More on Nursing Mixtures

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ABSTRACT

A series of experiments in Ireland and Britain have demonstrated that the growth of Sitka spruce (*Picea sitchensis* (Bong.) Carr) can be enhanced on poor soils by the presence of Japanese larch (*Larix leptolepis* Sieb.), Scots pine (*Pinus sylvestris* L.) and lodgepole pine (*Pinus contorta*). The improved growth, or so called "nurse effect", is related to greater availability of soil nitrogen and a more rapid turnover of nitrogen in mixtures compared with spruce monocultures. It becomes noticeable some 8-10 years after planting. Research results suggest that the effect is closely related to the root activity of the nurse species and substantial differences have been found in the mycorrhizal fungal flora on pure spruce compared with spruce grown in mixture with larch or pine.

Mixtures are now advocated for site types such as oligotrophic peats and podsolised mineral soils where nitrogen deficiency is often a problem. Although they may be more difficult to manage than monocultures, their use is likely to greatly reduce the need for top dressing with fertiliser nitrogen and at the same time add diversity to species selection. Self-thinning mixtures of spruce and a slow growing provenance of lodgepole pine or Scots pine are suggested as an option for high production wet mineral soils where windblow is often associated with conventional thinning.

INTRODUCTION

The positive effect of one species of tree on the growth of an adjacent different species has long fascinated foresters, some of whom have advocated mixed species forests rather than monocultures. As a result there are now about 42,000 ha of mixed plantations in the Irish Republic of one kind or another, representing about 11 per cent of the forest estate. There are also substantial areas of mixtures in Britain (Garforth, 1979).

Besides planting mixtures because of the so called "nursing" or beneficial effect of one species on the other two other philosophies

have played a part in their popularity over the last thirty years or so. One related to uncertainty as regards what to plant on poor land and anxiety over its potential to grow Sitka spruce satisfactorily without regular inputs of fertiliser nigrogen. The other was very likely influenced by Anderson's (1950) ideas on species selection. Besides advocating that species should be site adapted, he encouraged the planting of mixed crops so as to exploit any potential synergistic effects and as well as this strengthen ecological stability. There is little hard evidence worldwide now to support the hypothesis of monocultures being less stable than mixed forest plantations (Will, 1984). Nevertheless, Anderson's views were often in foresters' minds when it came to deciding on planting mixtures, best expressed perhaps in the concept of "not putting all of one's eggs into one basket".

Although it was observed as early as the mid 1930s (Zehetmayr, 1960) that Sitka spruce growing on heather dominated heathlands often recovered from check if planted near pine or birch, real evidence for a beneficial effect has been hard to obtain. Recently, however, there have been several observations, in properly designed experiments on poor soils, in both Ireland and Britain, of improved growth of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) when planted in mixture with larch or pines (both lodgepole *Pinus contorta* Dougl. and Scots pine *Pinus sylvestris* L.). This improved growth relates to better nitrogen nutrition when spruce is planted in mixture rather than in monocultures. Pure spruce crops growing on such soils do respond well to top dressings of fertiliser nitrogen (Carey & Griffin, 1981, McIntosh, 1983). However, the cost element of the operation, and uncertainty over the number of doses necessary to sustain an acceptable growth pattern, has added weight to the mixtures option. As a result substantial areas of mixed spruce and pine have been planted in Scotland in recent years (Taylor, 1985) and research programmes, supported by EEC funding and aimed at gaining an understanding of the "mixed effect", have been intensified.

The purpose of this presentation is to describe the relevant experiments in both Ireland and Scotland and to provide a summary of the recent research that has been carried out. Secondly, based on the results from these investigations, recommendations will be made on the possible role of mixtures in future planting programmes and finally comments will be made on the extent and management of existing mixed plantations and of the role of self thinning mixtures on unstable sites.

Mixture Experiments

There are four experiments pertinent to the present discussion, details of which are outlined in Table 1. Three are in Britain: Inchnacardoch, Mabie and Culloden forests; the fourth, the oldest and now 27 years of age, is situated at Avondhu forest, Co. Cork in the Republic of Ireland. Other experiments have been laid down in recent years but none has yielded results yet.

