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Effect of early formative shaping on newly planted broadleaves – Part 1: Quality

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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, height and diameter growth. Over a 4-year period, trees were assessed for quality annually after leaf-fall, using a standardised ranking system. This paper (Part 1) describes the effect of formative shaping on the quality 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.). Overall, quality among trees of all eight species was improved by formative shaping. Part 2 describes the effect of formative shaping on height and diameter growth.

Keywords: broadleaves, leading shoot quality, formative shaping, quality measurement, apical training, early management

Introduction
It is estimated that between 20,000-25,000 ha of broadleaves will be planted in Ireland in the period 1990-99. Most of these plantations will be on moderately good to good quality farmland. Government policy indicates a broadleaf target of 20% of all new grant-aided planting (Anon., 1996). Including premium payments, this would suggest an investment in new broadleaf plantations by the European Union and the Irish Government of between IR£112-140 million. In this context, the development of management systems to promote quality in broadleaf plantations is a key element in achieving a return on this investment.

In commercial forestry, the most important part of any tree, particularly a broadleaf tree, is the lower section of the stem, as this is the portion which yields the greatest financial return. It is therefore essential that a sufficient number of quality stems from which to select the final crop are left *in situ* after first and second thinning. It is considered unwise to aim to have just enough quality stems at the second and third thinning stage to carry through to the final crop (approximately 500 stems/ha at year 20 for YC 12 common ash (*Fraxinus excelsior* L.) and sycamore (*Acer pseudoplatanus* L.), as indicated by Hamilton and Christie (1971)). Instead, it is essential to have in place during the early years a much greater number of quality stems than that required for an adequately stocked final crop.

The reason for advocating greater numbers is due to the high attrition rate of main stem quality in the early years following establishment (Balandier, 1997).

Lawson (1597, cited in Evelyn, 1664) provides one of the earliest references to formative shaping: "Neither let any man ever so much as think, that it is unprofitable, much less unpossible, to reform any Tree of what kind soever: for (believe me), I have tried it: I can bring any Tree (beginning betime) to any form." In a publication written in old English and entitled *Silva: or a Discourse of Forest Trees*, John Evelyn (1664) summarises what might be considered as best practice for today: "It is by the discreet leaving the Side-boughs in convenient places, sparing the smaller, and taking away the bigger, that you may advance a Tree to what determined Height you desire: Thus, bring up the Leader, and when you would have that spread and breakout, cut off all the Side-boughs, and especially at Midsummer, if you espy them breaking out. Young Trees may every Year be pruned and as they grow older at longer Intervals, as at three, five, seven or sooner, that the wounds may recover, and nothing being deformed."

From the forestry literature at the end of the 18th and beginning of the 19th century, there appears to have been two approaches to the planting of broadleaf species. One practice was to plant at wide, possibly final (7.6 m and over), spacing (Harris, 1998). This would be akin to current agroforestry methods, whereby each tree is intensively managed and tended. The second was to plant at high densities and to utilise the subsequent crowding effect to induce self-pruning. Main (1839) states that this latter practice "may be so far economical... but neither the soundness or the diametric bulk of the trees individually is promoted by such neglect. Superior trees will there be found, but they are only superior by accident." Nicol (1820) states: "Notwithstanding that we here fully admit the great utility of close masses for the procuring of straight clean timber, it must be obvious to everyone, that, for a number of the earlier years of the forest, however extensive it may be, the plants will not feel that influence from proximity which is necessary to give them the upright tendency or direction that is so highly desirable. Hence the necessity of early pruning of forest plantations."

There is little recent literature on formative shaping of broadleaves (Balandier, 1997). In a Forestry Commission handbook entitled *Urban Forestry Practice*, Hibberd (1989) describes formative pruning as "the removal of twigs and small branches", with "lopping" being the term applied to the removal of large branches. The same author indicates that formative pruning is best carried out to shape trees for the purpose of producing a desirable appearance and preventing the formation of weak forks. In an article on formative pruning, Kerr (1992) suggests that the objective of formative shaping "is to produce a single straight stem of at least 5 metres in length with small branches that will quickly die at the onset of canopy closure leaving the bole virtually defect free." In their publication *Growing Broadleaves for Timber*, Kerr and Evans (1993) suggest that formative pruning "is becoming increasingly important as a remedial treatment for the poorly developing form of many timber species planted in the last 10 years on bare ground." They indicate that "all species will benefit from some formative pruning but some more so than others." They identify oak and common beech (*Fagus sylvatica* L.), both lacking apical dominance, as two species most likely to require formative pruning. Bulfin (1992) suggests that 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."

A number of references refer to actual research work on formative shaping. In a publication devoted to formative shaping and pruning, Hubert and Courraud (1987) define the objective of formative shaping as "an attempt to give to the tree a satisfactory form and to obtain an optimum length of straight vertical stem." They define the process of formative shaping as "the suppression of double or multiple heads (leaders) or the slowing down or suppression of branches which, through too strong development, may risk damage to the trunk." Balandier (1997) states that it is necessary to distinguish systematic pruning, i.e. the pruning of a fixed length of stem to remove all branches (also referred to as stem pruning), from formative shaping. The concept of formative shaping in this research is based on that used by Hubert and Courraud (1987), which entails "suppressing the branches that interfere with the formation of a straight cylindrical bole." These authors define such branches as "forks, shoots with an acute angle of insertion, large branches competing with the main stem, etc."

