

Influence of pruning on diametric growth of cork oak (*Quercus suber* L.)

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Keywords: *Quercus suber*, silviculture, growth, pruning, Spain

ABSTRACT: Pruning is one of the most common cultural practices in the management of cork oak forest, mainly used to increase acorn production and eliminate death crown biomass. Nevertheless, the effect of the reduction of aerial biomass and photosynthetic tissues on the diametric growth of *Quercus suber* L. has not been studied, although knowledge about diameter growth trends is one of the main issues to improve sustainable management of cork oak stands. In this work, the influence of pruning on the circumference growth of this species is studied in an experimental plot in Huelva (Spain). Three treatments of aerial biomass reduction were applied (intensive thinning, light thinning and no thinning) to three homogeneous groups of 19 trees. Circumference growth was analysed with dendrometer bands with monthly measurements. Two yield tables of pruning products are made. Effect of thinning was analysed through graphic representation of current and accumulated growth, the factorial analysis of the variables and an analysis of the variance of two linear models that relate pruning treatments with a pruning index and the accumulated growth at the end of a period of seven months. A rational pruning, with less than 30 % of the crown biomass is removed, has a low influence on cork plus wood growth, at less during the seven first months after pruning.

1 INTRODUCTION

In western Mediterranean countries, the cork oak (*Quercus suber* L.) forests cover around 2.400.000 ha, mainly in southwest of Europe (Portugal, Spain, Italy and France) and north of Magreb (Algeria, Morocco and Tunisia). The economical, ecological and social values of this mediterranean sclerofilous forests are very important. Their economical and social importance derives, notably, from non timber forest products, like cork, acorns, pastures, game, etc., and firewood and charcoal production. On the other hand, biodiversity, landscape, soil protection, and others ecological aspects are essentials in the cork oak woodlands. The cork oak silviculture must make possible the conservation, health and production of this forests. Currently, the cork oak silviculture is focused to cork production, at denses forests, or mixed production of cork and pastures at open woodlands, so called “dehesas” in Spain and “montados” in Portugal. It is in these open woodlands where the pruning of adults trees is an extensive practice. Normaly, the pruning is made every nine or ten years, between two cork harvests, and less of 30 % of crown is removed. The cork oak pruning is mainly used to increase acorn production and eliminate death crown biomass by improve the cork quality. Only some experiments were carried out in Portugal and Spain, designed to determinate the effects of pruning on cork growth and acorn production (Vieira Natividade 1932,1950,

Santos and Rodrigues 1975, Pascoa and Silva 1986, Montero and Curras 1990, Cañellas and Montero 2002). Nevertheless, the effect of the reduction of aerial biomass and photosynthetic tissues on the diametric growth of *Quercus suber* L. has not been studied, although knowledge about diameter growth trends is one of the main issues to improve sustainable management of cork oak stands.

Within a more extensive project on environmental and silvicultural effects on cork oak growth, this work presents the first results of a pruning trial located at a cork oak woodland in Huelva, south Spain.

The aims of this study are:

- To quantify the biomass yield of trees with different pruning intensity.
- To describe the intraannual cork plus wood growth of trees with different pruning intensity.
- To study the factors affecting the diametral cork oak growth and their relations.

To study the differences between the diametral growth of cork oaks with different pruning intensity.

2 MATERIAL AND METHODS

2.1 Study site

The wood studied is situated at southeast of Huelva province (south of Spain). The trial is located at the place known as “Los Algarbes”, into “Montes Propios de Hinojos” wood, belonging to the Council. It establishes on sandy soils and nearly flat grounds, under a Semiarid Mediterranean climate, or Dry Hot Genuine Mediterranean IV₂ (Allué 1990). The potential vegetation is that of *Oleo sylvestris* - *Querceto suberis sigmetum* (Rivas Martínez 1987) type of cork oak forest.

The selected site is composed by a regular stand where different levels of stand density and debarking intensity can be found. Trees are regularly pruned, once every ten years, and the last cork stripping was carried out in 1996, being the cork ten years old at that moment. Therefore, the next cork stripping is expected to be in 2006. The place is not pastured, so that natural regeneration as well as thicket is abundant.