Table 1: Experiments in Ireland and Scotland where growth of Sitka has been improved by the presence of a nurse species.

Location	P/Year	Site Type	Species/Provenance Used as Nurse
Avondhu	1960	ORS*	Inland lodgepole pine & Japanese larch
Inchnacardoch	1965	Blanket bog	North coastal lodgepole pine Skagway, Alaska. Also Japanese larch
Mabie	1967	Lowland raised bog	North coastal lodgepole pine Petersburgh, Alaska. Also Hybrid larch
Culloden	1969	ORS*	Scots pine

* ORS=Old Red Sandstone

There are a number of features common to all four experiments:

1. All were established on poor soils known to be deficient in nitrogen for Sitka spruce.

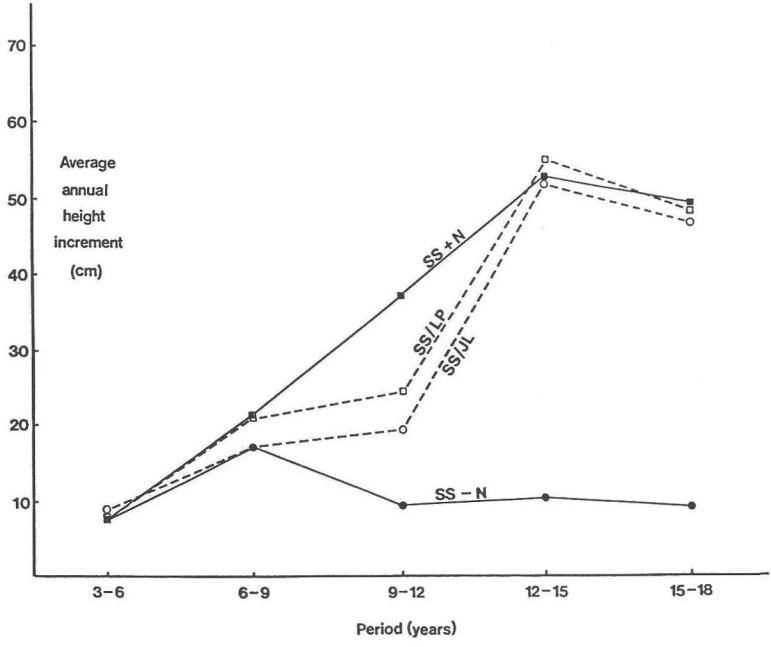
2. No measurable effects of the nurse species on tree growth were observed at any of the sites until some 8-10 years after planting.

3. Substantial improvements were obtained in height and diameter growth and dry matter production of spruce when grown in the presence of pine or larch, with a few minor exceptions, at (i) Avondhu where the pine effect (inland provenance), although statistically significant, meant little from a practical viewpoint and at (ii) Mabie forest where the spruce was totally suppressed by the lodgepole pine. On the lowland raised bogs of south west

Scotland lodgepole pine performs particularly well and even the slow growing provenances out-grow Sitka spruce (Taylor, C., personal communication).

It is not intended to pursue the results from each experiment in detail. The Avondhu trial has already been written up in an earlier issue of this Journal by O Carroll (1978) and other experiments are described comprehensively by Carlyle and Malcolm (1986) and in reports prepared for the European Commission (Carey *et al,* 1986; Miller *et al,* 1986). However, the Inchnacardoch and Culloden trials will be referred to briefly because of their significance to Irish forestry. The former, located on acid (pH 4.0) blanket bog in Scotland, had the following treatments: (1) pure Sitka spruce without fertiliser; (2) pure Sitka spruce with fertiliser (nitrogen was added when needed, a total of 804 kg/ha N in 5 applications between 1969 and 1984); (3) Sitka spruce/lodgepole pine mixture, and (4) Sitka spruce/Japanese larch mixture. Significantly tree growth in the pure spruce with nitrogen fertiliser was only marginally better than the spruce in the mixture plots (Figure 1).

Figure 1 Average annual height increment for different treatments at Inchnacardoch 164p65 (from Taylor, 1985). Blanket peat. Elevation 295m.



