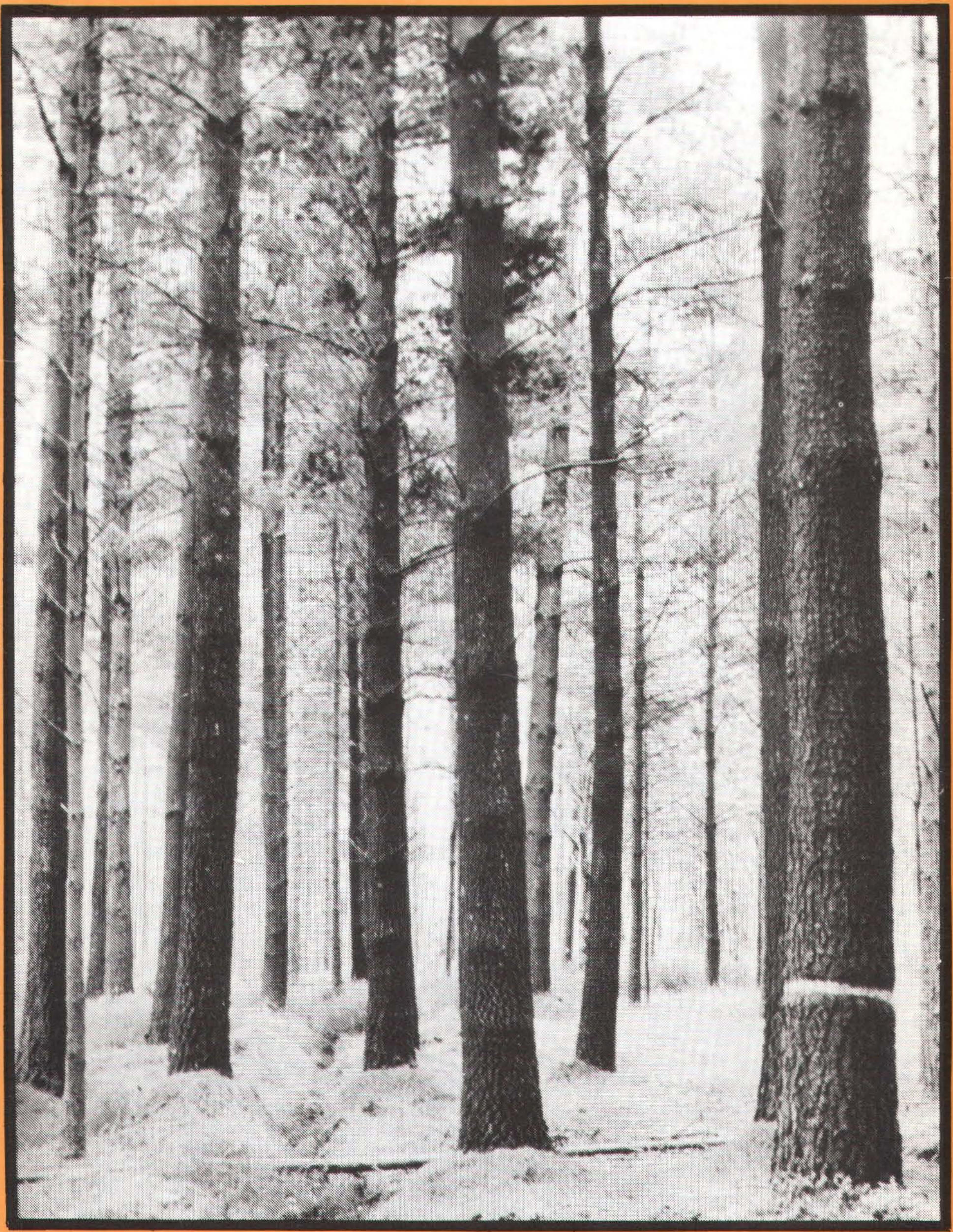

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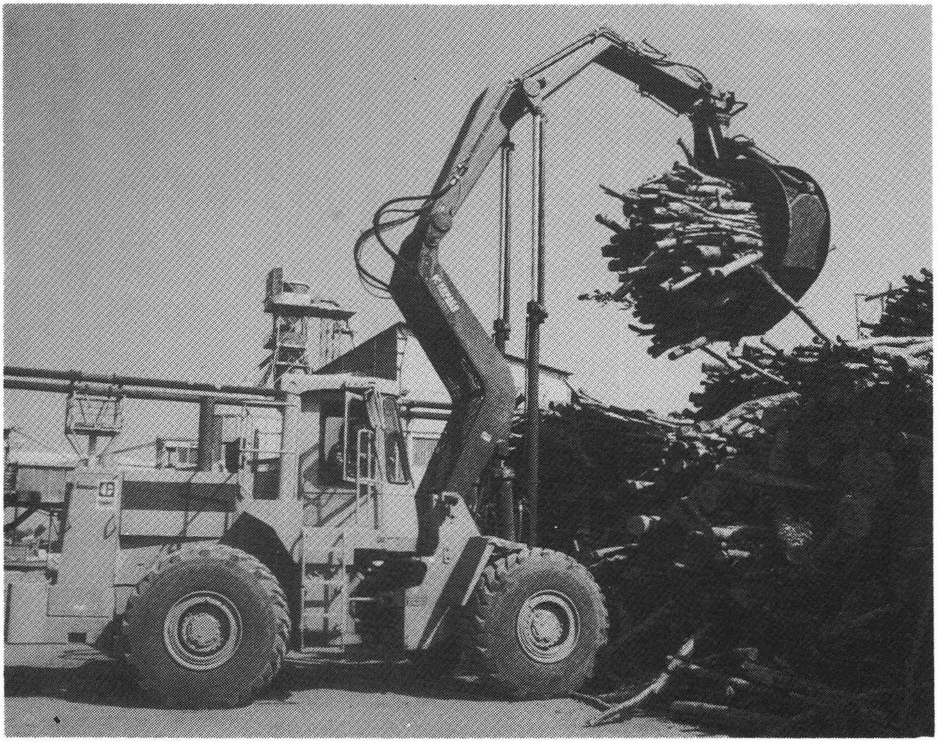

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4. Nomenclature, symbols and abbreviations should follow convention. The metric system should be used throughout.

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Contents

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Cover: Lodgepole pine, Clogheen Forest (Photo: J. O'Driscoll).

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EDITORIAL

Privatisation

Over the years the State has created a substantial national forest resource, funded largely by an older generation, in the expectation that someday it would become a national asset. The objective was to ensure the maximum benefit to the nation in wealth creation. The forest estate created is the product of investment in time as well as in financial resources and as such has carried with it a substantial element of risk.

The recent bid by private enterprises for State forests suggests an attempt to jump aboard the bandwagon when the risk has diminished and the pay-off is closer. Yet, before we condemn this approach by the private sector, we should think long and hard about the implications. The State sector is at present undercapitalised, while the financial institutions have ample capital for investment. Is there any way in which this capital can be drawn into forestry? A substantial injection of capital into the afforestation programme at this time would be a real shot in the arm for the whole forestry profession in the country. It would bring back the exhilaration of the 1950's and 60's when foresters were faced with new worlds to conquer and fresh challenges were their daily diet. It would create employment and most of all it would utilise much waste land as an investment for the nation. This willingness by the private sector to participate in forestry must be judged in relation to the objectives of wealth creation for the people of Ireland.

The boundary for the individual between making a compulsory investment in forestry through taxation and a voluntary investment through pension funds is perhaps tenuous. Is it possible then to forge some kind of partnership between the State and private sectors in which each will make a contribution to the generation of increased investment for the nation? The matter is worthy of serious consideration by foresters.

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The Society of Irish Foresters was founded in 1942 to advance and spread in Ireland the knowledge of forestry in all its aspects.

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The Management of Australian Forests — A Personal View

G. MURPHY