2.2 Selection of the sample:

One hundred and seven trees were numbered, identifying them by metallic plates. A forest inventory was made at this stand. The location of each tree in the plot was measured by means of a topographical total station to account for level of competition between them.

After that, fifty-seven trees were chosen between those central classes of the breast height circumference distribution, which concentrated the 84% of the trees in the stand. These fifty-seven trees samples were divided in three sub-samples, so that the different treatments were applied to triplets of trees with similar characteristics of breast height circumference and debarking coefficient. The position of the trees was also taken into account so that the sub-samples would present a homogeneous distribution into the experimental plot. With regard to micro-ecological conditions, particular attention was paid to not grant a privilege to any sub-sample.

2.3 Instalation of the material at the plot.

In order to study the pruning influence on perimeter growth, it was decided to install own-made aluminium band dendrometers on every tree, reading them once every month.

Band dendrometers reflect periodic growth of the complete stem section, being able to detect discrete diameter growth with low cost and sufficient accuracy. Once installed, they are easy to read: two holes are drilled, one on the collar and another one on the band, next to the collar. Then, the distance that the hole on the band moves away from the hole on the collar is periodically measured with the aid of a caliper. Besides, every time a measure is taken, a line is inscribed next to the collar, so that when the period studied finishes, the dendrometers can be removed from the trees and the distances between lines can be measured in the laboratory with more precision.

2.4 *Application of the treatments.*

The trees of the plot were pruned in March 2003. Two pruning intensities were applied, (light and intensive ones) being the third treatment that of no pruning at all.

It is difficult to establish “a priori” different pruning intensities, quantifying them before the treatments were applied. Therefore, initially two trees were pruned as the staff that carried out the works used to do, and it was considered that it seemed to be an intensive pruning. So, some instructions were given to the staff, letting them to cut as they used to do in those trees of the intensive pruning treatment, but insisting them to not eliminate all the interior branches in the light pruning case.

The researching team supervised the whole operation. In both treatments no principal branches were cut off. It was wanted to be careful not removing too thick branches with more than twenty centimeters of diameter (Montero and Curras 1990) but in fact, not even branches with more than ten centimeters of diameter were cut off. It was because of the trees are regularly pruned and they are not able to develop so thick branches in only ten years. With regard to this fact, some difficulties were found in light pruning case, when attention was paid to leave some interior branches. It was because as a result of the repeated prunes, sometimes too intensive applied, the most of the interior branches were suckers. It made that sometimes it was endangered to decide which branches must be cut off and which ones must be left.

Therefore, in general, the pruning consisted of cleaning the first-order branches from suckers and from those other ones that could disturb the stripping operation. The works were conditioned by the preceding prunes, but it in spite of that, it was considered interesting to quantify the products in a cork oak stand regularly pruned. In the case of light pruning, special attention was paid to leave some interior branches maintaining the crown equilibrium. In both cases, light pruning and intensive pruning, less than 30 % of total biomass of crown is removed.

The cuts were carried out with a mechanical saw, not too close to the principal branch but not leaving stumps. The cut surfaces were looked after being sloping enough to drain the rainwater. Finally, dry twigs were removed bringing them down with a grappling wood.

Once the biomass was cut off, leaves were pulled out from the shoots by hand. In every tree, pruning products were divided in classes as follows, and weighted separately: a) firewood, above five centimetres of diameter, b) brushwood, under five centimetres of diameter and c) leaves.

Samples from each fraction were taken in every tree, identifying them, keeping them into hermetically closed bags, and carrying them to the laboratory to determinate their humidity percentage at the moment of the weight operation.

2.5 *Data gathering.*

The next variables were measured for every tree:

a) Silvicultural measured variables related to cork production: Breast height circumference (BHC), Circumferences at the top (TC), the base (BC), and at the middle of the trunk (MC), as well as the mean circumference of the stripped branches (CB_i), Stripped length of the trunk (TL) and of the stripped branches (BL_i), thickness of at least two samples of the cork from every tree. All the measures were taken in centimetres, by means of tape measure, except the cork thickness, which was measured in millimetres with a caliper.

