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Effect of early formative shaping on newly planted broadleaves – Part 2: Height and diameter growth

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Abstract
Formative shaping for quality was applied to 1,380 trees, commencing during the second growing season after planting. A similar number was kept as a control. The purpose of this trial was to assess the effect, if any, of formative shaping on early stem quality. Over a 4-year period, height and diameter growth were also monitored, to assess the effect, if any, of formative shaping on these parameters. This paper (Part 2) describes the effect of formative shaping on the height and diameter growth of eight species included in the trial: common ash (*Fraxinus excelsior* L.); common beech (*Fagus sylvatica* L.); cherry (*Prunus avium* L.); pedunculate oak (*Quercus robur* L.); sweet chestnut (*Castanea sativa* Mill.); sessile oak (*Q. petraea* (Mattuschka) Lieblein); sycamore (*Acer pseudoplatanus* L.); and common walnut (*Juglans regia* L.). Formative shaping had a significant positive effect on the height growth of ash, sweet chestnut and sycamore, and a significant negative effect on the diameter growth of ash, cherry, sweet chestnut, sycamore and walnut. The negative effect on diameter is regarded from a silvicultural perspective as being of negligible importance. Formative shaping should commence as early as possible in the rotation, ideally when trees are 1.0-1.6 m in height.

Keywords: broadleaves, leading shoot quality, formative shaping, height growth, diameter growth, apical training, early management

Introduction
This paper is the second part of a study of formative shaping in broadleaves. Part 1 (Bulfin and Radford, 1998) describes the effect of formative shaping on the early stem quality of eight broadleaf species: common ash (*Fraxinus excelsior* L.); common beech (*Fagus sylvatica* L.); cherry (*Prunus avium* L.); pedunculate oak (*Quercus robur* L.); sweet chestnut (*Castanea sativa* Mill.); sessile oak (*Q. petraea* (Mattuschka) Lieblein); sycamore (*Acer pseudoplatanus* L.); and common walnut (*Juglans regia* L.). This paper (Part 2) reports on the effect of formative shaping on the height and diameter growth of these species. As stated in Part 1, "In the context of this study, early formative shaping is defined as work carried out to maintain a single, straight stemmed and apically dominant leading shoot on broadleaf trees…It involved the removal of: (i) forks; (ii) codominant shoots competing with the leader; and (iii) disproportionately large branches lower down the stem which were likely to damage the long-term straightness of the stem." Formative shaping was nor-

mally carried to at least 3.0 m above ground level. As suggested by Bulfin (1992), the objective of formative shaping is "to stimulate the same effect on the crop as natural crowding in natural regeneration situations, which causes broadleaves to tend to grow straight and to lose their side branches at an early age."

As described in Part 1 and recommended by Barton (1993), Balandier (1997) and Hubert and Courraud (1987), formative shaping in this study was applied in the June/July period, commencing during the second growing season and repeated annually, where required. There were a number of reasons for selecting this time of the year for shaping. At the end of winter, damage from frost and cold winds will result in dead leading shoot buds and dead or damaged leading shoots. In some cases, leading shoots which continued to grow late into the autumn may have been damaged by frost and subsequently attacked in their weakened state by disease. This damage weakens the leader, allowing it to be overtaken by branches lower down the stem which then become competing codominants. Also, in the case of ash, damage to the leading shoot bud in late spring may be caused by the ash bud moth (*Prays fraxinella*). It is only by early summer that all of these types of damage will have manifested themselves as a weakened or dying leading shoot or a dead terminal bud which has been replaced by two side buds to create a fork. In effect, shaping in the June/July period tackles the problem as soon as it becomes apparent, and before lignification has occurred. The new shoots are green and pliable and will tend towards the vertical. Remphrey and Davidson (1992), who worked extensively with ash, observed this plasticity in the case of natural shoot tip abortion, noting "a reduction in the angle of divergence of lateral shoots in response...the terminal replacements being the most acute." Two competing shoots in a fork still, however, tend to push each other apart, particularly at the base. The removal of one side of such a fork allows the remaining leading shoot to straighten and to assume as near vertical a position as possible. This shaping will limit the bayoneting defect caused by forking (Balandier, 1997).

