Lemon trees response to different long-term mechanical and manual pruning practices

Bernardo Martin-Gorriz[1,*], Carlos Martinez Barba[1], Antonio Torregrosa[2]

[1] Escuela Técnica Superior de Ingeniería Agronómica, Universidad Politécnica de Cartagena. Paseo Alfonso XIII, 48. 30203 Cartagena, Spain.

[2] Universitat Politècnica de València. Dpto. Ingeniería Rural y Agroalimentaria. Camino de Vera s/n, 46022, Valencia, Spain.

* *Corresponding author*: b.martin@upct.es

Abstract

Mechanical pruning can be integrated into a management strategy to reduce pruning costs in lemon [*Citrus x Lemon* (L.) Osbeck] orchards. The present study evaluates mechanical pruning combined with manual pruning in the 'Fino 95' lemon cultivar over four years. Five pruning treatments involving different intensities of mechanisation have been carried out: (1) manual pruning (control); (2) mechanical pruning of all the tree (topping, skirting and both sides hedging) in even years and manual pruning of all the tree in odd years; (3) top and skirts mechanically pruned and follow-up manually pruned; (4) mechanical pruning of all the tree with the exception of a lateral side and manual pruning of that half side of the tree; and finally, (5) mechanical pruning of top, skirts and one side of the tree, with the opposite side remaining unpruned, and alternating the pruned and unpruned sides yearly. Pruned biomass, pruning costs, yield, fruit size and net economic value have been analysed. The results of four years of observations have proved that the treatment of manual pruning alternated yearly with mechanical pruning and the treatment of exclusively mechanical pruning reduced the time required to perform the task, and also increased the economic benefit obtained,

with respect to manual pruning. Farmers will find the treatment of mechanical pruning alternated annually with manual pruning to be more acceptable, since the tree management differs very little from the traditional system. The treatments consisting in manual and mechanical pruning (3 and 4) carried out in the same year obtained the worst results: they failed to reduce the time required to perform the task, and did not increase the yield and consequently the economic profit.

Keywords: 'Fino 95'; Citrus; Crop management; Mechanisation; Agricultural machinery.

1. Introduction

Spain is the second largest producer of lemons in the world, after Argentina, but is the first global exporter of lemons for fresh consumption. Spanish lemon production is concentrated in the Mediterranean area of the regions of Murcia, Valencia and Andalusia. 'Fino' and 'Verna' are the leading lemon varieties grown in Spain, accounting for 72 and 26 percent of the total production, respectively (MAPA, 2020). Spain produces lemons mainly for the fresh market, and exports 94% of its production to other EU countries, mainly to Germany, France, and the United Kingdom (FEPEX, 2020).

In recent years, the profitability of the citrus crop has decreased in Spain, with 2018 being the worst citrus season in the last 25 years (Maestre, 2018). Several consecutive years of economic slowdown have affected the Spanish citrus sector, driving farmers to leave citrus production in favour of more profitable crops such as avocado (USDA, 2018).

The competitiveness of citrus producers must be improved, and a key factor for this is the reduction of costs through mechanisation. The mechanisation of farming practices on citrus orchards is lower than other fruit crops such as olives, apples, grapes, etc. (Chueca et al, 2020); principally due to the focus on marketing high-quality fresh produce (Caballero et al., 2010). After harvesting, pruning is the second most expensive task in the Spanish citrus crop production. Overall, manual pruning costs represent between 10% and 15% of the total costs of citrus production (Mateu et al., 2018); and account for between 30% and 50% of the total labour costs in citrus production (Martin-Gorriz et al., 2018). Consequently, pruning mechanisation is one of the most appropriate objectives aimed at reducing costs.

Pruning practices in citriculture are important in supporting plant health to reach an acceptable balance between vegetative and reproductive growth, which is a key factor in many stages of citrus grove development (Intrigliolo and Roccuzzo, 2011). In general, the tree response to pruning depends on several factors, including variety, rootstock, tree age, growing conditions, time of pruning, and production practices (Vashisht et al., 2019).