In detailing his methods of apical training of blackwood (*Acacia melanoxylon*) in New Zealand, Barton (1993) states, in relation to failing leaders which form stunted growth, that "Stem remodelling requires occlusion of the pruning defect - a delay in pruning, or the retention of a stub, will delay occlusion and prevent remodelling." Where forking has occurred, the same author comments that "Forks are codominant stems, they lack a branch collar, and the defect after pruning is slow to occlude. Rapid occlusion and remodelling demand the early recognition of forks - delaying pruning until the following winter will leave a persistent stem kink."

Kerr and Evans (1993) state that their "guidelines are based on observation and some limited experience." In outlining the aim of formative shaping, they state that "the objective of formative pruning is to produce a single straight stem of at least 5 m in height with small branches that will die quickly at the onset of canopy closure leaving the bole virtually defect free." They advocate the removal of forks and disproportionally large branches, i.e. branches with "a diameter greater than 50% of the main stem at the point of intersection with the main stem." They further state that "ideally branches removed in formative shaping should not be allowed to become too large to cut with a knife or a secateurs." They also suggest that "the treatment should be started soon after establishment and ideally continued annually until the objective of a single straight stem of at least 5 m in height is satisfied." This echoes the words of Nicol (1820), who urges his readers "to commence pruning at the infancy of the trees and thence-forward to continue at intervals of one or at most two years."

Working with both broadleaves and conifers, Aufsess (1975) indicates that a protective zone develops at the base of branches even before the branch has died naturally. He suggests that the formation of the protective layer requires living parenchyma, and that in broadleaves, this protective layer cannot be complete where heartwood is present. This would indicate that formative shaping on young trees or pruning on older trees should be carried out before the onset of heartwood. This work indicates that branch or fork removal should be carried out before branches reach 3.0 cm in basal diameter, as supported by Soutrenon (1995). Winterfeld (1956) found that, in dominant beech, pruning wounds healed twice as fast as scars left by naturally shed branches. He also found that fungal infection, which was invariably present, ceased to progress once the scar had occluded. Nicol (1820) suggests that it is preferable over time not to allow any branch, even twigs, to die *in situ* on the bole, as "These frequently become *dead branches*; and if such were allowed to remain at all on the trees, they would infallibly produce blemishes calculated greatly to diminish the value of the timber: hence the impropriety of allowing any branch to die on the bole of a tree. Indeed all branches should be removed when they are *alive*." Roth (1948) indicates that the early removal of branches is preferable. In dealing with pruning wounds on oak, he found that wounds more than 3.75 cm in diameter may result in decay.

In detailing when to prune or shape, Kerr (1992) relies heavily on the work presented by Lonsdale (1991) at a seminar entitled 'Research for Practical Arboriculture' in York, April, 1990. It should be emphasised that Lonsdale's work was confined initially to the practice of stub pruning (Lonsdale, 1987), but during the above seminar, he also detailed measurements of ridge and flush cut pruning methods. Lonsdale's ridge method corresponds to the pruning methods advocated by Shigo (1989a & b). Lonsdale also worked on the pruning of branches with a diameter of 5.0-8.5 cm. This is, however, outside the range for formative shaping, where, as most of the work is carried out using secateurs or loppers, branches removed are rarely greater than 2.0 cm in diameter. In discussing pruning, Evans (1984) states that "it is rarely worthwhile pruning branches more than 5 cm in diameter or higher (up the stem) than 5-6 m." The same author states that "generally pruning up to 3 m should be done at or prior to first thinning", indicating that he is not referring, in this context, to the process of formative shaping.

In dealing with the time of pruning of large branches, i.e. branches with a diameter up to 5.0 cm, Evans (1984) states that "For rapid wound occlusion most species are best pruned in late winter or early spring, but there are exceptions. To minimise sap exudation birches, maples and sycamore should be pruned at any time except the spring, and walnut only when in full leaf in July or August. Cherry should only be pruned between June and August to minimise the risk from bacterial and silver leaf disease. In general, to help prevent entry of disease, pruning should not be done between mid-March and the end of May when a tree is flushing since its resistance to infection is believed to be at a minimum at that period."

In dealing with when to shape, Kerr and Evans (1993) state that the timing for pruning applies equally to "formative pruning". Barton (1993) favours early summer apical training. He adds that, if a branch is allowed to grow through to the end of the season and then removed, "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'." Nicol (1820) agrees with this sentiment of lost opportunity: "Is it not evident, that if these branches had been timeously checked, the greater part of the matter forming their solid contents, would have settled in the trunk itself...whereas if the superfluous or competing branches had been removed annually and before they attained a large size, the places from which they issued would be imperceptible, or at least not hurtful to the timber...timely pruning is, therefore, a matter of the utmost importance."

Balandier (1997) clearly indicates that formative shaping is to be carried out in June-July. Hubert and Courraud (1987) also 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. They state that shaping at a later date, when some lignification has taken place, should be carried out using a secateurs, with branches cut at their base.

