The Nursing of Sitka spruce 2. Nitrogen-fixing species

NIALL O CARROLL

Department of Fisheries and Forestry,
Forest and Wildlife Service, Leeson Lane, Dublin 2.

SUMMARY

Three experiments covering the use of common broom, two species of lupin and two species of alder as aids in the establishment of Sitka spruce crops are described. One experiment was begun in 1961 and the others in 1964. Of the species tested common broom and tree lupin showed most promise. Broom when young is susceptible to destruction by hares, and tree lupin dies after about 5 years.

A combination of tree lupin and broom has resulted in a satisfactorily growing crop of Sitka spruce after 20 years. Establishment of tree lupin is improved by ground limestone and by intensive cultivation, but the long-term benefit of tree lupin alone to a tree crop has not been established.

It is suggested that further work is required to investigate the use of a shrubby or dwarf species of alder and also into the use of the native dwarf furze as nurses for Sitka spruce.

INTRODUCTION

The use of leguminous plants, such as clover, to supply nitrogen to associated agricultural crops, such as grass, has been practised for centuries, but it is only in the present century that their potential in forest practice has been examined.

The earliest investigations were carried out in Germany and the results are summarised by Baule and Fricker (1967). Substantial positive and long lasting effects of lupins on the growth of young crops were achieved. The yellow annual lupin *(Lupinus luteus* L.) is recommended for infertile sandy soils, and the perennial lupin *(L. polyphyllus* Lindl.) for other soils. Underplantings of perennial lupin to improve the growth of poor pine stands have also been successful. The need for adequate supplies of phosphorus, potassium, calcium and magnesium in order to achieve best results is also pointed out.

IRISH FORESTRY, 1982, Vol. 39, No. 1: 17-29

Investigations in Britain were reported in some detail by Nimmo and Weatherell (1962) who obtained promising results using broom *(Cytisus* spp.) although there were difficulties in interpreting their results because of a confounding of the effects of the broom with the effects of additional quantities of phosphorus fertiliser applied to encourage it.

More recent work in New Zealand has examined the contribution of tree lupin (*L. arboreus* Sims.), originally intended to provide shelter in the early stages of sand dune afforestation. Cadgil (1971) has estimated a maximum fixation rate of 240kg N per ha over the first 1½ years of lupin growth, with a subsequent sharp reduction. In this sequence the lupin crop is suppressed by the developing tree canopy but grows again from seed after the tree crop is thinned.

Work in Britain on mica wastes derived from china clay extraction has shown that naturally occurring colonies of tree lupin can accumulate nitrogen at about 185kg per ha per year over a period of 5 years (Palaniappan *et al.* 1979).

When forest research was begun in the Republic of Ireland in the late 1950s one of the problems tackled was the afforestation of the impoverished mineral soils of Old Red Sandstone origin in the southern counties. In addition to a known deficiency of phosphorous, many of these soils suffered from depletion of organic matter through the removal of shallow peat layers for domestic fuel in earlier times. One possible ameliorative measure appeared to be the use of nitrogen fixing nurses.

Three early experiments are reported in this paper. The first was established in Cappoquin forest in 1961. The two others, designed to follow up questions suggested by the early results in Cappoquin, were established in Rathluirc forest in 1964.

SITES AND METHODS

Cappoquin

Cappoquin State Forest, Boggaghduff. National grid reference S 0405, elevation 180m. The soil is a peaty podsolised gley derived from glacial drift comprised mainly of sandstone; present peat depth about 8-15cm. Slope 4° facing southwest. The natural vegetation was dominated by *Calluna vulgaris* Hull. and *Molinia caerulea* Moench. together with some *Erica tetralix* L. and *E. cinerea* L.

Rathluirc experiment 1

Rathluirc State Forest, Ballycoskery. National grid reference R 56 16, elevation 230m. The soil is a gley derived from glacial drift material of Old Red Sandstone origin, and the texture sandy with a high stone content. The site is flat and the natural vegetation was dominated by *Calluna vulgaris, Molinia caerulea* and *Tricophorum caespitosum* Hartm. (*Scirpus caespitosus* L.).

