The nursing of Sika spruce by Douglas fir

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Abstract

Nursing of Sitka spruce (*Picea sitchensis*) by Douglas fir (*Pseudotsuga menziesii*) arose unexpectedly in a field experiment established at Ballyhoura Forest in 1976. The original aim of the experiment was to examine the potential of intensive soil reclamation to improve the establishment of Sitka spruce and Douglas fir on poor Old Red Sandstone soils. The soil at the site was a modified podzol, changed from its original state by past management practices. It was nonetheless marginal for Sitka spruce, requiring frequent nitrogen fertilisation in the absence of nurse species.

The experiment layout placed plots of the two species immediately adjacent to one another. The nursing effect was first noted eight years after the establishment in plots of Sitka spruce adjacent to Douglas fir. Height, leader length and diameter of the Sitka spruce were measured in lines parallel and adjacent to the Douglas fir to determine the spatial progress of nursing. Foliage analysis indicated that the effect was nutritional, rather than due to shelter.

The nursing effect occurred in a less than ideal spatial arrangement of the two species; it is contended that a more favourable result for the Sitka spruce could have been achieved with an intimate mixture. Douglas fir/Sitka spruce mixtures should be considered on similar soils, the main benefits being the extended species choice, increased diversity, and reduced need for fertilisation.

Keywords

Douglas fir, nursing, mixtures, nitrogen fertilisation, nitrogen fixation, nutrition, Old Red Sandstone, Sitka spruce, soil reclamation.

Introduction

It is known that certain species (nurses) have a capacity to extract and make available nitrogen to other tree species growing in mixture. The nurse has the capacity to utilise scarce nitrogen, either by extracting it from a relatively unavailable fraction of some soils, and/or by fixing it from the atmosphere, and to contribute some of this nitrogen to a nursed species. Legumes, including broom (*Cytisus* spp.), false acacia (*Robinia* spp.), alder (*Alnus* spp.) and lupins (*Lupinus* spp.) have long been known to have beneficial nutritional effects on agricultural and forest species, having the capacity to fix up to 300 kg N/ha (*Robinia*) in their early years (Baule and Fricker 1967).

A number of coniferous species are known to be able to nurse Sitka spruce on nitrogen-poor sites. On mineral soils, Japanese larch (*Larix leptolepis*) and lodgepole pine (*Pinus contorta*) have been the best nurse species (OCarroll 1978, Carey et al. 1988), while the evidence from Britain (Taylor 1985) of a similar nurse effect by Scots pine (*Pinus sylvestris*) has not been confirmed in Ireland. On peat soils, lodgepole pine has been associated with successful nursing of Sitka spruce in Britain (Taylor 1985, Miller et al. 1986), although the authors are not aware of a convincing case in Ireland.

How the nurse species increases nitrogen availability is not known but may be due to its ability to take up soil nitrogen which is unavailable, or at least less available, to the nursed species (Miller et al. 1986). The transfer of nitrogen from nurse to receptor species is by

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root contact; this is clearly demonstrated by an observation in the experiment described here of the absence of any increase in foliage nitrogen levels of Sitka spruce where cut-off drains between nurse and nursed species prevented root contact.

The abundance of soils in Ireland with low reserves of nitrogen, or poor nitrogen availability, limits the ability of Sitka spruce to grow successfully on them without frequent applications of fertiliser nitrogen. The option of using nursing mixtures on such soils is clearly an attractive one, both from the point of view of reducing the need for fertiliser inputs and reducing any potential environmental impacts from repeated fertilisation.

This paper provides experimental evidence for a nursing effect of Douglas fir on Sitka spruce on an infertile soil derived from Old Red Sandstone in the foothills of the Ballyhoura Mountains, on the Cork-Limerick county boundary.

Background

The experiment in question, Ballyhoura 30/76, was not designed to investigate nursing effects, but rather to determine the effect of a variety of intensive reclamation techniques on the establishment of Sitka spruce and Douglas fir on Old Red Sandstone soils.