Background to shaping experiments

As described by Bulfin (1995), 2.0 ha of broadleaves were planted at the Teagasc Kinsealy Research Centre as a broadleaf mixture experiment. After the first year, the rate of deterioration in tree quality, as assessed by a specially devised quality ranking system, was alarming. Surveys of other broadleaf plantations and experience with ash and sycamore at the Teagasc Johnstown Castle Research Centre, Co. Wexford, and with other broadleaf species at the Teagasc Grange and Kinsealy Research Centres, indicated a similar pattern of decline in the number of quality stems. It became obvious that some form of remedial action was essential. In a 13-year old plantation of ash planted at 2,500 stems/ha, Ningre *et al.* (1992) found that only 30% of the trees remained unforked. It was therefore decided to apply the practices advocated by Shigo (1989a) and Barton (1993), to attempt to maintain good stem form and apical dominance. While his work concentrated on older trees, it was a postulation of this experiment that Shigo's pruning methods would be equally valid for the type of formative shaping advocated by Barton (1993).

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. Formative shaping commenced when the 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. 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. While these authors would agree with the target of 5 m of single straight stem advocated by Kerr (1992), achieving this would require extra effort and tools other than those used in this study, i.e. secateurs and loppers.

Methodology

During the 1992/93 planting season, 2.0 ha of broadleaves were planted at the Teagasc Kinsealy Research Centre, north Dublin (National Grid reference 3215 2430). As described fully by Bulfin (1995), the plantation comprised a broadleaf mixture experiment including 10 species in six different mixtures, with three repetitions of each mixture. The soil is classified as a moderately well drained grey brown podzolic of high base status, mostly derived from Irish Sea drift. The site is a smooth, very gently sloping field under continuous arable use prior to the establishment of the experiment. It is classified as a moderately exposed to exposed site, with little shelter from surrounding trees or hedges. It differs little from many new broadleaf plantation sites in Ireland, with the exception of its distance from the sea. Due to the research centre's proximity to the east coast, the site is particularly exposed to cold east winds. The ground was ploughed and harrowed prior to planting. After planting, simazine was applied at a rate of 3.0 kg/ha. Further physical, soil and climatic details pertaining to the site are provided in Table 1.

Table 2 lists the species planted in the mixture experiment, together with the number of individual trees of each included in the subsequent shaping trial.

No attempt was made to influence the quality of the planting stock, which originated from a number of commercial nurseries. This ensured that the type of material used in the trial was similar to that being delivered in the field. As a result, there was considerable variation in initial quality.

A spacing of 1.5 m x 1.5 m was used for pedunculate oak (*Quercus robur* L.), sessile oak (*Q. petraea* (Mattuschka) Lieblein), red oak (*Q. rubra* L.) and beech, and for some of the ash and sycamore. The remaining ash and sycamore were planted at 2.0 m x 2.0 m spacing, as were all of the remaining species, except common walnut (*Juglans regia* L.) and cherry (*Prunus avium* L.), which were planted at 2.5 m x 2.5 m spacing. As the newly planted trees were small and sufficiently far apart at these spacings not to be influenced by

Table 1. *Physical, soil and climatic details of the experiment site at the Teagasc Kinsealy Research Centre, Dublin.*

Physical features	
Elevation	35 m OD
Topography	Flat to gently undulating
Slope	0-3°
Aspect	North to northeast
Distance from sea	1.6 km
Soil data	
Soil classification	Grey brown podzolic
Texture	Loam to clay loam
Structure	Moderate to weak aggregates
Drainage	Moderately well drained
Parent material	Calcareous glacial drift of Irish Sea origin, predominantly limestone with some shale
pH	Topsoil ranges from pH 7.0-8.0
Organic matter	7-10%
Climate	
Exposure	Moderately exposed to exposed
Annual rainfall	700 mm
Annual air temperature	9.5°C mean (13.0°C mean max., 6.0°C mean min.)
Annual mean duration of bright sunshine	4.05 hours
Average annual actual evapotranspiration	455 mm

Table 2. *Species planted in the mixture experiment, and the number of trees of each included in the shaping trial.*

Species	*No. of trees included in shaping trial*
Common ash (*Fraxinus excelsior* L.)	826
Common beech (*Fagus sylvatica* L.)	156
Cherry (*Prunus avium* L.)	144
Pedunculate oak (*Quercus robur* L.)	234
Red oak (*Q. rubra* L.)	180
Sweet chestnut (*Castanea sativa* Mill.)	120
Southern beech (*Nothofagus procera* (Poepp. and Endl.) Oerst.)	80
Sessile oak (*Q. petraea* (Mattuschka) Lieblein)	156
Sycamore (*Acer pseudoplatanus* L.)	736
Common walnut (*Juglans regia* L.)	128
Total	2,760

each other's growth, each tree was regarded as an independent entity, i.e. a single tree plot.

A ranking system with five separate categories was devised to assess stem quality. This system was based on whether or not a tree possessed a single, straight stem and an apically dominant and vigorous leading shoot. As the trees grew, straightness and the lack of disproportionately large side branches on the developing stems were also taken into account. The objective of the quality ranking system was to assess whether each individual tree was capable of producing a stem of high quality timber.

The various categories are described below, with a visual guide to the characteristics of each given in Figure 1.

- Category 1: Very good quality, with straight stem and dominant leader.
- Category 2: Good quality, stem not as straight *and/or* tendency towards codominant shoots.
- Category 3: Moderate quality, stem somewhat wavy *and/or* shaped leaders not regaining straightness, still capable of improving with treatment.
- Category 4: Poor quality, stem forked, kinked or very wavy *and/or* prone to multiple shoots.
- Category 5: Very poor quality, bush-like, no observable apically dominant shoot.