Another major argument for summer shaping is to concentrate the vigour of growth onto one single leading shoot. Where shaping is delayed until late in the season, branches carrying up to half of the leaf area may be lost if one side of a developed fork is removed. Similarly, as described by Barton (1993), if a branch is allowed to grow through to the end of the year and then removed over the winter, "The energy locked up in the discarded branch could have been made available to the main stem leader, with a resultant increase in height and vigour. There has been a sharing, rather than a concentration, of growth potential. The discarded branch is therefore a 'lost opportunity'." Hubert and Courraud (1987) indicate that the optimum time for formative shaping is from mid-June onwards, after the effect of spring frosts has become apparent, and can be carried out by pinching off the new green forked branch tips by hand. This comment about hand shaping reflects the early stage at which shaping is recommended, to minimise the leaf area removed and to concentrate growth as early as possible on one single leader. Davidson and Remphrey (1994) indicate that there is differential compensation for such a loss of leading shoot, and that a replacement leading shoot from just below the dead leader is favoured over other shoots slightly lower in the crown. The early removal of one side of this incipient fork caused by leader death will concentrate this preferential energy into one replacement shoot.

Side branches contribute to the overall welfare of the tree stem below the point of attachment with the stem (Kozlowski and Pallardy, 1997; Shigo, 1989a & b). In species characterised by branches arranged in whorls (such as cherry), there is a distinct step in diameter above and below the whorl. One particular problem associated with pruning cherry is whether to remove all or part of a whorl. Total whorl removal may limit diameter growth, while partial removal will result in the development of large branches among those retained (Balandier, 1997).

The removal of living tissue in shaping may be construed as removing the growth potential of a tree. The question at issue is whether this removal has beneficial or detrimental effects on tree growth and quality. As described in Part 1 (Bulfin and Radford, 1998), formative shaping was found to have a generally positive effect on early stem quality of the eight broadleaf species studied. This paper reports on the effect of formative shaping on the height and diameter growth.

Methodology

This paper describes the effect of formative shaping on the height and diameter growth of eight broadleaf species. The background, site description and overall methodology for this experiment is described in Part 1 (Bulfin and Radford, 1998), with further details in Bulfin (1995). Height (measured to the highest living point on the tree) and stem diameter (measured at 20 cm above ground level) were recorded each year after leaf-fall. Formative shaping commenced during the second growing season after planting when trees were less than 1.0-1.6 m in height (depending on species and planting stock), and was repeated each year, where required, up to a height of 3.0 m or more. This is the height of a person standing on the ground and working with hand tools such as secateurs or loppers. Using each tree as a single plot, an analysis of variance was carried out between treatments for each species, to test for effect on height and diameter growth.

Results

Effect of formative shaping on height growth

Very distinct effects on height growth were observed among different species in response to formative shaping. As formative shaping is aimed at maintaining a single dominant leader, it is perhaps not surprising that the shaping treatment would have a positive effect on height growth. Increases in height growth after four growing seasons (1993-96) in response to shaping proved significant at the 0.1% level among ash, sweet chestnut and sycamore (Table 1). In the case of ash and sycamore, the control of damage through formative shaping appeared to have encouraged the development of straight leaders. These leaders subsequently grew longer than those of the unshaped trees, where growth and energy were dissipated over a number of competing shoots. With the exception of sessile oak and walnut, which showed a 2.3 cm and 1.2 cm decrease in height growth respectively, formative shaping appeared to have improved height growth of all species after four growing seasons (Table 1).

Height growth of trees in the 'very good' and 'good' quality categories (Categories 1 and 2; see Part 1) combined after four growing seasons (1993-96) is detailed in Table 2 and illustrated in Figure 1.

In Table 2 and Figure 1, the best trees from each treatment, which are most likely to be kept during first and second thinning, are compared. With the exception of cherry and walnut, there is a positive difference in overall height growth in favour of the shaped trees. Sweet chestnut showed the greatest difference in height growth (28.0 cm). Yet the average height of sweet chestnut for all categories was generally small at the end of the final growing season (129.0 cm and 103.5 cm for the shaped and unshaped trees, respectively). Within the shaped treatment, however, the average height of sweet chestnut trees in Cate-

Table 1. *Effect of formative shaping on height growth after four growing seasons (1993-96) (NS not significant; * significant at 5% level; ** significant at 1% level; *** significant at 0.1% level).*

