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Original article

Influence of cutting methods and dates on stump sprouting in Holm oak (*Quercus ilex* L) coppice

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Summary — The goals of this study were to compare height growth of stump sprouts in *Quercus ilex* stools cut by different methods at various times during the year. Four cutting methods were compared: chain saw at ground level and at 15 cm above ground, axe, and 'saut du piquet' ('stump breaking'). Cuttings were carried out every 2 months for a period of 1 year. Several important results can be described 4 years after cutting. Cuttings performed during the dormant season resulted in minimum stool mortality, and maximum new sprout number, height and diameter growth. An exception was cutting made during a winter frost period. Summer cuttings led to the poorest growth which, however, tended to be regained in subsequent years. Axe and chain saw cuttings yielded better results than 'saut du piquet' cutting. This last method resulted in high stool mortality and both fewer and smaller sprouts. Sprouts appeared to be more numerous and grew better when the stools initially had large and numerous shoots.

***Quercus ilex* L / coppice / stump sprout / cutting method / cutting date**

Résumé — Influence des méthodes et dates d'exploitation sur la régénération par rejets de souche des taillis de chêne vert (*Quercus ilex* L). *L'objectif de cette étude est de comparer la croissance de cépées de chêne vert (*Quercus ilex *L) exploitées par différentes méthodes, à différentes époques de l'année. Quatre méthodes d'exploitation ont été comparées : tronçonneuse au ras du sol et à 15 cm au-dessus du sol, hache et «saut du piquet». Les exploitations ont été faites tous les 2 mois pendant une année entière. Les principaux résultats obtenus 4 années après exploitation sont les suivants. Les exploitations faites hors saison de végétation donnent les meilleurs résultats du point de vue de la survie des cépées initiales, du nombre et de la croissance en hauteur et en diamètre des nouveaux rejets, à l'exception des exploitations faites en période de gel hivernal. Les exploitations pendant l'été donnent de moins bons résultats mais il semble y avoir un rattrapage les années suivantes. Les exploitations à la hache et à la tronçonneuse donnent de meilleurs résultats que la méthode du «saut du piquet» qui cumule une mortalité importante des cépées, et des rejets plus petits et en nombre moins important. Il apparaît enfin que les rejets sont d'autant plus nombreux et vigoureux que les cépées initiales ont beaucoup de brins et que ceux-ci sont de grande dimension.*

Quercus ilex *L / taillis / rejets de souche / méthode de coupe / date d'exploitation*

INTRODUCTION

Coppice regeneration occurs through stump sprouting rather than sexual reproduction. This is the basis for managing most of the *Quercus ilex* stands. It is thus essential that clearcutting for coppice regeneration be performed under the best conditions to optimize density and growth of the new sprouts which will constitute the new forest.

A "coppice" is a forest stand composed of stools. A "stool" is the entire physiological system comprised of a "clump" of 1 or several "shoots" (= stems) and the attached underground system. After coppicing, several "stubs" (the base of the cut shoots) remain on the stump. The "stump" is the underground part of the stool remaining attached to the roots after coppicing. The sprouting of adventitious or dormant proventitious buds on the stubs produces numerous "stump sprouts" which will become the shoots of the new clump. This process is repeated each time the stand is coppiced. It is often impossible, when studying a stool, to determine how many times it has been coppiced, and the age of the underground part of a stool is often unknown.

Cutting tools and methods in *Quercus ilex* coppices have changed over the years. Former techniques such as 'coupe entre deux terres' (cutting just under ground level) and 'saut du piquet' (stump breaking) (Regimbeau 1879, de Larminat 1893), widely employed at the end of the 19th century, along with the use of axes and scythes, all but vanished 50 years ago; the use of chain saws is now common.

Cutting dates may vary for coppice, even though cuttings are usually performed during the dormant season. However, cuttings made during the sap ascension period at the beginning of the growing season - as was commonly done when the holm oak's bark was used for tannin production –, during summer droughts, or winter frosts were and still are numerous and frequent.

Few references appear in the literature comparing cutting methods and these only examine chestnut (Phillips, 1971; Cabanettes and Pagès, 1986, 1990) or poplars (Crist *et al,* 1983). Results being different from 1 species to another and with no information on *Quercus ilex* reaction, more work is needed on that species.

References on cutting height are more numerous: Belanger (1979) for sycamore, De Bell and Alford (1972), Crist *et al* (1983) for poplar, Harrington (1984) for red alder, Cabanettes and Pagès (1990) for chestnut, Piskoric (1963) for holm oak and Martinez and Martin (1985) for eucalyptus among others. Results vary from 1 species to the other and need to be carefully studied.

Coppicing dates were sometimes studied in relation either to stool physiology (Riedacker, 1973; Dubroca, 1983; MacDonald and Powell, 1985), bud origin (Bartet, 1890; Harmer, 1988), bud activity or dormancy (Bartet, 1890; Warnier, 1931; Wenger, 1953; Riedacker, 1973), or photoperiodic (Wenger, 1953; Wargo, 1979) or hormonal (Avery *et al,* 1937; Vogt and Cox 1970; Riedacker 1973) mechanisms controlling bud activity. Some studies dealt with coppice yield in relation to coppicing date (Ciancio and Morandini, 1971; Cianco, 1977). However, there are only a few studies using recent advances and techniques of modern physiology (Blake and Raitanen, 1981; Ferm and Kauppi, 1990).