Forest and Wildlife Service, Sidmonton Place, Bray, Co. Wicklow.

ABSTRACT
The management of Australian forests is discussed in relation to the biological and socio-economic factors affecting it. The demands placed on native forests and softwood plantations are examined together with the diverse management systems used to resolve the various conflicts.

INTRODUCTION
Forestry plays an important role in natural resource management in Australia despite the relatively small percentage of land area covered by forests. Forest lands are used for a wide range of activities. These include timber production, water catchment protection and, amenity. Timber production was the dominant use in the past. However, there is now a greater demand for other uses and consequently conflicts have developed. This is particularly true in the management of the native forests. The rise of public interest in their use coincided with the increased concern for the environment which was first highlighted in the 1960s. Softwood plantations, which are mainly dedicated to the establishment of a highly productive timber resource, are not subject to the same types of environmental pressure. The difficulties faced by foresters in the management of plantations are mainly of an economic and marketing nature, once the decision to devote the land to plantation use has been made. A controversial issue surrounds this land use decision because many of the plantations have replaced less productive native forest.

The extent to which the various demands on Australian forests are met depends on the management regime adopted which is shaped by various political, socio-economic, and biological factors. First, it is necessary to describe the forest resource.

DESCRIPTION OF THE FOREST RESOURCE
About 5% (41 million hectares) of the Australian continent supports vegetation which is classified as forest. Plantations make

IRISH FORESTRY, 1985, Vol. 42, No. 2: 67-75.

up only 1.9% of this forested area, the balance is natural stands. The distribution and types of forests have been determined both by the physiographic and climatic conditions, and by the actions of man. Australia consists of a continuous, reasonably well watered, and comparatively fertile rim, representing a third of the continent, around a larger, dry and infertile core (Carron, 1979). The forests are largely restricted to this outer fertile zone of high and reliable rainfall. This occurs over most of Tasmania and extends from the Victorian-South Australian border, up the eastern Queensland coast, around parts of the northern coast, and in the south west coast of Western Australia. As the annual rainfall falls below 900mm the forests tend to be replaced by open woodland. In the vast and arid interior vegetation is mainly low scrub.

