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- The establishment of oak plantations has increased since the introduction of the Forest Premium Scheme with almost 2,600 ha planted between 2001 and 2006.
- High quality oak plantations can be difficult to establish on bare sites due to frost and exposure causing extremely poor stem form.
- Nursing mixtures of conifers (European larch and Scots pine) with oak are currently used to provide shelter for oak as well as restricting side branch development and promoting height growth through competition.
- Scots pine often had difficulties establishing on heavy soils and grew slower than the oak thus providing little shelter.
- Alternate line mixtures of oak and European larch require intensive and skilled management due to the vigour of the conifer nurse suppressing the oak.
- Thinning of alternate line mixtures established to date will require careful and well planned management.
- From this study alternate planting patterns are recommended, particularly band mixtures with 3 to 4 lines of oak which are more robust and easier to manage than the alternate line mixtures.
- Common alder may be an alternative nurse species on wet soils. Birch is considered suitable on a wide range of sites.
- Research trials should be established to test various combinations of planting patterns, nurse crop species and planting densities.

## Nursing of oak in Ireland

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### Background

In Ireland, oak was planted at various sites in band mixtures with Norway spruce during the first half of the 20th century. Due to the lack of timely removal of the dominant Norway spruce nurse, stands often became predominantly coniferous with some suppressed oaks remaining. As a result, it was seen as necessary to consider other nurse species to aid the establishment of high quality oak plantations.

Since 1997 the Forest Service has provided establishment grants and annual premium payments for the following methods of planting oak in Ireland:

- pure oak plantations (6,600 trees/ha).
- oak when planted in mixtures in the form of alternate lines with either European larch or Scots pine (4,550 trees/ha).

Most of the oak plantations to date have been established using the latter method. The silvicultural basis is that the admixed conifer acts as a temporary nurse protecting the tender and young oak trees from temperature extremes and exposure. Additionally, the role of the nurse species is to restrict side branch development of the oak and promote height growth by competition (Figure 1).

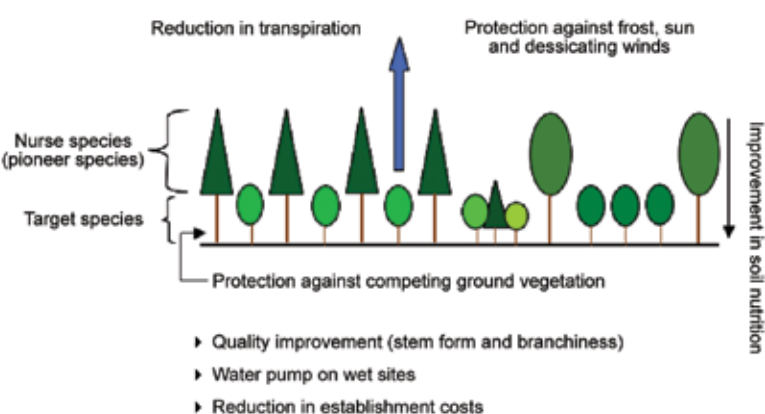


Figure 1: The benefits of a nurse crop used in afforestation (modified from Pommerening and Murphy 2004).

After a decade of intensive planting, the existence of alternate line mixtures of oak/Scots pine and oak/European larch plantations offered the opportunity to carry out a first assessment of stand development.

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There is currently a debate concerning this method of establishing oak plantations and whether it should be used in the future. There are concerns about whether the European larch and Scots pine fulfil their role in nursing the oak as many poor oak trees have been observed in such mixtures. There are also questions concerning the robustness, the suitability of the growth dynamics of the nurse species, and the time at which the nurse species should be removed. Other methods of establishing oak such as band mixtures exist. However, these have been of minor importance to date. In 2006 a study was established to provide scientific data to inform the debate. Suitable stands were selected:

- oak/Scots pine and oak/European larch stands established by planting alternate lines,
- oak/Norway spruce stands established by planting bands,
- oak/European larch stands established by planting bands and lines.