In *Quercus ilex,* little is known of the functioning of coppice and more particularly of stools which are the real biological units for coppice. Only extremely old references (Bedel 1866, Regimbeau 1879, de Larminat 1893) are available for this species. This is the reason why we started studying the impact of partial cuttings (thinning) or clear cuttings on coppices (Ducrey, 1988). The first results concerned coppice behaviour when thinnings were performed with variable intensity in different age stands (Ducrey and Toth, 1992).

The aim of the present paper is to study the influence of both cutting methods and dates on number and growth of newly formed sprouts. Cutting methods compare traditional methods such as 'saut du piquet' (described in *Materials and methods*) and axe with the modern chain saw method. Chain saw cutting height was also considered. Cuttings were performed every 2 months for a year. Our goal is not to recommend 1 method over another because chain saw coppicing is nowadays the only method used. Our objective is to compare these different methods and to determine their short-term effect on coppice sprouting. We will try to understand the influence they might have on the long term subsistence and vigour of holm oak coppice.

MATERIAL AND METHODS

The stand

The studied stand is located in the communal forest of La Bruguière, 5 km north of Uzès (Gard, France). This forest grows on a relatively flat limestone plateau at 250-300 m elevation. It is typical of *Quercus ilex* forests in this region (Garrigues du Gard): annual rainfall averages 1 000 mm and summer drought does not exceed 2 months. Since 1881, the harvest method used has been simple coppicing with a 25-30 year rotation. Previously, rotations were shorter, less than 20 years, and coppice was grazed from 10 years after coppicing to the next coppicing time.

The studied stand is part of compartment 10 of this forest and has an area of 0.7 ha. In 1985, the inventory revealed an average age of 30 years for the compartment. Preceding coppicings, around 1955 and 1930, were performed with a combination of 'axe' and 'saut du piquet' techniques.

Experimental design

The experimental design (Ducrey and Turrel, 1986) consisted of 6 adjacent plots where all stools with at least 1 shoot whose girth 50 cm above ground was at least 10 cm were recorded shoot by shoot. Girth at 50 cm was measured for all recorded shoots. Total number of shoots in each parent stool was used to distribute stools according to shoot number classes, and mean girth of shoots in each stool was used to distribute stools according to shoot girth classes. Stools were comprised of 1–25 shoots. A histogram of distribution of the number of stools according to their number of shoots showed an exponential decrease. Length of the longest shoot of each stool was also measured. The six plots were shared among 2 relatively homogeneous blocks. Their dendrometric characteristics are shown in table I.

Each plot was divided into 2 sub-plots and each of the 12 sub-plots was a working unit: every 2 months for a year (from September 1985 to July 1986), 2 sub-plots (one in each block) were cut. Figure 1 shows the climatic conditions throughout the cutting period.

For each cutting, 4 methods were used: chain saw at ground level (S0), chain saw at 15 cm height (S15), axe at ground level (A) and 'saut du piquet' (SP). 'Saut du piquet' is an old technique that combines cutting the shoot at 50 cm and horizontally knocking off the remaining part of the shoot where it is attached to the stump with the flat end of an axe or sledge hammer to detach the shoot from the stump. The objective of this method was to rejuvenate stools through individualization of shoots and roots of the same stool by stump division (Regimbeau, 1879).

In a given sub-plot, each cutting method was applied on 9 stools selected for their shoot number and mean shoot girth. Nine stool types were defined using 3 shoot classes (1 shoot, 2-3 shoots, 4-7 shoots) and 3 girth classes (10-15 cm, 15-20 cm and 20-25 cm). In each of these types, 4 stools were randomly chosen and cut using 1 of each the cutting methods.

Additional stools, with higher shoot number or larger shoots, were selected and cut by S0 or S15 methods for a better study of initial stool influence on stump sprouting. They belonged to shoot classes 4 (8-10 shoots) and 5 (more than 10 shoots) and girth classes 4 (25-30 cm) and 5 (more than 30 cm). In each sub-plot, an average

Table I. Dendrometric characteristics of initial coppice for each plot in the experimental design.

Plot	*Block*	*No of stools per ha*	*No of shoots per ha*	*Mean girth (cm)*	*Basal area (m^2/ha)*	*Mean height (m)*
1		5918	1657	17.9	16.77	3.71
2	1	6419	1581	17.9	17.22	3.77
3		5208	1608	17.5	14.41	3.59
4		7755	2073	17.1	20.27	3.79
5	2	7952	2000	15.6	18.03	3.49
6		7967	2122	16.5	19.08	3.63

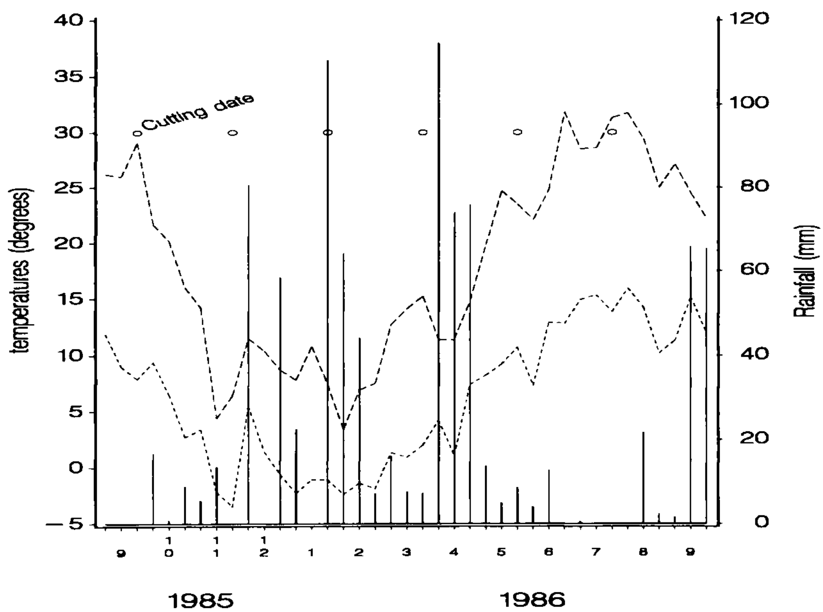

Fig 1. Climactic data: rainfall, minimum and maximum temperatures during coppice regeneration.