The first trials of non-selective mechanical pruning were carried out in the USA in the 1960s (Moore, 1958); and today, hedging and topping are very common cultural grove-management practices in Florida (Vashisht et al., 2019). The first pruning machines in Spain for pruning citrus trees were tested nearly fifty years ago. 'Washington Navel' and 'Salustiana' oranges were used in experimental trials comparing non-pruning, hand pruning, mechanical pruning, and mechanical pruning followed up by hand pruning (Ortiz-Cañavate, 1979; Zaragoza and Alonso, 1980, 1981); these trials compared non-pruning, hand pruning, mechanical pruning, and mechanical pruning followed up by hand pruning. After one year of pruning, all the trees remained unpruned the following year. The experiment was conducted over four years and on two orange varieties, 'Washington Navel' and 'Salustiana'. It was noticed that in the year of pruning, the yield in the pruned trees decreased with respect to the unpruned trees, but in the following year, when all the trees remained unpruned, yields were similar in all the treatments. On average for the two biennia, the yields in all pruning treatments of ‘Washington Navel’ oranges were lower than in no-pruning treatments (14%). In ‘Salustiana’ oranges, however, there were no differences between unpruned or hand pruned trees, but there was a reduction of 17% in the yield of those that were pruned mechanically with respect to the unpruned ones. There were no differences between trees pruned mechanically and those that were pruned first mechanically and then followed up by hand. Fruit size was inversely proportional to yield, but no appreciable differences were observed among pruning treatments in terms of the soluble solid content, acidity or maturity index. Since then, very few experiences on mechanical pruning have been published in Spain. After that, interest in mechanical pruning declined, but with the need to reduce production costs in the decade 2009-2019, it once again attracted attention. A number of experiments were carried out in this period, pre-pruning, hedging and topping cutting planes combined or not with hand-pruning in ‘Valencia Late’ oranges (Velázquez and Fernández, 2010); and in ‘Fortune’ mandarins (Martin-Gorriz el al., 2014). Currently, mechanical pruning, either alone or in combination with hand pruning, is used by some Spanish citrus farmers, mainly orange growers. However, lemon growers have not adopted the technique very widely yet; among other reasons due to a lack of experience in mechanical pruning by the Spanish fresh market citrus farmers.

The aim of the present research was to obtain detailed information on the response of ‘Fino 95’ lemon trees to mechanical pruning and how it should be integrated with manual pruning into a management strategy to reduce pruning costs. This information would help farmers and technicians to improve their pruning decisions to produce fresh market lemons.

2. Materials and Methods

2.1. Experimental site

The trials were performed in an orchard of 'Fino 95' (*Citrus limon* (L.) Burm F.) lemons grafted on 'Cleopatra' (*Citrus - reshni*) mandarin rootstock, around 20 years old, planted within a frame with an in-row spacing of 6 m and 7.5 m between rows (222 trees/ha), and with trees reaching heights of 3.5 m. The field, with a total area of 300 ha, was located in Alhama de Murcia (37º52'51.1"N, 1º17'20.3"W; 176 m altitude), Region of Murcia (Spain). Five rows with 15 trees per row were used for the pruning trials. The 75 trees selected were uniform in size and vigour. The pruning trials of the next campaign were carried out after the harvest of the previous campaign, on March 10th and 18th, 2016; on March 15th and 17th, 2017; on February 16th and March 6th, 2018; and on March 7th and 13th, 2019. On the earliest pruning date (February 16th, 2018) the buds were swelling, some isolated flowers were seen, and on the latest pruning date (March 18th, 2016) the flowers were developed, although the petals were closed.

2.2. Equipment used

Manual pruning was conducted with hand saws and shears. This labour was carried out by a team of 10 specialised workers.

Mechanical pruning was performed with a pruner (Industrias David, Yecla, Murcia, Spain). The pruner was hitched onto the front of a narrow tractor (Kubota M8540, 64 kW) and consisted of a linear arm equipped with five shearing discs; each disc was driven by a hydraulic motor. (Fig. 1). Additionally, the skirts were pruned with a manual hedge trimmer (STIHL HS-82 R) with a 60 cm-long blade.

Figure 1. Disc pruner used in the lemon pruning trials.