It was established in 1976 because the standard establishment techniques on such soils at that time – single mouldboard Clark ploughing, 500 kg ground rock phosphate/ha at planting, and nitrogen fertiliser when required – were found to be of limited value on infertile Old Red Sandstone soils. Severe growth-check usually developed in Sitka spruce within five years of planting, due to lack of nitrogen. Application of nitrogen brought about short-lived growth responses, but the frequent fertiliser applications necessary for satisfactory growth were economically questionable. One of the main objectives the experiment sought to examine was the potential of nitrogen-fixing leguminous species – furze (*Ulex gallii*), broom (*Cytisus scoparius*) and clover (*Trifolium* spp.) – to provide a supply of nitrogen to enable Douglas fir and Sitka spruce to be self-sustaining in terms of their nitrogen needs.

The emergence of the nursing effects, some eight years after the establishment of the experiment, was an unforeseen development.

Materials and methods

Site location

The experiment was located at an elevation of 120 m in Ballyguyroe North townland (national grid reference R 67 13), Ballyhoura (now Mallow) forest. The forest is owned and managed by Coillte, the Irish Forestry Board.

The predominant soil type was a podzol with some podzolised gleys. Detailed soil descriptions are given in the Appendix. The vegetation was a uniform poor heath type, with a poorly developed dwarf shrub layer (20 cm high, 30-40% cover, moss layer 85% cover) composed mostly of *Sphagnum* spp. There was no dominant species among the higher plants; *Erica tetralix, Molinia caerulea* and *Narthecium ossifragum* were the most common.

Treatments, experiment design and plot layout

Treatments

The main plot experimental treatments are given in Table 1. Each main plot was comprised of a pair of Douglas fir and Sitka spruce sub-plots. The plants were normal nursery stock (30-40 cm Sitka spruce and 40-60 cm Douglas fir).

Table 1. *Main plot treatments and nitrogen sources at Ballyhoura 30/76.*

Treatment	*Nitrogen source*	*Treatment designation*
Single mouldboard Clark ploughing at 2 m (control)	None	O
Complete Clark ploughing + rotovation + KCl + superphosphate + limestone + clover	Clover	C
Complete Clark ploughing + rotovation + KCl + furze (Ulex gallii)	Furze	U
Complete Clarke ploughing + rotovation + KCl + limestone + broom	Broom	B
Complete Clarke ploughing + rotovation + KCl + Calcium ammonium nitrate	Fertiliser	M

The fertiliser types and auxiliary nitrogen-fixing species used in the main treatments are further elaborated in Table 2.

Table 2. *Nutrient sources, rates of fertiliser application and auxiliary nitrogen fixing species used at Ballyhoura 30/76.*

Nutrient source	*Rate*
Basal treatment with ground rock phosphate	500 kg/ha (1975) + 350 kg/ha (1985)
KCl (potassium chloride)	250 kg/ha (125 kg K/ha)
Superphosphate	187 kg/ha (30 kg P/ha)
Limestone	1,253 kg/ha (1976) + 5,012 kg/ha (1979)
Clover (white)	4.5 kg seed/ha, broadcast
Furze (Ulex gallii)	7,500 seedlings/ha, spot-planted
Broom (common yellow)	4.5 kg seed/ha, spot-sown
CAN (calcium ammonium nitrate)	200 kg N/ha (1982) + 150 kg N/ha (1984)

Experiment design

The treatments were laid out in a split-plot design with three replications. The main plots were intensive reclamation treatments (32 x 64 m). Each main plot was split into Douglas fir and Sitka spruce sub-plots (32 x 32 m).

Experiment layout
The block, plot, and sub-plot layout is shown in Figure 1. The subplots are numbered 1 – 30. The treatment designations are as in Table 1.

		Block I		
1 U DF	*2 B* SS	*3 M* DF	*4 C* SS	*5 O* DF
10 U SS	*9 B* DF	*8 M* SS	*7 C* DF	*6 O* SS
		Block II		
11 O SS	*12 M* SS	*13 B* SS	*14 C* DF	*15 U* SS
20 O DF	*19 M* DF	*18 B* DF	*17 C* SS	*16 U* DF
		Block III		
21 B DF	*22 O* SS	*23 C* SS	*24 U* SS	*25 M* SS
30 B SS	*29 O* DF	*28 C* DF	*27 U* DF	*26 M* DF

Figure 1. *Block, plot and sub-plot layout at Ballyhoura 30/76* (SS: Sitka spruce, DF Douglas fir. *The nursing effect was measured in the shaded sub-plots:* *Sitka spruce,* *Douglas fir*).

