Elsevier Editorial System(tm) for Scientia Horticulturae
Manuscript Draft

Manuscript Number: HORTI13751R1

Title: Olive genotypes cultivated in an adult high-density orchard respond differently to canopy restraining by mechanical and manual pruning

Article Type: Research Paper

Section/Category: Tree crops, Fruit, Postharvest biology and storage studies, Tree and fruit physiology

Keywords: pruning mechanization, pruned biomass, tree canopy growth, olive yield, varietal behavior

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Abstract: Three-year observations about the canopy restraining of 15 olive cultivars trained according to the high-density system were made in order to supply up-to-date information about the varietal behavior for adult orchards of this new cropping system. The mechanical pruning started at the end of the 6th year from planting, and it was repeated for the following two years. Cultivar vigour affected pruning biomass and olive yield. Canonical discriminant analysis was performed to identify differences among cultivars. Medium-low vigour cultivars (Spanish and Greek) can be successfully controlled by mechanical and manual prunings without compromising their yield; instead, medium-high vigour cultivars (traditional and new Italian) require mechanical prunings to control canopy size, but this operation can hardly compromise their yield level and constancy. Further investigations are required to understand the right width of hedging to reach the correct equilibrium between vegetative and reproductive activity in adult orchards. At the moment, the correct varietal choice remains the only way to ensure the agronomical and economic sustainability of the high-density cropping systems, waiting for new results from breeding programs.

Highlights

Varietal behaviors cannot be distinguished on the basis of the biomass pruned

Italian cultivars require mechanical prunings to control canopy size

Mechanical prunings hardly compromise Italian cultivars yield level and constancy

Spanish and Greek cultivars can be controlled by mechanical and manual prunings

Manual pruning allows trees more suited to mechanical harvesting

Olive genotypes cultivated in an adult high-density orchard respond differently to canopy restraining by mechanical and manual pruning

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ABSTRACT

Three-year observations about the canopy restraining of 15 olive cultivars trained according to the high-density system were made in order to supply up-to-date information about the varietal behavior for adult orchards of this new cropping system. The mechanical pruning started at the end of the 6th year from planting, and it was repeated for the following two years. Cultivar vigour affected pruning biomass and olive yield. Canonical discriminant analysis was performed to identify differences among cultivars. Medium-low vigour cultivars (Spanish and Greek) can be successfully controlled by mechanical and manual prunings without compromising their yield; instead, medium-high vigour cultivars (traditional and new Italian) require mechanical prunings to control canopy size, but this operation can hardly compromise their yield level and constancy. Further investigations are required to understand the right width of hedging to reach the correct equilibrium between vegetative and reproductive activity in adult orchards. At the moment, the correct varietal choice remains the only way to ensure the agronomical and economic sustainability of the high-density cropping systems, waiting for new results from breeding programs.

Keywords: pruning mechanization, pruned biomass, tree canopy growth, olive yield, varietal behavior

1. Introduction

The new high-density oliveculture system, with over 1,200 trees per hectare, is characterized basically by a strong reduction of production costs thanks to the full mechanization of all agricultural practices, from planting to harvesting, operated by over-the-row machines (Camposeo et al., 2008). In the high-density olive orchard, the concept of the individual tree is substituted by that of the continuous hedge (Connor et al., 2014). Pruning is essential to set up the entire cropping system; in fact, in this oliveculture, pruning must (i) quickly shape the canopy as a continuous hedgerow, (ii) easily keep it at the size required by the continuous harvesting machine employed and (iii) allow stable yield level of 7-10 t of olives per hectare for as long a time as possible (Caruso et al., 2014; Godini et al., 2011). In particular, the problem of pruning mechanization arises from the necessity of equilibrating two conflicting requirements: saving the productive branches and, at the same time, restraining the canopy section crosswise to the direction of the hedgerow, within the limits compatible with the harvest tunnel sizes (height, thickness, form); these last may vary for different harvesting machines and, for each one, with possible adjustments (Tous, 2011). Pruning is a technique yet to be defined for this cropping system: when to start and which operations, times, and turns are topics still under investigation (Tombesi et al., 2012; 2014).

Canopy restraining in high-density olive orchards could be carried out mechanically for topping, hedging and trimming, and manually for thinning. Pruning by topping and hedging limits the olive canopy height and width at 2.5-2.7 m and 1.5-2.0 m, respectively, according to the harvester tunnel sizes (Tous et al., 2010). Trimming is the cutting of the branches placed below the olives intercepting members (scales, buckets) of the straddle harvesters that are generally positioned at 50-70 cm from the ground in order to allow herbicide application and limit fruit losses; trimming is already necessary starting from the first bearing and removes only the part of canopy that is not harvested by the harvester machine (Tombesi et al., 2014). Thinning is the cutting of the branches transverse to the direction of the hedgerow, with a cross section over 3-4 cm, in order to avoid beater damages; thinning usually occurs from the 3rd-4th year after planting. This manual thinning commonly integrates the annual mechanical hedging regulating the vegetative flat surface width to a distance not over 50-60 cm from the central axis at each side of the tree/hedgerow. Nonetheless, manual thinning could be completely replaced by a heavy mechanical hedging made every three years by cutting off the lateral canopy at 15-20 cm from the central axis on alternating sides, even if this kind of pruning is still in the experimental phase (Rius and Lacarte, 2010).

The canopy restraining mechanization by topping, hedging and trimming is done with machines that arose from the disk pruners employed for a time in traditional and intensive grape, citrus and other orchards (Gatti et al., 2011; Intrigliolo and Roccuzzo, 2011; Kurtural et al., 2013; Malvicini et al., 2014).