[Figure 1. insert here]

2.3. Experimental design of pruning treatments

The experimental design for the trials consisted in a Latin square (5 treatment x 5 rows) with three trees per plot. The 5 treatments were distributed on the row, and replicated in 5 rows (1 row means 1 repetition). 15 trees were selected in each row, and the treatments were applied in plots of 3 consecutive trees. The central tree of each plot was used to measure yield and fruit diameter.

The pruning trials were carried out over a four-year period. The pruning schedule for each treatment for the trial period is given in Table 1. Each pruning treatment involved one or more of the following elemental operations:

- CTL. Manual pruning of the tree. This was the control treatment (1), and was the pruning system commonly used in the farm.
- M. Manual pruning in treatment 2. This was performed in odd years and was the same elemental operation as the CTL.
- F1. Manual pruning in treatment 3. This was done after the mechanical pruning and consisted of subsequently manual pruning all the tree. This operation was done in one pass, a few days after the mechanical pruning.
- F2. Manual pruning in treatment 4. This was done after the mechanical pruning and consisted of manual pruning one side of the tree; the other side had already been mechanically pruned.
- N. Mechanical hedging of the North side of the tree. This was carried out with a

10-degree inclination from the bottom to the top of the tree, and was done in treatments 4 and 5 in even years.

- S. Mechanical hedging of the South side of the tree. This was done in treatments 4 and 5 in odd years.
- NS. Mechanical hedging of both sides of the tree. This was applied in treatment 2 in even years.
- T. Mechanical topping. This was carried out with the pruner machine. Topping was done at approximately a 15-degree inclination on both sides. It was done in all treatments except treatment 1, which was never topped, and treatment 2, which was topped only in even years.
- K. Skirting. This was carried out with a manual hedge trimmer, and was conducted in all the treatments, with the exception of treatment 1.

Table 1. Pruning schedule for each treatment for the four years.

[Table 1. insert here]

The following variables relating to pruned biomass and canopy dimensions were measured during the pruning time:

Pruned biomass characterisation and tree canopy volume. Pruning disposals were weighed and the diameters and lengths of the cut branches were measured. After pruning, in six trees by treatment, in-row and across-row canopy diameters were measured at 1.2 m above the ground and also canopy height. Tree canopy volume of each tree was calculated and based on the assumption that the canopy naturally developed as one-half of an ellipsoid, according to the equation reported by Whitney et al. (1995) as follows:

$$CV = (0.52)\,(H)\,(D_A)\,(D_I) \qquad (1)$$

where CV = canopy volume (m); H = canopy height (m); D_A = horizontal canopy dimension across-row (m); D_I = horizontal canopy dimension in-row (m).

Productivity (h/ha) of manual and mechanical pruning. In the case of hand pruning, the time taken by a team of 10 workers was measured. The productivity of mechanical pruning was calculated according to the number of passes that the machine performed per row, the tractor advance speed (km/h), and considering 15% of the time used in manoeuvres to change rows.

At harvesting, the following variables were analysed:

Yield per tree (kg/tree). The production of 25 trees was weighed, one tree for each treatment and row.

Fruit equatorial diameter. At harvest, a random sample of 100 fruits per tree (100 x 25 = 2500 fruits) were measured with a digital calliper.

Harvesting was performed by hand on December 21, 2016; December 4, 2017; February 5, 2019; and December 17, 2019, coinciding with the harvesting dates of the orchard, which were selected on market demands. Data were analysed using one factor variance analysis in order to assess the effect of the pruning treatment on the crop yield and fruit size. Tukey HSD intervals (α=0.05) were used to compare the mean values of the different treatments, and regression models were developed in order to relate the time necessary to prune the trees and the amount of biomass cut. Statistical analyses were performed using a commercially available statistics package (Statgraphics Plus, version 5.1, STSC Inc., Rockville, MD, USA).

The pruning costs were calculated as follows:

- Manual pruning costs were based on a labour rate of 10 €/h (personal communication, cost in this farm), including taxes, with that labour being carried out by external specialised workers who perform this work annually on the farm.

- Mechanical pruning costs amounted to 60 €/h, and included the tractor with its driver as well as the pruner machine. This task was performed by external dealers (services) for the four years.
- Skirt pruning costs were 11.1 €/h, and this task was carried out by one specialised worker with a manual hedge trimmer.

