inner positions in hedgerows between which transport of assimilates is usually relatively high (Smith and Samach, 2013).

3.4. Vertical profile of oil-yield components and fruit characteristics at hedgerows

Vertical distributions of oil production, its components and fruit characteristics 2016 and 2017 are presented in Tables 1 and 2. Across sides and depths 70 and 55% of total oil production and fruit number, respectively, were concentrated within 1.0–2.0 m of canopy height. Distribution of oil-production components was similar down both pruned and unpruned sides, with maximum fruit density and oil production in middle canopy positions and decreasing toward the base, consistent with vertical oil yield component previously described in narrow hedgerows by Trentacoste et al. (2015b).

Fruit oil concentration and pulp/pit ratio were highest in the top layer and lowest at the base of the hedgerows. Fruit dry weight and maturity index decreased from the top and remained stable below 1.5 m height. In contrast fruit water content increased from canopy top to base.

In summary, the results presented here reveal that hedging alternating sides allowed maintenance of similar hedgerow dimensions and oil production in two successive growing seasons. Lateral pruning retained fruit load on one side that controlled vegetative growth on the pruned side and improved irradiance transmission within hedgerow, both possibly associated with productivity of inner layers. Suggested analyses for the future are other pruning strategies focused to define the impact of hedging frequency to one and both hedgerow sides, and also to other cultivars. Wider application of the methods developed here for analysis of yield profiles in outer and inner hedgerow positions, and efficiency of this research, could be improved by combination with corresponding profiles of irradiance. Such modeling (Connor et al.,

2016) was able to explain fruiting characteristics in narrow hedgerows with various row orientations and spacing in which fruits were located only in the outer canopy.

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