of 45 stools were identified. Five hundred and forty-six stools from a total of 1290 stools were selected for the whole experimental design.

Observations and measurements

On half the plots (block 1), sprouting dates were noted every 15 days from May to October 1986; the first sprouts began to appear only at the beginning of the1986 growing season.

At the end of each of the first 2 growing seasons, the importance of sprouting was estimated by measuring the space the new stools occupied. Stool volume and crown area were estimated by measuring total stool height and diameter.

Mean canopy height was estimated, and longest sprout length of each stool was measured for 4 consecutive years, in each stool. Each stool was recorded at the end of 1989 by measuring diameters at 50 cm above ground of all sprouts with a diameter greater than or equal to 1 cm. All sprouts were inventoried on one sub-plot.

RESULTS

Data were analyzed using a 3-way analysis of variance: 'cutting method', 'cutting date' and 'block'. Neither block nor interaction effects were significant. Thus, only the results for 'cutting method' and 'cutting date' effects are described below.

Dynamic study of coppice regeneration

Sprouting was observed between May and October 1986 because sprouting did not start before the beginning of the 1986 growing season, even for stools cut in September 1985. Observations were only made within block 1. Sprouting dynamics were expressed by the percentage of new clumps with optimun development (*ie* more than 10 sprouts over 10 cm in length on each stub of a stool) at a given date (fig 2).

No differences occurred during September, November and March cuttings: well-developed clumps appeared as early as the second half of May 1986 and 90% of all stools had reached this stage by the end of July 1986. Stools cut in May 1986, *ie* when sprout growth usually begins for *Quercus ilex*, had reached the same developmental stage 1 month later. Only 73% of stools cut in January produced well-developed young clumps. This was due to climatic conditions during the first half of February where the mean of minimum temperatures was –2 °C and absolute minimum temperature was –15 °C. After the July 1986 cutting, sprouts appeared as early as the beginning of September and 54% of the stools were well-developed by the end of October.

Yearly measurements of stools showed that differences among cutting dates in clump development during the first growing season were the same for all measured variables (fig 3): mean and maximum height, stool crown area and volume. Stools cut in July progressively regained

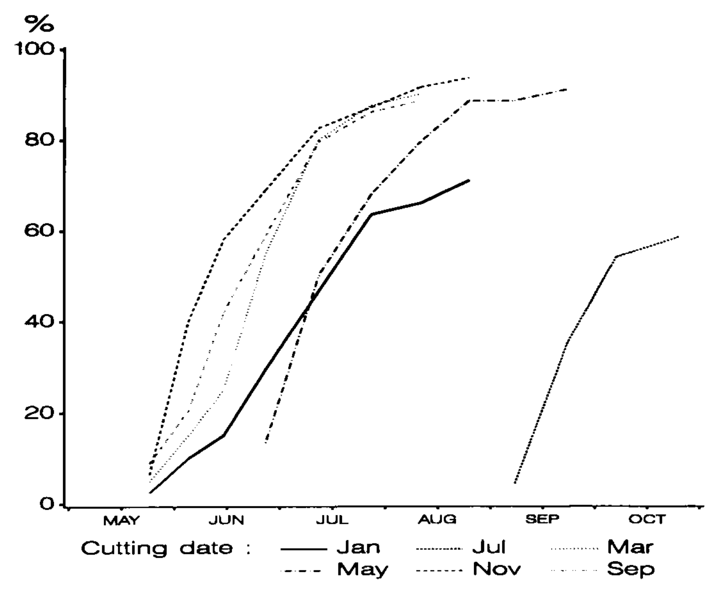

Fig 2. Percentage of stools with well-developed clumps during 1986 growing season, for each cutting date.

their initial growth loss in subsequent years. However, general tendencies, particularly those linked with February 1986 frosts, still persisted after 4 years.

Coppice behaviour was more thoroughly studied during the winter of 1989-1990.

Influence of cutting methods

Cutting methods influenced the number of living stools 4 years after coppice regeneration. Mortality was 3.6% for S0, 3.8% for S15, 1.6% for A and 14.8% for SP (fig 4).

