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**Original article**

# An evaluation of decapitation as a method for selecting clonal *Quercus petraea* (Matt) Liebl with different branching intensities

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**Summary** — The effect of decapitation on branch production in 5 clones of oak was observed over the 2 flushes of growth occurring during 1 season. Concurrent experiments were carried out under natural conditions in the nursery and 2 different temperature regimes in growth chambers. Decapitation had no effect on the number of buds becoming active but usually increased both the proportion of active buds forming branches and the number of branches produced during each flush. More branches were formed during the first flush of growth but the largest effect of decapitation occurred during the second flush. There were significant differences between clones but the clonal order of branchiness varied between flushes and treatment. Lower temperatures reduced the rate of shoot development but had only small effects on the length of new leading shoot and the proportion of buds becoming branches. The significance of these results for the selection of oaks with different branching patterns is discussed.

***Quercus petraea* / clone / bud / branching**

**Résumé — Une évaluation de la décapitation comme méthode de sélection clonale de *Quercus petraea* (Matt) Liebl présentant différentes intensités de branchaison.** *Les effets produits par la décapitation sur la ramification observée sur 5 clones de chêne ont été étudiés au cours des 2 vagues de croissance se produisant en une saison. Des expériences sont effectuées simultanément en pépinière, dans des conditions naturelles, et en laboratoire, en ayant recours à 2 régimes de températures différents. La décapitation n'affecte en rien le nombre des bourgeons devenant actifs (tableau III), alors qu'elle augmente généralement à la fois la proportion de bourgeons actifs formant des branches et le nombre de branches produites pendant chaque vague de croissance (fig 4). Bien que la ramification soit plus fréquente sur le dernier cycle de l'année précédente que sur le premier cycle de l'année en cours, la décapitation a une plus grande influence sur la ramification dans le second cas que dans le premier (figs 5 et 6). Des variations significatives apparaissent d'un clone à l'autre, mais aussi selon le cycle de croissance considéré et selon les traitements (tableau IV). Il s'avère que les températures plus basses réduisent la vitesse de développement de la pousse, mais n'ont que peu d'effet sur la longueur*

*de la nouvelle pousse apicale et la proportion de bourgeons donnant naissance à des branches (figs 2 et 3). La portée qu'ont ces résultats sur la sélection des chênes présentant des systèmes de ramification différents fait l'objet de discussions.*

**Quercus petraea / *chêne / clone / bourgeon / ramification***

## INTRODUCTION

Deciduous oaks are some of the most important hardwood timber trees in north-temperate Europe and, for example, in Great Britain they form 30% of broadleaved high forest providing 25–30% of hardwood timber for sawmills (Evans, 1984). However, the quality of oak timber is very variable and there may be a 10-fold difference in the value of high- and low-grade timber (Whiteman *et al,* 1991). Despite the commercial importance of oak there has been little emphasis on improvement of planting stock by the selection of superior genotypes and large scale trans-European provenance trials with *Quercus robur* L and *Q petraea* (Matt) Liebl are only just beginning. These will not yield final results for several decades and the uncertainty of seed supply may, even then, prevent use of the best provenances. Several studies have shown that it is possible to produce clonal oaks either by micropropagation of softwood cuttings (Kleinschmit *et al,* 1975a; Spethmann, 1986; Meier-Dinkel, 1987; San-Jose *et al,* 1990). Such procedures could be used to supply suitable planting stock and avoid the vagaries of seed supply. At present these methods are only successful with some juvenile material but there is no current method for determining whether the juvenile clones capable of mass propagation will produce high quality trees. The UK Forestry Commission's oak improvement programme is investigating methods of identifying superior trees when they are juvenile and can be used for clonal propagation.

The quality of oaks for saw logs is related to the size and number of branches on the trunk; large branches, or large numbers of branches will significantly reduce the quality and hence value of oak timber. Careful silvicultural practice can be used to manipulate branching but the normal tendency of oak to produce a spreading crown with large branches is difficult to suppress whilst maintaining an acceptable combination of height and diameter growth. An important part of our oak improvement programme aims to gain a better understanding of the development and control of branching and identify genotypes with superior stem and crown form.

Studies with obeche (*Triplochiton scleroxylon*, K Schum), a fast growing tropical tree, have shown that it is possible to relate branching in small, young, clonal plants to that of larger plants growing in the field. When small plants were decapitated, the number of branches produced varied between clones (Leakey and Longman, 1986); clonal field trials showed that after 5 years' growth the number of branches on the main stem was positively correlated with branch production in decapitation experiments (Leakey and Ladipo, 1987). The following experiments were carried out in order to evaluate the use of decapitation as a method for selecting oaks with different branching patterns. Growth in oak is determinate and there are 1 or more discrete periods of shoot extension during the growing season which are, in part, under endogenous control (Barnola *et al,* 1986; Alatou *et al,* 1989; Barnola *et al,* 1990; Parmentier *et al,* 1991; Barnola *et al,* 1993). As the formation of lateral branches appears to differ between periods of growth occurring at different times of the year

(Harmer, 1992b), experiments were carried out using overwintered shoots and those produced during the first period of growth in spring.