Species	*Shaped cm*	*Unshaped cm*	*Significance*
Common ash	289.1	277.7	***
Common beech	122.6	109.9	NS
Cherry	300.2	295.7	NS
Pedunculate oak	103.1	101.1	NS
Sweet chestnut	129.0	103.5	***
Sessile oak	108.1	110.4	NS
Sycamore	235.0	215.2	***
Common walnut	138.1	139.3	NS

Table 2. *Height growth of trees in Categories 1 and 2 combined after four growing seasons (1993-96).*

Species	*Shaped cm*	*Unshaped cm*	*Difference cm*	*Difference %*
Common ash	290.0	275.4	14.6	5.3
Common beech	122.7	107.9	14.8	13.7
Cherry	300.9	304.8	-3.9	-1.3
Pedunculate oak	127.2	122.3	4.9	4.0
Sweet chestnut	134.3	106.3	28.0	26.3
Sessile oak	126.6	107.0	19.6	18.3
Sycamore	232.8	226.6	6.2	2.7
Common walnut	143.3	143.5	-0.2	-0.1

gory 1 ('very good') is 140.0 cm. This suggests that shaping has a beneficial effect on the height of sweet chestnut by concentrating growth into a single leading shoot. Sessile oak showed the second greatest difference in height growth (19.6 cm), but the general performance of oak was disappointing. Beech showed the third greatest difference (14.8 cm).

At 134.3 cm, height growth among Category 1 and 2 shaped sweet chestnut is well behind that of cherry, ash, sycamore and even walnut. As shown in Figure 1, there were no trees in Categories 1 and 2 among unshaped sweet chestnut and walnut for certain years. Cherry had the greatest height growth at 300.9 cm, followed by ash and sycamore. Ash and sycamore responded well to formative shaping (Table 2). Both showed a slight positive response in height growth to formative shaping, with respective improvements of 5.3% and 2.7% in shaped over unshaped trees.

The key point demonstrated by Figure 1 for all species, with the exception of pedunculate and sessile oak, is that the effect of formative shaping on differences in height growth is slow but cumulative over the four growing seasons. Both oak species showed an anomalous growth pattern, particularly at the end of the 1995 growing season.