3. Results

3.1. Working time and economic cost of pruning

Table 2 shows the annual working time (h/ha) by pruning treatment from 2016 to 2019, the average time in four years, and also the percentage of time reduction in relation to the hand-pruning control treatment. Considering the average value for the four years, all the treatments reduced the pruning time with respect to the control (CTL). In the treatments involving both mechanical and manual pruning (treatments 2, 3 and 4) the reduction in working time was low, 19% to 30% of the CTL. A considerable reduction in time (95%) was only achieved with the purely mechanical treatment (treatment 5).

Treatment 3 was the one that reduced the time the least (19%) with respect to the treatment control (treatment 1; Table 1). The time saved in treatments 2 and 4 was similar (30% and 27% of reduction versus treatment 1; Table 1), although treatment 2 would be more desirable than treatment 4, because as the first alternates manual and mechanical pruning treatments, between years, it is easier to accomplish by the workers, who, in our experience, when they must manually prune the trees following the mechanical pruning, have problems to quantify the amount of wood they must remove and no time reductions are more often obtained.

When manual pruning was alternated with mechanical pruning (treatment 2), more biomass was eliminated in the manual pruning years than in the equivalent control treatment. Therefore, the pruning time reduction achieved in the years of mechanical pruning, was negatively compensated by a greater time requirement in the manual pruning years (Table 2).

Table 2. Annual and average working time in the four years per pruning treatment.

[Table 2. insert here]

The annual and average cost of pruning treatments are shown in Table 3. When taking the four years into account, treatments 3 and 4 (mechanical plus manual pruning follow-up) only managed to lower the pruning costs by 7-10% with respect to the control. Treatment 2 obtained a higher cost reduction of 18% with respect to the control, whilst the highest saving of 78% with respect to the control was achieved with the mechanical treatment (5).

Table 3. Annual and average costs per pruning treatment (€/ha).

[Table 3. insert here]

3.2. Pruned biomass characterisation

Table 1S (supplementary material) shows the length and diameter of pruned branches by annual operation; and Table 2S shows canopy volume by pruning treatment. In general, hand pruning operations (CTL, M, F1 or F2) eliminated branches of greater length and diameter than mechanical pruning operations (topping, hedging or skirting), and when manual pruning was performed in alternate years (treatment 2), the pruned branches were longer and thicker. On the other hand, it was observed that in the topping and hedging operations, the length of the cut branches increased throughout the four years.

Tree dimensions after pruning were as follows:

- The average height of hand-pruned trees (CTL) was 3.50 m (std. ±0.33 m), which was taller than the trees with mechanical topping (3.03 m, std. ±0.18 m; Table 2S). However, after three months, the heights of the trees pruned by hand and with mechanical topping were practically the same. On the other hand, in the treatments with mechanical topping, the new sprouts appeared fundamentally at the height of the cutting area, so the trees produced the fruit in more elevated zones than the CTL, thus complicating harvesting that fruit.
- In 2016 and 2017, no significant differences were found in canopy diameters (in-row and across-row) between treatments. However, significant differences were found among the treatments in across-row diameter in 2018. The treatment with two sides hedging (2) gave the smaller diameter (4.52 m), but without significant differences with the treatments with one side hedging (4 and 5). Treatment with no hedging (3) had a higher diameter (4.91 m), but with significant differences only with treatment 2. Control was the treatment with the highest across-row diameter (5.09 m) (Table 2S). In all cases, the alleys were wide enough for the passage of machines.
- No significant differences were found between pruning treatments in tree canopy volume (Table 2S); the canopy volume of control treatment trees was only significantly greater than the other treatments in 2018. The average distance from the lowest branches to the ground was 0.35 m (std. ± 0.19 m) in the trees with unpruned skirts (CTL and M) compared to 0.54 m (std. ± 0.12 m) in the

skirted ones. Despite this, no differences were found at harvest. There were fruits touching the ground in all treatments.

- In treatment 5 (only mechanical pruning all the years) the inner zone of the trees had dry branches and less vegetative development, so there were fewer fruit in that zone compared to the CTL. The inner zone of the trees with consecutive years of mechanical pruning became darker and with more dense vegetation including shoots and some dry branches than the trees that were manually pruned, continuously or alternated.