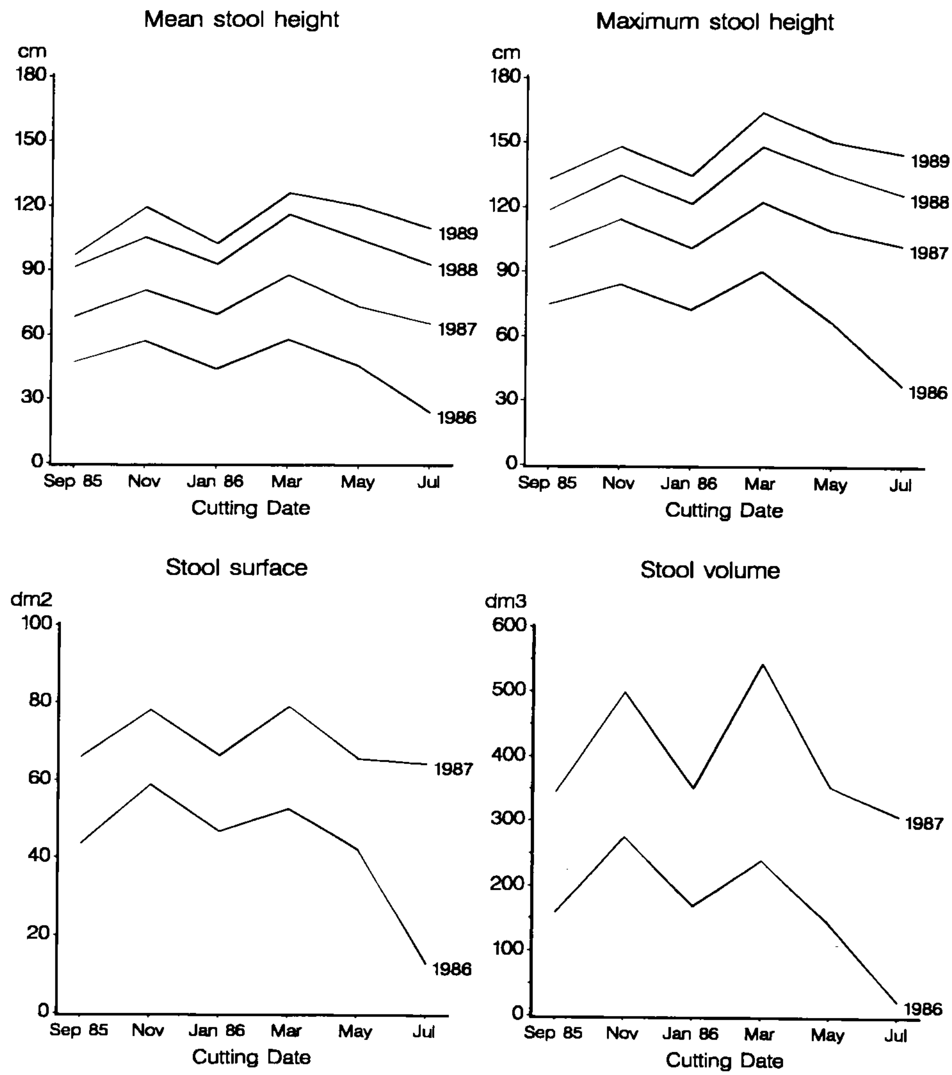

Fig 3. Stool mean height, maximum height, crown area and volume *versus* cutting dates for 4 years following coppice regeneration.