Manner, time and frequency of canopy restraining execution in high-density olive orchards mainly depend on tree age, varietal behavior and pedoclimatic conditions, but the main factor affecting pruning is the vigour of the cultivated genotype (Connor et al., 2014). On the other hand, appropriate cultivar selection represents the key factor for success of the whole high-density oliveculture system (Caruso et al., 2014). Indeed, up to now only two Spanish cultivars, Arbequina and Arbosana, and the Greek Koroneiki have been demonstrated to have vegetative (medium-low vigour, slow canopy growth) and productive (early bearing, high yield efficiency) parameters fitting this new cropping system (Camposeo et al., 2008; Camposeo and Godini, 2010; Connor et al., 2014). Several aspects of varietal behavior have already begun to be studied for this new cropping system in Mediterranean environments: productive and vegetative parameters (Camposeo et al., 2008; Tous et al., 2010; Tombesi and Farinelli 2011, 2014; Allalout et al., 2011; Moutier et al., 2011; Papachatzis et al., 2011; Larbi et al., 2015; Proietti et al., 2015), plant architecture (Rosati et al., 2013; Strippoli et al., 2013), light interception (Connor and Gómez-del-Campo, 2013), soil management (Camposeo and Vivaldi, 2011; Russo et al., 2014), ecophysiology and irrigation (Proietti et al., 2012; Gómez-del-Campo, 2010; 2013; Vivaldi et al., 2013), harvesting time (Camposeo et al., 2013). So, varietal response to pruning is still a crucial topic to be investigated in order to supply information about the agronomic management of high-density oliveculture for different cultivated genotypes (Connor et al., 2014). In fact, once introduced the over-the-row harvesters, pruning became the operation requiring about 48% of the total cropping practices costs, the largest economic investment (Rius and Lacarte, 2010). Moreover, in young high-density orchards (<4 years old) pruning operations should be limited to trimming in order to avoid the tree equilibrium imbalance between vegetative and reproductive activity (Tombesi et al., 2014). No data are available in the literature about canopy management for adult high-density olive orchards (>5 years old) but only for other tree species (Schupp et al., 2008; Velázquez Martí et al ., 2010; Martin-Gorriz et al., 2014).

This paper concerns three-year observations made in the Apulia region (Southern Italy) regarding the canopy restraining of 15 different Italian, Spanish and Greek olive cultivars in an adult high-density olive orchard (6-8 years old) in order to investigate the varietal response to mechanical and manual pruning.

2. Materials and methods

2.1. Orchard characteristics

A three-year study (2011-2013) was carried out in the olive grove located at the department experimental farm at Valenzano (Bari, Southern Italy; 41° 01 N; 16° 45 E; 110 m a.s.l.) on a sandy clay soil (sand, 630 g kg^{-1}; silt, 160 g kg^{-1}; clay, 210 g kg^{-1}) classified as a Typic Haploxeralf (USDA) or Chromi-Cutanic Luvisol (FAO). The site is characterized by a typical Mediterranean climate with a long-term average annual rainfall of 560 mm, two-thirds concentrated from autumn to winter, and a long-term average annual temperature of 15.6 °C. The olive grove was planted in spring 2006; the trees were trained according to the central leader system and spaced 4.0 m × 1.5 m (1,667 trees ha^{-1}) with a north–south row orientation, according to the Spanish high-density cropping system. Props, drip irrigation and routine cultural practices (nutrition, weeds and disease control) were set up as already described (Camposeo and Vivaldi, 2011; Camposeo et al., 2013). First significant yield occurred in autumn 2008, at the 3rd year after planting (Camposeo and Godini, 2010).

2.2. Pruning operations

Starting from winter 2009-2010, at the end of the 4th year after plantation (YAP), only thinning was operated every year. In winter 2012 (end of 6th YAP) mechanical pruning started. The study was carried out for three consecutive years: 2011, 2012 and 2013, at 6th, 7th and 8th YAP, respectively. The pruning operations performed during these three years are reported in Table 1. Within a year, all cultivars are subjected to the same pruning operations (Fig. 1).

The topping and hedging operations were executed at a height of 240 cm from the ground and at 50 cm from the central stem, respectively. Both operations were carried out by means of a double articulated disk pruner (model PF-40.14-D, Jumar Agricola sl, Spain), coupled at the front of a tractor (Fig. 2). This pruner worked on two rows simultaneously, going along the inter-row with an average travel speed of 0.55 m s^{-1}.

The mechanical cutting of the branches placed at 60 cm from the ground was carried out by means of a trimming machine (model NBH 1090 D, Jumar Agricola sl, Spain), coupled at the front of a tractor (Fig. 3). This implement, realized on a bilateral mast, was equipped with a mechanical scanner system to operate without damaging the stems. Also, the trimming machine operated on two rows simultaneously, going along the inter-row with an average travel speed of 0.40 m s^{-1}.

Thinning was operated manually, cutting off the branches with a cross section over 3-4 cm and transverse to the direction of the hedgerow (Fig. 4).

2.2. Experimental design

The study was performed on 15 cultivars (= plots): the well-adapted Arbequina, Arbosana and Koroneiki, in comparison with the most diffused traditional (Carolea, Cima di Bitonto, Coratina, Frantoio, Leccino, Maurino, Nociara and Peranzana) and new (Don Carlo, Fs-17, I-77 and Urano) Italian cultivars. Fs-17 and Urano showed interesting features for high-density oliveculture (Camposeo et al., 2008); the remaining Italian traditional and new cultivars are characterized by medium to high vigour and late bearing (Godini, 2000; Tombesi 2011). Each plot included 38 trees belonging to the same cultivar; the 15 plots are randomly arranged in the experimental field. For each plot, 15 trees (3 replications of 5 contiguous trees) were labelled, on which every year were measured in the following order: tree fruit production (Y; kg tree^{-1}) by manual harvesting; canopy height (H; cm); canopy transversal width (W; cm); fresh biomass belonging to manual pruning (thinning, MAB; kg tree^{-1}); fresh biomass belonging to mechanical pruning (topping, hedging, trimming, MEB; kg tree^{-1}). Finally, the total pruning biomass (TOB; kg tree^{-1}) was calculated as MAB + MEB.

2.3. Statistical analyses

Descriptive statistics were computed to synthesize the main features of data distribution. Assumption of normality was evaluated through the Shapiro-Wilk test and homogeneity of variances through the Levene test. As most parameters showed departure from normality and heteroscedasticity (data not shown), a non-parametric analysis of variance (Kruskal-Wallis test) was performed and the Nemenyi-Damico-Wolfe-Dunn test ($p<0.05$) was used to assess differences among groups by using the R 2.15.0 software (R Foundation for Statistical Computing). The Spearman's correlation coefficients were calculated separately for Italian and non-Italian cultivars, to better evaluate varietal behaviors and pruning effects.