Soil description and analyses
Soils typical of the experiment area were described by investigation of representative soil profiles, supplemented by laboratory analysis of soil samples taken from the selected soil profiles to determine their fertility status.

The soils of the area show many of the characteristics found in the classic podzols developed on Old Red Sandstone parent material. However, modifications have occurred in many of these podzols through, for example, removal of part or all of the peat from the surface of the soil for fuel, and/or cultivation of the soil, resulting in a mixing of the upper soil horizons. Left untouched, these soils would have been peaty podzols. The experiment area was largely covered by one soil type, a modified podzol (formerly a peaty podzol), with small areas of podzolised gleys (formerly peaty podzolised gleys). Douglas fir and Sitka spruce grew well on the free-draining podzols, but poorly where podzolised gleys occurred. The nursing of Sitka spruce by Douglas fir was consequently only evident on the free-draining modified podzols. Analytical descriptions of the soil types are given in the Appendix.

Growth assessments

Following the observation in 1985 of more vigorous growth and a greener foliage colour in Sitka spruce trees adjacent to Douglas fir plots it was decided to assess the Sitka spruce line by line (line 1 being nearest to Douglas fir and line 7 being furthest from Douglas fir). Seven lines of Sitka spruce were assessed separately in each of three plots (17, 22 and 23) for mean height (all trees in each line) in each year from 1985 and for diameter breast height (DBH) from 1991. The general yield class was based on the mean height of the two largest DBH trees per plot.

The general yield class was determined in 1992 and 2000 in Douglas fir plots (16, 28 and 29) adjacent to the nursed Sitka spruce plots (17, 22 and 23), based on the mean height of the two largest DBH trees per plot.

Nutrient content

Foliage samples were collected from the Sitka spruce from each of seven lines of trees with decreasing distance from the Douglas fir. Samples were collected on six occasions: in the dormant periods of 1985/86, 1987/88, 1990/91, 1991/92 and 1992/93. The foliage was analysed to determine nutrient content, particularly nitrogen, to establish if the difference in height growth between lines of Sitka spruce was related to nutritional differences. Total nitrogen was determined in the laboratory using a micro-Kjeldahl method (Jackson 1958).

Results

Growth of Sitka spruce

Height growth of the Sitka spruce is presented for representative years for the 15-year period, 1985-2000 (Table 3). The heights are the means of corresponding lines in three plots (plots 17, 22 and 23). From the 1990 assessment onwards there was an overall significant effect of distance from the Douglas fir on the height of the Sitka spruce, with significant differences between each line; height declined with distance from the nurse species. This trend continued over time, with an almost 6 m difference between lines 1 and 7 by 2000 (Table 3, Figure 2).

Table 3. *Effect of distance from Douglas fir on the height growth of Sitka spruce over the period 1985-2000.*

Year	*Age years*	*Line 1 (nearest to Douglas fir)*	*Line 3*	*Line 5*	*Line 7 (furthest from Douglas fir)*	*Fisher's LSD test ($p \leq 0.01$)[a]*
				m		
1985	10	3.36	2.75	2.68	2.44	Not significant
1990	15	7.45 A	5.00 B	4.53 C	3.62 D	Significant
1995	20	12.13 A	10.02 AB	8.38 BC	6.78 C	Significant
2000	25	16.71 A	14.03 AB	13.24 BC	10.85 C	Significant

[a] For a given year, means followed by the same letter do not differ significantly from each other at the $p \leq 0.01$ level.