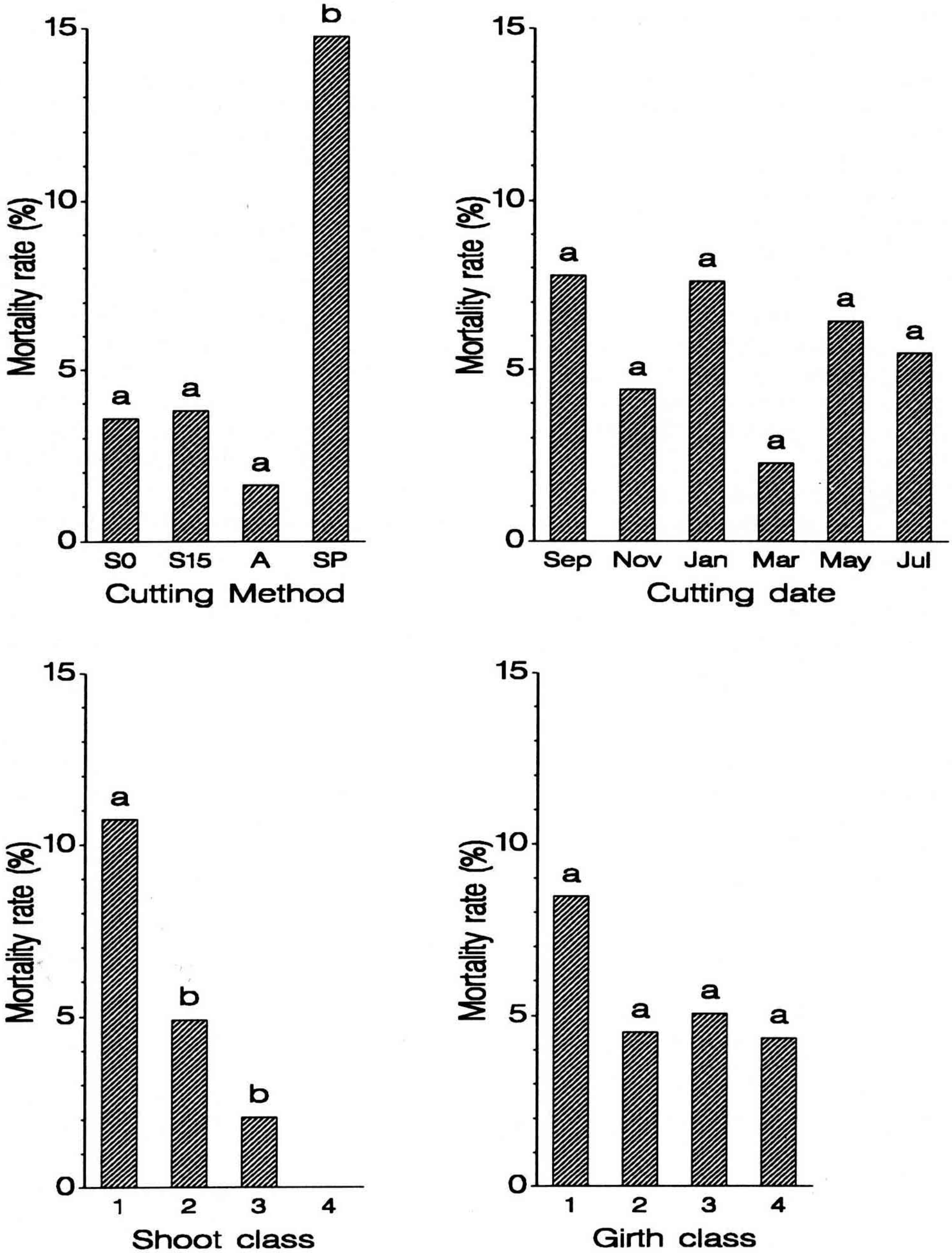

Fig 4. Stool mortality at the end of 1989 in relation to cutting method, cutting date and initial stool characteristics. Identical letters indicate means do not differ significantly at 5% level.

The axe method apparently disturbed stool activity the least. Chain saw cuttings produced somewhat poorer, but not significantly different results. No difference was observed between the 2 cutting heights. The 'saut du piquet' method resulted in the greatest stool mortality. Data analysis showed that small stools cut in January were the most negatively affected by this method.

Table II summarizes cutting method effects on stool growth, *ie* mean canopy height, longest sprout length, number of sprouts over 1 cm in diameter, mean diameter of these sprouts and largest sprout diameter.

Number of sprouts per stool varied between 7.6 and 8.2 for the S0, S15 and A methods and was 4.4 for the 'saut du piquet' method, which was significantly different from the first 3 methods. Heights were slightly greater for S15 and slightly smaller for SP. No significant differences were found for diameters from 1 method to the other.

For a more detailed analysis of sprouting dynamics within each stool, the diameter of all shoots with a height over 50 cm were measured at the end of 1989 in one sub-plot. For this analysis, 10 stools were measured for each cutting method (table III). The number of large sprouts (diameter over 1 cm) was comparable to that found for the whole experimental design, although there were differences in the total number of sprouts. Large sprouts represented 1/3 of the total for ground level chain saw and axe cuttings, but only 1/4 for chain saw at 15 cm and 'saut du piquet' cuttings.

Histograms in figure 5 specify these results and show the large number of small diameter sprouts in stools cut using the S15 method as well as the negative effect of the 'saut du piquet' method on sprout number and size.

Table II. Influence of cutting method on the number of sprouts, sprout length and sprout diameter. Partial results from analysis of variance and comparison of means. Cutting method effect (tool effect) was significant at 1% level (**), at 5% level (*) or not significant at 5% level (NS). Identical letters indicate means not significantly different at 5% level for each variable (Duncan test).

		No of sprouts	*Mean height (cm)*	*Maximum height (cm)*	*Mean diameter (mm)*	*Maximum diameter (mm)*
Means per tool	Chain saw at 0 cm	7.8 a	110.9 ab	146.5 ab	13.2 a	16.9 a
	Chain saw at 15 cm	8.2 a	117.7 a	152.9 a	13.2 a	17.4a
	Axe	7.6 a	114.3 ab	146.9 ab	12.9 a	16.6 a
	'Saut du piquet'	4.4 b	106.8 b	136.8 b	13.0 a	16.1a
Tool effect F test		6.02 (**)	3.34 (**)	3.64 (**)	0.52 (NS)	1.19 (NS)

Table III. Total number of sprouts and number of sprouts with a diameter equal to or greater than 10 mm (at a 50 cm height) in relation to cutting method (means calculated from 10 stools).

Cutting method	*Total No of sprouts per stool*	*No of big sprouts per stools (diam ≥ 10 mm)*	*Big sprout percentage (%)*
Chain saw at groud level	33.2	10.6	31.9
Chain saw at 15 cm height	49.9	12.9	25.8
Axe	35.2	11.3	32.1
'Saut du piquet'	19.2	4.5	23.4

Influence of cutting dates

Cutting dates did not directly influence stool mortality (fig 4). However, observed trends showed that mortality increased when cuttings were made in May, July and September during the growing season and decreased when made in November and March outside the growing season. Cuttings in January were followed by frost and wind which may have led to high mortality.

Cutting dates generally had a highly significant effect (1% level) for all the variables characterizing stool growth (table IV). Number of sprouts per stool was the highest for March (9.5) and November (8.4) cuttings and the lowest for July (5.6) cuttings. Mean and maximum height followed similar trends: the highest for March cuttings followed by May and November cuttings and the lowest for January and September cuttings.

Mean and maximum diameters were less variable, and significantly larger sprouts were only observed for March cuttings. In conclusion, it seems that March and November cuttings were the most favourable for sprout growth. On the contrary, winter cutting, in conjunction with frost, reduced both sprout number and height growth. Results from cuttings made during the growing season, particularly in July and September, were average to poor.

Influence of initial stool characteristics

Individual stool characteristics prior to cutting were used to stratify the stool sample based on the following 2 criteria: mean girth of shoots within a stool (girth class) and number of shoots per stool (shoot class).