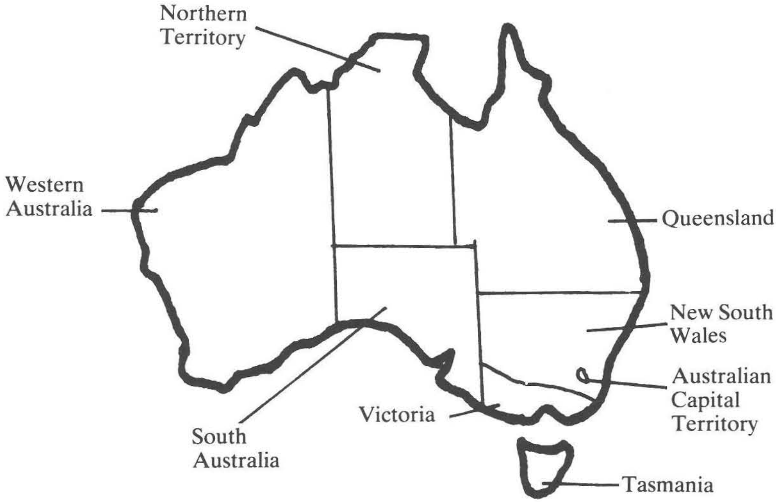

Fig 1. Map of Australia showing States and Territories.

Native Forests

The native forests are classified into two major categories: closed and open forests depending on the crown cover. The former, or rainforests, have a very limited distribution and are concentrated along the east coast of the continent, and in scattered isolated areas of Tasmania and northern Australia. The open forest formation is dominated by eucalypts of which there are over 500 species. It has a vegetation gradient from tall, high quality stands to low stands of poor quality. These types are often referred to as wet sclerophyll and dry sclerophyll forest respectively and are now seen to be associated largely with a gradient in soil fertility status (Florence, 1983).

Rainforests form a very small percentage of the total native forest (Table 1). This is important from the conservation point of view. On the other hand the eucalypt forests, especially the stands of lower productivity, form the major part of the total.

Table 1 Native forest areas by forest type group in 1980 (000s hectares)

Forest type group	Total area	% area
Rainforest	1,884	4.6
*Eucalypt I	2,688	6.6
Eucalypt II	13,635	38.3
Eucalypt III	11,778	28.8
Tropical eucalypt and paperbark	6,528	16.00
Cypress pine	4,371	10.7

(Source: Anon, 1981)

*Eucalypt forests are grouped into productivity classes in descending order of productivity.

Most of the forest land is in public ownership and over 28% of it is permanently dedicated to timber production (Table 2). However, the area under National Parks has increased from 5% in 1971 to 9% in 1980. This reflects the changing public attitudes to the use of forest land and further changes in public land tenure are likely over the next few years. These changes will be carried out on the basis of comprehensive land use studies and surveys (Forwood, 1974).

Plantation Forests

Softwood plantations were first established in the late 1800s both to alleviate a natural hardwood/softwood imbalance and to provide a high yielding wood resource for industry within concentrated areas of management. In the 1960s there was a rapid expansion of the plantation programme which was aided by extra federal funds. The declared policy was to establish 1.2 million hectares of plantations by planting 29,000 hectares annually (Forwood, 1974). At present the plantations supply approximately 40% of the total wood production although they make up only 1.9% (over 766,000 hectares) of the forest area; almost half is aged 10 years or less.

Table 2 Native forest areas by ownership categories in 1980 (000s hectares)

Ownership category	Area	% area
State Forest (a)	11,405	27.9
Other Public (b)	16,940	41.4
National Park (c)	3,782	9.3
Private	8,757	21.4

(a) Publicly-owned land, permanently reserved or dedicated primarily for timber production.

(b) Publicly-owned land, vacant or occupied under lease, not specifically secured for permanent timber production but on which control of timber rests with the Government.

(c) Publicly-owned land, permanently reserved for purposes other than timber production, such as water catchment, recreation, protection, reservation of unique flora communities.

(Source: Anon, 1981)

Coniferous plantations produce from 15-25m^3 of wood per hectare per annum. This yield can be achieved by few native eucalypt stands — with averages of only 0.5m^3 to 3.0m^3 per hectare per annum. This low yield is the result of the inherent biological character of the native forest and historical influences (Florence, 1983).

Most of the plantations are concentrated into large blocks in a few regions where growing conditions are favourable. This is done so as to meet the needs of highly capitalised and integrated forest industries.