Rathluirc experiment 2

Rathluirc State Forest, Garrane. National grid reference R 58 17, elevation 265m. The soil is an ironpan podsol derived from glacial drift of Old Red Sandstone origin and of loamy sand texture. Slope is 4° facing north. The natural vegetation was dominated by *Calluna vulgaris* and *Molinia caerulea* with occasional *Tricophorum caespitosum* and *Narthecium ossifragum* Huds.

Establishment methods

In so far as possible the basal establishment treatments were the same as those in general local use, except where they were modified to take account of the other treatments, as in the use of basic slag rather than rock phosphate as a source of phosphorus in experiments where ground limestone was used, either as a basal treatment or as an experimental factor.

In Cappoquin the experiment site was completely ploughed with a Clark single mouldboard tine plough. Basic slag was applied after ploughing at the rate of 500kg, supplying about 35kg P, per ha.

Rathluirc experiment 1 was treated after planting with basic slag as at Cappoquin. As an added precaution copper sulphate was applied at the rate of 17kg per ha, broadcast in the plots completely ploughed, and spread along the ribbons in the spaced-ploughing plots. The Sitka spruce (*Picea sitchensis* (Bong.) Carr) was raised from seed of Queen Charlotte Islands, B.C., Canada, origin.

Rathluirc experiment 2 was completely ploughed as in Cappoquin, treated with 5.02 tonnes ground limestone per ha, half before and half after ploughing, and given basic slag as in Cappoquin.

EXPERIMENTAL TREATMENTS

Cappoquin

1. Ground limestone at 6026kg per ha, half before and half after ploughing.
2. Potassium-magnesium sulphate at 200kg per ha.
3. Common broom (*Cytisus scoparius* L. syn. *Sarothamnus scoparius* Wimm.) and tree lupin (*Lupinus arboreus* Sims.) seeded in early March 1961 at 10.1 and 3.4kg per ha respectively. Seed mixed before sowing broadcast.

4. All treatment combinations were replicated with each of the three species Sitka spruce (seed origin "western north America"), Scots pine (*Pinus sylvestris* L.) (seed origin Scotland), and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) (seed origin inland Oregon, U.S.A.) but the results obtained with the pine species were generally negative and are not reported in detail.

The treatments were combined factorially giving 2 x 2 x 2 x 3 = 24 combinations, all replicated twice in randomised blocks. The plots were 335m^2 in area.

Rathluirc experiment 1

1. (a) Spaced ploughing. Single mouldboard Clark tine plough with furrows at 1.5m.
   (b) Complete ploughing. Complete ploughing with single mouldboard Clark tine plough.
2. Ground limestone applied at 5.02 tonnes per ha, half before and half after ploughing.
3. Tree lupin direct seeded at 3.4kg per ha in mid-May 1964. The seed was sown in bands about 15cm wide between lines of plants in complete ploughing plots, and in patches about 22cm square on ribbons midway between plants in spaced ploughing plots.

The experimental design was split plot. Ploughing treatments were applied to whole plots and these were replicated five times in randomised pairs. Each whole plot was divided into 4 square sub-plots, each 405m^2, which were randomly assigned to the four combinations of a 2 x 2 factorial of limestone and lupins.

Rathluirc experiment 2

1. Control. No auxiliary species.
2. Tree lupin seeded at 3.4kg per ha.
3. Herbaceous lupin *(L. luteus)* seeded at 3.4kg per ha.
4. Common broom seeded at 11.3kg per ha.
5. Alder. Grey alder (*Alnus incana* (L.) Moench.) and red alder (*Alnus rubra* Bong.), the latter used in two replications and planted four years later than the rest of the experiment.

The treatments were assigned as a 5 x 5 latin square with plots of 804m^2.

RESULTS

Cappoquin

Both broom and lupin germinated satisfactorily in the first year but the broom was selectively attacked and eaten back to ground level by hares (*Lepus timidus hibernicus* Bell). It grew normally when the site was protected by a fence during the second year. The establishment of lupin, both in stocking and vigour, was significantly improved by limestone (Table 1) but there was no effect of the potassium-magnesium sulphate, nor any effect of either of these treatments on the broom. In the spring of 1963 the lupins were observed to be bearing perennial walnut-sized root nodules with the internal tissue of the lobes showing a bright red colour indicating nitrogen fixation (C. L. Masterson, personal communication).