Canonical discriminant analysis (CDA) was performed to identify differences among the groups of olive cultivars as a function of 4 variables: H, W, TOB and Y. A biplot was thus computed in order to show simultaneously mean (canonical) scores of the canonical variables (CDF) and standardized canonical coefficients, as geometric vectors for each variable. The centroids of the experimental groups were plotted in an ordination diagram in which the bidimensional space is represented by the first two canonical variables. CDA was performed using R 2.15.0 software (R Foundation for Statistical Computing Vienna, Austria). This multivariate analysis procedure has already been successfully used in olive (Petrakis et al., 2008).

3. Results

3.1. Canopy sizes

In Figure 5 and in Figure 6, canopy H and W mean values of the 15 cultivars during the three years are reported, respectively. At the end of the 6th year after planting (autumn 2011), all the cultivars abundantly exceeded the threshold values of 2.5 m in H and of 1.0 m in W. The mean H was 3.5 m, and the mean W was 2.3 m. In particular, most of the Italian genotypes and the Greek Koroneiki overcame 3.5 m in H and 2.0 m in W; absolutely, Leccino, Nociara and Peranzana exceed 2.5 m in W; only H of Arbosana and Urano trees was under 3.0 m, and only Fs-17, I/77 and Arbosana trees were narrower than 2.0 m. The first ever mechanical pruning, made in February 2012, restrained all the canopies at 2.4 m in H and 1.0 m in W.

At the end of the 7th year after planting (one year after the first ever mechanical pruning; autumn 2012), H fell within the range 2.5-3.0 m for all the cultivars, and about one half of them were narrower than 2.0 m; none exceeded 2.5 m in W. The mean H was 2.8 m, and the mean W was 2.0 m. The second mechanical pruning, made in March 2013, restrained all the canopies at the same standard size.

At the end of the 8th year after planting (one year after the second-ever mechanical pruning; autumn 2013), the cultivars fell within the range 2.7-3.3 m in H and 1.8-2.2 m in W. The mean H was 3.0 m, slightly greater than the previous year, and the mean W was 2.0 m, identical to the previous year. Arbequina, Arbosana and Urano showed, in both years after mechanical pruning, the lowest H and W values.

3.2. Pruning biomass

3.2.1. Total pruning biomass

The cultivated varieties under study showed different amounts of TOB over three years (Fig. 7). At the first pruning, Coratina, Cima di Bitonto, Fs-17, Leccino, Koroneiki, Frantoio and I/77 showed values between 3.2 and 4.2 kg per tree; Carolea reached about 5 kg per tree; for the remaining cultivars, the TOB values ranged from 1.6 kg per tree (Peranzana) to 2.2 kg per tree (Arbequina); Arbosana showed the lowest value of 0.8 kg per tree. At the second pruning, Carolea again reached the highest value (1.7 kg per tree); Frantoio, Cima di Bitonto and Koroneiki showed values between 1.0 and 1.4 kg per tree; for the remaining cultivars, the TOB values were less than 1.0 kg per tree: Peranzana showed the lowest value of 0.4 kg per tree. Finally, in 2013, Coratina and Urano showed the highest values (6.8 and 5.3 kg per tree respectively), followed by Leccino, Frantoio and Cima di Bitonto (5.16, 5.0 and 4.8 kg per tree respectively). All the other cultivars ranged from 2.0 kg per tree (I-77) and 3.9 kg per tree (Koroneiki). Only Arbosana did not surpass 1.5 kg per tree.

3.2.2. *Biomass form mechanical and manual pruning*

Data on pruning biomass coming from mechanical (MEB) and manual (MAB) operations highlighted significant differences among cultivars in all years (Figs. 8-9).

At the first pruning, the MEB values spread the genotypes into the same ranks as TOB values did. Cima di Bitonto, Leccino, Frantoio, Coratina, Fs-17, Koroneiki and I/77 showed values between 3.0 and 3.9 kg per tree; Carolea reached 4.8 kg per tree; the values of MEB for the remaining cultivars ranged from 1.4 kg per tree (Nociara) to 2.1 kg per tree (Urano); Arbosana showed the lowest value of 0.6 kg per tree. At the second pruning, Carolea, Cima di Bitonto and Frantoio showed the highest values (1.0-1.5 kg per tree), while the remaining cultivar produced MEB values ranging from 0.3 kg per tree (Peranzana and Nociara) to 0.7 kg per tree. Also, for TOB in 2013, Coratina, Urano, Leccino and Cima di Bitonto showed the highest MEB values (4.0 to 6.0 kg per tree); on the contrary, Arbosana showed the lowest one of 0.7 kg per tree.

MAB values were, in general, similar among the cultivars, and they did not exceed 1.0 kg per tree, except Frantoio at the third year. Moreover, MAB values represented 18% of the TOB, on average, and they tended to increase from the 6^{th} to 8^{th} YAP for most of the cultivars, except for Arbequina and Fs-17.

3.3. Olives yield

In Figure 10, olives productions per tree (Y) are reported. In 2011, at the 6^{th} YAP, Arbequina, Arbosana, Koroneiki and Maurino showed the highest Y (about 6.4 kg tree^{-1} on average), followed by Peranzana, Nociara and Urano, which yielded a mean of about 4.0 kg tree^{-1}. All the other cultivars showed significantly lower, as Coratina (1.5 kg tree^{-1}), and negligible Y values, such as Carolea, Cima di Bitonto, Don Carlo, Frantoio, Fs-17, I/77 and Leccino. In the following year (2012, 7^{th} YAP), after the first mechanical pruning, Arbequina and Arbosana were again the most productive ones (5.8 and 4.8 kg tree^{-1}, respectively), followed by Don Carlo and Nociara (4.0 kg and 3.5 kg tree^{-1}, respectively), while Koroneiki collapsed around 1.0 kg tree^{-1}, together with, Peranzana, Urano. Cima di Bitonto, Coratina and Maurino did not produce. Finally, in the last year of the trial (2013, 8^{th} YAP), after the second mechanical pruning, Koroneiki came back to be the most productive cultivar (6.8 kg per tree^{-1}), followed by Don Carlo, Arbosana and Arbequina (5.0 kg tree^{-1}, 4.6 kg tree^{-1} and 4.5 kg tree^{-1}, respectively). Coratina, Frantoio, Fs-17, I/77, Leccino, Maurino, Urano did not surpass 1.0 kg tree^{-1}. Nociara and Peranzana showed a more yield constancy (3.5 kg tree^{-1} and 2.3 kg tree^{-1} on average, respectively).