The main species used in the plantations is radiata pine (*Pinus radiata*) which covers almost 66% of the area planted (Table 3). Slash pine (*Pinus elliottii*) is the next most important species and it is planted mainly in the coastal fringe of Queensland where the climate does not suit radiata pine. Caribbean pine (*Pinus caribaea*) is tending to replace slash pine on the drier sites where it has more rapid growth. Hoop pine (*Araucaria cunninghamii*), a native species, is used in the more northerly areas of Queensland on the sites of the indigenous hoop pine rainforests. The only other species of any significance is pinaster pine (*Pinus pinaster*), and it was planted mainly on the infertile areas of Western Australia but is now not widely used.

Over 29% of the total plantation estate is privately owned, mainly by industrial and investment companies. Farm woodlots make up only a small percentage of the private plantations.

Table 3 Total plantation area by species and ownership in 1980 (hectares)

Species	Public ownership	Private ownership	Total	(%) area
Coniferous				
Pinus radiata	*344,009*	*161,284*	*505,294*	*66.0*
Pinus elliottii	66,829	35,882	102,711	13.4
Pinus pinaster	29,685	1,188	30,882	4.1
Pinus caribaea	16,272	2,068	18,340	2.4
Araucaria spp.	42,354	724	43,078	5.6
Other conifers	15,485	2,461	17,943	2.3
Broadleaved				
Eucalypts spp.	27,734	16,836	44,570	5.8
Poplar spp.	15	2,626	2,641	0.3
Other	535	91	626	0.1
	542,928 (70.9%)	223,161 (29.1%)	766,089	

(Source: Anon, 1981)

Little emphasis is placed on broadleafed plantations. The policy of most State Forest Services is to concentrate investment on the establishment of softwood plantations and maintain hardwood forests by natural regeneration. In addition, growth stresses in young fast grown eucalypt trees have hampered attempts to saw small logs and thus have restricted the potential of eucalypt as a sawlog plantation tree. However, recent technological developments should see this problem diminish to a significant extent (Forwood, 1974). A few paper companies, such as Associated Pulp and Paper Mills Ltd. in Tasmania, have established eucalypt plantations with a rotation of about 16 years. The short fibres of the eucalypts' wood is mixed with the long fibres of the radiata pine in the pulping process. A small area of poplar plantations has also been established, mainly by private landowners for matchwood and veneers and in agroforestry schemes.

MANAGEMENT OF AUSTRALIAN FORESTS

It is difficult to generalise about the management of Australian forests, not only because of the two different types of forestry systems, i.e. native forests and softwood plantations, but also because of the various economic, social, technical and environmental issues affecting them. Because the native forests and plantations are so different in biological and policy terms, their management and the issues affecting them are discussed separately.

Native forest management

In recent decades the management of native forests has become increasingly complex. The various demands placed on this resource have inevitably led to conflict. One of the ways to lessen this conflict has been to divide the native forest estate into State Forests and National Parks. The State Forests are predominantly utilised for wood production. A wide variety of silvicultural systems are used for their management, ranging from single tree selection to clearfelling with development of fully stocked even-aged stands. The most intensive form of eucalypt forest management, involving clearfelling followed by natural or artificial seeding, is applied to only a small proportion of the native forest (Forwood, 1974).

Environmental considerations can play a major role in determining the type of management system adopted in the State Forests and in some cases take precedence. For example, an area high in wildlife value will often be managed for such as a priority, to the detriment or exclusion of wood production. The principle of multiple use has become prevalent in forest management thinking to meet the new 'environmental awareness'. This concept of multiple use calls for a balance among the different activities.

However, in trying to reconcile the different uses in State Forests and placing priorities, the forest managers face many difficulties and pressures. A number of issues such as the integrated sawlog/woodchip programmes and the logging of rainforests have focussed on these difficulties and on the controversial nature of native forest management.

The creation of an export market for woodchips to Japan in 1967 allowed the establishment of integrated sawlog/woodchip programmes which foresters feel will improve the productivity of degraded native stands. These integrated programmes involve the clearcutting of forest areas in large coupes with subsequent natural regeneration. Some environmentalists argue that this practice causes damage to the ecosystem through nutrient losses, increase in soil pathogens, a decrease in water catchment protection, and loss of unique vegetation and wildlife. As a result of public pressure, foresters have attempted to minimise environmental effects in their management of forests for the woodchip programmes by adopting smaller coupe sizes, retaining buffer strips along streams, leaving uncut wildlife corridors and minimising landscape disturbance. A range of silvicultural regimes are used to suit different conditions. Selection logging is carried out where applicable, such as in the more open drier forests where regeneration is not a major problem.

The logging of rainforests is another issue which has aroused considerable public concern. Among the arguments put forward against it are the belief that it irreversibly damages fragile ecosystems and a valuable gene pool, that it reduces aesthetic and recreation values, and, that very important ecosystems for scientific study are not maintained. Foresters have argued that, with stringent standards, it is possible to maintain the ecosystem in perpetuity and still supply valuable timber. In a recent study the Queensland Forest Service found that careful management of harvesting such as directional felling, low ground pressure extraction, strict diameter limits, and rainy season logging bans, will ensure that selective felling does not exceed the rate and degree of a forest's natural disturbance (Caufield, 1983). In other States rainforests are not managed to the same standard as in Queensland. The New South Wales Government abandoned all logging in rainforests because of the huge public concern for the conservation of these areas.