## METHODS

### *Plant culture and experimental treatments*

During summer 1989 leafy cuttings were taken from shoots growing on stumps of 10-year-old *Q petraea* trees felled during winter 1988. Cuttings were rooted using methods described by Harmer and Baker (1991). Surviving cuttings were overwintered in the trays of substrate used for rooting and then grown outdoors for 1 season in 10 cm plastic pots containing 3:1 peat/grit compost with slow release fertiliser (18:11:10, N:$P_2O_5$:$K_2O$, 4.3 kg $m^{-3}$).

In February 1991, similar sized plants from 5 clones from parents with apparently different growth form were repotted into 12.5 cm diameter plastic pots of compost. The plants selected had produced 2 flushes of growth in 1990 and had a live terminal bud. Most plants had produced 1–2 branches which were removed after repotting. Plants were then randomly assigned to 2 decapitation treatments in 3 environmental conditions; there were 5–10 plants of each clone receiving the decapitation treatments in each environment.

i. Decapitation — the terminal bud was removed, using forceps, from half of the plants at the start of both the first and second flushes of growth; the remaining plants were untreated, intact, controls.

ii. Environment — equivalent numbers of each clone receiving the 2 decapitation treatments were grown in growth chambers under 2 different temperature regimes: warm, 20°/15° day/night; cool, 15°/10° day/night. Plants were also grown under natural conditions in the nursery.

Environmental differences between chambers were minimised: day length was 18 h and supplied by both fluorescent tubes (Sylvania, Cool white) and tungsten lamps; photosynthetically active radiation at canopy height was adjusted weekly to 145 μmol $m^{-2}$ $s^{-1}$; day/night water vapour pressure deficits were approximately 2.3/1.0 mb, respectively. Pots were watered as required and given liquid fertiliser (N:$P_2O_5$:$K_2O$, 8:4:4) at 14-d intervals. During the first 6 weeks of the experiment, leaves on some plants in the warm environment developed mildew; these leaves were removed immediately. No mildew developed on plants in the cool chamber. The few aphids that appeared were controlled by hand during experimental observations. Plants in the nursery were sprayed with pyrethrum-based insecticide and sulphur to control aphids and mildew, respectively.

### *Assessment*

The plants in the growth chambers were observed on alternate days throughout the experiment, which lasted for 2 periods of shoot growth. Three sections of leading shoot were observed during the experiment (fig 1): a) *original* shoot — the terminal section of shoot produced by the second period of growth in 1990, this carried overwintering buds; b) *first-flush* shoot — the section produced during the first period of growth in the experiment; and c) *second-flush* shoot — the section produced during the second period of growth in the experiment. For decapitated plants the leading shoot was defined as the longest branch which grew from the lateral buds at the tip of the shoot.

The times taken to reach the following states of development were scored for the most advanced bud on the *original* shoot during the first period of growth: d) bud expansion — green areas appearing between bud scales but no leaves visible, buds which reached this state were regarded as active; e) first visible leaf — beginning of bud opening and shoot extension; f) leaf expansion — new shoot no longer extending, leaves expanding; and g) end of flush — leaves fully expanded. The same features, except (e), were assessed for buds on the *first-flush* shoot during the second period of growth. During both periods of growth the total number of buds active was assessed at 8-d intervals.

At the end of the first period of growth the number of lateral branches on the *original* shoot was counted before removing all new growth except the leading shoot. During the second period of growth a few buds became active on the *original* shoot, these were not counted. After completion of the second period of growth the number of lateral branches on the *first-flush* shoot was counted

and the lengths of the leading shoots produced during both the first and second periods of growth measured.

Plants growing under natural conditions in the nursery were treated in the same way as those in the growth chambers but only shoot lengths and branch numbers were assessed.

After the mother trees had been felled, measurements were made of the length and number of branches on the final 3 sections of shoot present on the leader and the 4 major crown branches. These sections, which were equivalent to those of the experimental plants, are also termed *original*, *first-flush* and *second-flush* shoots (fig 1).