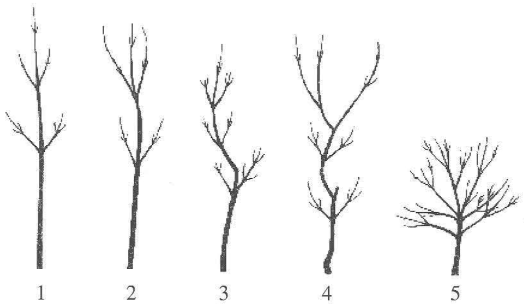

Figure 1. *A visual guide to the characteristics of Categories 1 to 5.*

Good vegetation control, using glyphosate, was applied in order to reduce variability in the experiment caused by weed competition.

Quality assessment was carried out each year after leaf-fall. Each species was judged on its own merits. Inter-species comparisons were not made and no statistical analysis between species was undertaken.

During the June/July period of the second growing season (1994), formative shaping was applied to trees in one half of each row, with trees in the second half remaining unshaped as an experimental control. In the case of forking, formative shaping involved the removal of the weaker or poorer quality shoot. Where competing codominants were present, all were removed or, where this might involve the removal of too great a portion of the foliage, the upper one third of each competing shoot was removed (a technique referred to as tipping). In some cases, a combination of the two treatments was used, with very strong codominants removed and others tipped. Finally, disproportionately large side branches (defined as branches with a basal diameter greater than 50% of the stem diameter at the point of attachment) lower down the stem were also removed. In this context, the relative size of the branch in relation to the tree, and not its absolute size, is the important factor. Only those trees requiring treatment were shaped. Each tree was assessed annually, receiving treatment only if necessary. Therefore, some stems in Category 1 in the shaped treatment may never have received a shaping treatment. Thus, the shaping treatment is related to the requirements of each individual tree, and the data relate to the aggregate of all trees in the shaped or unshaped treatments. Using each tree as a single plot, an analysis of variance was carried out between treatments for each species, to test for effect on quality.

Results

Red oak and southern beech (*Nothofagus procera* (Poepp. and Endl.) Oerst.) are both excluded from the following results, due to a general failure of both species on the site.

Loss of quality of unshaped trees

The performance of those trees which did not undergo shaping is of interest, as their progress indicates the rate of quality decline in crops receiving no formative shaping. During the first growing season (1993), the trend in most species was a dramatic overall decline in stem quality. Figure 2 details the percentage of trees of each species in Categories 1 and 2 combined, immediately after planting and at leaf-fall in the first year of the trial.

The greatest decline in quality during the first year took place in pedunculate and sessile oak, followed by sweet chestnut (*Castanea sativa* Mill.), walnut and sycamore. The decline in sycamore, which started out with over 85% of stems in Categories 1 and 2 combined, was serious, with only 40% remaining in these categories by leaf-fall of the first year. Ash and cherry showed the least decline in quality. The number of good quality ash stems immediately after planting was below 50%, but this level was maintained through the first year. Overall, however, these results indicate an obvious and serious pattern in the loss of quality in untreated plantation broadleaf trees during the first year of establishment.

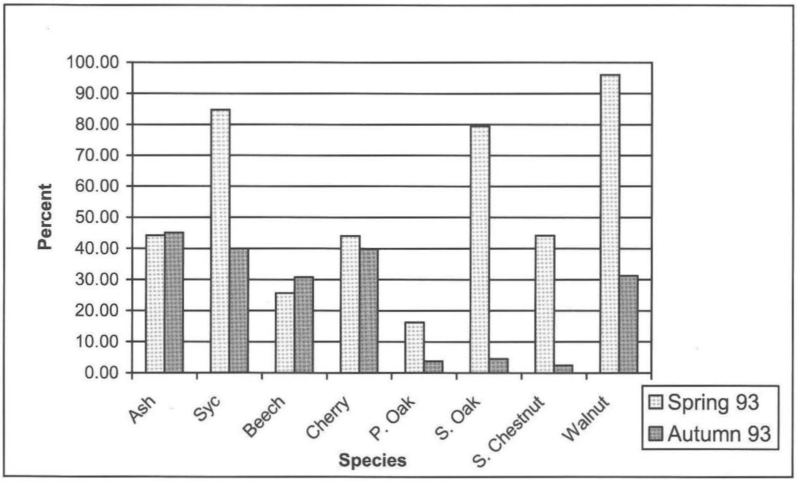

Figure 2. *Percentage of trees of each species in Categories 1 and 2 combined, immediately after planting (spring 1993) and at leaf-fall in the first year of the trial (autumn/winter 1993).*

Effect of formative shaping on quality

Figure 3 illustrates the percentage of all species combined within each of the five quality categories at the end of the fourth growing season (1996), demonstrating the general effect of shaping over the 4-year period of the trial. Within the shaped group, approximately 57% of those trees which underwent shaping were in the 'very good' or 'good' quality categories (Categories 1 and 2). Approximately 67% of the unshaped trees fell within the 'poor' or 'very poor' categories (Categories 4 and 5). When Category 3 trees are included, approximately 85% of the shaped trees lie within Categories 1-3.