Plantation forest management

There is great diversity in approach to the management of forest plantations in the State Forest Services because of the different market situations, forest policies, and biological conditions that exist in each State. Most of the plantation management systems have intensive establishment and early tending regimes which include cultivation, and the application of fertiliser and herbicide. The latter is important because, in an arid country like Australia, competition for the limited water and nutrients must be reduced to a negligible level. A major proportion of the current planting is with improved genetic planting stock.

A decline in productivity in second rotation crops in the south east region of South Australia reported in the 1960s has emphasised the need for improved establishment techniques. This decline prompted an intensive review of establishment practices in South Australia and Victoria. The loss of organic matter and nutrients through burning of litter and logging residue appears to be the major cause of the decline in yield between successive crops planted on sandy soils. The devastating wild fires of February 1983 that swept through many Australian States resulted in the loss of

18,700ha of plantation in South Australia. The Wood and Forests Department sowed subterranean clover over large areas of burnt forests within three months of the fire in an attempt to replace some of the lost nutrients and organic matter.

Other factors affecting the biological productivity of forests include wind and insect (e.g. *Sirex* sp.) damage. Their occurrence is often related to thinning practices and have assumed increasing importance in plantation forest management.

The type of silvicultural management with regard to thinning, spacing and pruning, varies considerably between the States. South Australia follows a conventional system similar to Ireland. Their silvicultural management objectives were outlined by Lewis et al., (1976) as follows:

(1) every thinning is to produce a commercial yield.

(2) the site is to be used to full production capacity.

(3) the forest stands must remain stable.

(4) on average, final crop trees of 50-60cm dbh are expected to be produced in a rotation of 50 years.

The fire of February 1983 has forced the Department to re-assess its strategies, in order to maintain these objectives, resulting in some upset to established silvicultural management. Most of the timber burnt was in the older age classes. In order to keep the sawmills in production the crop rotation may have to be reduced. Nearly a million tonnes of timber was salvaged and is being stored in a fresh water lake or under sprinklers to prevent the development of blue stain. It is hoped to use this material to supplement the annual timber input into the mills over the next 4 years.

The South Australian approach to silvicultural management was prevalent until the early 1970s. Foresters in other States are now finding that this approach of frequent light thinnings is not always suitable to their situation. Tasmania and Western Australia have diverged sharply from this more conventional system (Kerruish et al., 1981) and now have systems which are quite similar to the radical silvicultural regimes in New Zealand. They have adopted wider spacing and pre-commercial thinning as a solution to their limited smallwood market. Silvicultural policies in the other States have tended to be more opportunistic in that silvicultural management has been modified periodically to meet the exigencies of the times (Kerruish et al., 1981). For example, the Queensland Forest Service is now adopting silvicultural options to suit local conditions. Departures from the conventional system are often necessary because of the lack of pulpwood markets and/or because of the distance from available markets. However, they are reluctant to change completely from a conventional system to a more radical approach because it would hinder the ability to attract a major forest pulp industry to the area. Regions are zoned into either integrated sawlog-pulpwood areas or sawlog-only areas depending on the smallwood market. In the sawlog-only areas the stands are pre-commercially thinned and the final crop trees pruned. The integrated sawlog-pulpwood zones are treated silviculturally in the conventional way by light thinnings.

IN CONCLUSION

It is impossible to do full justice to as wide a subject as the management of Australian forests because of the diversity of the biological and socio-economic factors affecting it. The different approaches by the States to these factors further complicates the discussion. However, it can be said that foresters have moved towards more flexible planning and innovative management techinques so as to meet the various demands on the forests in a co-ordinated and rational manner.

ACKNOWLEDGEMENTS

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Long-term study of Sitka spruce
(Picea sitchensis (Bong.) Carr)
on blanket peat

1. THE RESPONSE TO FERTILISERS AND LIME

E. P. FARRELL

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ABSTRACT

A nitrogen and phosphorus fertiliser experiment on Sitka spruce (*Picea sitchensis* (Bong.) Carr., which had been running since 1967, was subdivided in 1977. Half of the original experimental plots were left untreated, half received lime and further applications of nitrogen and phosphorus in factorial combination. In the plots of the section unlimed and unfertilised in 1977, the 1967 fertiliser application has shortened the rotation by 6 to 9 years. The section limed and fertilised in 1977 showed growth responses to the new applications of nitrogen and phosphorus. Nevertheless, the indications were that the unlimed trees were superior to those which had been limed. The results indicate that no benefit is to be gained from liming under these circumstances. There is no evidence of nitrogen deficiency in either experiment, but it is possible that further applications of phosphate will prove beneficial.