### *Statistical analysis and presentation of data*

Due to the large differences in experiment times and conditions, data for plants grown in the growth chambers, the nursery and the field have been analysed separately. The effects of clones and treatments were investigated by analysis of variance. As previous studies have shown that bud and branch numbers are related to shoot length (Harmer, 1989a, 1992a) analyses of these data used length as a covariate; any levels of significance given in the text, tables or figures result from these analyses. However, the means and standard errors of differences between means presented in tables and figures are not adjusted for the covariate.

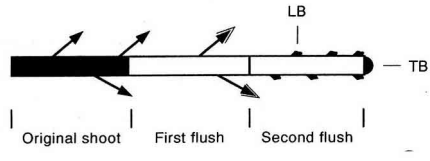


**Fig 1.** Diagrammatic representation of shoots on clonal plants and mother trees. Branches formed on *original* shoots that were removed from experimental clonal plants at the end of the first period of growth ⟶; these formed from overwintered buds. Branches produced on the *first-flush* shoot during the second period of growth ⟶; these formed from lateral buds produced during the first period of growth. LB = lateral bud; TB = terminal bud.

## RESULTS

There were significant effects of clone and decapitation on the branching of plants but, with the exception of rate development, the effects of temperature were small (table I, fig 2). The presence or absence of the terminal bud had no significant influence on the time taken to reach each stage of development therefore figure 2 shows the means of data over both decapitation treatments. There were significant differences between clones and between temperature conditions in the number of days taken for the most advanced bud to reach each stage of development. Overwintered buds on clones in the warm chamber reached bud expansion in about 11 d and finished their development after 26 d, the second period of growth started at day 54 and finished 10 d later. Plants in the cool growth chamber developed more slowly; the first period of growth lasted for 42 d and the second period started at day 79 and lasted 25 d. The rate of development of plants growing under natural conditions was slower than that for either chamber. Expansion of overwintered buds began in

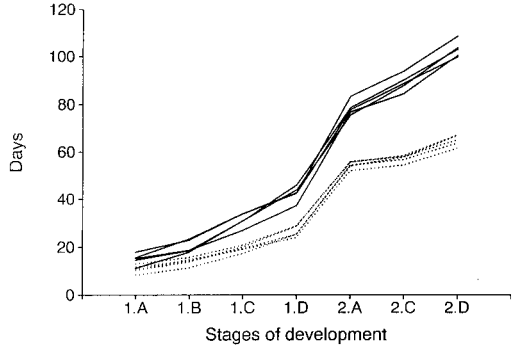


**Fig 2.** Mean number of days taken by plants in the warm and cool chambers to reach each stage of development. 1 = First period of growth; 2 = second period of growth. A = Bud expansion; B = first visible leaf; C = leaf expansion; D = end of flush. Solid line: plants in cold chamber; dotted line: plants in warm chamber. Each line is the mean value for one clone.

**Table I.** Summary table of statistical analyses for plants grown in growth chambers.

| *Factor* | *Variable* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Shoot length* | | | *Active buds* | | *Proportion* | | *No of branches* | |
| | Original | 1st | 2nd | Original | 1st | Original | 1st | Original | 1st |
| Clone | NS | *** | *** | * | NS | *** | * | *** | *** |
| Temp | NS | NS | * | NS | NS | * | NS | NS | NS |
| Decap | NS | NS | NS | NS | NS | *** | *** | *** | *** |
| Clone x Temp | NS | NS | NS | NS | NS | NS | * | NS | NS |
| Clone x Decap | NS | NS | NS | NS | NS | NS | *** | NS | ** |
| Temps x Decap | NS | NS | NS | NS | NS | NS | * | NS | NS |
| Clone x Temp x Decap | NS | NS | NS | NS | NS | NS | ** | NS | * |
| Length Covariate | – | – | – | *** | NS | NS | *** | *** | *** |

Proportion = proportion of active buds becoming branches. Temp = temperature. Decap = decapitation. 1st = *first-flush* shoot; 2nd = *second-flush* shoot. NS = not significant; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

the last week of March, the first period of growth being completed by the end of May after about 70 d; the second period of growth started in June and ended in July. This observation is similar to those describing the normal pattern of growth under natural conditions.

For plants in the growth chambers, decapitation had no significant effect on length of the leading shoot produced and whilst lower temperatures reduced the length of the *second-flush* leading shoot by between 6 and 30%, the effect was only significant at the 5% level (table I). The mean lengths of the leading shoots produced by each clone during each period of growth over all treatments are shown in figure 3a. The mean length of the *original* shoot varied between 37 and 50 mm and did not differ significantly between clones. For all clones the mean length of the *first-flush* was always smaller than the *original* shoot; clone 7 was the shortest and clone 4 the largest, at 14 and 37 mm respectively (fig 3a). The *second-flush* shoots were about 3.5–5-fold longer than the *first-flush* shoots and there were significant differences between clones ($p \leq 0.001$), the mean length varying between 50 and 175 mm for clones 7 and 4 respectively. For both the *first-flush* and the *second-flush* leading shoots the rank of clones according to length was clone 7 < 10 < 5 < 2 < 4.