b) Silvicultural calculated variables related to cork production: One difficulty founded, was that the trees had been stripped some years ago, not in the moment to take the silvicultural measures. It means an obstacle to take measures under cork, and so, to know the stripped surface (SS). Therefore, it was decided to drench the trees, removing at least two samples of the cork from every one, taking them out from different heights but at the same position. In those taller cork oaks, or in those ones with stripped branches, a third sample of cork was also taken out. The cork thickness of the samples was measured in millimetres with a caliper. So that, the mean cork thickness per tree, at the studied moment, was calculated, and on this basis, the stripped surface was estimated. The silvicultural calculated variables are: Debarking coefficient (DC), or total stripped length over breast height circumference, estimated at the moment of the study, instead at the end of the cork cycle,

Stripped surface (SS) in square meters, Debarking intensity (DI) or the relation between the total stripped surface (SS) and the basal area under the cork, and the mean cork thickness per tree, at the studied moment in millimetres.

c) Silvicultural measured variables related to level of competition between the trees: (heights measured in meters by means a Vertex, position) X-Y-Z coordinates of every tree measured by means of topographical total station, Total height (TH) and Crown height (CH), or height of the first alive branch, measured in metres by means a Vertex and four Crown radios per tree in four orientations (NR, ER, SR, WR).

d) Silvicultural calculated variables related to level of competition between the trees: Eight competition indices were calculated for every tree taking into account their influence area. That is to say, the area where the tree competes with its neighbours for site factors. The index calculated were those of unilateral type: all the adjacent ones which intercept that area are considered competitors if their size is bigger than the target tree (Gonçalves et al. 1998). The formula of the unilateral competition index based in influence areas overlapping is (Tomé and Burkhart 1989)

$$AO_i = \frac{1}{AI_i} \sum_{j=1}^n \left(\frac{ao_{ij}}{AI_i} \right) \cdot (R_{ij})^k \quad (1)$$

where AO_i is the competence index of the tree i , AI_i is the influence area of the tree i , ao_{ij} is the overlapped area between the competitors i and j , and R_{ij} is the quotient between any dimensions of the competitor trees i and j . In this work R_{ij} is calculated as the quotient between the circumferences of the competitor trees. The radio of the influence area, R_i , of the tree i is computed so:

$$R_i = b \cdot HBC \quad (2)$$

The coefficients used to elaborate the eight Competition Index are: $k=1$, $b=0,1$ (CI_1), $k=1$, $b=0,15$ (CI_2), $k=1$, $b=0,20$ (CI_3), $k=1$, $b=0,25$ (CI_4), $k=2$, $b=0,1$ (CI_5), $k=2$, $b=0,15$ (CI_6), $k=2$, $b=0,2$ (CI_7) and $k=2$, $b=0,25$ (CI_8).

e) Measured variables related to pruning quantification: Weight of green biomass, whether for every fractions of pruning products (firewood, brushwood and leaves) whether the total harvested biomass, weighted by steelyard in kilograms, and Weight of dry biomass, whether for every fractions of pruning products whether the total biomass the humidity percentage at the moment of the weight operation for every fraction of every tree, measured in a sub sample at the laboratory by means of a dry oven and an electronic balance.

f) Calculated variables related to pruning quantification: Humidity percentage at the moment of the weight operation for every fraction of every tree and Pruning Index (PI), calculated as the weight of total dry biomass in kilogrammes over the basal area in square metres.

g) Growth variables: Monthly perimetral tree growth, or Current growth (CG_j), measured in milimetres by means of a caliper, and Accumulated growth in a period of some months. With regard to the measures taken with the band dendrometers, at the present moment data of a period of eight months is available, from March 2003 to October 2003.

2.6 Data analysis.

With regard to pruning quantification, all the values of dry biomass were averaged for every circumferences class, and yield tables were made for light pruning treatments.

Moreover, a factorial analysis of principal components was made looking for the variables that were able to explain the variance. Variables taken into account were: Breast height circumference (BHC), Debarking Coefficient (DC) estimated at the moment of the study, Pruning Index (PI), Accumulated growth (AG), and the eight competition index (CI_1 , CI_2 ... CI_8). A matrix of components was built for the first three components.

A plot of monthly growth, for light and intensive pruning, is given along with two-univariable analysis of variance of Pruning Index (PI) and Accumulated growth (AG) to detect the possible existence of differences between pruning treatments. The proposed models are:

$$PI = \alpha + \beta P + \mu \quad (3)$$

$$AG = \alpha' + \beta' P + \mu' \quad (4)$$

where P is a symbolic variable of the pruning treatments, no pruning, light pruning and intensive pruning.