INTRODUCTION

When this study was begun in 1967, peatland forestry in Ireland was little more than 15 years old. Attitudes towards selection of species were confused and the issue was as controversial as it is today. There was a recognition that contorta pine (*Pinus contorta* var *contorta* Loud.), as it was known, was more tolerant of difficult site conditions than the preferred species Sitka spruce (*Picea sitchensis* (Bong.) Carr.), and the problems of growing the spruce were a cause of serious concern. The need for phosphate was well recognised and a spot application at planting had been standard practice for both species since the early 1950s. Nevertheless, really healthy crops of Sitka were rare and many stands had gone into check, a common condition in young spruce crops on blanket peat, at that time (Parker 1957, McConaghy *et al.* 1960, Dickson 1965). The nature of the problem was not fully understood and the remedy uncertain.

IRISH FORESTRY, 1985, Vol, 42, No. 2: 76-91.

The experiment was established in a crop which appeared to be going into check. In fact, a true check situation never developed. Growth, while it was always poor in untreated plots, continued throughout the life of the experiment. Foliar analysis at the time the experiment was established indicated severe nitrogen deficiency in chlorotic trees scattered throughout the crop. Experience with nitrogenous fertilisers had been generally disappointing (Jack 1965, McConaghy *et al.* 1960, O'Carroll 1967), possibly because checked crops may often have been suffering from deficiencies of both nitrogen and phosphorus. Increased foliar nitrogen concentrations had been reported following application of rock phosphate to checked crops (O'Hare 1967, O'Carroll 1967). While the mechanism of this response was not understood, it did seem a more fruitful approach to the problem.

In the initial period of the experiment, nitrogen and phosphorus were applied in factorial combination at moderate to high levels. The results confirmed the inadequacy of the original spot application of phosphate (85g ground rock phosphate per plant). Plots which did not receive nitrogen or phosphate suffered from deficiencies of both elements and consequent growth stagnation. Both fertilisers produced significant increases in height growth in the early years (Farrell and McAleese 1972). Phosphate had the greatest effect although no additional response was obtained above the lowest level of rock phosphate application (373kg fertiliser per ha).

At the end of the 1976 season it was decided to divide the original experiment in two. Half of the original area, to be known as Experiment 1, was left untreated. In the other half (Experiment 2), all the plots were limed and the effect of new applications of nitrogen and phosphorus examined.

EXPERIMENTAL

The experiment was located on oligotrophic blanket bog at Glenamoy State Forest in north-west Co. Mayo. The climate of the area is extreme maritime, annual rainfall averages 1,400mm, distributed over 270 days. The wind climate is very severe with gales in almost every month.

The *Schoenus nigricans* L. association dominates the natural flora (O'Hare 1959). Principal species include *Schoenus nigricans* L., *Molinia caerulea* Moench., *Eriophorum angustifolium* Honck., and *E. vaginatum* L. The top 50cm of peat has an ash content of

2.5% and humification 5 to 6 on the Von Post scale (Walsh and Barry, 1958). Bulk density is about 0.09g per cm^3 in the 0-5cm layer and 0.10g per cm^3 at 5-10cm. Saturated hydraulic conductivity is about 1cm per day (Burke 1967).

Preliminary drainage to 1m depth was carried out at 31m spacing in 1954. Prior to afforestation in 1962, the area received double mouldboard ploughing producing a shallow drainage channel and two continuous lines of planting ribbons. The area was planted with Sitka spruce at 1.5m x 1.5m spacing in 1962. The trees received a spot application of 3oz (85g) of ground rock phosphate per plant at planting. The fertilisation experiment comprising 48 x 0.03ha plots was installed in 1967. A randomised block design was employed with four levels of ground rock phosphate and three levels of sulphate of ammonia in factorial combination, replicated four times. All fertilisers were applied broadcast, without incorporation, in April 1967, with a further application of nitrogen to some plots in 1969 (Table 1).

In spring 1977, the original experiment was divided in two. In two of the original four blocks no further treatments were applied (Experiment 1). In the other two blocks (Experiment 2), all plots received an application of 8 tonnes of ground limestone per ha. In addition, nitrogen and phosphorus were applied in the same plots as previously but at different rates and using calcium ammonium nitrate as source of nitrogen and superphosphate as source of phosphorus. Treatments applied in Experiments 1 and 2 are summarised in Table 1.

Height measurements were made in spring 1967 and at the end of the 1967, 1968, 1969, 1970, 1972, 1975 and 1979 growing seasons, and basal area calculated from stem counts and diameter breast height at the close of the 1975, 1979 and 1981 seasons. Samples for foliar analysis were collected in the autumn of the years 1966, 1967, 1968, 1969 1972, 1975 and 1979.