Length data for the plants grown under natural conditions are presented in figure 3b. Overall trends between flushes were similar to those for plants grown in chambers: the *first-flush* shoots were the shortest and *second-flush* usually the longest, but shoots were generally shorter and the rank order of clones differed.

The mean lengths of the shoots present on the mother trees were always greater than those on the clonal plants (table II; fig 3a,b). Whilst the *first-flush* shoots of these trees were usually shorter than the *original* shoots the difference between *second-flush* and *original* was less obvious than for the clonal plants.

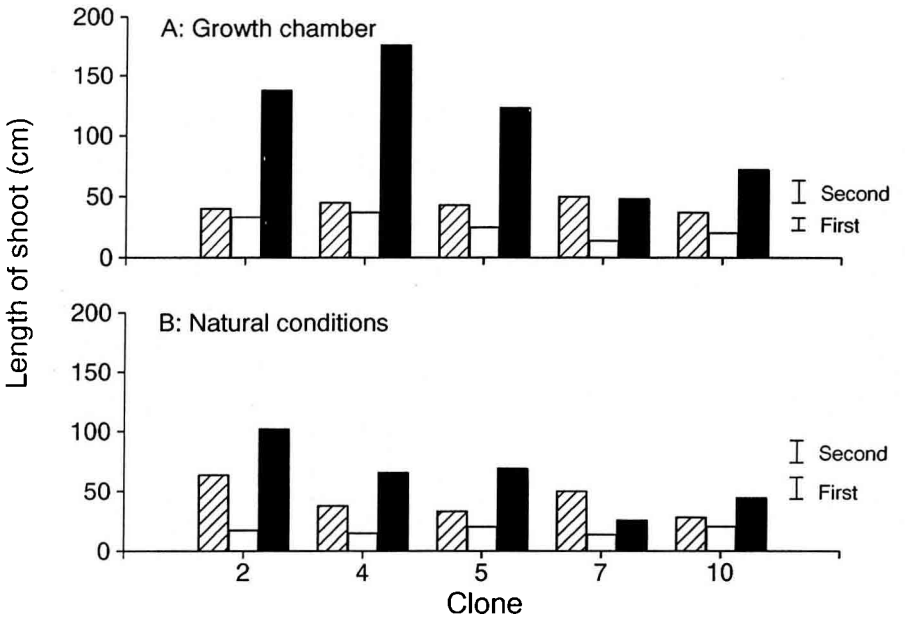


**Fig 3.** Mean lengths (mm) of original, *first-flush* and *second-flush* shoots. A = plants grown in growth chambers. B = plants grown under natural conditions in the nursery. ▨ = *original* shoot; □ = *first-flush* shoot; ■ = *second-flush* shoot. Standard errors of differences between means of *second-flush*, *first-flush* and *original* shoot lengths are shown.

**Table II.** Mean lengths (mm) and number of branches (± standard errors) on *original*, *first-flush* and *second-flush* shoots of mother trees.

| *Tree* | *Length of shoot (mm)* | | | *No of branches* | |
|---|---|---|---|---|---|
| | Original | First | Second | Original | First |
| 2 | 142 ± 37 | 210 ± 32 | 404 ± 107 | 3.8 ± 1.8 | 1.8 ± 1.1 |
| 4 | 204 ± 69 | 66 ± 13 | 204 ± 33 | 2.6 ± 0.9 | 0.6 ± 0.4 |
| 5 | 132 ± 32 | 78 ± 14 | 298 ± 58 | 4.4 ± 0.4 | 2.4 ± 0.7 |
| 7 | 278 ± 44 | 54 ± 13 | 258 ± 75 | 5.6 ± 1.4 | 1.8 ± 0.4 |
| 10 | 354 ± 33 | 162 ± 18 | 354 ± 23 | 8.2 ± 1.2 | 0.4 ± 0.4 |
| | NS | *** | NS | NS | * |

NS = not significant; * $p \leq 0.05$; *** $p \leq 0.001$.

**Table III.** Mean number of active buds present on the *original* and *first-flush* shoots of plants in the growth chambers.

| *Clone* | Original | First-flush |
|---|---|---|
| 2 | 8.3<br>$n = 19$ | 5.0<br>$n = 19$ |
| 4 | 6.8<br>$n = 20$ | 5.8<br>$n = 20$ |
| 5 | 8.3<br>$n = 19$ | 5.8<br>$n = 19$ |
| 7 | 9.8<br>$n = 40$ | 4.9<br>$n = 40$ |
| 10 | 7.0<br>$n = 40$ | 5.6<br>$n = 40$ |
| | $p \leq 0.05$<br>SED = 0.8 | NS |

$n$ = number of replicates; SED = standard error of difference between means, for comparing means with fewest replicates.