3.4. Canonical discriminant analysis

CDA showed a canonical correlation of 79.0% of total variation. The first canonical function (CAN1), which explained 41% of total variation, was positively correlated to yield (Y; 0.69) and negatively to crown width (W; -1.10); lower positive values were observed for TOB (0.32). On the second canonical function (CAN2), which explained 38.0% of total variation, Y and W weighted more and negatively (-0.87 and -0.81), and H and TOB positively (0.62 and 0.29) (Fig. 11). Thus, CAN1 allowed the identification of two major groups of cultivars: the first more productive (with Arbequina and Arbosana as highest yielding cultivars), and the second characterized on average by higher crown width (with highest values for Leccino and Nociara). In addition, CAN2 allowed cultivars with higher or lower values of both crown width and yield to be distinguished (Fig. 11).

4. Discussion

In an adult high-density olive orchard, the canopy has to be managed in order to have a continuously good yield level (around 5 kg tree^{-1}) and to respect harvesting machine requirements: 250 cm in height and 150 cm in width (Tombesi et al., 2014, Tous et al., 2011). When canopy growth exceeds these limits, the main problem is the yield decrease due to reciprocal shading (Gómez del Campo et al., 2009). At this moment, mechanical pruning becomes necessary. All examined cultivars overcame these limits at 6th YAP. On average, the first topping operation reduced the canopy height by 28%, while the following second and third interventions reduced it by only 10% and 17%, respectively. In contrast, hedging reduced canopy width of the same quantity (50%) in both years, on average. These data are supported by the values of MEB: in particular, Arbequina, Arbosana and Peranzana always showed the lowest MEB values, while the other Italian cultivars showed, in general, the highest ones. The different tree vigour is the key factor (Connor et al., 2014; Godini et al., 2011). Koroneiki behaved as a more vigorous cultivar with respect to the two Spanish ones, confirming what was reported in different environments (Tous et al., 2011). The significant lower values of MEB and TOB in 2012 are clearly due to the lack of hedging during this year.

After mechanical prunings, yields of the medium-low vigour cultivars (Arbequina, Arbosana, Nociara and Peranzana) were not changed significantly with respect to previous values. In contrast, yield performances of the more vigorous, late bearing Italian cultivars were certainly inadequate, with an unclear response to pruning. Removal of peripheral branches by mechanical topping and hedging decreases canopy volume but increases sylleptic bud breaking and sprout growth, while the competition between vegetative and reproductive shoots reduce total fruit yield, especially for medium-high vigour cultivars (Tombesi and Farinelli, 2011). Arbequina and Arbosana behaviors demonstrated that these two cultivars did not alternate, maintaining a high level of production near

5.0 kg tree^{-1} as the high-density system requires (Camposeo and Godini, 2010); moreover, prunings performed did not influence their yield. Nociara and Peranzana showed similar behavior, but their production levels were under this threshold value, never overcoming 4.0 kg tree^{-1}. On the other hand, Spearman's correlation coefficients highlighted that (i) yields of the well-adapted cultivars, Arbequina, Arbosana and Koroneiki, did not depend on quantity of biomass pruned and that (ii) mechanical and manual pruning biomasses are independent (Tab. 2). As already observed, the Spanish cultivars invest less in permanent structures per unit of fruiting sites, so they have more branches with smaller diameters, with more fruiting shoots per unit of canopy volume (Rosati et al., 2013). On the contrary (Tab. 3), Italian cultivars' yields were significantly and negatively affected by mechanically pruned biomass, and this last is correlated with the manual one, i.e. with the quantity of thinned transversal branches. The traditional and new Italian cultivars indeed have branches that are fewer in number but are thicker and longer, with fruiting shoots mostly concentrated in the periphery of the canopy; this results in a serious loss of production sites, especially during mechanical pruning (Pascuzzi and Guarella, 2010; Rosati et al., 2013). Heavy pruning reduces fruit yield also for other tree species (Ikinci, 2014; Sabbatini et al., 2015).

On the other hand, in this high-density olive orchard, repeated manual pruning as annual thinning established palmette-shaped olive trees for both well-adapted cultivars, such as Koroneiki, and poorly-adapted cultivars, such as Coratina (Fig. 12). Unfortunately, this acquired tree shape did not change the tree vigour, as already reported for olive (Moutier et al., 2011); the contrary happens for pear (Corelli-Grappadelli, 1998) and cherry (Moreno et al., 1998).

In general, CDA demonstrated that varietal behaviors cannot be distinguished on the basis of the biomass pruned, being TOB vector very little. Notwithstanding, CDA allowed to highlight the vegetative–reproductive balance, discriminating 5 different cultivar groups as functions of W and Y. The first group encloses the well-adapted genotypes (Arbosana, Arbequina and Koroneiki) showing higher Y and lower W; the second group (Peranzana, Nociara and Urano) those with good Y but highest W; the third group (Carolea and I/77) those characterized by poor Y and lowest W; the fourth group (Coratina, Frantoio, Cima di Bitonto and Leccino) those showing lowest Y and medium W. The last group (Maurino, Don Carlo and Fs-17) showed scores of centroids very near the axes' origin, thus with no prominent features (negative or positive) and values close to the average.