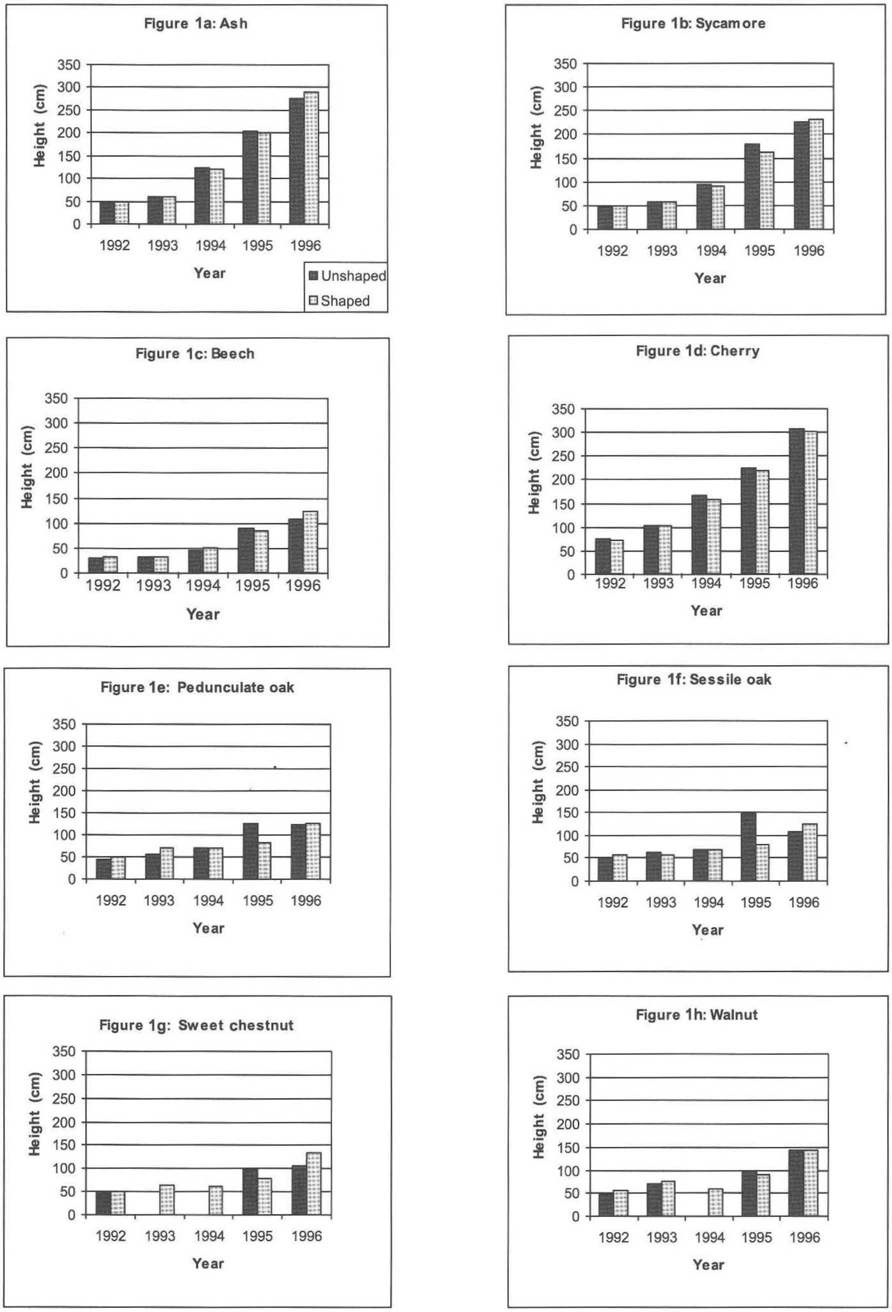

Figure 1. *The effect of formative shaping on the height growth of Categories 1 and 2 trees combined of eight broadleaf species, 1993-96. (Note: 1992 represents the planting season winter 1992/spring 1993).*

Effect of formative shaping on diameter growth

Table 3 details the diameter growth of all trees in all quality categories (Categories 1-5) after four growing seasons (1993-96). Formative shaping had a small but significant (at the 0.1% level) negative effect after four years of growth on the diameter of ash, cherry, sycamore and walnut. The effect was significant at the 5% level for sweet chestnut.

Table 3. *Effect of shaping on diameter growth after four growing seasons (1993-96) (NS not significant; * significant at 5% level; ** significant at 1% level; *** significant at 0.1% level).*

Species	*Shaped* *mm*	*Unshaped* *mm*	*Significance*
Common ash	42.0	46.3	***
Common beech	17.3	17.9	NS
Cherry	52.3	63.0	***
Pedunculate oak	17.4	19.3	NS
Sweet chestnut	32.3	36.0	*
Sessile oak	18.0	19.5	NS
Sycamore	35.7	39.9	***
Common walnut	38.5	47.1	***

The effect of formative shaping on diameter growth in relation to Categories 1 and 2 trees combined is detailed in Table 4 and illustrated in Figure 2.

Table 4. *Diameter growth of trees in Categories 1 and 2 combined after four growing seasons (1993-96).*

Species	*Shaped* *mm*	*Unshaped* *mm*	*Difference* *mm*	*Difference* *%*
Common ash	45.4	46.0	-0.6	-1.3
Common beech	18.0	17.7	0.3	1.7
Cherry	60.6	63.8	-3.2	-5.0
Pedunculate oak	19.5	25.4	-5.9	-23.2
Sweet chestnut	35.2	41.0	-5.8	-14.1
Sessile oak	20.3	28.7	-8.4	-29.3
Sycamore	39.7	38.9	0.8	2.1
Common walnut	46.5	47.2	-0.7	-1.5

The progress of diameter growth over the four growing seasons, as shown in Figure 2, indicates that, with the exception of pedunculate and sessile oak, diameter growth is similar for shaped and unshaped. In the case of pedunculate and sessile oak, diameter growth begins to diverge in the final two growing seasons.