The numbers of buds that became active on growth chamber plants during the 1st and 2nd period of growth are shown in table III; these were not influenced by decapitation or temperature (table I). More buds became active on the *original* shoot than on the *first-flush* shoot, the number varied between 6.8–9.8 and 4.9–5.8, respectively.

Both clone and decapitation had significant effects on the proportion of active buds that became branches on *original* and *first-flush* shoots ($p \leq 0.001$) (table I; fig 4). For intact, control plants the proportion of active buds forming branches on the *original* shoot varied from 0.13 to 0.42 (fig 4), decapitation increased this to between 0.33 and 0.60. The proportions of active *first-flush* buds forming branches were similar to these, ranging between 0.08–0.55 and 0.29–0.60 for control and decapitated plants, respectively (fig 4). Plants in the cool chamber produced approximately 25% more branches on *original* shoots than those in the warm chamber ($p \leq 0.05$). Analysis of the data for the *first-flush* shoots showed significant interactions between clones, terminal and temperature treatments (table I) which were due to clones 5 and 7 that showed a less obvious or opposite response to decapitation at the different temperatures.

The numbers of branches present on each shoot are shown in figures 5 and 6; as the only effect of temperature was a small 3-way interaction (table I), the data for both warm and cool chambers have been combined (fig 5). There were no sylleptic branches. For plants under all conditions there were significant differences between clones in the number of branches formed on each shoot. In general, the *original* shoots carried more branches than *first-flush* shoots and over all clones and treatments the mean number of branches present on a shoot varied from 0 to 5.75; these values were found for clone 4 grown under natural conditions (figs 5 and 6). The effects of decapitation were usually positive with the largest percentage increases in numbers of branches occurring after decapitation of the *first-flush* shoots (figs 5 and 6). Decapitation caused increases of 0–140% in the number of branches on *original* shoots and 10–560% on *first-flush* shoots. The only exception was clone 5 growing under natural conditions, where decapitation caused a 60% reduction in number of branches on the *first-flush*. On mother trees the *original* shoots also carried the most branches and in general each shoot had more branches than comparable control, clonal plants (table II, figs 5 and 6).

In order to compare the branchiness of each shoot it was necessary to allow for the large differences in length by calculating number of branches per unit length of shoot

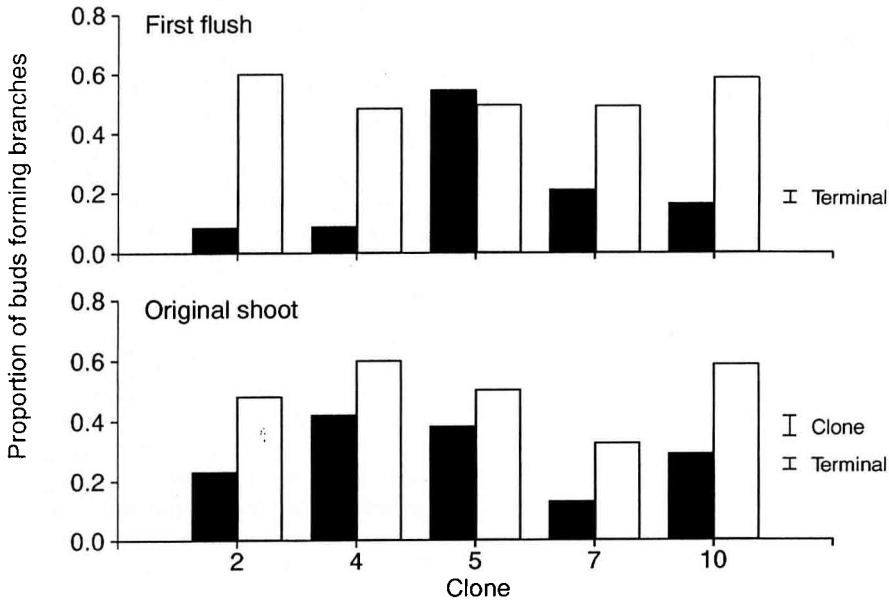


**Fig 4.** Proportion of active buds that became branches on *original* and *first-flush* shoots: ■, control; □, decapitated. Standard errors of differences between means for decapitation treatment and clone are shown.