It is important to note that the stands selected were not experiments, but rather afforestation carried out by landowners, reflecting the range of stand types that currently exist.

Basic growth parameters were measured to gain information concerning the stand development of the nurse and target species (oak) mixtures, and the quality development of the

oak within them. For each mixture type growth parameters were used to find out:

- the suitability of the protection offered by the nurse species (European larch, Scots pine or Norway spruce) to the tender oak species,
- the robustness of the planting pattern when using alternate lines (European larch or Scots pine with oak) and by looking at the suitability of the growth dynamics of the nurse species,
- the effect the nurse species has on the quality development (branchiness and apical dominance/stem form) of the oak.

## Materials and methods

### Stand selection

In April and May 2007 following the inspection of potentially suitable stands, 14 were selected for inclusion in the study. The location, planting year, species and planting pattern of the stands are outlined in Figure 2. It illustrates that seven oak/Scots pine and six oak/European larch stands were selected and included in the study. Unfortunately only one band mixture stand of oak/Norway spruce and one oak/European larch band line mixture existed, so comparative studies were not possible.

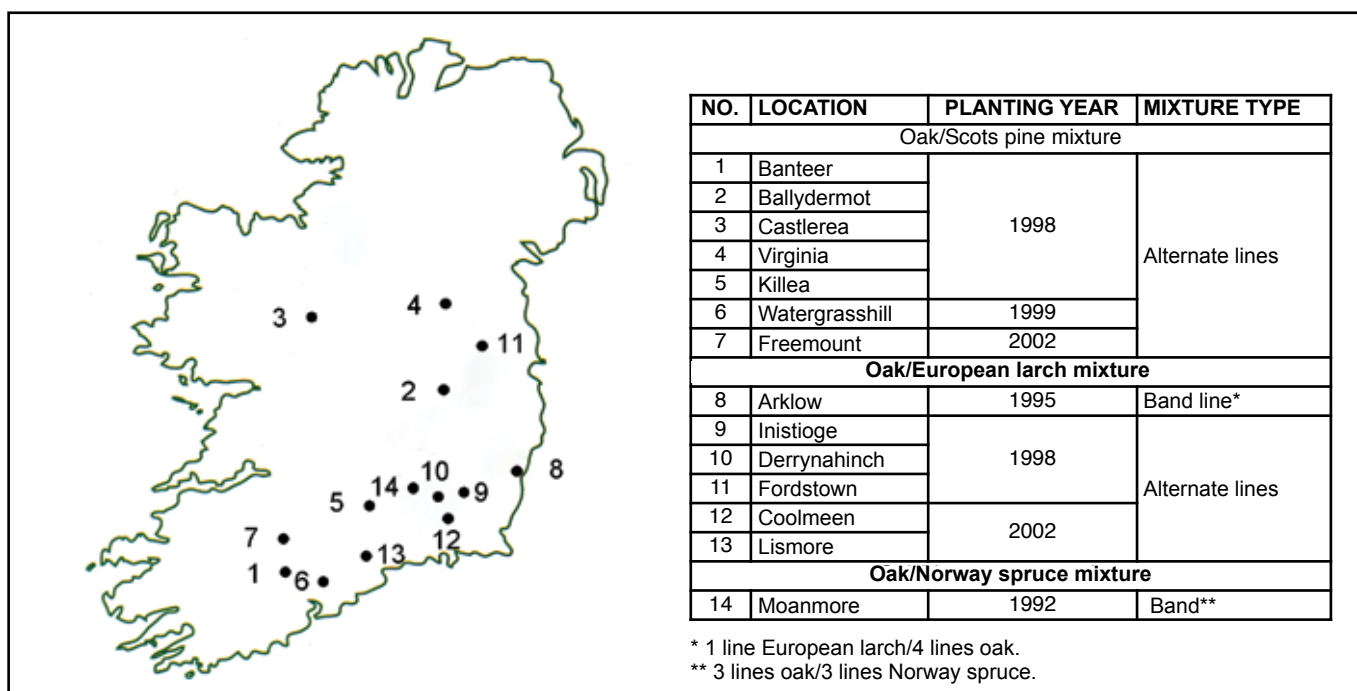


Figure 2: Location, planting year, species and planting pattern of all the stands included in the study.