The annual, average and accumulated biomass removed over the four years per pruning treatment is shown in Table 4. The treatments can be classified according to the amount of biomass pruned, as being:

(i) severe, this is the case of the control treatment (CTL) and treatment 2 with 166 and 164 kg/tree of accumulated biomass removed over the four years. However, differences did exist between both treatments: in the case of the control, between 25.9 and 65.3 kg/tree were removed each year, whilst in the case of treatment 2, in the mechanical pruning years (2016 and 2018) 9.0 and 11.2 kg/tree were removed, similar to treatment 5, versus 85.2 and 58.6 kg/tree in 2017 and 2019, respectively. This amounted to 50% (2019) and 140% (2017) more biomass than the control treatment in the same year.

(ii) intermediate, which was the case of treatments 3 and 4, in which 52% and 57%, respectively, of biomass was removed compared with the CTL treatment.

(iii) light, this was the case of treatment 5, which only employed mechanical pruning, with less biomass being removed, 38.0 kg/tree.

Table 4. Annual, average and accumulated biomass removed during the four years per pruning treatment.

[Table 4. insert here]

3.3. Yield and diameter of fruits

The control treatment (1) had an average yield for the four years of 289 kg/tree (Table 5), being surpassed by treatment 5, which was the most productive with 357 kg/tree, and by treatment 2, with 325 kg/tree. In the latter case, the years with mechanical pruning (2016 and 2018), were the most productive, but the yield was lower than the CTL in the manual pruning years (2017 and 2019). Treatments 3, 4, and the control achieved similar yields of between 276 and 289 kg/tree, with no significant differences among them.

Table 5. Annual and average yield in the four years per pruning treatment.

[Table 5. insert here]

The data were also analysed in two groups taking into account the pruning type carried out each year: one group (i) that included all the trees that were pruned exclusively by machine that year (treatment 2 in 2016 and 2018; and treatment 5 all years); and a the second group (ii) that included all the trees that were pruned, total or partially, by hand that year (treatments 1, 3 and 4 all the years, and treatment 2 in 2017 and 2019). This highlighted the differences more clearly: an annual yield of 321 kg/tree was obtained in the first system versus 273 kg/tree in the latter (Fig. 2).

Figure 2. Tukey HSD intervals at 95% confidence level for the yield in years of exclusively mechanical pruning (i) versus years with some type of manual pruning (ii).

[Figure 2. insert here]

The higher amount of biomass pruned in the treatments with some elemental operation of manual pruning (group ii) has clearly reduced the yield.

Treatment 2 produced the fruits with the largest sizes, on average, for the four years (62.95 mm), and also for the last three years (Table 6). Treatment 1 (control) was second in fruit size (61.67 mm), treatments 4 and 5 produced smaller fruits, albeit with minor differences between them (60.81 mm and 60.82 mm respectively) and treatment 3 gave the smallest fruits (60.14 mm).

Table 6. Average diameter and percentage of lemons with diameter greater than 58 mm in four years of pruning treatment.

[Table 6. insert here]

Fresh market lemons require a calibre over 58 mm, while fruits under that limit are usually for industry and consequently have a lower value. The amount of fruit for fresh and for industry has been calculated considering that limit for each year and treatment (Table 3S, supplementary material). It can be observed that with this classification by fruit size, treatment 2 was the most productive for the fresh market with 261 kg/tree, followed by treatment 5 with 249 kg/tree. The CTL treatment was in an intermediate position, whilst treatments 3 and 4 were the least productive.

It should also be noted that treatment 5 provided the most regular yield over the years; conversely, treatment 2, obtained highly irregular yields over the years since it combined very different pruning intensities, mechanical one year and manual the following.

3.4. Economic assessment

Table 4S shows the annual and average net economic value of production by treatment. The net economic value has been calculated as the value of commercial production for fresh market (size >58 mm) and for industrial processing with the pruning costs (Table 3) being discounted in both cases. The sale prices in origin (fresh market) of lemons were those officially published by the Government of the Region of Murcia (CARM, 2020) for the harvesting week (0.29 €/kg in 2016; 0.36 €/kg in 2017; 0.19 €/kg in 2018 and 0.41 €/kg in 2019). The sale prices for industrial processing in the years 2018 and 2019 ranged between 0.08-0.12 €/kg (ASAJA, 2020); an average of 0.10 €/kg has been considered in this study.