Nitrogen was not included as a treatment at the Culloden site (an Old Red Sandstone soil). The control plots (pure Sitka spruce) were badly affected by nitrogen deficiency within ten years of planting whereas the spruce grown in the presence of Scots pine were vigorous and had satisfactory nitrogen levels in the foliage. Scots pine, although popular in planting programmes in Ireland between 1930 and 1950, has been largely replaced by the more vigorous lodgepole pine, a species not without its problems (Carey & Hendrick, 1986). Although Scots pine was not included as a treatment in the Irish experiment, there is circumstantial evidence in some plantations in the Old Red Sandstone region in the southerly part of the country, that the species is having a positive effect on the growth of adjacent Sitka spruce. Thus, although Japanese larch has been reasonably effective on both the Old Red Sandstone and Blanket peat soils (Avondhu and Inchnacardoch) it is possible that Scots pine may be an acceptable alternative as a nurse on the Old Red Sandstone site types. Its overall poor performance on blanket peat in the west of Ireland suggests, however, that it (Scots pine) would not be effective in such situations.

The Nurse Phenomenon

Besides the practical significance of mixed as against pure plantations, one of the questions that has been foremost in the minds of some forest scientists in recent years has been the nature of the mechanism behind the nursing phenomenon. If the effect was fully understood then it is conceivable that it could be simulated in the absence of the nurse species thereby enabling forest productivity to be increased without the need to apply nitrogenous fertilisers. The result would have advantages both economically and environmentally. With this in mind, two research teams, one in Ireland (the Forest Service), the other in Scotland (Macaulay Institute, Aberdeen, in association with Edinburgh University and the Forestry Commission of Great Britain), set out in 1983, with the aid of EEC funding, to study in greater detail the processes operating in a number of the treatments at the Avondhu, Inchnacardoch and Culloden sites.

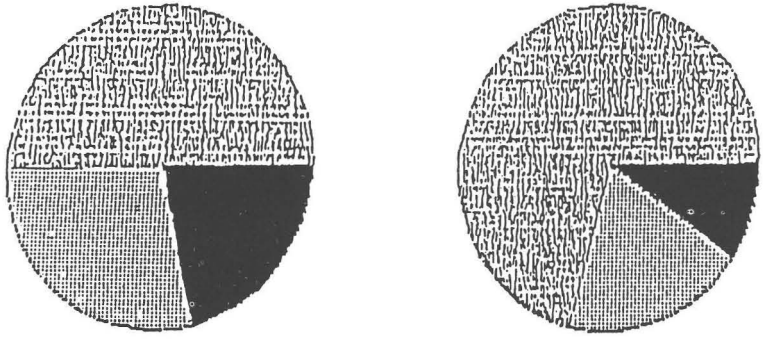
Earlier work by O Carroll (1978) at the Avondhu site had shown that the presence of Japanese larch resulted in increased availability of nitrogen for Sitka spruce but it was far from clear how the effect arose. It was suggested that the annual litterfall from the deciduous larch might serve as a source of nitrogen for the spruce, although doubts were raised over whether the decomposition of the litter would be sufficiently rapid to enable

such an effect to occur. Other suggestions included the possibility that nitrogen was being fixed by the nurse species – as in the case of clover in agriculture, although studies by Carlyle (1984) subsequently ruled out this option. Other suggestions included the possibility that rainwater passing through the forest canopy actually leached nitrogen from the foliage of the nurse species which was passed on to the spruce and/or that mycorrhizal fungi might be involved in the overall process.

The EEC funding, together with that provided by the organisations in both Member States, enabled all of these possibilities to be investigated. Details of the studies and their results can be found elsewhere (see Carey *et al* and Miller *et al,* 1986). In summary they showed that:

1. There were considerably higher nitrogen concentrations in the spruce trees in mixed plots compared with pure spruce plots. This was also reflected in the overall nitrogen budget for both situations. At Avondhu, for instance, the total nitrogen content of the larch and spruce trees (including roots) came to 307 kg/ha compared with 110 kg/ha in the pure spruce plots (Figure 2). The spruce trees in the mixture plots contained 210 kg of the 307 kg of nitrogen present in the treatment.