Not all the stands met the stand selection criteria, as poor densities of the nurse crop species were found in a number of stands. This was due to the inability to establish these species on certain site types and to possible poor management.

### Tree characteristics measured

The tree characteristics measured at each stand are listed in Table 1. In addition, a stand history detailing all management practices to date was obtained for each stand.

Table 1: Tree characteristics measured at each stand in the study.

CHARACTERISTICS MEASURED	
All trees	Potential crop tree candidates
Height	Height
Diameter	Diameter
Deformation	Diameter of branches
	Length of branches
	Stem form
	Deformation

### Sample plot establishment

Oak/Scots pine and oak/European larch sample plots (alternate line mixture): at each of the 13 oak/Scots pine and oak/European larch stands selected, 2 rectangular sample plots were established, each 40 x 10 m consisting of 3 lines of Scots pine or European larch and two lines of oak (Figure 3).

Oak/European larch sample plots (band line mixture): as only one stand of this particular mixture existed, 4 sample plots were established at the stand concerned, each being 10 x 12 m and containing 4 lines of oak and 2 lines of European larch, one at either side of the oak band (Figure 4).

Oak/Norway spruce sample plots (band mixture): as only one stand of this particular mixture existed, 4 sample plots were established at the site concerned, each 10 x 10 m and containing 3 lines of oak and 2 lines of Norway spruce, one at either side of the oak band (Figure 5).

## Results and discussion

### Height

In the oak/Scots pine alternate line mixtures the Scots pine was on average 0-0.8 m taller than the oak after 9 growing seasons (Table 2, Photo 1). These results indicate that the oak at many of the stands received minimal if any nursing from the Scots pine.

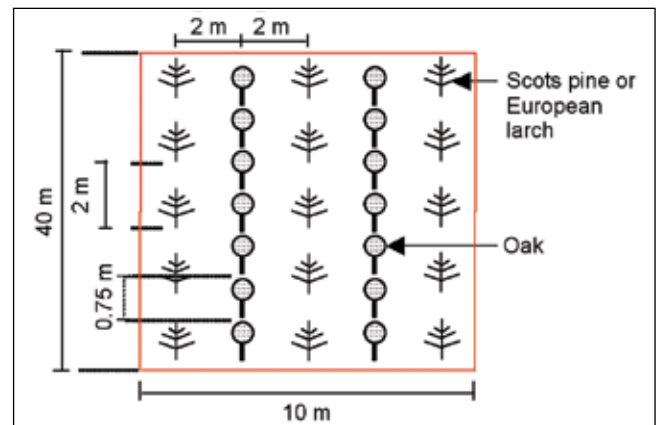


Figure 3: The planting pattern and spatial arrangement of the oak/Scots pine and oak/European larch alternate line mixture sample plots.

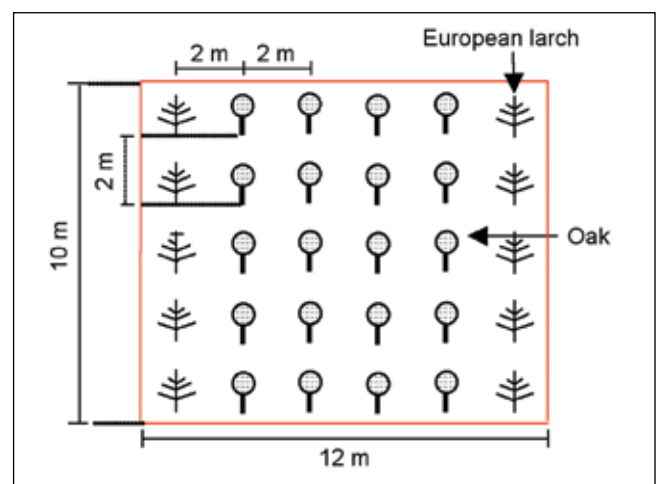


Figure 4: The planting pattern and spatial arrangement of the oak/European larch band line mixture sample plots.