(table IV). In most cases, control trees were less branched than corresponding decapitated plants under the same growing conditions, and shoots on mother trees were nearly always less branched than experimental plants; the difference between flushes was less marked. The number of branches per millimetre varied between zero, for control *first-flush* shoots of clone 4 under natural conditions, and 0.335 for the *original* shoots of clone 2 receiving the same treatment. The rank numbers of the clones according to branchiness for each treatment are also presented in table IV. Although the *original* shoot of clone 7 was generally the least branched, the rank order of the clones depended on treatment. There was no obvious relationship between branchiness of the experimental plants and the mother trees.

## DISCUSSION

These investigations showed that decapitation stimulated lateral branch production but the magnitude of the response varied between clones. Although the influence of decapitation was the same for each section of shoot there appeared to be quantitative differences between *original* and *first-flush* shoots that varied with growth conditions. Differences in response between these shoots was probably related to their physiological state reflecting the differences between acrotony (apical control) and apical dominance (Brown *et al,* 1967; Champagnat *et al,* 1971; Champagnat, 1978; Crabbé, 1987; Champagnat, 1989). *Original* shoots were leafless, with new shoot growth developing from *ca* 6-month-old buds emerging

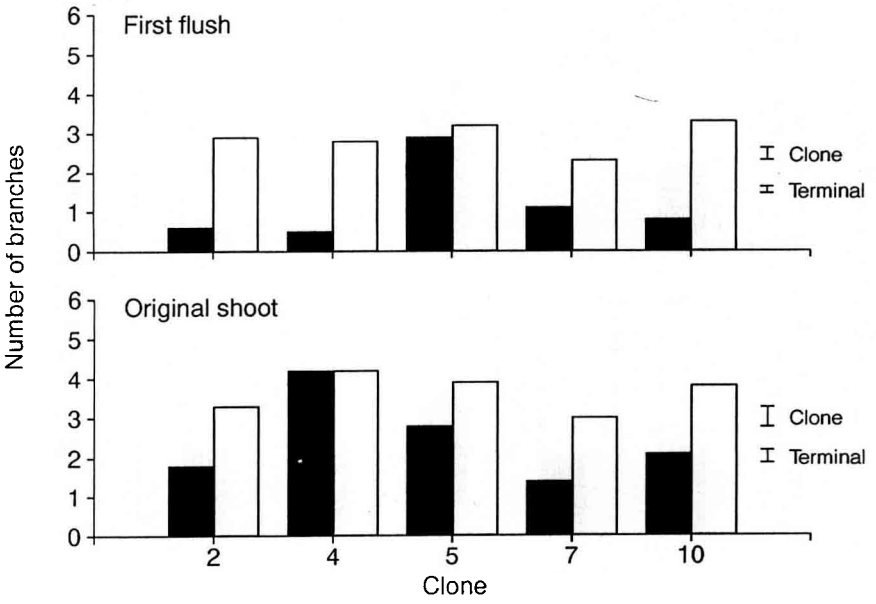


**Fig 5.** Number of branches formed on the *original* and *first-flush* shoots on plants grown in the growth chambers: ■ , control; □ , decapitated. Standard errors of differences between means for decapitation treatment and clone are shown.

from a period of winter dormancy. In contrast, *first-flush* shoots were leafy, actively growing and their new shoots developed from buds that had experienced only a short period of rest.

Casual observations of seedlings growing in the nursery and greenhouse, and shoots developing within and outside treeshelters (Potter, 1991) had suggested that temperature was an important factor influencing branching. However, results from plants growing in the controlled environment chambers suggest that the effects of temperature are relatively small compared to other factors. Low temperature had the predictable effect of reducing rate of development (fig 2) but had few other significant effects which were most often apparent as interactions with other factors (table I). Although these results were consistent with those of Leakey and Longman (1986), who found that temperature had little effect on percentage bud activity, the influence of temperature on branching is unclear. Most studies of apical dominance have been with herbaceous plants and results on the influence of temperature on both these and woody plants are inconclusive. There are a number of studies which show that lower temperatures can reduce apical dominance and increase branching (Bollman *et al,* 1986; Rosa, 1986; Moe, 1988) but there are others which show the opposite or no effect (White and Mansfield, 1978; Struik *et al,* 1989). In the experiments described using oak, only 1 chamber was used for each temperature and any effects ascribed to temperature may be due to other unknown differences in conditions between chambers. Further experiments