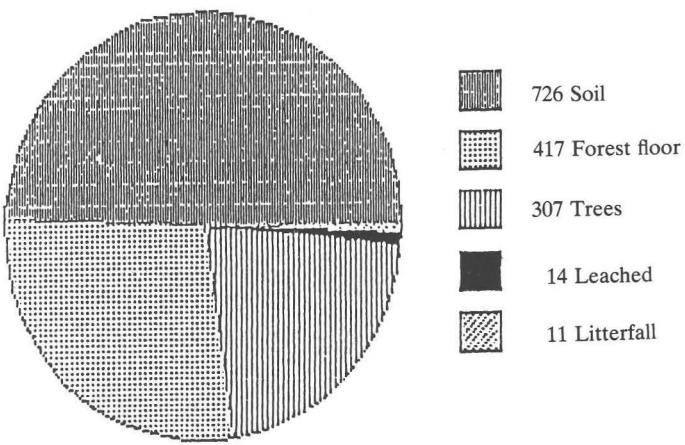
Figure 2 Distribution of nitrogen in the pure Sitka spruce plots and in the mixture plots (kg ha^{-1}) at Avondhu.



2. The extra nitrogen present in the trees in the mixed plots came from the soil; the soil in the mixture plots showed a corresponding decrease in total nitrogen.

3. There was more rapid turnover of nitrogen in the mixtures compared with the pure spruce plots. For instance, litterfall contained higher concentrations and contents of nitrogen but the differences were not sufficient to explain the enhanced growth pattern of the spruce when grown in the presence of larch or pine. Throughfall in the mixed plots also contained substantially more nitrogen than that in pure spruce at all the study sites. There were also strong suggestions at Avondhu that some nitrogen (about 14 kg/ha/annum) was leached from the tree canopy by the rainfall (Figure 3). However, the amount, as in the case of litterfall, would not be sufficient to account for the extra growth recorded for the spruce in mixed plots at any of the study sites.

Figure 3 Avondhu Forest, Experiment 4/60. Nitrogen budget in the SS /JL mixture plots (kg N ha^{-1}).



4. Although the mycorrhizal studies did not commence until the latter stages of the project in 1985, there were strong indications of substantial differences in the fungal flora associated with spruce mycorrhizae from pure and mixed stands. Differences in other associated fungi were also evident. The results suggested that it was possible that the improved nitrogen status of spruce in mixed stands may be due to direct transport of nitrogen from either the nurses species, the soil or both. Until more work is carried out this must remain conjecture; however, there remains the fact that

the nursing effect does appear in one way or another to be closely related to root activity. This is evident not only in mixture experiments but also in plantations generally where pine or larch and spruce are grown alongside each other on poor soils. Invariably the enhanced growth of the spruce extends over a distance of three to four metres from the nurse species. On ploughed ground the effect is much more pronounced along rather than across the ribbons or turves, a feature that has practical implications when it comes to decide on spatial arrangement – see below. Much of the rooting activity on ploughed ground occurs in the ribbons or turves, particularly on wet peatland sites where the watertable is high.

Sites Suitable for Mixtures

1. Nitrogen deficient soils

(i) Oligotrophic (i.e. low nutrient status) peats in blanket and raised bogs.

As Carey and Griffin (1981) point out, nitrogen deficiency usually does not occur on these sites in Ireland until some eight to ten years after planting, provided phosphate has been applied at planting. This period of stress coincides with the time when the nurse species becomes effective in terms of stimulating growth of the spruce, as shown in the experiments.

(ii) Mineral soils derived from Old Red Sandstone parent materials, particularly those where the nitrogen-fixing species *Ulex gallii* is absent.

On poor Old Red Sandstone soils, nitrogen deficiency is likely to occur as early as three to five years after planting. In such cases one application of nitrogen to the spruce may be necessary to ensure it maintains pace with the nurse species before the latter becomes effective. The problems of nitrogen deficiency on these site types and the responsiveness of Sitka spruce growing on them to nitrogenous fertilisers have been described in previous papers (e.g. Carey and Griffin 1981, Carey and Hendrick 1986).