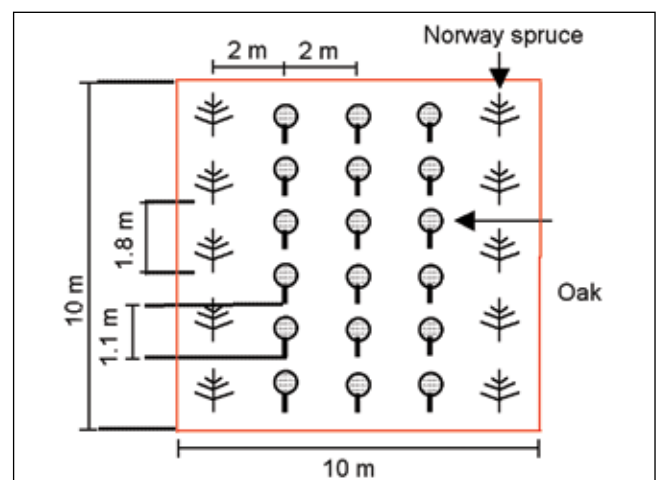


Figure 5: The planting pattern and spatial arrangement of the oak/Norway spruce band mixture sample plots.

Table 2: Height characteristics concerning oak and Scots pine in the oak/Scots pine alternate line mixtures.

Stand	Planting year	Mean height		Max. height	
		Oak	Scots pine	Oak	Scots pine
Ballydermot	1998	4.2	± 0	5.2	+ 0.2
Banteer		4.2	+ 0.4	5.6	+ 0.4
Castlerea		4.1	+ 0.1	5.6	+ 0.2
Killea		4.2	+ 0.4	6.3	+ 0.1
Virginia		4.3	+ 0.8	7.3	- 1.1
Watergrasshill	1999	2.4	+ 0.3	4.4	- 0.3
Freemount	2001	1.7	- 0.8	2.6	- 0.8



Photo 1: 8-year old oak/Scots pine alternate line mixture at Watergrasshill. After 8 growing seasons the oak was receiving minimal or no nursing, as the Scots pines were on average only 0.3 m taller with the tallest oak (4.4 m) being taller than the tallest Scots pine (4.1 m).



Photo 2: 5-year-old oak/Scots pine alternate line mixture at Freemount. The oak are devoid of any nursing effect as the Scots pine are on average 0.8 m smaller than the oak. In most cases it will take up to 8 years for SP to catch up with the oak, even longer on a good oak site. This means that oak is effectively free growing for this period, totally devoid of any shelter.

Table 3: Height characteristics concerning oak and European larch in the oak/European larch alternate line mixtures.

Stand	Planting year	Mean height		Max. height	
		Oak	E. larch	Oak	E. larch
Derrynahinch	1998	4.8	+ 2.3	6.7	+ 3.6
Fordstown		4.4	+ 2.8	6.0	+ 4.4
Inistioge		4.9	+ 1.4	7.0	+ 1.1
Ballyhale	2000	3.6	+ 1.6	5.5	+ 1.6
Lismore	2002	2.1	+ 1.1	3.4	+ 1.3



Photo 3: 8-year old oak/European larch alternate line mixture at Fordstown. The European larch are starting to suppress the oak with an average height advantage of 2.8 m, necessitating the immediate removal of the dominant larch.

Additionally, the height results from Freemount illustrated that Scots pine is not a suitable nurse species for oak when both species are planted at the same time, as it takes too long for the Scots pine to catch up with the oak (Table 2, Photo 2), especially on sites unsuited to the species.

An average height advantage of 1.4-2.8 m of the European larch in the oak/European larch alternate line mixtures after 9 growing seasons, created difficult conditions for the height growth of oak (Table 3, Photo 3).

This was exacerbated by the fact that many European larch at some stands (notably at Fordstown and Derrynahinch) tend to lean away from the prevailing wind thus interfering with the crowns of the oaks. This could have been confounded by the use of faster growing hybrid/Japanese larch in some instances.