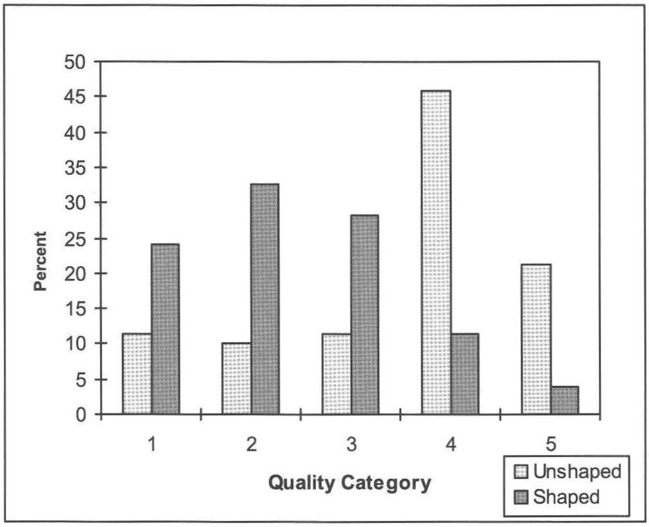

Figure 3. *Percentage of all species combined within each of the five quality categories at the end of the fourth growing season (1996).*

While Figure 3 indicates a general trend, there was considerable variation between individual species. This variation is detailed in Table 3, which lists the effect of formative shaping on the progress of each species. This is shown by giving the percentage of the total number of trees of each species in Categories 1 and 2 combined over the 1994-96 period. Table 3 shows that some species benefited more than others from early formative shaping. Although there was a slight improvement in quality within the unshaped group during the second growing season, the percentage of quality trees again decreased during the third season, followed by an even more dramatic decline during the fourth. Some species, notably sycamore and ash, declined in quality in the unshaped control, while maintaining or improving in quality in the shaped treatment. The percentage of Category 1 and 2 trees in the unshaped ash declined from 61.2% to 40.0% during the 1994-96 period, while that in the unshaped sycamore declined from 37.2% to just 8.2%. The percentage of Category 1 and 2 trees in the shaped ash fluctuated slightly each year, but was at least 25 percentage points better than that in the unshaped ash. The improvement in sycamore was also significant, with a continuous improvement recorded in the shaped trees. The difference between shaped and unshaped sycamore is the greatest for any species. Table 3 also indicates that the quality of some species within the unshaped group, notably sessile oak, gradually improved during this trial, due to the emergence of long straight shoots in the third or fourth growing season.

Table 3. *Percentage of the total number of trees of each species in Categories 1 and 2 combined over the period 1994-96.*

Species	*1994*		*1995*		*1996*	
	Shaped %	*Unshaped* %	*Shaped* %	*Unshaped* %	*Shaped* %	*Unshaped* %
Common ash	71.5	61.2	73.7	56.3	67.1	40.0
Common beech	41.9	47.2	54.7	63.9	74.4	50.0
Cherry	29.4	28.6	53.7	24.3	51.4	22.2
Pedunculate oak	19.7	7.4	21.9	7.4	30.3	10.3
Sweet chestnut	23.7	0.0	39.0	5.3	53.3	5.0
Sessile oak	21.4	6.3	21.4	10.6	28.6	16.7
Sycamore	46.3	37.2	53.7	29.6	62.2	8.2
Common walnut	3.1	0.0	31.3	21.9	39.1	10.9

Quality ranking of individual species

Table 4 lists the mean quality category of shaped and unshaped trees of each species, together with the level of statistical significance. It can be seen that formative shaping had a highly significant effect on the mean quality ranking of the different species. The effect on all species, except beech and sessile oak, was significant at the 0.1% level. Beech was significant at the 5% level. This clearly indicates the positive effect of formative shaping on the quality of the most commonly used broadleaf species planted at 1.5 m x 1.5 m to 2.5 m x 2.5 m spacing. Only one species – sessile oak – showed no statistically significant effect from shaping. The performance of oak in Kinsealy experimental plots was, however, generally poor over the period of the study.

Table 4. *Analysis of the mean quality category of shaped and unshaped trees of each species after four growing seasons (1993-96) (NS not significant; * significant at 5% level; ** significant at 1% level; *** significant at 0.1% level).*

Species	*Shaped*	*Unshaped*	*Significance*
Common ash	2.05	2.89	***
Common beech	2.02	2.61	*
Cherry	2.40	3.49	***
Pedunculate oak	3.23	3.96	***
Sweet chestnut	2.46	4.17	***
Sessile oak	3.26	3.67	NS
Sycamore	2.27	4.08	***
Common walnut	2.73	3.84	***

Additional analysis was carried out on the performance of trees of each species which were ranked in the two top quality categories. These trees represent the individuals most likely to be favoured during second and third thinning to form the basis for the final crop. Table 5 details the percentage of trees within the shaped and unshaped treatment within Categories 1 and 2 combined at the end of the fourth growing season (1996). The greatest percentage difference between shaped and unshaped is that for sycamore (54.0%), indicating that, of all those species studied, sycamore has benefited the most from formative shaping. Sweet chestnut and cherry also benefited from shaping, as indicated by a difference of 48.3% and 29.2% respectively. Beech, ash and walnut also show considerable differences, ranging from 24.4% to 28.2%.

Table 5. *Percentage of shaped and unshaped trees within each species in Categories 1 and 2 combined after four growing seasons (1993-96).*

Species	*Shaped* %	*Unshaped* %	*Difference* %
Common ash	67.1	40.0	27.1
Common beech	74.4	50.0	24.4
Cherry	51.4	22.2	29.2
Pedunculate oak	30.3	10.3	20.0
Sweet chestnut	53.3	5.0	48.3
Sessile oak	28.6	16.7	11.9
Sycamore	62.2	8.2	54.0
Common walnut	39.1	10.9	28.2

Figure 4 illustrates the performance of shaped and unshaped trees over the four growing seasons, 1993-96. Following a serious decline in quality during the first growing season, formative shaping improved the quality of most species over the following three seasons.