When analysis is confined to Categories 1 and 2, the results differ from the overall statistical analysis of all quality rankings. The greatest physical differences in diameter now occur in the two oak species, with diameter growth in unshaped pedunculate and sessile

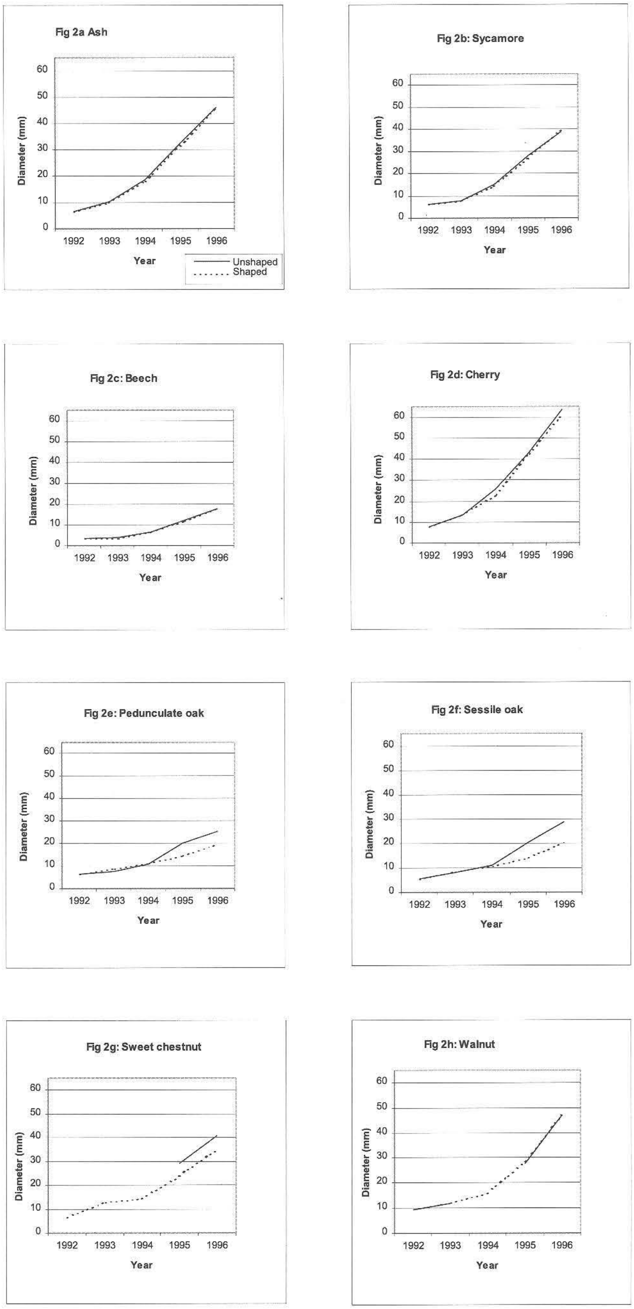

Figure 2. *The effect of formative shaping on the diameter growth of Categories 1 and 2 trees combined of eight broadleaf species, 1993-96. (Note: 1992 represents the planting season winter 1992/spring 1993).*

oak stems being considerably greater than that of their counterparts within the shaped group. This is to be expected, as any attempt to reduce oak to a single stem resulted in a considerable loss of branches and leaf area and an associated loss in diameter increment. In the case of sweet chestnut, attempts to develop a single dominant shoot by shaping resulted in a considerable loss of branches and leaf area, and a concomitant loss of 14.1% in diameter growth. It is noted that losses in diameter growth were greatest among species displaying the bushiest and poorest form in their unshaped state, i.e. sessile oak, pedunculate oak and sweet chestnut. The loss in diameter growth within pedunculate and sessile oak appears greater due to the poor overall growth of these species over the 4-year period. Ash suffered a loss of 0.6 mm or 1.3%. Shaped sycamore showed a slight increase in diameter of 2.1% over the unshaped sycamore.

Discussion

Height

The primary purpose of formative shaping is to improve early stem quality. The reason for examining its impact on height growth is to assess whether shaping had any undesirable effect on overall tree growth. In this experiment, formative shaping had a significant positive effect on the height growth of ash, sweet chestnut and sycamore. There was no significant effect on any of the other species. Of the above three species, ash and sycamore are the most important. As shown in Part 1, they are also two of the species whose quality is significantly improved by formative shaping. Thus, the net effect of formative shaping on two of Ireland's most important broadleaf species is positive for both quality and height growth.

Within the shaped treatment, leading shoots which were naturally apically dominant or which had been formatively shaped concentrated height growth into a single leader and thus maintained dominance in one shoot. Trees with a single stem then put on greater height growth than trees with forks or competing codominant shoots.

Sweet chestnut produced the greatest percentage height increase in response to formative shaping. Unshaped individuals tended towards a globular, bush-like form, with numerous branching shoots, none of which seemed to possess the ability to become a dominant leader. Formative shaping, however, concentrated the height growth onto one single leader, thus forcing dominance on one shoot. The result is a discrete, if not very high quality, single stem, which puts on greater height growth than the multiple stems of the unshaped trees.