5. Conclusions

From a productive point of view, canopy restraining of medium-low vigour cultivars, such as Arbequina, Arbosana and Koroneiki, can be successfully controlled by mechanical (topping, hedging and trimming) and manual (thinning) prunings, because the branches removed are those that get stuck within the tunnel of the harvester machine, and fruiting shoots are well spread inside the canopy. On the contrary, medium-high vigour cultivars, such as traditional and new Italian, require mechanical prunings, especially hedging, to control canopy size and to allow the passage of the harvesting machine, but this operation hardly compromises their yield level and constancy because fruiting shoots are mostly concentrated in the periphery of the canopy.

From a mechanical point of view, manual pruning makes trees of both Spanish-Greek and Italian cultivars more suited to continuous harvesting, thanks to its palmette shaping, but it could not be useful for medium-high vigour control of Italian genotypes.

These are the first ever data available in the literature about canopy management of an adult high-density orchard up to the eighth year after plantation: this period represents its estimated half-life (Connor et al., 2014). Further investigations are required to understand the right width of hedging to reach the correct equilibrium between vegetative and reproductive activity in adult orchards, with an architectural approach. At the moment, the correct varietal choice remains the only way to keep agronomical and economic sustainability of the high-density cropping systems, because low vigour and slow growing are confirmed as relevant parameters for this new oliveculture.

Acknowledgments

This research had the partial financial support of the National Research Program (PRIN-MIUR, Project "Biological processes and environmental factors involved in the vegetative growth, fruiting and oil quality control in superintensive olive (*Olea europaea* L.) plantings" and the grant of the University of Bari.

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Table(s)

Table 1.
Pruning operations performed in the adult high-density olive orchard during the three subsequent years (YAP = year after plantation).

Pruning operations		End 6th YAP (Feb. 2012)	End 7th YAP (Mar. 2013)	End 8th YAP (Feb. 2014)
Mechanical	**Topping**	X	X	X
	Hedging	X		X
	Trimming		X	X
Manual	**Thinning**	X	X	X

Table 2.
Spearman's correlation coefficients during three years for Spanish and Greek cultivars (n= 45; *** p≤0.001; ** p≤0.01; n.s. = not significant).

	MAB	**MEB**	**H**	**W**	**Y**
TOB	0.17 ns	0.45 **	0.46 **	0.38 **	-0.06 ns
MAB	1.00	0.11 ns	-0.02 ns	-0.01 ns	0.06 ns
MEB		1.00	0.66 ***	0.53 ***	0.03 ns
H			1.00	0.67 ***	0.08 ns
W				1.00	-0.14 ns

Table 3.
Spearman's correlation coefficients during three years for Italian cultivars (n = 180; *** p≤0.001; ** p≤0.01; n.s. = not significant).

	MAB	**MEB**	**H**	**W**	**Y**
TOB	0.18 ns	0.47 ***	0.64 ***	0.31 ***	-0.31 ***
MAB	1.00	0.29 ***	-0.02 ns	-0.08 ns	0.02 ns
MEB		1.00	0.58 ***	0.29 ***	-0.21 **
H			1.00	0.46 ***	-0.04 ns
W				1.00	-0.08 ns

Figures

Fig. 1: Olive trees hedgerow before (left) and after (right) mechanical pruning.

Fig. 2: Double articulated disk pruner machine at work for topping.

Fig. 3: Trimming machine at work.

Fig. 4: Manual pruning (thinning).

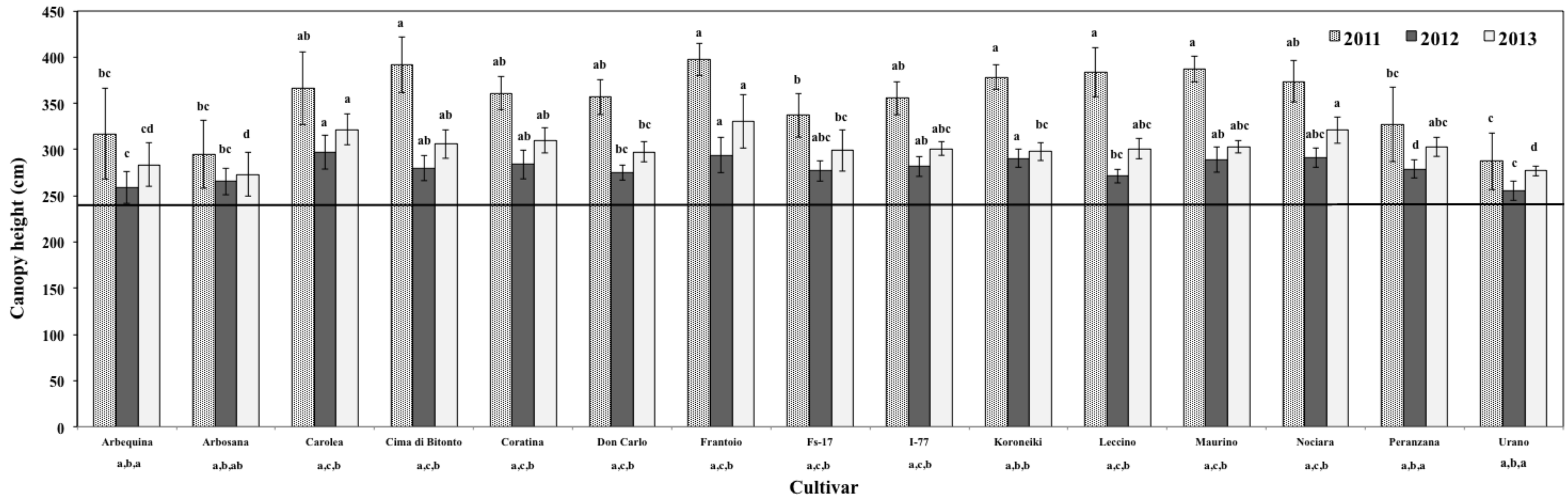

Fig. 5: Canopy height (cm) of 15 cultivars during 2011, 2012 and 2013. Means within each cultivar are separated by Nemenyi-Damico-Wolf-Dunn test (P<0.05). Error bars show ± SE. Letters on x-axis denote statistical differences among years for each cultivar; letters on histograms denote statistical differences among cultivars for each year.