The quality of the original ash stock was generally poor, with only 44% falling into Categories 1 and 2 combined immediately after planting. There was little decline in the percentage of good quality ash over the first growing season (Figure 4a). This was followed by a slight improvement in stem quality over the next growing season. There was a slight decline in the third and a considerably steeper decline in the fourth growing season. While the rate of deterioration in stem quality in ash was not as rapid as that in sycamore, there was a serious rate of decline in the number of quality stems over the 4-year period of the trial. As forking and, to an increasing degree, windsnap, are the damaging defects in ash, the use of early shaping is essential in the production of a quality crop. When shaping is applied, ash maintains a substantial percentage of trees in the top two quality categories.

Sycamore showed the most positive response to formative shaping. There was a clear response to shaping in each year, while the unshaped trees showed a severe decline in quality (Figure 4b).

The quality of the original beech planting material was poor, with just over 20% of the trees falling into Categories 1 and 2. Considerable filling-in was required during the second and third year after planting. The quality of the filling-in material was better, and this, allied with the onset of side shelter, increased the number of individuals in the top categories. In the third (1995) and fourth (1996) growing seasons, beech performed well. In these latter years, the response of the species to shaping was very encouraging (Figure 4c).

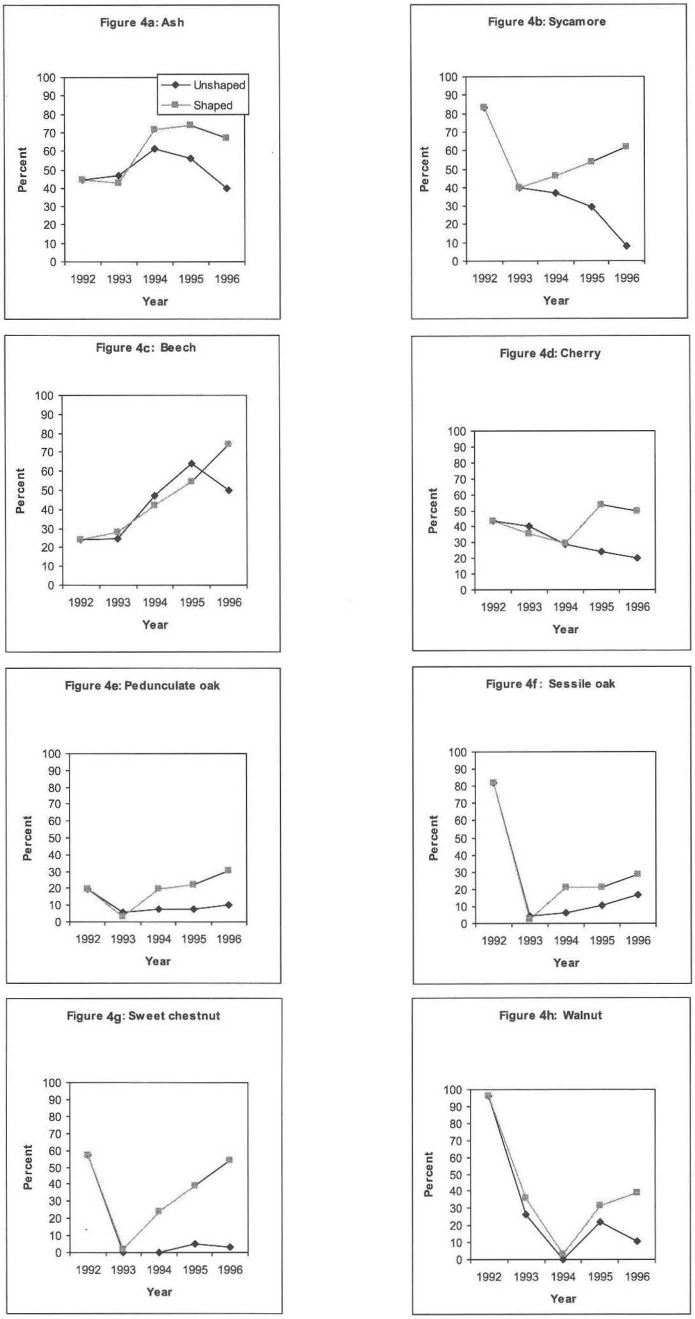

Figure 4. *Percentage of trees of each species in Categories 1 and 2 combined in the shaped and unshaped treatments, 1992-96 (Note: 1992 represents the planting season winter 1992/spring 1993).*

From 1994, the effect of shaping became more evident. In 1996, the percentage of good quality trees in the unshaped treatment declined, while the percentage of good quality trees in the shaped treatment continued to increase.

Cherry tends to be a very coarse branching species. While the unshaped cherry resembled orchard trees at the end of the fourth season, the gap between the shaped and unshaped treatments declined in the later years (Figure 4d).

While the initial quality of sessile oak was quite good, both pedunculate and sessile oak suffered severe decline in quality after the first season's growth. Formative shaping had some positive effects, as shown by the increase in the gap between shaped and unshaped trees (Figures 4e and 4f).

The quality of sweet chestnut declined seriously during the first growing season (Figure 4g), possibly due to exposure. The number of stems within the top quality category fell from 41% to just 3%. While unshaped trees remained at this low level throughout the duration of the trial, shaped trees greatly improved over the years. The number of individuals within Categories 1 and 2 increased to 54%, but the overall quality is still not good.