These results highlight that over time alternate line mixtures may not be robust when using both a light demanding nurse crop species and a light demanding target species.

Additionally, results show that on average the oak after 9 growing seasons were taller in the oak/European larch mixtures than the oak in the oak/Scots pine mixtures,

suggesting that European larch nurses oak better than Scots pine.

### *Band and band line mixtures*

The results from the oak/Norway spruce band mixture at Moanmore (Table 4) and the oak/European larch band line mixture at Arklow (Table 5) illustrate that even though there is an average height difference of 2.5 and 3.6 m respectively between the nurse crop and the oak, multiple lines of oak mean that if thinning interventions are delayed, not all the oak are in danger of rapid suppression followed by mortality (Photo 4, Photo 5). These mixtures are therefore more robust. However, the height results emphasise that whatever the planting pattern used, delay in primary thinning interventions will result in the target species oak becoming suppressed, followed by a rise in mortality over time.

Table 4: Height characteristics concerning oak and Norway spruce in the oak/Norway spruce band mixture stand at Moanmore.

Planting year	Mean height		Max. height	
	Oak	N. spruce	Oak	N. spruce
1992	6.2	+ 2.5	9.0	+ 0.5

Table 5: Height characteristics of oak and European larch in the oak/European larch band line mixture stand at Arklow.

Planting year	Mean height		Max. height	
	Oak	E. larch	Oak	E. larch
1995	5.6	+ 3.6	9.0	+ 0.5

### *Deformations and stem form*

#### *Alternate line mixtures*

The potential crop tree candidates in the oak/European larch alternate line mixtures were generally superior to those candidates in the oak/Scots pine alternate line mixtures, by having the least amount of deformation and better stem form (Table 6). No straight potential crop tree candidates were found in the oak/Scots pine alternate line mixtures and at only two stands (Ballydermot and Virginia) were potential crop tree candidates with only one leader found, 5% and 10% respectively. Between 60 and 90% of all potential crop tree candidates planted in 1998 had multiple leaders and of these between 50 and 100% were crooked. Unlike the relatively high amount of crooked potential crop tree candidates in the oak/Scots pine alternate line mixtures planted in 1998, crooked candidates in oak/European larch alternate line mixtures planted in 1998 were only present at Fordstown and Inistioge with 45%.



Photo 4: 15-year-old oak/Norway spruce band mixture at Moanmore. Although the Norway spruce are on average 2.5 m taller than the oak, multiple lines of the oak mean that if thinning interventions are delayed, not all the oak are in danger of suppression followed by mortality over time.



Photo 5: 12-year-old oak/European larch band line mixture at Arklow. Even though the European larch are on average 3.6 m taller than the oak, multiple lines of the oak mean that if thinning interventions are delayed, not all the oak are in danger of suppression followed by mortality over time.

Between 55 and 85% of the potential crop tree candidates in stands planted in 1998 were intermediate in terms of stem form and at the Derrynahinch stand only 15% had straight stems. Additionally, no potential crop tree candidates which were planted in 1998 had only one leader and between 35 and 65% of these respective trees have either forks or multiple leaders.

#### *Band and band line mixtures*

The potential crop tree candidates in the oak/Norway spruce band mixture and in the oak/European larch band line mixture were of better quality than those in both alternate line mixture types (Table 6). The potential crop tree candidates at the Moanmore stand had a straight and intermediate stem form of 42% and 58% respectively with 83% forked and 17% with multiple leaders.

Table 6: Quality attributes of potential crop tree candidates in various mixture types.

1L = 1 leader, F = forked (2 lateral branches assuming dominance), ML = multiple leaders (3 or more lateral branches assuming dominance).