2. Surface water gleys

On unstable fertile soils, particularly surface water gleys, the idea of self-thinning mixtures of pine and spruce are also worth consideration. There are several examples of the system working out very satisfactorily in Ireland and Britain. One such example is at Swanlinbar Forest, Co. Cavan. The stand, planted in 1962 on surface water gley at an elevation of 150m, is composed of a row by row mixture (i.e. 1:1) of Sitka spruce and Inland lodgepole

pine. The initial stocking was 3100 stems/ha, but the present live stocking is at 1840 stems/ha, 84 per cent of the lodgepole pine having been suppressed by the spruce, the yield class of which is equivalent to 22.

Apart from the highly desirable level of self-thinning occurring at this site the other, and probably more outstanding feature of the crop, is that there has been no windblow. This is all the more noteworthy for two reasons: (1) windblow is widespread in the adjacent pure spruce crops and (2) the site was cultivated using a single mouldboard plough, a method notorious for predisposing crops to windblow. The use of self-thinning mixtures appears to be a highly promising approach, and may be the only one, to growing Sitka spruce to full rotation on the highly fertile but windblow-susceptible gley soils.

Effective Nurse Species

The experiments have shown that lodgepole pine, Scots pine and Japanese larch are equally effective as a nurse, depending on provenance and site type. In addition, Douglas fir has recently been observed to have a powerful nursing influence on Sitka spruce at Ballyhoura Forest, Co. Cork, the effects of which have been measured over the last three years (in press). South coastal provenances of lodgepole pine are most unsuitable for nursing spruce – they are far too vigorous and will probably suppress the spruce. Alaskan provenances are most effective and the much maligned Lulu Island provenance, which was planted quite widely in Ireland in the 1960s, appears particularly promising. While lodgepole pine appears equally effective on both organic and mineral soils as a nurse species, this is not so with either Scots pine or larch, both of which should be confined to the mineral soils where mixtures are being considered. Larch tends to suffer badly from exposure on blanket peat and Scots pine, as pointed out earlier, generally grows poorly on such sites.

Spatial Arrangement and Proportion of Nurse Species

In the experiments reported, the nurse species comprises between 50 and 75 per cent of the crop. The spatial arrangements vary as follows:

Avondhu

(1) intimate mixture of nurse with Sitka spruce and
(2) alternative double rows of nurse and Sitka spruce .

Inchnacardoch
one pure line of the nurse species with neighbouring line consisting of three nurse plants to three Sitka spruce.

Culloden and Mabie
lines consisting of groups of three nurse and three Sitka spruce plants. Sitka spruce bound by nurse triplets in neighbouring lines.

There are indications that a lower proportion of the nurse species would be equally effective, particularly if the two species are mixed intimately along rather than across the lines of plants. A one (nurse) in three plants is suggested. Although planting the nurse species in lines may be preferable from a management point of view, it is likely to be less effective in terms of nitrogen nutrition because there is less opportunity for close interaction of the root systems of the nurse and Sitka spruce, essential it seems to the nursing effect. Maintaining the proportion of the nurse species in or around 33 per cent will ensure a good stocking of spruce and very likely result in the nurse dying out after canopy closure when its original objective has been completed. Increasing the proportion of nurse species above 50 per cent will present management problems at the thinning stage and very likely reduce overall production potential. However, on poor sites with difficult access, a "no-thin" regime may be indicated and in that case a 50/50 mixture would be best, 2-SS/2-nurse in the same line. 2 row/2 row Sitka spruce/Scots pine mixtures are proving quite successful on heathlands in eastern Scotland (Taylor, C., personal communication).

Management of Mixtures

The immediate objective in the management of mixtures is to achieve satisfactory crop establishment, thereby reaching thicket stage with little or no need for nitrogen fertiliser inputs. The ultimate objective is to maximise the growth of the primary species, that is, the species being nursed.

It should be borne in mind that even though the primary species is normally more valuable financially than the secondary species (nurse) it may not be the dominant one in the canopy. Indeed it is a feature of many mixtures that the nurse is the dominant species. This is often the position for example where Sitka spruce is in mixture with the more vigorous provenances of lodgepole pine. In these situations it requires much skill and attention by the forester to promote the growth of the primary species in the most effective way possible.