Table 1 Cappoquin. Effects of ground limestone on stocking and vigour of tree lupin in second year (July 1962).

	No. of plants per m^2	Mean of longest shoot per plant (cm)
Without limestone	0.98	41
With limestone	1.95	49
Significance	0.001	0.05

Small nodules were also seen on the broom. However, the lupins proved relatively short lived, for in the summer of 1965 they were generally moribund and by July 1966 they were all dead. The broom has continued to grow vigorously except where suppressed by the developing tree canopy.

After three growing seasons both mean height and foliar nitrogen content were improved independently by both the legumes and the limestone (Table 2). There was no effect of the potassium-magnesium sulphate. The effect of limestone on foliar N content had disappeared in 1965 while at that time foliar N was significantly increased from 1.50% to 1.84% by the legumes. About this time the overall height increment began to slow down, and in 1969 it averaged about 10cm irrespective of treatment, although the trees in the legume plots were clearly of a deeper green colour than those in the plots without legumes.

In the summer of 1971, at age 10-11 years, all plots were treated broadcast with 91kg P as ground rock phosphate, and 105kg K as potassium sulphate, per ha.

Table 2 Cappoquin. Effects of legumes (broom and lupin) and ground limestone on mean height (cm) and foliar nitrogen (% d.m.) of Sitka spruce after 3 years.

	Mean height	Foliar N
Without legumes	66	1.92
With legumes	77	2.17
Significance	0.01	0.01
Without limestone	67	1.93
With limestone	76	2.15
Significance	0.05	0.05

A year later visual observation suggested that a response was developing in the Sitka spruce in the legume plots (now pure broom) but not in those without legumes. This was confirmed by measurements which showed that legumes significantly increased height increment from 0.20 to 0.41m in 1973 and from 0.27 to 0.69m in 1974. (Table 3)

At age 17 (1977) the effect of the legumes was to increase mean height from 3.8 to 6.1m and basal area from 10.3 to 25.2m^2 per ha. The effect of ground limestone on both of these growth indicators was appreciable but failed to reach statistical significance. At this time also foliar N was significantly increased by legumes from 1.04 to 1.22% d.m.

At age 20, after thinning four of the eight legume plots, mean height stood at 5.2m in plots without legumes compared with 8.0m in plots with legumes. At this time also soil analysis indicated that the pH of

Table 3 Cappoquin. Effects of legumes (only broom surviving) on growth of Sitka spruce.

Age	13	14	17	17	20
Year	1973	1974	1977	1977	1980
Indicator	Ht. inc.	Ht. inc.	Ht.	B.A.	Ht.
Unit	m	m	m	m^2/ha	m
Without legumes	0.20	0.27	3.8	10.3	5.2
With legumes	0.41	0.69	6.1	25.2	8.0*
Significance	0.01	0.001	0.001	0.001	0.001

* After thinning

the top 15cm had been increased from a mean of 4.3 without limestone to a mean of 4.7 with limestone. The legume results are summarised in Table 3.

Rathluirc experiment 1

The lupin grew well from the start, and was noticeably more vigorous with ground limestone, especially with complete ploughing, but it established itself well with standard spaced furrow ploughing also. No quantitative assessment of lupin establishment here was carried out.

By the second summer the lupin had in places suppressed the indigenous vegetation, but at this time also some dying of the lupin was observed. By 1967 the lupin was described as "moribund, particularly in plots without limestone", and in August 1968 as "mostly dead". It was all dead in April 1970.

Assessments after 3 and 6 years (Table 4) showed that complete ploughing (compared with spaced furrow ploughing), lupins, and ground limestone all significantly, and independently, increased tree growth. Analysis of a small number of surface soil (0-15cm) samples in 1970 indicated that the limestone had caused a change in the pH (no limestone: pH4.3, 4.7; limestone: pH 5.2, 5.4, 5.9). Foliar nutrient levels were not assessed in the Rathluirc experiments.