Measurements were initially made inside a buffer strip, two rows of trees wide, in each plot. Due to concern about the spread of fertiliser effects between plots, assessment was confined from 1972 on, to the 16 trees closest to plot centre. Trenches were dug between plots in 1976 to prevent further spread of fertiliser effects along plough ribbons. From 1975 on, the five trees of largest diameter per plot were taken for height measurement and the mean value used as an estimate of top height. Foliage samples were collected and analysed as previously described (Farrell and McAleese 1972).

Table 1. Summary of Treatments Applied in Experiment 1 and Experiment 2 (kg nutrient ha^{-1}). All treatments applied in springtime.

Year	N_0	N_1	N_2	P_0	P_1	P_2	P_3
1967[1,2]	0	132	264	0	55	110	220
1969	0	132	0	0	0	0	0
			Experiment 1				
1977/ 1979			No further treatments applied.				
			Experiment 2				
1977[3,4]	0	75	75	0	35	70	105
1978	0	0	75	0	0	0	0
1979	0	0	75	0	0	0	0

1 N applied as sulphate of ammonia; P as ground rock phosphate.
2 Sulphate of potash (42% K) was applied to all plots at 125kg per ha and copper sulphate (25% Cu) at 11kg per ha.
3 N applied as calcium ammonium nitrate; P as superphosphate.
4 All plots limed at 8t ground limestone per ha.

RESULTS

Experiment 1

By 1972, the response pattern established in the early years of the experiment (Farrell and McAleese 1972) had begun to change. In the plots which make up the present Experiment 1, the influence of applied nitrogen on growth had ceased to be significant and only phosphate was still effective (Table 2). In later years this effect too weakened. The massive effect of phosphate in the 1967-1972 period, which increased height growth by 67% over the control, fell to 17% in 1973-1975 and 23% in 1976-1979. In neither of these later periods was the effect of phosphate statistically significant (Table 2). No significant effect of treatment was observed in basal area increment either (Table 3).

A clearer picture of productivity trends can be seen by examination of top height in individual treatments (Table 4). In almost every case there is a decline over time in Yield Class as determined by top height-age relationships. However, even the 1979 (age 18) figures may overestimate potential maximum annual volume increment. Yield Class estimation in stands of such varying growth rate can be misleading. In these circumstances, top height increment

Table 2 Experiment 1. Mean Height Increment in the seasons 1967-1972, Top Height Increment 1973-1975 and 1976-1979. Main effect means (m).

Season	Age at end of period	N_0	N_1	N_2	SE Treatment Mean	P_0	P_1	P_2	P_3	SE Treatment Mean
1967-1972	11	2.93	3.21	3.43	0.190	2.13	3.42	3.63	3.59	0.219a
1973-1975	14	1.18	1.57	1.38	0.178	1.22	1.37	1.44	1.47	0.205
1976-1979	18	1.89	2.00	2.32	0.242	1.76	2.06	2.34	2.12	0.250

a $P_0 < P_1, P_2, P_3$ $p < 0.01$

Table 3 Experiment 1. Mean Basal Area Increment (m^2/ha) in the seasons 1976-1979 and 1980-1981. Main Effect Means.

Season	Age at end of period	N_0	N_1	N_2	SE Treatment Mean	P_0	P_1	P_2	P_3	SE Treatment Mean
1976-1979	18	16.6	17.4	18.2	1.70	15.6	16.8	18.0	19.2	1.96
1980-1981	20	6.2	6.8	6.7	0.72	7.1	5.9	6.6	6.5	0.84

may provide a better estimate of true productivity (Edwards and Christie 1981). Top height increment, 1976-1979, indicates a Yield Class of about 8 for the Po plots and 12 to 14 for the phosphate treated plots. Basal area data for 1981 (Table 4) would indicate potential volume production greatly in excess of that indicated by Yield Class. However, but these results should be treated with caution as extrapolation of basal area per ha from the small number of trees used for assessment in the later years of the experiment is subject to a wide margin of error.

It has been suggested that improved nutrient cycling following canopy closure might increase nutrient mineralisation and lead to improved uptake. Foliar nutrient concentrations for 1979, 13 years after phosphate application and 11 to 13 years after nitrogen was last applied, follow a similar pattern to earlier years (Farrell and McAleese 1972) with the effect of applied phosphate on foliar phosphorus and magnesium concentrations still in evidence (Table 5). Examination of variation in mean nutrient concentration since establishment of the experiment in 1967 (Fig 1) shows that foliar phosphorus responded to the fertiliser application in 1967 and then gradually declined. It is interesting to speculate if the increase in nitrogen concentration between 1975 and 1979 might represent a real upturn in nitrogen mineralisation following canopy closure. There is little reason to expect an increase in the rate of forest floor breakdown, at least until after thinning. This was conducted in 1982, but the experiment was terminated at that time and no subsequent results are available.