Mortality was significantly higher for '1-shoot' stools and aslo tended to be higher for stools with mean shoot girth between 10 and 15 cm (fig 4). 'One-shoot' stools could be true coppice stools, or may have grown from seeds, or may come from root suckers. In the latter cases, 'saut du piquet' cutting practically removed the stool from the ground and led to a high mortality.

Results from the 2-way analysis of variance ('shoot class' and 'girth class') conducted on data from stools cut using the S0 method are given in table V. Except for mean diameter where no 'shoot class' effect could be demonstrate, effects were significant in all other cases and no interaction was found between the 2 factors.

For each of the 5 studied variables, mean values per class increased regularly

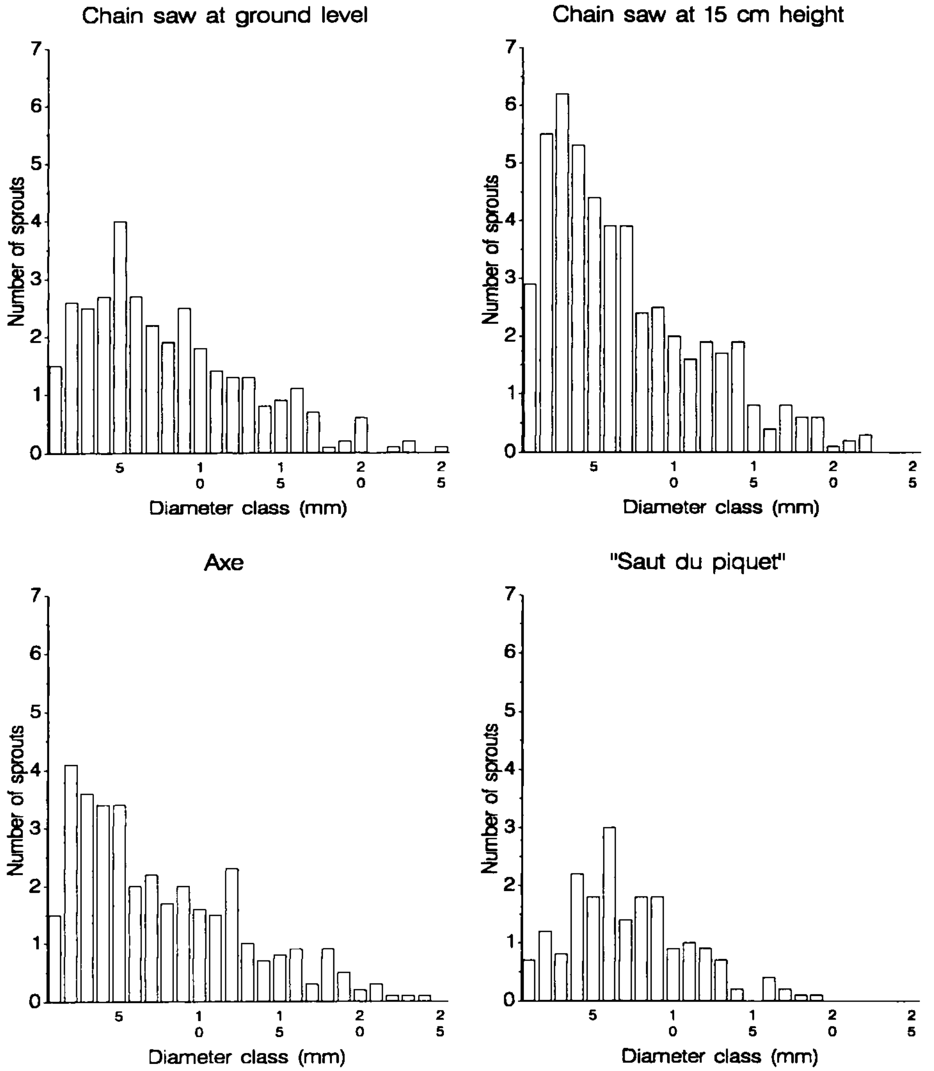

Fig 5. Distribution of young sprouts in relation to their diameter 50 cm above ground, 4 years after cutting, for each cutting method. Means were based on 10 stools per cutting method, from the coppicing of November 1985.

from class 1 to class 5 both for shoot classes and girth classes. Thus, when the initial stool had more numerous and larger shoots, subsequent sprouts were more numerous and showed greater growth. This result is confirmed by the analysis conducted on individual characteristics of initial stools.

New-clump characteristics such as number of sprouts, mean and maximum sprout diameter, mean and maximum sprout length were correlated to individual charac-

Table IV. Influence of cutting date on the numbar of sprouts, sprout length and sprout diameter. Partial results from analysis of variance and comparison of means. Cutting date effect (date effect) was significant at 1% level (**), at 5% level (*) or not significant at 5% level (NS). Identical letters indicate means not significantly different at 5% level for each variable (Duncan test).