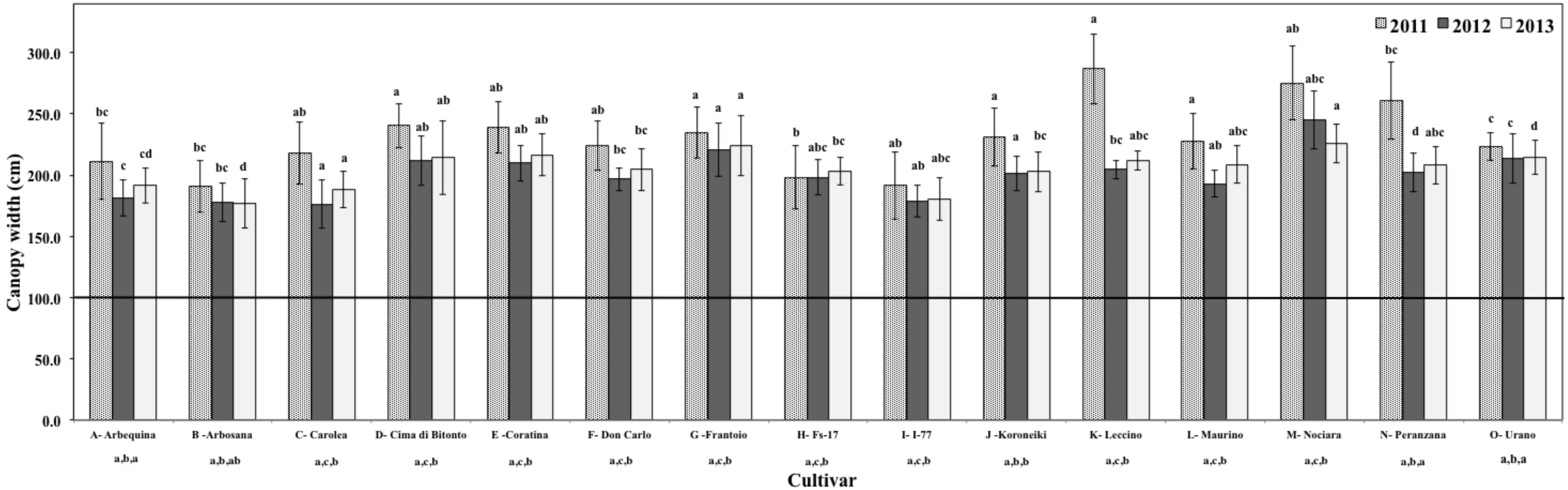

Fig. 6: Canopy width (cm) of 15 cultivars during 2011, 2012 and 2013. Means within each cultivar are separated by Nemenyi-Damico-Wolf-Dunn test (P<0.05). Error bars show ± SE. Letters on x-axis denote statistical differences among years for each cultivar; letters on histograms denote statistical differences among cultivars for each year.

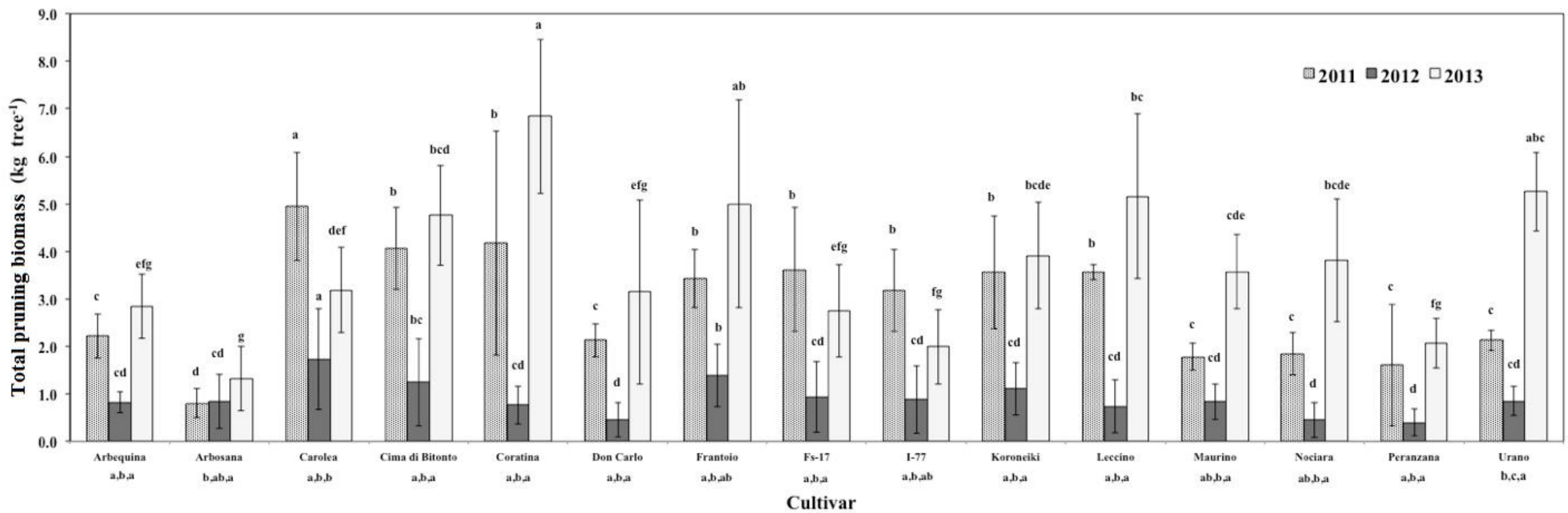

Fig. 7: Total pruning biomass (kg tree^{-1}) of 15 cultivars during 2011, 2012 and 2013. Means within each cultivar are separated by Nemenyi-Damico-Wolf-Dunn test ($P<0.05$). Error bars show ± SE. Letters on x-axis denote statistical differences among years for each cultivar; letters on histograms denote statistical differences among cultivars for each year.