The average results for the four years show that treatments 2 and 5 were the most economically profitable, with 14% and 23% more profit than the CTL; however, treatments 3 and 4 were 12% less valuable than CTL. These results confirm that economically speaking, it is not beneficial to practice mechanical pruning and manual pruning in the same year for any of the combinations tested (KTF1, KTNF2 and KTSF2).

The majority of the income belongs to the fresh market fraction in all the treatments, which in treatments 2 and CTL accounted for 92% and 89%, respectively, of the total crop value.

With respect to the pruning costs analysed in section 2.1, they were lowest in treatment 5 (0.8 €/tree), considerably less than those of the next lowest, treatment 2, with 3.0 €/tree, which was slightly cheaper than CTL, 3.6 €/tree. These costs amounted to 5% of the economic value of fruit in treatment 1 (CTL); 4% in treatment 2; and 1% in treatment 5.

4. Discussion

4.1. Pruning field capacity and biomass

In the case of pruning tasks carried out by hand or with mechanical and hand pruning combined (CTL, M, F1 in KTF1, and F2 in KTNF2 and KTSF2) the relationship between biomass removed and pruning time was analysed, and a potential equation (Fig. 3) was obtained that related both parameters well (R^2= 83%). This result is similar to that obtained by Velazquez and Fernández (2010) in 'Valencia Late' orange trees showing a potential relationship between pruning time and biomass removed with a similar determination coefficient.

Figure 3. Biomass pruned from the tree (y) versus time taken in manual pruning operations (x).

[Figure 3. insert here]

Regarding mechanical pruning, the amount of biomass removed and the time used by the pruner were independent, because the machine worked at the same speed (1.5 to 2 km/h) irrespective of the number of branches cut. The pruner advanced at a velocity similar to that reported by other authors in Spanish crop conditions (Martin-Gorriz et al., 2014; Mateu et al., 2017; Velázquez and Fernández, 2010).

Related to working time, our results in treatment 5 agree with those obtained by Spina et al. (1984) in 'Tarocco' oranges, where the reduction rate in mechanical pruning was 99% with respect to manual pruning.

4.2. Pruned biomass and crop yield

A relationship between crop yield and pruned biomass was found (Figure 1S;

Supplementary material). In contrast, the results obtained by other authors have not always presented the same picture. Mateu et al. (2017) in ‘Navel Foios’ oranges found no significant differences in crop production between mechanical pruning and manual or manual combined with mechanical pruning treatments, despite less biomass being removed in mechanical pruning compared to the other treatments. Conversely, Velázquez and Fernández (2010) in ‘Valencia Late’ oranges reported that treatments with mechanical pruning combined with manual pruning, despite removing more biomass than the treatments with only mechanical pruning, obtained a higher yield than the latter. In ‘Fortune’ mandarins continued mechanical pruning performed for three years reduced the yield, despite the mechanical pruning removing less biomass than manual pruning (Martin-Gorriz et al., 2014). These different results among varieties for similar pruning systems have been observed by several authors, who suggest that the trees response to pruning depends on several factors, such as variety, rootstock, vigour, tree age, etc. (Kallsen, 2005; Raciti et al., 1982; Vashisht et al., 2017; Zaragoza and Alonso, 1980; 1981); *e.g.* in 'Santa Teresa' lemon variety, rootstocks significantly affected cumulative yield and fruit quality: fruit weight, fruit diameter and fruit juice content (Yildirim et al., 2010b).

In 'Star Ruby' grapefruit, in some cases, mechanical pruning decreased yield. However, the application of hedging for one year and topping during the following year on the same tree, had a more beneficial effect on yield compared to the yearly application of topping or hedging (Yildirim et al., 2010a).

In contrast, in 'Feminello Comune' lemon variety, hedging two sides did not affect yields (Raciti et al., 1981). Similarly, in 'Limoneira 8A' lemon variety, skirting did not affect yields and reduced the percentage of fruit infected with brown rot (Phillips et al., 1990).