Even with the positive effects recorded, it is clear from the data that the overall rate of growth was totally unacceptable for the

Table 4 Rathluirc experiment 1. Effects of ploughing method, lupins and ground limestone on mean height (m) of Sitka spruce.

Age	3	6	9	13
Complete ploughing	0.71	1.16	1.48	2.01
Spaced ploughing	0.61	1.07	1.24	1.55
Significance	0.05	0.05	0.05	0.001
Without lupin	0.61	1.00	1.19	1.53
With lupin	0.71	1.33	1.53	2.03
Significance	0.001	0.001	0.001	0.001
Without limestone	0.60	0.93	1.13	1.53
With limestone	0.73	1.35	1.59	2.03
Significance	0.001	0.001	0.001	0.001

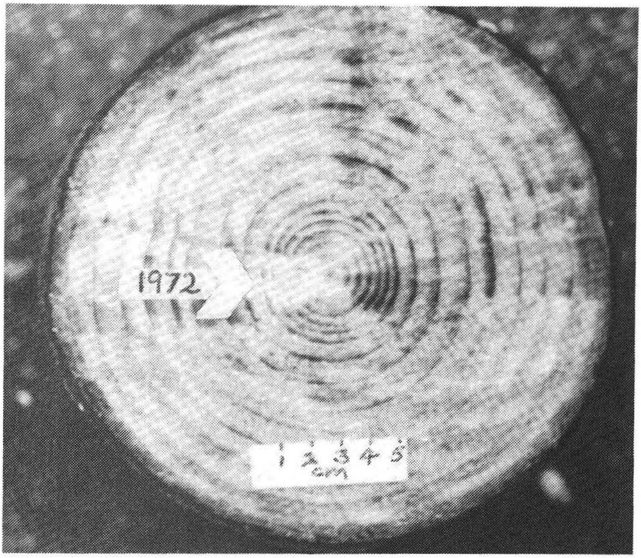

Fig 1 Cappoquin. Cross section of Sitka spruce from plot with legumes showing diameter growth response since 1972 to the PK treatment in 1971.

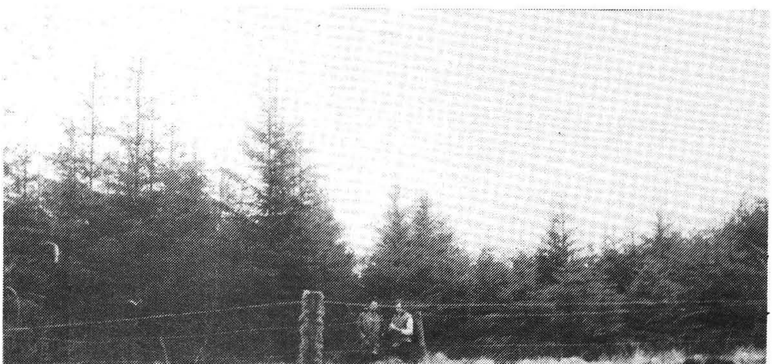

Fig 2 Cappoquin, Sitka spruce age 21. Legumes, left; no legumes, right.

purposes of economic forestry, and in February 1973, age 9 years, all plots were given a broadcast application of 91kg P as rock phosphate and 125kg K as potassium sulphate per ha.

Assessments of current height increment and mean height at age 17 are shown in Table 5. While the growth associated with complete ploughing is still significantly greater than that following spaced furrow ploughing, there is now a significant interaction, in both assessments, between lupins and ground limestone. Current height increment is significantly reduced by ground limestone in the absence of lupins, but is significantly increased both by lupins alone and, additively, by lupins and ground limestone together. Effects on mean height are similar, except that the negative effect of limestone alone on height increment is not reflected in a lower mean height at this stage.

Rathluirc experiment 2

Establishment of all legumes was sporadic and poor in this experiment, even though protectively fenced from the start. Alder establishment was also variable. In those patches where it was successful it has tended to outgrow the spruce and repeated cutting back of the alder has been necessary to prevent supression of the spruce. In later years dwarf furze (*Ulex gallii* Planch) has been spreading spontaneously over the site. After 17 years the mean height of the Sitka spruce is 3.50m, with no significant effects of any of the experimental treatments.