The statistical data analysis was made with the aid of the software SPSS 10.0.6.

3 RESULTS.

3.1 Pruning quantification.

As it is shown at Tables 1 and 2, the most important fraction of biomass in both treatments, intensive and light pruning, is brushwood, that means biomass under five centimeters of diameter, whereas firewood production is very low. The reduction of biomass, including photosynthetic tissues or green leaves, in strongly pruned trees is higher than in lightly pruned trees.

Table 1. Dry biomass obtained from intensive pruning.

Circ. Classes	DC (m)		Brushwood (kg/tree)		Firewood (kg/tree)		Leaves (kg/tree)		Biomass (kg/tree)		PI (kg/m ²)	
	average	sd	average	sd	average	sd	average	sd	average	sd	average	sd
70-80	1.86	0,37	12,39	8,17	0,00	0,00	5,19	5,67	17,59	13,81	0,04	0,03
80-90	2.05	0,38	15,05	3,89	0,19	0,34	6,73	7,65	21,98	6,71	0,04	0,01
90-100	1.76	0,80	24,58	8,15	1,42	2,45	9,04	6,71	35,04	17,28	0,05	0,02
100-110	1.5	0,37	31,12	0,73	2,56	2,70	5,46	1,35	39,14	2,50	0,04	0,00
110-120	1.79	0,41	38,99	6,38	8,01	2,34	25,09	7,61	72,08	4,66	0,06	0,00
120-130	1.61	0,00	22,07	0,00	8,30	0,00	2,97	0,00	33,35	0,00	0,03	0,00
130-140	1.64	0,22	35,94	13,87	0,00	-	12,55	0,44	48,48	14,31	0,03	0,01
140-150	1.79	-	57,35	-	4,40	-	31,44	-	93,19	0,00	0,05	0,00

Table 2. Dry biomass obtained from light pruning

Circ. Classes	DC (m)		Brushwood (kg/tree)		Firewood (kg/tree)		Leaves (kg/tree)		Biomass (kg/tree)		PI (kg/m ²)	
	average	sd	average	sd	average	sd	average	sd	average	sd	average	sd
70-80	1,81	0,32	8,45	1,53	0,00	0,00	2,02	0,49	10,47	1,64	0,02	0,00
80-90	2,09	0,44	5,99	4,28	0,56	0,98	2,23	0,14	8,79	4,96	0,02	0,01
90-100	1,70	0,38	9,40	4,41	1,48	1,58	4,58	4,64	15,46	10,54	0,02	0,02
100-110	1,51	0,33	12,74	7,58	4,28	3,73	3,50	0,85	20,53	11,94	0,02	0,02
110-120	1,53	0,42	16,67	11,91	0,00	0,00	3,79	1,45	20,45	13,10	0,02	0,01
120-130	1,07	0,00	17,79	0,00	4,09	0,00	13,63	0,00	35,51	0,00	0,03	0,00
130-140	1,86	0,49	22,35	0,44	3,03	4,28	7,29	5,68	32,66	9,52	0,03	0,01
140-150	1,59	-	83,54	-	12,64	-	24,68	-	120,86	-	0,07	-

3.2 Monthly growth

Circumference current growths for the different treatments and their 95 % confidence intervals are shown in Fig. 1. A decrease of current growth can be appreciated in summer months due to hydric stress. Although there are not significative differences between the current growths for the different groups, it is interesting to comprove that after the application of the treatments no pruned trees

get the highest growths (specially in July), however, the differences of the current growths decrease as time goes on (October, November).