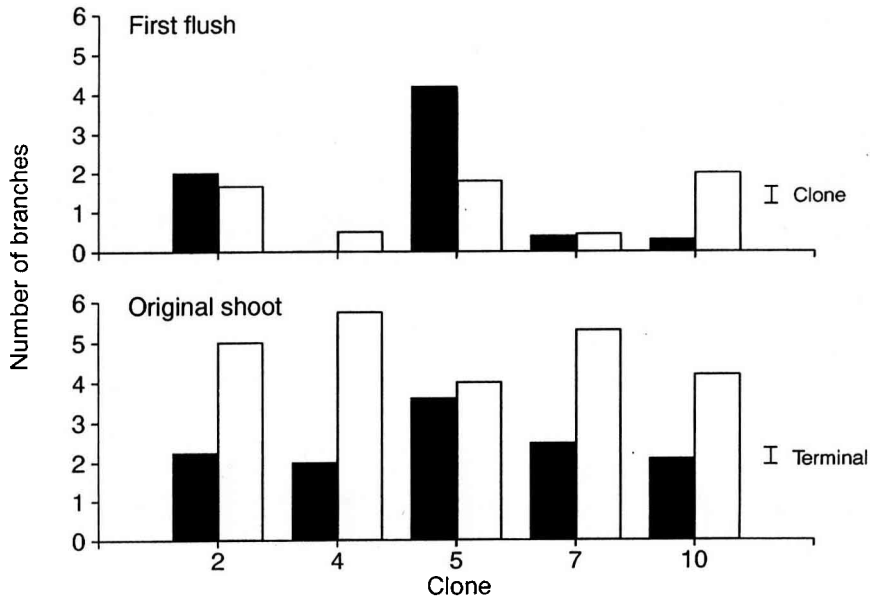


**Fig 6.** Number of branches formed on the *original* and *first-flush* shoots on plants grown under natural conditions in the nursery: ■, control; □, decapitated. Standard errors of differences between means for decapitation treatment and clone are shown.

are needed to define more precisely the role of temperature in branching and growth of oak.

The relative lengths of shoot produced during the first and second periods of growth by each clone was typical of oak. The *first-flush* shoot is usually shorter than the *second-flush* shoot produced by recurrent flushing during summer in both field and nursery grown plants (Dostal, 1927; Gruber, 1987; Harmer, 1992b). The reasons for this are unknown but may be due to a better supply of mineral nutrients and carbohydrate to the buds from plants with active roots and leaves compared to the leafless *original* shoot.

Although these experiments found that length of shoot varied with clone, decapitation had no effect on length of the new leading shoot produced during each period of growth. Comparison of this result with those for other temperate trees is difficult to do, not only because the results of pruning experiments are very variable, depending on many factors including vigour, growing conditions, time of treatment and plant age (Mika, 1986; Crabbé, 1987), but also because the pattern of growth shown by oak is different from that for temperate fruit trees for which most information is available. In general, dormant pruning of temperate fruit trees stimulates the development of longer shoots (Mika, 1986) but as these grow more or less continuously when conditions are favourable they are not comparable to oak shoots which grown rhythmically even when conditions are ideal. The length of new leader produced by lateral buds on decapitated plants was not significantly different from that for terminal

**Table IV.** Mean number of branches per millimetre on *original* and *first-flush* shoots of plants grown in Warm and Cool growth chambers, the natural environment in the nursery, and mother trees.

| *Clone* | *Warm* | | *Cool* | | *Natural* | | *Mother tree* |
|---|---|---|---|---|---|---|---|
| | + | − | + | − | + | − | |
| *Original shoot* | | | | | | | |
| 2 | 0.023 (5) | 0.179 (1) | 0.101 (2) | 0.076 (4) | 0.335 (1) | 0.104 (5) | 0.021 (3) |
| 4 | 0.091 (4) | 0.107 (3) | 0.075 (4) | 0.182 (1) | 0.073 (3) | 0.120 (3) | 0.019 (4) |
| 5 | 0.078 (2) | 0.093 (4) | 0.084 (3) | 0.088 (3) | 0.071 (4) | 0.231 (1) | 0.045 (1) |
| 7 | 0.033 (4) | 0.063 (5) | 0.020 (5) | 0.059 (5) | 0.044 (5) | 0.106 (4) | 0.020 (5) |
| 10 | 0.052 (3) | 0.150 (2) | 0.111 (1) | 0.165 (2) | 0.132 (2) | 0.159 (2) | 0.024 (2) |
| *First-flush shoot* | | | | | | | |
| 2 | 0.057 (3) | 0.136 (3) | 0.021 (3) | 0.118 (4) | 0.082 (2) | 0.125 (2) | 0.007 (4) |
| 4 | 0.008 (5) | 0.168 (1) | 0.004 (5) | 0.060 (5) | 0.000 (5) | 0.033 (4) | 0.009 (3) |
| 5 | 0.123 (1) | 0.116 (4) | 0.142 (1) | 0.177 (2) | 0.236 (1) | 0.108 (3) | 0.036 (2) |
| 7 | 0.051 (4) | 0.168 (2) | 0.015 (4) | 0.180 (1) | 0.033 (3) | 0.031 (5) | 0.047 (1) |
| 10 | 0.067 (2) | 0.025 (5) | 0.061 (2) | 0.151 (3) | 0.016 (4) | 0.148 (1) | 0.002 (5) |

+ = intact controls with terminal bud; − = decapitated. Figures in parentheses are rank orders of clones for each flush in each environment.

buds on untreated plants. This was unexpected as the terminal bud is usually the largest on a shoot and it suggests that there may be little relationship between bud size and shoot length and that bud and shoot growth is strongly influenced by correlative effects.