Table 5 Rathluirc experiment 1. Effects of ploughing method, lupin and ground limestone on current height increment and mean height (m) of Sitka spruce at age 17.

	Height increment		Mean height	
Complete ploughing	0.27		2.51	
Spaced ploughing	0.18		1.88	
Significance	0.05		0.05	
	Without limestone	With limestone	Without limestone	With limestone
Without lupin	0.20	0.10	1.72	1.76
With lupin	0.27	0.33	2.27	2.96
Least significant difference at 5%	0.06		0.15	

Discussion

The experiment at Cappoquin was designed to test the efficacy, under local conditions, of three treatments — legumes, limestone, and potassium-magnesium — which had been found useful in continental Europe. These were tested under conditions of intensive cultivation, achieved by complete ploughing. Rathluirc experiment 1 was designed to examine further the cultivation and liming requirements of tree lupin, which at an early stage appeared to be more promising than broom. Rathluirc experiment 2 was designed to examine the separate effects of lupin and broom, together with another possible auxiliary crop, alder.

The presence of ground limestone led to improved establishment of tree lupin (Table 1). Legumes and ground limestone both resulted, independently, in improved early growth of Sitka spruce (Table 2). Although the data on mean height (Table 6) suggest that there may have been an indirect effect of the limestone on the spruce, through its improvement in lupin establishment (the effect of limestone is greater in the presence of legumes), the interaction does not reach statistical significance. The foliar N data (Table 6), where the combined effect of legumes and limestone is less than the sum of their separate effects, suggests an opposite trend, but the main effect of limestone on foliar N (Table 2) is adequate to explain its effect on tree growth.

There is not enough specific information, either in the data from this experiment, or in relevant literature, to offer a detailed explanation of the effect of limestone on nitrogen uptake and tree growth. In agricultural practice it was generally assumed in the past that the effect of liming arose from the mobilisation of nitrogen and other nutrients from soil organic matter, through increased biological activity, although there may also be direct effects on nutrient availability. (In modern practice, where mineral fertilisers are widely used, the effects of lime applications have been seriously questioned). The biological explanation would be consistent with the results of this experiment. A positive effect of limestone on early growth of Sitka spruce was obtained in another experiment on old red sandstone soil (O'Carroll, 1972). Similar effects have not been recorded on peat soils.

An overall growth stagnation at Cappoquin was corrected, at least in the legume plots by a topdressing of P and K after 10 years (Fig 1). Available data do not permit definite ascription of the improvement to either the P or the K component, but since foliar K at age 5 varied from 0.8 to 1.0%, and since there were no early effects of potassium-magnesium on tree growth, it is probable that the improvement was due to the P. This would suggest that an

Table 6 Cappoquin. Two-way tables showing mean height (cm) and foliar N (% d.m.) after three years with and without legumes and limestone.

	Without legumes		With legumes	
	Height	N	Height	N
Without limestone	0.62	1.78	0.71	2.09
With limestone	0.69	2.06	0.83	2.25

Note: In neither case was the interaction statistically significant. For main effects see Table 2.

application of 35kg P/ha as basic slag at planting time is inadequate to maintain Sitka spruce growth on this site.

Data on subsequent growth (Table 3) indicate a consistent superiority where legumes are present (Fig 2). Current height increment at 20 years indicates a growth rate equivalent to perhaps general yield class 18 or 20m^3 per ha (Hamilton and Christie, 1971), which would be acceptable in general forest management.

The overall sequence of events suggests satisfactory initial growth, improved by legumes and limestone, followed by the development of general P deficiency. When this was corrected a supply of N, here provided by legumes, became necessary to maintain growth.

Results in Rathluirc experiment 1 are generally consistent with the preceding hypothesis. Early growth is improved by limestone, by lupins, and by complete ploughing as compared with spaced ploughing. The effect of the ploughing may be ascribed to improved nutrient mobilisation under the influence of increased aeration. The response to the PK topdressing is developing more slowly than at Cappoquin, but this may be due to a site difference.