Formative shaping had a slight positive effect on walnut in the first two growing seasons. This effect increased in the final two seasons (Figure 4h).

Discussion

This experiment was originally designed as a broadleaf mixture trial. Due to the alarming rate of decline in the quality of the newly planted trees, a formative shaping trial was subsequently incorporated. The lower stem section is the portion of the tree which yields the highest financial return, either as sawlog or veneer. It is therefore essential that a sufficient number of straight quality stems from which to select the final crop remain after first and second thinning. It is also essential, particularly from the perspective of the private owner, that the material extracted in early thinnings is of sufficient quality to provide a valuable interim income. The British Forestry Commission recommends that 500 stems should remain *in situ* after the third thinning at year 20 for yield class 12 ash and sycamore, with a top height of approximately 15.0 m (Hamilton and Christie, 1971). The basis of a valuable crop will have been laid down if, at this stage, there is at least 6.0 m of straight, unforked and branch-free stem on most of the candidate trees. This indicates a need to have in excess of this number of quality trees available before first and through second thinning.

During this trial, it was decided to apply the pruning practices advocated by Shigo (1989a & b) and Barton (1993), in an attempt to maintain good stem form and apical dominance. The basic purpose of the experiment was to test the application of these broadleaf pruning methods to very young trees. The primary objective of the formative shaping was to maintain as many single, straight and apically-dominant leader shoots in the crop as possible. This was done by concentrating on apical training and the removal of disproportionately large side branches. Normal side branches which contributed to the welfare of the tree and which did not threaten stem form, were retained.

Effect of formative shaping on quality

The rapid decline in leading shoot quality recorded in this trial gives considerable cause for alarm. The rate of this decline is of crucial importance for the long-term availability of sufficient quality stems from which to select a final crop. Decline in the first year may be due to shock following lifting and replanting. Some species, most notably oak and beech, are more prone to planting shock, but there was also a serious decline in quality of sweet chestnut. While the quality of pedunculate oak was initially poor, even the better quality stems declined further. The decline in quality of sessile oak was even more dramatic.

Decline in stem quality of healthy trees after the first year in this trial reflects climatic factors, disease or inherent defects. The continuation of this decline in subsequent years raises serious concern regarding the quality of unmanaged broadleaf plantations. The annual fluctuation in the rate of loss of quality may be attributed to yearly variation in climatic or other factors. Formative shaping is essential to maintain a sufficient number of quality trees from which to select, where the attrition rate in early years of main stem/leading shoot quality is high (Balandier, 1997). Low forks in the first and second year, and multiple forking at the start of each year, were common problems among the unshaped trees included in this trial. Heavy side branches competing with weakened leading shoots, was also a common fault found among the unshaped groups of both oak species.

Formative shaping with secateurs and loppers up to 3.0 m in height contributed significantly to the quality of the lower stem of a number of broadleaf species studied, with sycamore, ash, beech and sweet chestnut benefiting the most. It is believed that formative shaping of all species will minimise core defects, enabling valuable girth increase. With the changes in veneer processing technology, such reduced defect cores will allow smaller diameters to be processed, thereby contributing to the value of the crop.

The timing of formative shaping should be based on the developmental stage of the tree, with height growth and leader development being the main criteria. Formative shaping should begin when the trees are between 1.2-1.6 m in height. Particular attention is needed over the first four years (particularly on fertile sites where vigorous growth takes place), during which period stem height is likely to reach between 2.0-4.0 m. Decisions should be based on the rate of decline over the first four years in the number of Categories 1 and 2 trees. Unless there is a sufficient number of shaped stems in place by the time the trees reach 3.0 m, straight, unforked quality stems cannot be created or induced later in the rotation. The formative shaped trees can be expected to be among those remaining after first and second thinning, and from which the final crop trees will be selected.

Forked stems or stems with multiple shoots at 1.0-3.0 m above ground level cannot be brought up to a sufficient quality by stem pruning in later years. Once these defects have become lignified, removal of one half of a fork will not result in the remaining leading shoot straightening into a good stem. A distinct bend occurs at the pruning site, referred to as a "bayonet" by Balandier (1997). Stems that have heavy lignified branches at 1.0-2.0 m above ground, and allowed to grow for a number of years, will also remain deformed after late pruning. The earlier shaping takes place, the better chance the tree has of straightening or "remodelling", as Barton (1993) describes it.

In the case of forking, it should be noted that both shoots constitute stem from a physiological perspective. Any form of shaping should therefore be carried out as early as possible after fork formation. Early June is considered best, as the shoot is still green and lignification has yet to take place. Hubert and Courraud (1987) advise the early "pinching off" (by hand, if necessary) of the green shoots of a fork. These authors indicate mid-June as the optimum time for this operation.

In the unshaped treatment, some species showed an improvement in form in the later growing seasons. Such improvement is, however, not guaranteed, nor does it occur in a sufficiently large proportion of stems to justify a non-intervention policy in the early management of broadleaf plantations. Thus, if quality broadleaves is the objective, there is a clear argument for formative shaping. Unless there is a sufficient number of quality stems at this stage of the crop, they cannot be created later during the rotation.