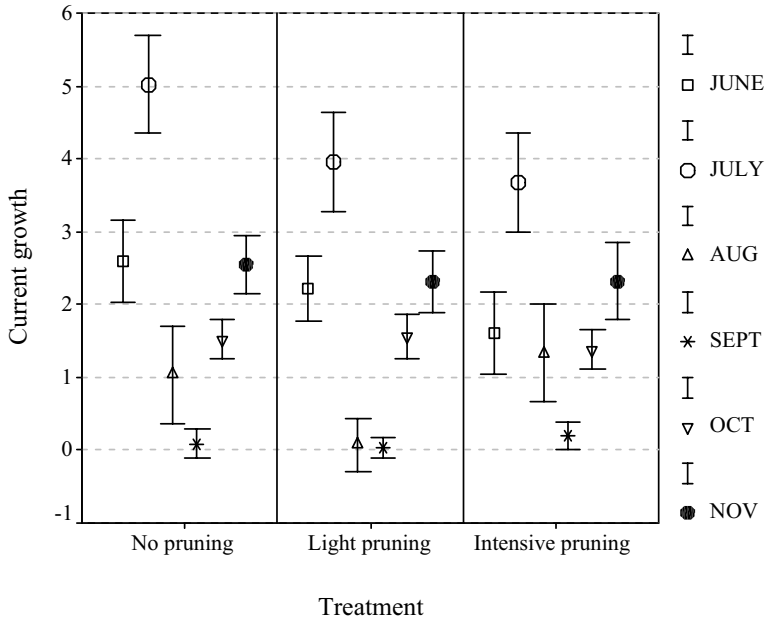


Figure 1. Current growth (mm) and 95 % confidence intervals for different pruning treatments.

The course of monthly-accumulated growth and their 95 % confidence intervals are graphically shown in Fig. 1. The period considered takes from May to November 2003, for the trees of the three treatments. The three groups of trees show similar growth trends, although no pruned trees get the highest growth at the end of the period. It is due to the increase that no pruned trees experienced in July, as above-mentioned.

3.3 Factorial analysis.

The results of the factorial analysis of principal components are shown in Tables 3 and 4. As it is shown in these tables, 81,189 % of variance is accounted for the three first principal components, relative to the total variance in all the variables. Only the first principal component accounts for 58,670 % and this principal component is mainly correlated with the competence variables, CI_1 until CI_8 . The second principal component, with 12,246 % of explained variance, is mainly correlated with Breast height circumference (BHC) and Accumulated growth (AG) at end of the period. At the same way, the third principal component, that only explains 10,272 % of the total variance, is mainly correlated with the Pruning Index (PI) and the Debarking Coefficient (DC). Thereby, the most important variability of the sample is related with the variables of competition between trees, following by the variables related with the size of the trees and, finally, by the silvicultural variables related with pruning and debarking.

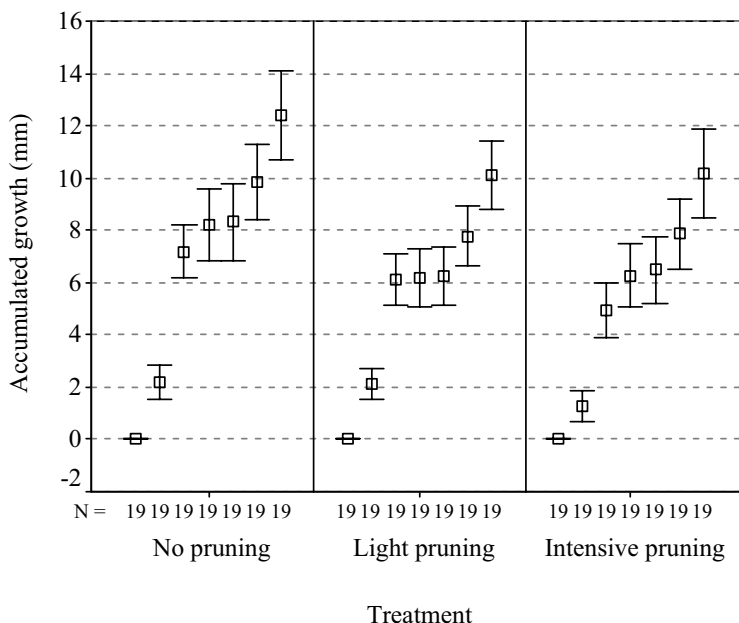


Figure 2. Accumulated growth (mm) and 95 % confidence intervals for different pruning treatments.