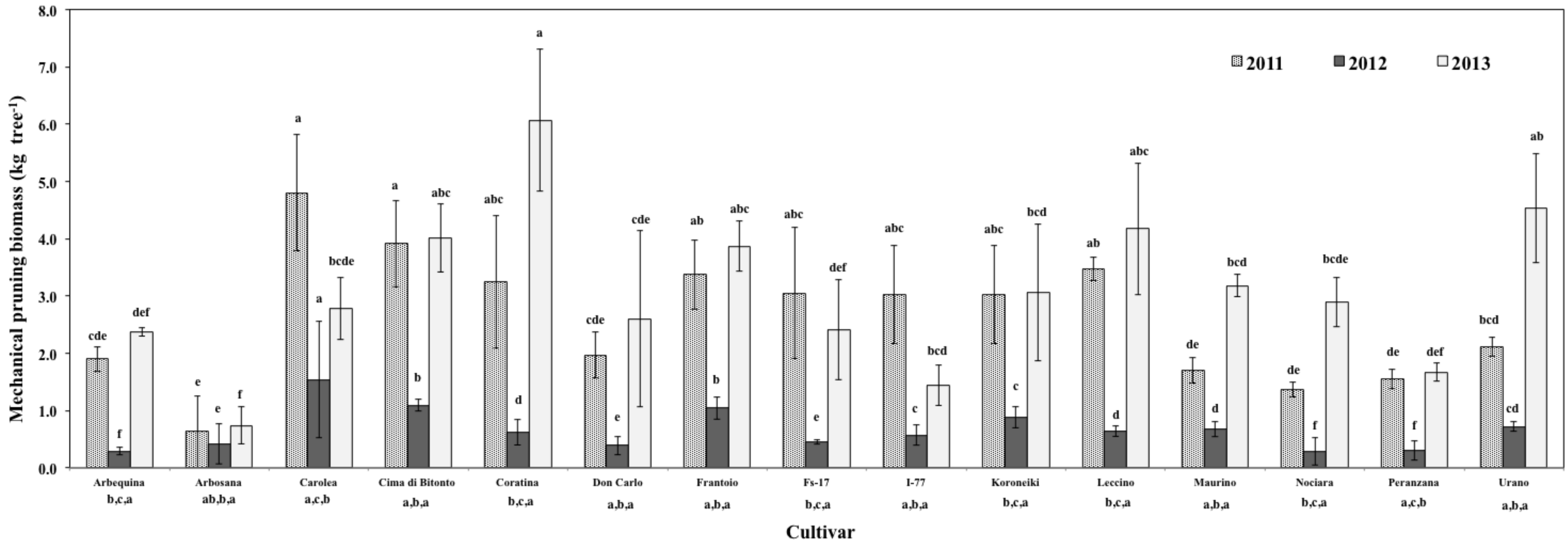

Fig. 8: Mechanical pruning biomass (kg tree^{-1}) of 15 cultivars during 2011, 2012 and 2013. Means within each cultivar are separated by Nemenyi-Damico-Wolf-Dunn test (P<0.05). Error bars show ± SE. Letters on x-axis denote statistical differences among years for each cultivar; letters on histograms denote statistical differences among cultivars for each year.

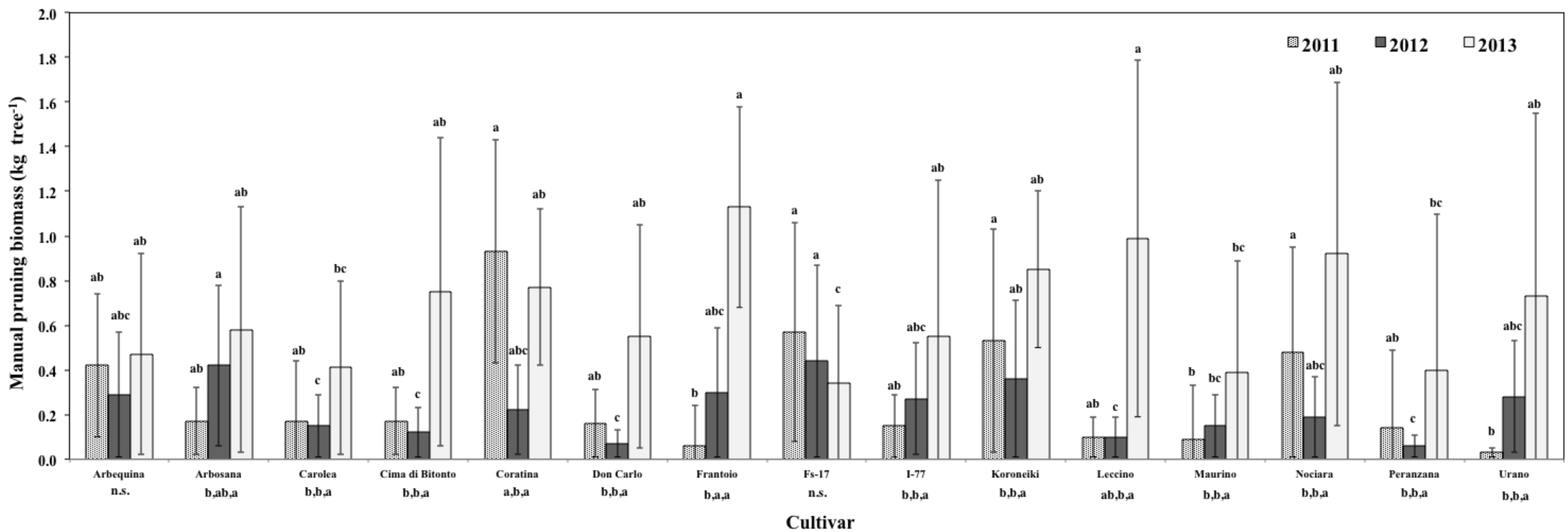

Fig. 9: Manual pruning biomass (kg tree^{-1}) of 15 cultivars during 2011, 2012 and 2013. Means within each cultivar are separated by Nemenyi-Damico-Wolf-Dunn test (P<0.05). Error bars show ± SE. Letters on x-axis denote statistical differences among years for each cultivar; letters on histograms denote statistical differences among cultivars for each year.