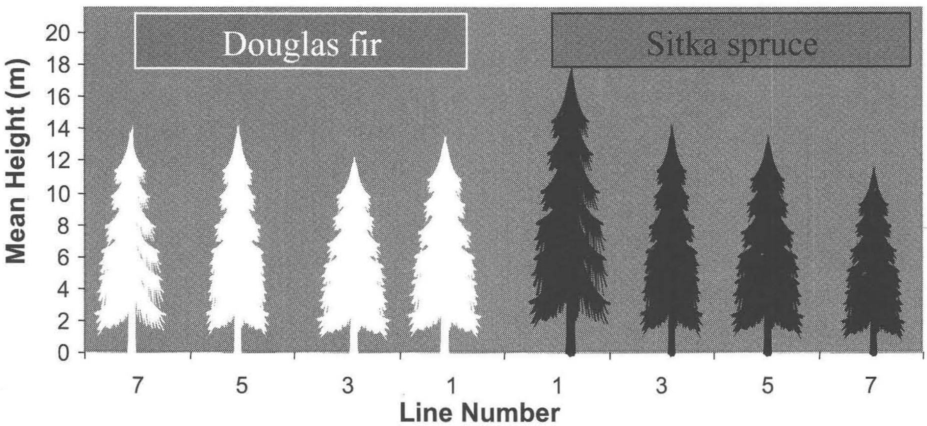

Figure 2: *Mean height of Douglas fir and Sitka spruce in 2000.*

The growth differences between Sitka spruce in the different lines was greater when expressed as general yield class (GYC). The difference in GYC evident at 10 years persisted to at least 25 years (2000), when last assessed (Table 4). The line nearest the Douglas fir improved from GYC 20 to 24, while the furthest away line improved from GYC 14 to 18. It took 15 years for line 5 to develop a productivity level (GYC 20 in 2000) equal to that of line 1 in 1985.

Table 4. *Effect of distance from Douglas fir on volume growth productivity of Sitka spruce over the period 1985-2000.*

Year	*Age years*	*Line 1 (line nearest to Douglas fir)*	*Line 3*	*Line 5*	*Line 7 (line furthest from Douglas fir)*
			GYC $m^3ha^{-1}year^{-1}$		
1985	10	20	16	16	14
1990	15	22	18	14	14
1995	20	24	20	18	16
2000	25	24	22	20	18

Growth of Douglas fir

The mean height of Douglas fir was measured for two representative years, 1992 and 2000 (Table 5). The line effect was determined in the plots adjacent to the Sitka spruce plots presented above, and in the same manner. In contrast to the growth of Sitka spruce, the height growth of Douglas fir showed no effect of line position.

Table 5. *Effect of distance from Sitka spruce on height growth of Douglas fir over the period 1992-2000.*

Year	*Age* *years*	*Line 1 (nearest to Sitka spruce)*	*Line 3*	*Line 5*	*Line 7 (furthest from Sitka spruce)*	*Fisher's LSD test ($p \leq 0.05$)*
				m		
1992	17	8.4	7.9	8.6	8.1	Not significant
2000	25	12.63	11.81	13.26	13.51	Not significant

There was no effect found of distance to the Sitka spruce on volume productivity of the Douglas fir (Table 6), which was to be expected given the uniformity of height growth of Douglas fir irrespective of line position.

Table 6. *Effect of distance from Sitka spruce on volume growth productivity of Douglas fir over the period 1992-2000.*

Year	*Age* *years*	*Line 1 (line nearest to Sitka spruce)*	*Line 3*	*Line 5*	*Line 7 (line furthest from Sitka spruce)*
			GYC $m^3ha^{-1}year^1$		
1992	17	16	14	16	16
2000	25	14/16	14	16	14/16

Nutrient content

For clarity of presentation, nutrient concentrations for only two of the periods, 1985/86 and 1992/93, are given. Nitrogen levels alone are presented (Table 7 and Figure 3) as it was the limiting nutrient at the site.