Table 3. Principal Components. Total variance explained

Component	Eigenvalues		
	Total	% of the variance	% accumulated
1	7,040	58,670	58,670
2	1,470	12,246	70,916
3	1,233	10,272	81,189
4	0,963	8,028	82,217
5	0,548	4,567	93,784
6	0,433	3,608	97,393
7	0,185	1,545	98,938
8	0,102	0,851	99,788
9	0,018	0,148	99,937
10	0,006	0,050	99,987
11	0,001	0,010	99,998
12	0,0003	0,002	100,000

3.4 Analysis of the variance

Table 5 shows the analysis of the variance results of the linear models (3) and (4). The purpose of these models is to relate the pruning treatment with the circumference accumulated growth at the end of the studied period (model 3), and with the Pruning Index calculated after the pruning (model 4).

Table 4. Matrix of principal components, correlation coefficients

	Component		
	1	2	3
DC	-0,110	0,016	0,590
BHC	-0,219	0,717	0,491
AG	-0,234	0,790	-0,288
CI1	0,863	0,319	-0,015
CI2	0,897	0,249	-0,011
CI3	0,937	0,216	-0,0009
CI4	0,942	0,155	-0,006
CI5	0,927	-0,088	0,077
CI6	0,967	-0,097	0,063
CI7	0,946	-0,180	0,059
CI8	0,949	-0,174	0,040
PI	-0,128	-0,129	0,739

The model (4) has a very high statistical significance, which seems to indicate that applied pruning treatments are really different and, thereby, it is possible to define three different homogeneous groups. These homogeneous groups are defined by the DHS Tukey Test (Table 6). Each pruning treatment has a different Pruning Index average.

However, the model (3) has not statistical significance. This indicates that is not possible to define different groups between the trees with different pruning treatments. After to apply the DHS Tukey Test, only one homogeneous group can be defined (Table 7). The groups with different pruning treatment have a similar accumulated growth. It is not possible to find statistical significant differences in accumulated growth between cork oaks with different pruning treatments.

Table 5. Analysis of the variance of the linear models (3) and (4).

Source	Model	Dependent variable	Sum of squares	Degrees of freedom	Quadratic average	F	Signification
Corrected model	3	AG	64,545	2	32,272	2,983	0,059
	4	PI	0,017	2	0,008	52,194	0,000
Intercept	3	AG	6761,71	1	6761,71	625,046	0,000
	4	PI	0,027	1	0,027	169,02	0,000
P	3	AG	64,545	2	32,272	2,983	0,059
	4	PI	0,017	2	0,008	52,194	0,000
Error	3	AG	584,169	54	10,818		
	4	PI	0,009	54	0,0002		
Total	3	AG	7410,423	57			
	4	PI	0,053	57			
Corr. Total	3	AG	648,713	56			
	4	PI	0,026	56			

Table 6. DHS Tukey Test. Homogeneous groups for model (4). Pruning Index average.

Treatment	N	PI Average		
		Group a	Group b	Group c
No pruning	19	0		
Light pruning	19		0,024	
Intensive pruning	19			0,042

Table 7. DHS Tukey Test Homogeneous groups for model (3). Accumulated growth (mm).

Treatment	N	Average (Group)
No pruning	19	12,395 (a)
Intensive pruning	19	10,179 (a)
Ligth pruning	19	10,1(a)

4 DISCUSSION

The values of the biomass of pruning products are lower than the obtained data by others authors (Pascoa and Silva 1986, Montero and Curras 1990, Cañellas and Montero 2002). This can be explained by the pruning rotation: ten years in this study and more years in the others studies.

Some authors, like Vieira Natividade (1950), propose that the rational pruning creates better conditions for the cork generating layer, rejuvenates the branch system and increases the growth rate and the cork yield. Others authors, like Cañellas and Montero (2002), propose that the moderate pruning has a low influence on cork production. Although, in this study the growth considered is wood growth together with cork growth, the results are according these second statement.

5 CONCLUSIONS

For pruning products with economical value, a rotation of ten years can be excessive. A rational pruning, with less than 30 % of the crown biomass is removed, has a low influence on cork plus wood growth, at less during the seven first months after pruning.

ACKNOWLEDGEMENTS

This study is included in the Research Projects SUBERWOOD, with financial aid of the V Frame Program R+D of the European Union, and SUBERCRE, with financial aid of the National Program of R+D of Spain. The authors want to thanks all those involved in the field and laboratory work, particularly A. Calzado, A.González and P. Quintero.

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