The performance of individual species to formative shaping

Comments on the response of individual species to formative shaping are given below. *Ash:* Ash responded well to formative shaping in this trial, and due to its fast vigorous growth, is a prime candidate for early shaping. Only 44% of the ash was ranked in the top two quality categories immediately after planting, indicating low initial quality. The rate of fall-off in quality among unshaped ash was a serious problem, with forking and wind-snap in trees greater than 2.0 m in height becoming major problems. While the rate of decline of trees initially classified as good was not rapid, it seemed to accelerate in the final two years. The experience of this study was that stems ranked as Category 3 because of forking or codominant leaders, could be brought into Categories 1 or 2 by judicious shaping, due to the 'plastic' and responsive nature of young shoots. The earlier one side of a forked stem is removed, the sooner the remaining shoot tends to straighten and move towards the vertical.

Sycamore: Of all those species studied, sycamore benefited the most from formative shaping, responding well to the removal of forks or codominants. The effect of formative shaping is particularly important, as the rate of fall-off in quality among the unshaped trees was dramatic, with just 8.2% remaining in the top two quality categories after four years. The main problem observed was the loss of the leading shoot bud, which led to the development of several competing codominant shoots. As with ash, however, the results of this study suggest that stems ranked as 'moderate' because of forking or codominant leaders, could be brought into Categories 1 or 2 by judicious shaping. In both sycamore and ash, due to the rapid growth of long straight leading shoots, formative shaping will result in significant lengths of good quality stem growth, adding substantially to the potential value of the crop.

Beech: Beech planting stock delivered at the beginning of this trial was small and of very poor quality, with significant filling-in required after the first year. Replacement stock was of better quality and once established, grew well. Results for beech are therefore confined to those trees which survived and grew into the 1996 planting season. Although slow to establish, the species is now one of the most impressive performers on this difficult site. Beech does not tolerate exposure and has a particular requirement for side shelter. In the latter years of this trial, beech was sheltered by the taller ash and sycamore, with which it was mixed. This suggests a possible establishment technique for beech on difficult exposed sites. It may be more profitable to plant beech in mixtures, and even to delay the planting for several years, while 'shelter wells' are created by surrounding trees of other included species.

Pedunculate and sessile oak: Both species of oak were of very poor form after the first growing season, with many trees developing a multiplicity of tiny twiggy branches. The development of profuse light branching made it difficult to detect any dominant leader which could be favoured during shaping. During the third and fourth growing season, however, a number of trees of both species produced long leading shoots. While some of these may be induced with shaping, most were crooked or at too steep an angle from the vertical to form good stems. Shaping did, however, make a small difference, raising the number of quality stems from 12% to 19% for sessile oak, and from 9% to 21% for pedunculate oak. While the effect of shaping on pedunculate oak was shown to be significant, practical observations suggested that no conclusions can be made from this trial regarding the formative shaping of oak at this stage of crop development. In general, unless the crop is performing exceptionally well, it is difficult to recommend shaping for oak until it produces a recognisable leading shoot, which, depending on the vigour of the plantation, tends to appear between year 3-5. Once the young trees begin to produce distinct long shoots, shaping in favour of these shoots may prove effective. Another alternative is 'stumping back', a treatment whereby poorly shaped and bushy plants are cut back to ground level and allowed to form straight coppice shoots, which are then singled to produce a suitable quality leader. This leader may subsequently require formative shaping.

Cherry: Cherry suffered from canker (*Pseudomonas* spp.) during the trial, so all comments must be taken in this context. Formative shaping did not appear to have added to the level of canker. The cherry tended to grow rapidly and achieved the greatest average height and stem diameter of all of those species studied. Even with formative shaping, it was difficult to control the quality of cherry and to confine growth to a single stem. As cherry is regarded as a valuable timber, formative shaping may still be relevant, as any increase in the length of good quality lower stem has the potential to add considerable value. Unshaped cherry tended to fork and to produce a multitude of heavy branches, resulting in an orchard-type form, with branching occurring at 1.0 m or less above ground level and a relatively thick stem close to the base. The application of formative shaping in an attempt to curb this growth pattern involved considerable branch removal, resulting in a tree with a somewhat spindly appearance. Although cherry benefited, the prevalence of canker makes shaping a questionable exercise. Unless provenance studies or disease-free selection procedures are developed for cherry, the canker problem calls into question the future of cherry as a forestry species in Ireland.

Sweet chestnut and walnut: Sweet chestnut and walnut were affected by frost and exposure during this trial, and were generally not suited to the site. The form of both species in the unshaped treatment was distinctly globular and bush-like in nature. Within the shaped treatment, however, some stems were held to good single leading shoots of acceptable quality. The straightening response, which was clearly evident among the shaped ash and sycamore, was not so apparent in sweet chestnut and walnut, resulting in the retention of kinks in the stem over the period of the trial. Results do, however, indicate that formative shaping can contribute to improved quality in sweet chestnut planted on suitable sites. Shaping produced some quality stems among walnut, but most of these were somewhat irregular. Overall, walnut produced very few quality stems, particularly when compared to ash and sycamore. As previously outlined, however, each species was assessed on its own merits.

Conclusion

In summary, the objective of early formative shaping is to produce an adequate number of quality stems to allow sufficient choice in the selection of final crop trees. Formative shaping greatly improved the lower stem quality up to a height of 3.0-4.0 m of many of the broadleaf species included in this experiment. Two of the most important species in the current national broadleaf planting programme, ash and sycamore, responded best to formative shaping. Thus, the overall conclusion of this experiment is that early formative shaping is a valuable tool in the management of broadleaf plantations under typical Irish conditions. The effect of formative shaping on height and diameter growth is described in Part 2.

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