Stand	Planting year	Deformation %				Stem form %	
		1L	F	ML	Straight	Intermediate	Crooked
<b>Oak/Scots pine alternate line mixture</b>							
Ballydermot	1998	5	35	60	-	50	50
Banteer	1998	-	15	85	-	50	50
Castlerea	1998	-	20	80	-	50	50
Killea	1998	-	10	90	-	30	70
Virginia	1998	10	-	90	-	-	100
Watergrasshill	1999	-	100	-	-	60	40
<b>Oak/European larch alternate line mixture</b>							
Derrynahinch	1998	-	55	45	15	85	-
Fordstown	1998	-	35	65	-	55	45
Inistioge	1998	-	65	35	10	75	45
Ballyhale	2000	5	70	25	25	75	-
Lismore	2002	20	65	10	-	40	60
<b>Oak/European larch alternate band line mixture</b>							
Arklow	1995	17	75	8	50	42	8
<b>Oak/Norway spruce band line mixture</b>							
Moanmore	1992	-	83	17	42	58	-

At the Arklow stand the potential crop tree candidates had a straight, intermediate and crooked stem form of 50%, 42% and 8% respectively. The reason for this higher quality in the band and band line mixtures may be due to the combination of shelter offered by a significantly taller nurse and higher intraspecific competition between the oak which arises as a result of planting bands.

### *Planting success*

On heavy soils, excessive filling-in of both European larch and Scots pine was necessary due to the inability of the species to re-establish their root systems after planting and withstand weed competition. On certain sites, alternative nurse crop species such as birch and common alder should be considered practical only in light of the *Phytophthora ramorum* outbreak in larch. Information concerning the beating up of Norway spruce at Moanmore was not available.

### *Frost effects*

Data from the closest synoptic station to each stand showed that the occurrence of late frosts is likely to have had a significant role to play in the poor quality of the oak at many locations; however, site specific data were unavailable.

### *The influence of provenance on deformations and stem form*

Although it seems likely that late frost occurrence has a major role to play in the high number of oak trees with

forked, multiple leaders and crooked stems, provenance may also be a contributing factor, but was not be considered in this study.

## **Recommendations and conclusions**

### *Management of existing oak/Scots pine alternate line mixtures*

In most cases the top height of both species was similar and it is unlikely that the Scots pine will suppress the oak in the coming years. The stands, however, require regular observation as height growth and competitive pressure of the nurse species cannot be predicted at this stage of stand development.

### *Management of existing oak/European larch alternate line mixtures*

Many of the oak/European larch stands require urgent thinning to release the oak from the dominant suppressing European larch (Photo 3). Two methods for thinning alternate line mixtures are:

- 1) Selective removal of dominant nurse crop trees in each line that are significantly taller than the oak. This should be carried out over a series of thinning interventions.
- 2) Removal of all the nurse crop trees in each line in a single thinning intervention.

Method (1) allows oak to adapt gradually to a wider growing space by removal of the nurse crop species over time, meaning that some nursing and lateral branch suppression continues. However, more skilled and knowledgeable supervision is required for the selective removal of individual trees and, together with the successive thinning interventions, is the more expensive method.

Another option is felling to waste or killing the nurse crop using an herbicide. A variety of methods for application are available.

Method (2) is the cheapest option of removing the nurse crop but is likely to have detrimental effects on the further height and quality development of the oak. The stability of the oak may also be affected. If a whole line of the nurse crop is removed, a distance of 4 m will exist between the oak lines. This will result in a lack of suppression of lateral branch development.

This particular method could be carried out using a small harvester that would fit between the lines (e.g. John Deere 770D is 2.4 m wide). The use of a harvester is cost dependent and directly related to the size of the young trees and the size of the plantation in question.

The decision to adopt removal method (1) or (2) must be based on a combination of silvicultural and economic considerations.

### *Alternative planting pattern*

Based on the results given, the use of oak/Scots pine and oak/European larch alternate line mixtures would appear not to meet expectations. On the one hand, the Scots pine did not provide the nursing effect desired. On the other hand, the vigour of the European larch suppressed the oak. Therefore, the use of band mixtures should be considered as one of the most practical and robust methods of establishing oak stands in the future. An additional benefit of using band mixtures is that they allow easy thinning of the nurse crop species.