Table 7. *Effect of distance from Douglas fir on foliar N levels of Sitka spruce for the years 1985/86 and 1992/93 (L1 being Sitka spruce line nearest to the nurse).*

	Sitka spruce line							
Year of analysis	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*Fisher's LSD test*
				Nitrogen % dry matter				
1985/86	1.55	1.40	1.23	1.11	0.99	1.03	1.04	Significant ($p \leq 0.05$)
1992/93	1.69	1.59	1.54	1.44	1.35	1.29	1.17	Significant ($p \leq 0.01$)

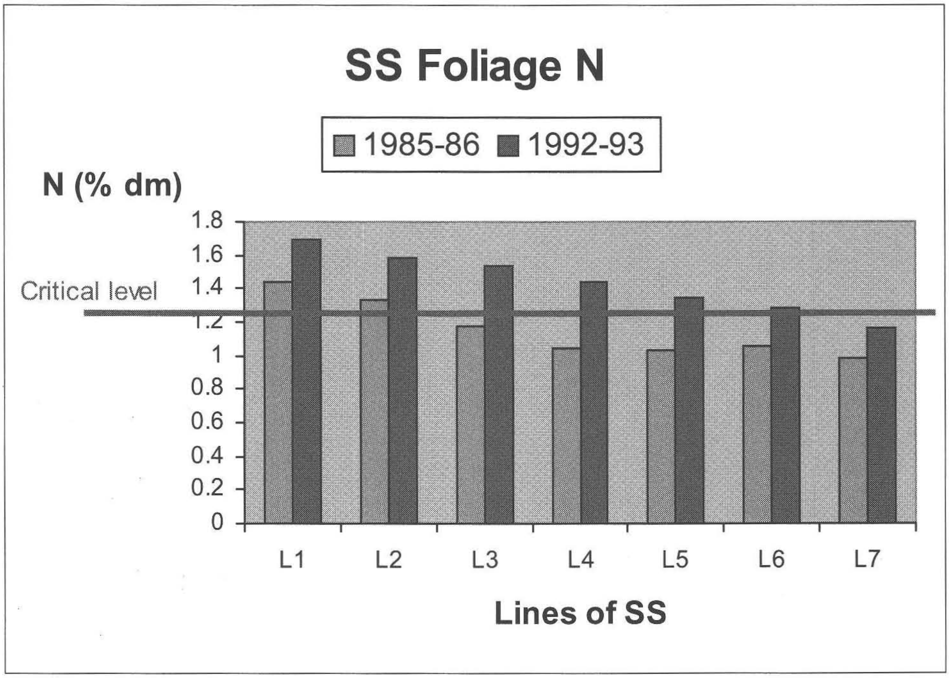

Figure 3. *Effect of distance from Douglas fir on foliar N levels of Sitka spruce for years 1985/86 and 1992/93 (L1 being Sitka spruce line nearest to nurse species).*

The main results were:

1. for any given year the nitrogen levels were greatest in the line (L1) of Sitka spruce nearest to the Douglas fir, decreasing with distance and lowest in the line (L7) most distant from the Douglas fir; the differences in foliage nutrient concentration between lines were significant at the $p \leq 0.05$ level in the 1985/86 analysis and significant at the $p \leq 0.01$ level in the 1992/93 analysis (Table 7);
2. nitrogen levels increased with time, by at least 0.13% from 1985/86 to 1992/93;
3. in 1985/86, only the two lines of Sitka spruce closest to the Douglas fir had nitrogen concentrations above the critical level (the level below which indicates deficiency or the level which indicates high probability of growth response to fertiliser treatment), while seven years later, by 1992/93, that had increased to six lines (Figure 3).

Discussion

Efforts to afforest poor Old Red Sandstone sites have been underway in Ireland since the 1920s (Wittich 1949) and have met with mixed results. While some have been successful silviculturally, they can be questioned on the grounds of economics (high cost of repeated N fertilisation in the case of Sitka spruce) or impracticality (use of nitrogen-fixing legumes). Although lodgepole pine grows vigorously on nitrogen-poor soils, because of its low nutrient needs (provided phosphorus supply is not limiting), it has generally poor stem form due to basal sweep and wind/snow damage. It is also susceptible to damage by pine shoot moth, pine beauty moth and pine sawfly.