Mixtures composed of compatible species (that is, where the primary species is not dominated by the nurse species) are clearly much more cost-effective since they require less management than where the nurse species is dominant. It is crucial therefore to select the right nurse species at planting, that is, one appropriate to the site and to the species to be nursed. More information is required on what constitutes the ideal mixture species for particular site types and regions, and this is one of the subjects being actively pursued in current research programmes.

There remains the question of how to manage existing mixture crops which are in varying degrees of stand development and perhaps including features (such as, an over-dominant nurse species) that it should be possible to avoid in future through a more prudent selection of species at planting. The following situations are the most common mixture problems faced by foresters and the solutions offered for each should be seen as general guidelines as to how to deal with mixtures:

1. Thicket stage crops, where the nurse species is dominant, and the stand top height is up to 5-6m.

Solution: Respacing should be considered, with emphasis on removing the nurse species. Of all mixture situations these young crops represent the greatest scope for promoting the growth of the primary species.

2. Young pole stage crops, where (i) both species are growing well, or (ii) one species is completely suppressed with a top height difference greater than 2m.

Solution: Manage as if crop were pure, applying normal management principles.

3. Young pole stage crops, where the top height of the nurse species exceeds that of the primary species by less than 2m.

Solution: Such situations usually indicate that the primary species will respond to thinning. Lines of trees at wide intervals may be removed, with a selection thinning in between, the aim being to favour the primary species. Further selection thinnings may follow, leading to a final crop composed mainly of the primary species.

4. Advanced pole stage crops, where the top height of the nurse species exceeds that of the primary species by less than 2m, with indications that the primary species will respond to thinning but thinning is inadvisable due to windblow risk.

Solution: A chemical thinning of the nurse species could be considered. The object would be to kill most of the nurse species (with herbicide) leaving no need for conventional thinnings, whilst

at the same time creating the conditions for a growth response from the primary species with minimum risk of windblow.

5. Advanced pole stage crops, where at least 500 stems/ha of the primary species are sufficiently free from competition to form the final crop.
Solution: No thinning treatment is necessary, or indeed desirable on windblow-susceptible sites.

Three important points must be borne in mind if mixtures are to be successfully managed:

(1) adequate phosphorus levels are essential to effective nursing.

(2) removal of the nurse species in one operation is not advisable because:

(a) this may allow growth of vegetation antagonistic to the primary species e.g. heather, and

(b) it may result in check where the nursing effect was still active (however, total removal of the nurse species may be feasible where furze, a source of nitrogen, is present).

(3) a fertiliser application may be required in conjunction with thinning or respacing. Foliage analysis will verify whether this is necessary. Sitka spruce in mixture with south coastal lodgepole pine on mineral soils often shows phosphorus deficiency at age 10-15 years, which can easily be rectified.

Conclusions

Although a full explanation has yet to be provided on the processes involved in mixed stands whereby the nurse species enables spruce to grow satisfactorily, it has been clearly demonstrated that the effect is real across a range of site types and that mixtures offer considerable promise as a silvicultural option on poor or impoverished soils. Besides the experiments reported, there is also widespread evidence in plantations throughout Britain and Ireland of satisfactory growth of spruce, particularly in the presence of pine. However, without proper replication, it is often difficult to state categorically that the good growth experienced by spruce at any particular site is due to the presence of the nurse species.

From a forester's viewpoint there is no doubt but that the overall management of mixtures is more difficult than that of monocultures. Initially there is the burden of the extra cost of planting two species followed by the necessity for the development

of a compatible growth relationship between the nurse and the nursed species if one or other is to avoid being suppressed in the earlier years. Later there is the problem of deciding what to do when it comes to first thinning. As Garforth (1979) points out, the number of occasions when the relationship works out well are rare. Nevertheless there is abundant circumstantial evidence now of successful mixtures of Sitka spruce and slow-growing provenances of lodgepole pine planted on impoverished mineral and peat soils in Ireland and Britain, yielding well at first thinning and with continued good prospects. In the situations where there is likely to be uncertainty over funding for fertiliser nitrogen the mixture option is an alternative worthy of serious consideration.

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