At first thinning, the nurse crop line either side of the oak bands can be easily harvested (Photo 6). The nurse crop trees to be removed are felled in the direction of the nurse crop band thus avoiding damage to the more sensitive oak.

Different band planting patterns may be considered for use in afforesting oak plantations.

A minimum of three lines of oak should be planted to ensure a robust design. A band design consisting of four lines of

oak would be ideal, as if the two outside oak lines struggle due to competition with the nurse crop, the two middle lines remain relatively unharmed allowing an ample matrix from which potential crop tree candidates can be chosen.

Another option of establishing oak with a nurse is by planting groups. These are favoured by many silviculturalists but prove to be impractical due to the skilled and intensive management required. No suitable stands of this type were available. Therefore this variant could not be included in the study.

### *Alternative nurse crop species*

The height results show that it is doubtful that Scots pine should be used as a nurse crop species for establishing oak. European larch may still be considered a suitable nurse crop species for establishing oak provided a robust planting pattern is used. However, as European larch is not suitable for use on poorly drained soils alternative species should be considered for use on such soils. Three species stand out as being potentially suitable as nurse crops for growing on the soils on which oak is often planted. These are common alder, downy and silver birch.

#### *Common alder as an alternative nurse crop species*

Site suitability: common alder is a strong light demanding and late frost tolerant species and is therefore ideal for use on bare afforestation sites. It is able to grow very well on cold wet soils (gley and pseudogley) on which a substantial amount of the pedunculate oak in Ireland is planted. On such soils common alder develops an intensive rooting system. Rooting of older alder up to a depth of 1.5 m on



Photo 6: Very good quality 16-year-old oak/Norway spruce band mixture (3 lines of each of species) at The Forest of Bowland, Lancashire. In 2005 the Norway spruce lines either side of the oak bands were removed.

gley soils has been observed (Institute of Silviculture, Göttingen 1992).

**Height growth:** strong height growth occurs within the first five years, meaning that this species can relatively quickly provide shelter for the tender target species by establishing a microclimate more suitable for oak.

**Crown morphology:** common alder grows with pronounced apical dominance, heavily investing its energy in height growth in its juvenile years. Therefore it produces shelter quickly rather than producing a wide crown.

#### *Birch as an alternative nurse crop species*

**Site suitability:** Both downy and silver birch are very frost tolerant. Lehtiniemi and Sarasto (1973) (cited by Perala and Alm 1990) maintained that silver birch can endure frosts of -2 to -3°C without injury to new growth. Both these species are light demanders; silver birch being slightly more light demanding than downy birch. Being frost tolerant and light demanding make them ideal for planting on bare sites.

**Height growth:** O'Connor (2005) reported that 4-year-old birch in a series of provenance trials, testing a range of native and continental sources, achieved a mean height of 3 m on a basic mineral soil in Tipperary and 2.7 m on an acid soil in Carlow. Both silver and downy birch are capable of rapid early growth to provide oak with shelter during the establishment phase.

**Crown morphology:** the architecture of birch crowns permits the transmission of a substantial amount of sunlight. Sahov et al. (1965) stated that birch canopies transmit more light than other deciduous species. Neuwirth (1962) calculated that moderately dense stands allow the transmission of 30% of full sunlight to the understorey. This would be very beneficial when nursing oak as it is a light demanding tree species.

## Further work

It must be acknowledged that afforesting bare sites with oak is never going to be an easy undertaking. However, successful nurse crop/target species mixtures for afforesting oak plantations in many European countries have been developed.

This study has shown that alternative nurse crop methods of establishing oak can now be suggested for use in Ireland, using various combinations of planting patterns, nurse crop

species and planting densities. It is, however, paramount that research trials be established focussing on:

- planting patterns, notably bands and band line mixtures as these are the most robust,
- the suitability of nurse crop species (common alder, downy birch and silver birch) on a range of site types varying in fertility and drainage,
- planting densities at which the nurse crop and target species are planted,
- planting the nurse crop species several years prior to the oak.

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