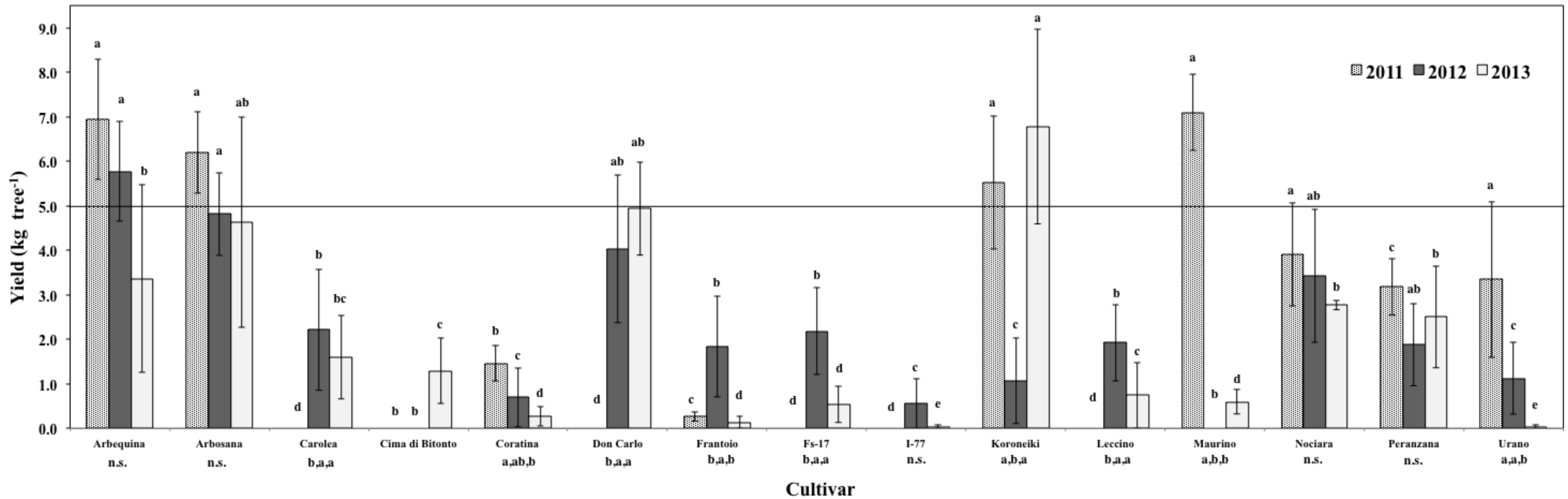

Fig. 10: Yield (kg tree^{-1}) of 15 cultivars during 2011, 2012 and 2013. Means within each cultivar are separated by Nemenyi-Damico-Wolf-Dunn test (P<0.05). Error bars show ± SE. Letters on x-axis denote statistical differences among years for each cultivar; letters on histograms denote statistical differences among cultivars for each year.

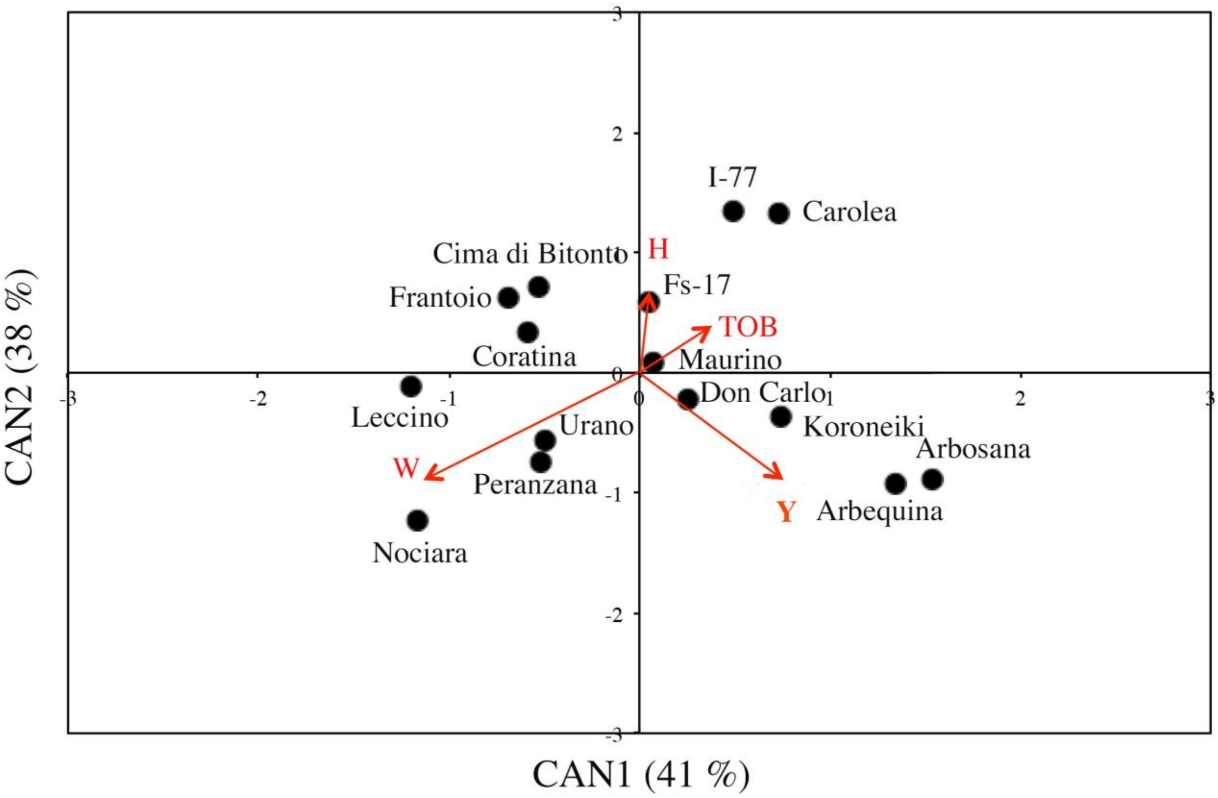

Fig. 12: Distribution of olive cultivars based on the first (CAN1) and second (CAN2) canonical functions of four parameters canopy (vectors); height (H), canopy width (W), total pruning biomass (TOB) and yield (Y).

Fig. 12: Coratina (left) and Koroneiki (right) trees palmette-shaped by repeated annual thinning