Studies of branch production following decapitation have also been made on temperate fruit trees where pruning usually increases the number of lateral branches produced (Barlow and Hancock, 1962; Mika 1986). Similar results have been found for *Morus alba* L (Suzuki *et al,* 1988), *Q rubra* L (Ward, 1964) and *T scleroxylon* (Leakey and Longman, 1986). Before investigating the differences in bud activity and branch production between clones of oak it was necessary to allow for shoot length which was very variable and has a close relationship with numbers of buds and branches (Ward, 1964; Harmer, 1989a; 1992a). Similar adjustments were needed in a study of branching in poplar clones (Sauer, 1959). Decapitation had no effect on the number of buds that became active but significantly increased both the proportion of buds that became branches and the number of branches on the shoot (table I). The greatest percentage increases in branch number occurred for *first-flush* shoots. These results reflect the pattern of apical dominance and control shown by oak (Brown *et al,* 1967; Champagnat, 1989): the buds on the overwintered *original* shoot are under weak apical control and many are able to form branches without decapitation; in contrast, buds on the *first-flush* are suppressed by strong apical dominance which is removed by decapitation. As most new

branch production in the field occurs during spring any selection test should probably be based on the observation of branching on the *original* shoot; unless the behaviour of *original* and *first-flush* shoots can be correlated this will restrict study to annual observations.

There have been few studies on growth using clonal oak and this is the first report of an experiment that has investigated branching in young clonal material generated from cuttings. Recent studies of clonal *Q rubra* derived from split embryos have shown significant differences in height and stem diameter between clones from a number of families (Kolb and Steiner, 1989). Similarly, the length of the new leading shoots also varied considerably amongst the small number of *Q petraea* clones investigated in the study described, which suggests that it could be possible to select clonal oaks that show differences in rate of height growth. Studies of 15–20-year-old grafted plants of *Q robur* and *Q petraea* have shown that there can be significant clonal differences in stem form, crown shape, branchiness, branch angle and tree from (Kleinschmit *et al,* 1975b) but it is not known how the form of these plants developed. In contrast, the experiments with clonal *Q petraea* described in the present study have shown significant clonal differences in shoot length and branch production, but the final form of these clones in the field is not yet known. In order to understand the relationships between the growth of young clonal plants and mature trees in the field, it will be necessary to establish trials such as that described by Leakey and Ladipo (1987), who found that the number of branches produced by clones of *T scleroxylon* in the field was strongly correlated with bud activity after decapitation of small plants in a 'predictive test'. At present, the only data available for the comparison of young and field grown clones are for the final 3 sections of shoot on branches of the mother trees (table II): the data in table IV show that there was no obvious relationship between young clonal plants and mother trees.

The experiments described, which investigated the relationship between genotype, branching and temperature, were made in order to evaluate the use of decapitation as a method for selecting clonal oak with different branching characteristics. Only a small number of clones were used but results show that the rank order of clones according to branchiness varies with growing conditions and period of growth observed. Reasons for this difference are not known but they probably result from variation in endogenous features such as those investigated in detailed physiological studies (Alatou *et al,* 1989; Champagnat, 1989; Parmentier *et al,* 1991). Similarly it is not known if the branching differences found will remain throughout the life of the tree or precisely how they will change as the plant grows giving rise to mature plants with patterns of branch growth and crown architecture which differs from that of juveniles (Bartelemy *et al,* 1989; Edelin, 1991). Although it may be possible to develop a 'predictive test' for branching that is based on decapitation, it is clear that the experimental environment, physiological stage and age of the plant need to be closely defined (Harmer, 1989b). In addition, in order to relate experimental results to growth in the field, it will be necessary to establish field trials where observation of branching takes place over several years. However, screening even a few clones is expensive and even if a suitable predictive test can be developed it may be impossible to screen large numbers of clones. We have established stock hedges and intend to produce sufficient plants from a variety of clones to establish field trials and continue exerimental observations of branching in order to gain a better understanding of plant growth and develop a method of selecting superior clones.

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