The significant reduction in height increment at age 17 by limestone in the absence of lupins (Table 5) is an effect not observed in Cappoquin. An explanation could be based on an assumption that increased mobilisation of soil nitrogen in the early years, under the influence of limestone, had led at this stage to the depletion of soil nitrogen to a level of deficiency greater than that which existed initially on this site.

The results in Rathluirc experiment 2 indicate that work on site classification needs to be undertaken before it will be possible with any degree of confidence to identify sites suitable for the use of nitrogen-fixing auxiliary crops.

Silvicultural implications

The results of these experiments support the hypothesis that the growth of Sitka spruce on Old Red Sandstone soils is limited by deficiencies of both phosphorus and nitrogen. Phosphorus deficiency can be corrected only by the application of mineral fertiliser, and this is relatively cheap and probably reasonably persistent with rock phosphate. Nitrogen can be either applied as mineral fertiliser, or supplied through the growth of auxiliary nitrogen-fixing plants. Mineral nitrogen fertilisers have increased rapidly in cost in recent years, and there is no reason to assume any reversal of that trend in future. The experiments show that both common broom and tree lupin may be useful as auxiliary crops. Both, however, appear to have disadvantages. Broom is susceptible to early destruction by hares. It is possible that if it were grown on a sufficiently extensive scale this destruction might be diluted to an acceptable level. Tree lupin, under the conditions of these experiments, is short lived — about 5 years — and it has yet to be established whether the quantity of nitrogen which could be fixed in that period could constitute a sufficient input for sustained growth. The indication for alder is that the species in present use in Ireland would be so aggressive as to suppress a nursed crop of Sitka spruce.

A shrubby or dwarf species of alder such as mountain or American green alder (*Alnus crispa* (Ait.) Pursh.) or Sitka alder (*A. sinuata* (Reg.) Rydb.) might be more promising. Until the necessary research has been carried out, attention may be directed to the proven value of Japanese larch (*Larix leptolepis* (Sieb. and Zucc.) Gordon) as a nurse for Sitka spruce (O'Carroll, 1978).

Another possibility is the use of dwarf furze, (*Ulex gallii* Planch.) which is native in the southern half of Ireland. Naturally occurring plants have been observed to bear root nodules, and many instances could be described where the presence of dwarf furze is associated with improved growth of Sitka spruce. It is admitted that such evidence is as yet wholly circumstantial, but more positive investigations are being carried out by Forest and Wildlife Service Research Branch.

Acknowledgements

The following were involved as Research Foresters in the field work of the experiments:

Messrs. M. MacGiolla Coda, J. A. Mannion, D. Keane, T. Horgan and M. O'Malley.

Foliar analysis were carried out in the Soil Laboratory, The Agricultural Institute, Johnstown Castle, Wexford.
I am also indebted for help to my colleagues Dr. M. L. Carey, Dr. R. McCarthy, Mr. J. Dillon and Mr. E. Hendrick.

REFERENCES

BAULE, H. and C. FRICKER. 1967. Die Düngung von Waldbäumen. BLV Bayerischer Landwirtschaftsverlag Gmb H, München Basal Wien. (Transl. C. L. Whittles. 1970. The fertiliser treatment of forest trees. Munich).

CADGIL, R. L. 1971. The nutritional role of *Lupinus arboreus* in coastal sand dune forestry. 3. Nitrogen distribution in the ecosystem before tree planting. Plant and Soil 35: 113-126.

HAMILTON, G. J. and J. M. CHRISTIE. 1971. Forest management tables (metric) F. C. Booklet 34, London.

NIMMO, M. and J. WEATHERELL. 1962. Experiences with leguminous nurses in forestry. F. C. Rep. For. Res 1961, London, 127-147.

O'CARROLL, N. 1972. Crop establishment, in Forest Research Review 1964-70. Stationery Office, Dublin.

O'CARROLL, N. 1978. The nursing of Sitka spruce, 1. Japanese larch. Irish For. 35: 60-65.

PALANIAPPAN, V. M., R. H. MARRS and A. D. BRADSHAW. 1979. The effect of *Lupinus arboreus* on the nitrogen status of china clay wastes. J. Appl. Ecol. 16: 825-831.