Formative shaping had a positive but not statistically significant effect on the height growth of beech. The performance of beech was initially poor, mainly due to the quality of the transplants, but it went on to become one of the most impressive performers on this difficult site. This is possibly due to the developing presence of side shelter created by taller ash and sycamore components of the mixture.

Diameter

Shaping is concentrated on the upper portion of the developing crown and on disproportionately large side branches, in an attempt to maintain one single apically-dominant shoot. While improving tree form, the removal of large side branches or clusters of codominant shoots may have an appreciable effect on diameter growth. Branches only affect the stem below their intersection point with it. Their removal may therefore reduce diameter growth of the stem below the intersection.

Formative shaping had a significant negative effect on the diameter growth of ash, cherry, sweet chestnut, sycamore and walnut. While a significant negative effect was recorded for both ash and sycamore, the actual difference was small. When only Categories 1 and 2 trees were examined, formative shaping had a positive effect on diameter growth in sycamore, suggesting that diameter growth of good quality sycamore stems is improved by shaping. As initial diameter measurements were carried out on transplants under 1.0 m in height, measurements were made at just 20 cm above ground. In order to maintain comparability, measurements were continued at this level for the duration of the experiment. If measurements were taken at 1.3 m, a different result might emerge for cherry, ash and sycamore, as many of the unshaped trees had forked below this level. This fact must be taken into consideration when assessing the diameter results.

While there was no significant effect on the diameter growth of pedunculate and sessile oak, there was an effect among Categories 1 and 2 trees combined, with those stems in the unshaped treatment which managed to maintained single leaders putting on diameter growth. This diameter growth was greater than that on trees in the shaped group, which were being forcibly maintained in the better quality categories by the removal of defects. With both species of oak, it was necessary in some cases to remove considerable amounts of branch material during shaping to produce any type of distinct leader. There is, therefore, a question regarding the best time to commence shaping in oak. There is a tendency for newly planted oak not to produce a discrete leading shoot for a number of years after planting. It may therefore be more advantageous to wait until a definite leading shoot is produced, and then to favour this shoot by shaping. Thus, with oak, it may be better to wait until the new crop begins to put out discrete leading shoots, rather than commencing the treatment when trees are between 1.0-1.6 m in height. It is, however, impossible to predict in which year after planting a plantation of oak will begin to 'shoot' discrete leaders. Therefore, from this experiment, it does not seem possible, as yet, to recommend a specific year or a specific height as the optimum time to commence formative shaping in oak.

Some species, most notably cherry, have a tendency to produce whorls of very heavy branches. In addition to formative shaping, therefore, the early removal of these heavy branches is also necessary to enhance quality. Hubert and Courraud (1987) indicate that not all large branches in a whorl on cherry should be removed at the same time. Rather, removal should be staggered over a number of annual shaping sessions.

While overall diameter growth was slightly reduced by formative shaping, this reduction must be offset against the improvement in form and quality of several species. The clean shaped stems also greatly reduces the diameter of the potentially defective core, compared to stems subjected to later pruning or allowed to self-prune naturally. The reduction in the defect core contributes to the overall value of the stem. While statistically significant, the reduction in diameter growth can be regarded on balance as a small price to pay for the increase in overall stem quality within the shaped group.

Conclusion

The purpose of this experiment was to determine the benefits, if any, of formative shaping. Part 1 (Bulfin and Radford, 1998) describes the positive effect of formative shaping on stem quality. Part 2 assesses the impact of formative shaping on height and diameter growth. Three species benefited significantly in height growth from formative shaping, two of which, ash and sycamore, are among Ireland's most important broadleaf plantation species. Although high quality sycamore stems did experience a slight increase, in general, shaping resulted in a reduced diameter growth after four growing seasons in all species. In practical forestry terms, however, the amount of reduction was not silviculturally important. Of more importance to the potential overall value was the reduction by early shaping in the extent of defect core. In general, formative shaping should begin as early as possible in the rotation, preferably when the trees have reached 1.0-1.6 m in height. The overall conclusion of this study is that formative shaping has a beneficial effect on all eight broadleaf species studied, with very significant benefits being conferred on ash and sycamore. The case for early formative shaping of oak requires further consideration.

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