The use of nurses in mixture with Sitka spruce has resulted in the enhancement of Sitka spruce growth on Old Red Sandstone sites where nitrogen deficiency is common (OCarroll 1978). The results presented here show that Douglas fir could be used as a nurse species in addition to Japanese larch, Scots pine and lodgepole pine. The higher foliage nitrogen levels found in Sitka spruce adjacent to Douglas fir tend to confirm that the latter was behaving in a nutritional manner rather than providing shelter. This is reinforced by the fact that non-nursed Sitka spruce in the fertiliser treatment plots had to receive fertiliser nitrogen twice in a three-year period, 1982-1984, to bring them out of recurring deficiency (results not reported here). By contrast, Sitka spruce nursed by Douglas fir has received no fertiliser nitrogen, as foliage analysis showed it was not required. Furthermore, Sitka spruce foliage nitrogen levels have increased over time, even in the lines furthest from the nurse.

Nevertheless, the arrangement of nurse (Douglas fir) to nursed (Sitka spruce) species in seven-line blocks is not efficient, as the nursing effect in lines furthest from the Douglas fir takes too long to achieve nitrogen sufficiency. This is particularly evident from the effect on volume productivity in the Sitka spruce (Table 4), ranging from GYC 24 in Sitka spruce nearest to Douglas fir to 18 in those furthest away. Indications from other current studies in the Ballyhoura area suggest that a 3/3-row mixture of nurse and nursed species is the best spatial arrangement.

Such mixtures also afford an opportunity to manipulate the composition of the final crop. For example, if the Douglas fir has excellent form, the Sitka spruce can be removed in thinnings, leaving the Douglas fir to grow to maturity as the final crop. On the other hand, if the form of the Douglas fir is less than satisfactory, it can be removed in thinnings once its nursing role has been fulfilled. Where both species are growing satisfactorily, consideration could be given when thinning to favouring the best stems of both species.

The evidence from this study suggests that Douglas fir has a commercial potential to complement its nursing role. A GYC of 16 for Douglas fir, at 17 years (1992), would yield a commercial return, particularly on such a difficult site, all the more so since the productivity was maintained up to 25 years (2000), with no indication of decline.

The finding that Douglas fir can nurse Sitka spruce opens up new silvicultural possibilities. First, it provides an additional nurse option, one in which it has commercial potential beyond that expected of the traditional nurse species. Second, Douglas fir/Sitka spruce mixtures can be expected to achieve high commercial productivity on *modified podzols*, soils which have been subject to intensive management in the recent or distant past, but which are nutritionally marginal for pure Sitka spruce. Additional benefits to use of Douglas fir/Sitka spruce mixtures would accrue from reduced need for fertilisation and increased species diversity.

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Appendix

Table 1. *Chemical analysis of a modified podzol at Ballyhoura 30/76.*

Horizon	*Depth cm*	*pH*	*OM %*	*P*	*K*	*Ca*	*Mg*
					µg/g		
Ap1	*0-10/20*	4.0	11	1	14	22	24
Ap2	*10/20-35/40*	4.3	5	1	11	4	13
B	*35/40-55/60*	4.7	2	0	15	1	6
C	*55/60 +*	4.8	2	1	24	1	8

Abbreviations: OM (organic matter), P (phosphorus), K (potassium), Ca (calcium) and Mg (magnesium).

Table 2. *Chemical analysis of podzolised gley at Ballyhoura 30/76.*

Horizon	*Depth cm*	*pH*	*OM %*	*P*	*K*	*Ca*	*Mg*
					µg/g		
Ap1	*0-10*	4.2	19	8	91	153	95
A21g	*10-25*	4.4	3	1	16	17	8
A22g	*25-35/40*	4.7	3	1	15	2	2
Bg	*35/40- 60*	4.9	3	1	25	6	6
Cg	*60- 80*	4.9	3	1	24	12	7

The analyses for both soils are quite similar with regard to soil reactions and P levels. Soil reactions are very acid, with pH ranging from pH 4.0/4.2 in the topsoil to pH 4.8/4.9 in the parent material. Soil P levels are very low, showing the clear need for application of P fertiliser at planting. The only point of difference in the analysis between the soils appears to be the relatively better overall nutrient status in the podzolised gley compared to that in the modified podzol.