	Cutting date	*No of sprouts*	*Mean height (cm)*	*Maximum height (cm)*	*Mean diameter (mm)*	*Maximum diameter (mm)*
Means per cutting date	September	6.0 bc	97.1 d	132.8 c	12.6 b	16.1 b
	November	8.4 ab	119.3 ab	147.9 b	13.1 b	17.4 ab
	January	6.2 bc	102.5 cd	134.4 c	13.0 b	16.0 b
	March	9.5 a	125.7 a	164.1 a	13.8 a	18.6 a
	May	6.6 bc	119.7 ab	150.4 b	13.0 b	16.3 b
	July	5.6 c	109.6 bc	144.5 bc	12.9 b	16.2 b
Date effect		3.22	10.31	6.67	2.38	3.07
F test		(**)	(**)	(**)	(*)	(**)

teristics of initial stools: number of shoots, mean shoot girth, mean shoot basal area, total basal area of the stool and length of the longest shoot of the stool (table VI). Only data from chain saw at ground level cuttings were investigated due to large var-

Table V. Influence of stool initial characteristics on the number of sprouts, sprout length and sprout diameter. Results from analysis of variance and comparison of means. Shoot class or girth class effects and interaction were significant at 1% level (**), at 5% level (*) or not significant at 5% level (NS). Identical letters indicate means not significantly different at 5% level for each variable and each factor (Duncan test).

		No of sprouts	*Mean height (cm)*	*Maximum height (cm)*	*Mean diameter (mm)*	*Maximum diameter (mm)*
Means per girth class	1	8.7 a	110.6 a	149.2 a	13.0 a	16.8 a
	2	12.2 a	115.6 ab	149.6 a	13.0 a	17.1 a
	3	13.4 a	129.4 ab	166.8 ab	13.9 a	20.1 a
	4	15.9 b	131.2 b	176.5 ab	14.4 a	20.4 a
	5	22.0 b	156.0 b	210.0 b	14.8 a	26.0 b
Means per sprout class	1	4.9 a	103.1 a	140.4 a	13.3 a	16.3 a
	2	7.1 a	116.0 ab	154.4 a	13.3 a	17.4 a
	3	13.9 b	128.4 b	166.0 ab	13.6 a	19.5 ab
	4	32.1 c	153.0 c	193.0 c	13.8 a	22.5 bc
	5	45.8 d	151.3 c	189.0 b	13.9 a	23.0 c
Girth class effect		F = 4.95	F = 7.01	F = 1.99	F= 5.99	F = 9.70
F test		(**)	(**)	(**)	(**)	(**)
Shoot class effect		F = 73.9	F = 15.86	F = 10.66	F = 1.18	F = 10.86
F test		(**)	(**)	(**)	(NS)	(**)
Interaction		F = 1.06	F = 0.75	F = 0.62	F = 1.05	F = 1.16
F test		(NS)	(NS)	(NS)	(NS)	(NS)

Table VI. Correlation coefficient (r) between dendometric characteristics of coppiced stools and characteristics of new-clump sprouts. On each line, bold- and italic type values indicate the 2 better correlation coefficients.

		Characteristics of initial stools				
		No of shoots	*Mean shoot girth*	*Mean shoot basal area*	*Total shoot basal area*	*Height*
Characteristics of new clumps	No of sprouts	*0.8088*	0.0761	0.0672	**0.8153**	0.3036
	Mean sprout length	0.4253	0.2559	0.2247	**0.5884**	*0.5602*
	Maximum sprout length	0.3450	0.2792	0.2556	*0.5109*	**0.5414**
	Mean sprout diameter	0.0811	**0.3155**	0.2937	*0.3073*	0.3013
	Maximum sprout diameter	0.3549	0.2936	0.2821	**0.5507**	**0.3983**

iability of the 156 stools cut by this method.

Number of sprouts was correlated to total basal area and shoot number ($r > 0.8$). Sprout length and maximum sprout diameter appeared to be correlated with basal area and height of the initial stool, *ie* with site fertility, but correlation coefficients, were relatively low. Low variability of mean sprout diameter could explain low correlation with initial stool characteristics.

DISCUSSION AND CONCLUSION

Impact of cutting date

Cutting date affected sprouting date, sprout numbers, and sprout growth. These results are comparable to those obtained by others (Bartet, 1890; Warnier, 1931; Wenger, 1953; Riedacker, 1973). They observed that when stools were cut in late summer or fall, they resprouted only the following year. When cutting was performed earlier, even the beginning of summer, sprouting followed immediately. In this study, however, there was a 1-month lag for the May cutting and a one and a half month lag for the July cutting. Harmer (1988) referred to a bud dormancy for summer cutting, which only cold winter temperatures could remove. Late summer sprouting may be dependent upon summer climatic conditions as well, particularly soil water reserves, since drought can increase bud dormancy. Riedacker (1973) reacher similar conclusions for eucalyptus.

This results of this study were in agreement with results obtained by other authors for sprout number and growth: when cutting was performed during the growing season, fewer sprouts with weaker growth appeared per stool; the most favourable cutting period for sprouting and sprout development was right before the beginning of the growing season (March cutting in this study).

However, except for the January cutting where climatic conditions could be responsible for the observed differences, cuttings performed outside the growing season were satisfactory.

Measurements of stool height, volume, and crown area conducted in previous years demonstrated that discrepancies between cutting dates appeared immediately in the first growing season and were still visible during the following years regardless of cutting method. Exceptions were May and July cuttings where a positive compensation occurred the following year.

The negative effect of winter cutting must certainly be related to sensitivity of holm oak to cold temperatures which has already been mentioned by Bedel in 1866 and by Regimbeau in 1879. Desiccation by frost of the stump's uppermost section and destruction of various tissues could explain the differences observed between January cuttings and other cuttings outside the growing season.

In July cuttings, summer drought was probably a limiting factor, since the best results (November and March cuttings) were obtained when cutting was followed by rain. However, strong sunlight and high temperatues could also induce desiccation of the uppermost stump tissues and destruction of dormant buds.