4.3. Yield and fruit size

Several research works have shown that fruit size is usually inversely proportional to yield (Agustí, 2003; Martin-Gorriz et al., 2014; Whitney et al., 1995), but in this experiment a clear pattern has not be seen in the relationship between fruit size and tree yield; treatments 3 and 4 had the lowest yields and also produced the smallest fruits. If the remaining treatments (1, 2 and 5) are considered separately, only treatment 5 clearly followed the commented rule, and was the most productive of these three, but also had the smallest fruits among them. But once again, the literature has reported different results, *i.e.*, in 'Valencia Late' oranges, mechanical pruning combined with follow-up manual pruning treatments obtained a higher yield than manual pruning alone, without significant differences in fruit size (Velázquez and Fernández, 2010); and in 'Orlando' tangelo, mechanical pruning, especially topping and hedging, increased the percentage of larger sized fruit and reduced the percentage of small fruit (Morales et al., 2000). In contrast, in 'Fortune' mandarins, treatments with manual pruning obtained a higher yield and smaller sizes than those involving a combination of mechanical and manual pruning (Martín-Górriz et al., 2014); and a similar result was obtained by Raciti et al. (1981) in 'Avana' mandarin, where mechanical pruning did not improve fruit size.

4.4. Economic assessment

The economic evaluation shows that treatments 2 and 5 were the most profitable, 14% and 23%, respectively, more than the CTL (Table 4S). These results demonstrate that introducing mechanical pruning in lemon 'Fino 95' is economically a profitable option, given the considerable increase in income, 2,221 €/ha and 3,533 €/ha, for treatments 2 and 5 respectively, with respect to the CTL (15,657 €/ha) (Table 4S). Similar findings were reported by Francis et al. (1975) in 'Eureka' lemon variety that, after seven years of trials, topping and hedging yearly treatment, were more profitable than hand pruning. Additionally, hand pruning alone does not appear to be advantageous to mechanical top pruning and hand pruning every year.

Treatment 2, mechanical and manual pruning in alternate years, closely resembles the current management practice used by farmers: any tree-growing deviation caused by mechanical pruning can be re-conducted by manual pruning. Moreover, this treatment increases the manual pruners' working capacity by 30% (Table 2), which is particularly relevant in a scenario of a lack of specialised workers. Treatment 5, only mechanical pruning, has given excellent results, although perhaps four years is not a long enough time frame to observe the tree's growth development.

5. Conclusions

The aim of this research was to obtain detailed information on the response of 'Fino 95' lemon trees to mechanical pruning with different levels of severity, and how said mechanical pruning should be integrated with manual pruning into a management strategy to reduce pruning costs and increase net economic value. This would help farmers to make pruning decisions to produce fresh market fruit.

After four years of experiences in pruning 'Fino 95' lemon trees for the fresh market, the results show that mechanical pruning presents advantages with respect to the manual pruning practices currently performed. The treatments of 'continuous mechanical pruning' and 'mechanical pruning alternated annually with manual pruning' reduced pruning times and costs; increased crop yield; and increased the economic profit of the crop.

The continued mechanical pruning treatment (5) was the fastest, the cheapest and the most productive, but it greatly transforms the tree vegetation compared to current pruning systems, since the centre of the tree becomes darker and fills with dry vegetation. Further testing of this system is required in order to verify that it does not affect other parameters, such as the quality of the fruit or the proliferation of pests.

The treatment involving mechanical pruning alternated with manual pruning will be the most readily accepted by farmers since the tree will continue to grow in a very similar way to the present system.

Mechanical and manual pruning combined in the same year is not recommendable in any of the two combinations tested; the yield and fruit size did not improve and the economic profit was lower than with the traditional system (CTL).

Overall, the data obtained in four years of trials show that it is possible to introduce mechanical pruning systems into a pruning management strategy to reduce costs without decreasing the yield.

Acknowledgements

The authors acknowledge the financial support of *Instituto Nacional de Investigaciones Agrarias* (INIA) and FEDER (Project no. RTA2014-00025-C05-02). The authors are grateful to Juan José Peña, Montano Pérez, Angel Pérez and Diego Guerra for their assistance with this research as well as to Fruca S.A. for providing orchards and farm tasks.

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