Impact of cutting method

No significant difference in sprout number, height or diameter could be demonstrated between 'axe' and 'chain saw at ground level' methods. Crist *et al* (1983) reached similar conclusions when comparing the effects of cutting methods using saw or pruning shear on sprout number and growth in poplars. Cabanettes and Pagès (1990) observed a positive effect of the axe method over the chain saw method on sprout growth in chestnut, but this effect could be the result of a higher cutting position in the axe method. Phillips (1971) observed a significant positive effect of the axe method for the same species. Our study showed that stool mortality was nominally but non-significantly reduced when stools were cut with the axe.

The 'saut du piquet' technique differed significantly from the other methods. Sprout number, height and diameter were smaller than with other cutting methods. One of the goals of this method was to decrease sprout numbers within stools in order to decrease sprout competition (Regimbeau, 1879; Des Chesnes, 1892). Our results did not support this expectation. Sprout height growth decreased along with sprout number, and stool mortality was higher in the 'saut du piquet' treatment. This technique may be harmful to stool physiology and weaken the stool. The negative effect seemed to be accentuated by unfavourable climatic conditions: among the 8 stools cut in January that died the first year, 6 had been cut using the 'saut du piquet' method.

Historically, this technique was used to rejuvenate stools through individualization of shoots and related roots by stump division. Regimbeau (1879) concluded that this was difficult to accomplish, as we discovered ourselves, and could not be used too often. Our study failed to demonstrate the 1 supposedly interesting by-product of this method: the appearance of root suckers.

Impact of cutting height

The number of small-diameter sprouts appeared to be higher on stools cut with a chain saw 15 cm above ground than at ground level, although large sprouts appeared in equal quantities. Thus, cutting height had an effect on sprout type rather than on the number of dominant sprouts.

Several authors have observed a positive correlation between sprout number and cutting height: Belanger (1979) on sycamore, de Bell and Alford (1972) and Crist *et al* (1983) on poplar, Harrington (1984) on red alder, Cabanettes and

Pagès (1990) on chestnut and Martinez and Martin (1985) on eucalyptus. However, results in oaks differ. Piskoric (1963) observed that sprouting intensity on *Quercus ilex* was not dependent on cutting height. Roth and Hepting (1943) demonstrated that cutting height had little influence on sprouting in several oak species since most sprouts appeared at the base of cut shoots.

Similarly, our study showed that mean sprout length was not significantly greater for stools cut at 15 cm above ground (118 cm) than for stools cut at ground level (111 cm), 4 years after cutting. These conclusions are similar to those of Piskoric (1963) on holm oak, de Bell and Alford (1972) on poplar, Belanger (1979) on sycamore and Cabanettes and Pagès (1986) on dominant sprouts of chestnut. However, Khan and Tripathi (1989) found that sprout growth of 4 species from an Himalayan tropical wet forest increased with cutting height.

Impact of initial stool characteristics

The originality of our work was to consider stubs not as individuals but as a part of a whole stool. It was sometimes difficult to determine what stool a shoot belong to. This may explain great data variability in the 2-way variance analysis (table V) and low correlation coefficients between characteristics of parent stools and young clumps (table VI). However, it appeared that when the initial stool had more numerous and larger shoots, subsequent sprouts were more numerous and showed grater growth.

Cabanettes and Pagès (1986, 1990), who also worked at a whole-stool level, found that growth of new sprouts was positively related to size and number of stubs of the initial stool. Other similar results may be found in the literature even if the authors generally worked at a stub level and not a whole-stool level. Sprouting is linked to stub size and age (Blake and Raitanen, 1981). In some cases and for some species, this relationship is positive as found by Wenger (1953) for sweetgum or Belanger (1979) for sycamore. In other cases, a negative relationship was found by Roth and Hepting (1943) for 5 oak species or Johnson (1975) for red oak.

Moreover, stub size is often positively related to age, and aging negatively affects sprouting (Blake 1981). So, it may be concluded in some cases that, for a given stub age, sprouting is positively related to stub size, and that sprouting usually decreases with stub age after a given species-dependant age.

In our study, coppicing rotations being 30 years, shoots were still young at coppicing time and stub size had a positive effect on number and growth of stump sprouts. However a negative additional effect could be due to aging and senescence of the stool root system.

Silvicultural consequences

Current results only covered 4 growing seasons after cutting. Future observations will be necessary for greater accuracy. Particularly, long term response of coppice to different coppicing methods should be analyzed during a whole rotation. The same studied stand should also be coppiced with the same techniques for two or more rotations.

Several observations are already possible. Since very few differences were shown between 'axe' and 'chain saw at ground level' cutting methods, holm oak coppice development was probably very little affected by using chain saws rather than axes for coppice regeneration. On the contrary, the formerly widespread 'saut du piquet' method might have caused a deterioration of holm oak stands especially when over used.

Cuttings performed during the growing season for bark harvest were probably partly responsible for low coppice productivity at the end of the 19th century. A 25-year-old coppice with total height averaging 2 meters was considered as a standard (Des Chesnes, 1892).

Traditional cutting methods in holm oak coppice are responsible for maintaining numerous stands in a degraded state characterized by semi-open or stunted stands. Modern cutting methods lead to better stump sprouting conditions and thus to better long term survival of the coppice. However, stump sprouting is only a 'half-regeneration' as the root system is but partly renewed. Thus, when holm oak coppice regeneration is studied, other features than stump sprouting should be considered, such as natural seed regeneration, appearance of root suckers and stump age.

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