Experiment 2

The possibility of covariance of growth since the 1977 treatment with growth prior to it was examined using height increment in the period 1973 to 1975 as covariate. The covariate had no influence on height increment in the 1976-1979 period and only a small but significant effect on basal area increment. Basal area increment is presented both as unadjusted and adjusted means.

Phosphate, applied as superphosphate in conjunction with lime, significantly increased height increment in the 1976-1979 period (Table 6). As before, the different levels of applied phosphate had essentially the same effect, even though the P_1 treatment represented an application of only 35kg/ha. The response pattern in basal area was similar, although here a significant effect of nitrogen also was recorded (Table 7).

The long-lived response of foliar phosphorus to applied phosphorus was again manifested (Table 8). Phosphorus also produced an increase in foliar nitrogen concentration. This phenomenon which was observed in the early years of the experiment (Farrell and McAleese 1972) and persisted up to 1972

Table 4. Experiment 1. Top Height (TH), Yield Class (YC) and Basal Area (BA) for Individual Treatments and Main Effect Means.

Year	1972		1975		1979		1976-1979	1981
Age	11		14		18		Annual	20
	TH	YC	TH	YC	TH	YC	TH Increment	BA
Treatment	(m)		(m)		(m)		(cm)	(m^2 per ha)
$N_0 P_0$	3.1	12	3.9	10	4.9	10	24	23
$N_0 P_1$	4.9	18	6.0	16	8.4	16	60	46
$N_0 P_2$	5.0	18	6.3	16	8.4	16	54	55
$N_0 P_3$	5.3	20	6.8	18	8.3	16	51	50
$N_1 P_0$	3.6	14	5.0	14	6.5	12	37	36
$N_1 P_1$	4.9	18	6.9	18	8.9	16	51	56
$N_1 P_2$	5.3	20	6.9	18	9.2	18	57	46
$N_1 P_3$	5.2	20	6.5	18	8.8	16	55	52
$N_2 P_0$	4.8	18	6.3	16	9.1	18	71	50
$N_2 P_1$	5.5	20	6.5	18	8.2	16	44	44
$N_2 P_2$	5.4	20	6.8	18	9.4	18	65	52
$N_2 P_3$	5.2	20	6.7	18	8.9	16	53	58
Main Effect Means								
N_0	4.6	18	5.7	16	7.6	14	47	43
N_1	5.1	20	6.3	16	8.3	16	50	47
N_2	4.9	18	6.6	18	8.9	16	58	51
P_0	3.7	14	5.1	14	6.8	12	44	36
P_1	5.5	20	6.5	18	8.5	16	52	48
P_2	5.3	20	6.7	18	9.0	18	59	51
P_3	5.0	18	6.7	18	8.8	16	53	53

Yield Class is taken from Top Height — Age curves in Everard (1974).

Table 5 Experiment 1. Foliar Nutrient Concentrations 1979 (age 18 years). Main Effect Means (% DM).

Main Effect	Nutrient Concentration % DM				
	N	P	K	Ca	Mg
N_0	1.45	0.16	0.91	0.48	0.15
N_1	1.52	0.17	0.82	0.44	0.14
N_2	1.49	0.18	0.84	0.51	0.18
SE Treatment Mean	0.10	0.009	0.084	0.026	0.012
P_0	1.40	0.12	0.98	0.43	0.13
P_1	1.58	0.16	0.76	0.50	0.19
P_2	1.41	0.19	0.84	0.46	0.17
P_3	1.56	0.21	0.84	0.51	0.14
SE Treatment Mean	0.12	0.010	0.097	0.030	0.014
		b			a

a $P_0 < P_1, P_2, P_3$ $p < 0.05$
b $P_0 < P_1, P_2, P_3$ $p < 0.01$

has usually been associated with application of rock phosphate rather than superphosphate. However, in view of the complex treatment history of these plots, it is difficult to assess the significance of this result. A significant influence of fertiliser nitrogen on foliar nitrogen concentration was recorded up to 1969 (Farrell and McAleese 1972). A similar effect was observed following the 1977-1979 treatments (Table 8).

Viewed simply, in terms of growth response, the treatments applied in 1977 have proved successful. Basal area increment in the 1976-1981 period (Table 7) shows a 63% increase in the phosphate treated plots over the P_0 treatment. The effect of nitrogen was smaller, a 28% increase in basal area over the 1976-1981 period, but nevertheless significant. It is not possible to say how long this response will be maintained. There is evidence that the response to phosphate was beginning to wane as it was less in the 1980-81 period than in 1976-1979.

Within the context of this experiment, the efficiency of the nitrogen and phosphorus treatments must be judged in association with the lime which was applied to all plots in 1977. In other studies with Sitka spruce on peat, lime has been shown to induce nitrogen deficiency and to retard growth, at least in the short term (Dickson 1972). It was hoped that the ultimate effect of the lime would be to stimulate microbial activity and lead to an increase in the

Table 6 Experiment 2. Mean Height Increment in the Seasons 1967-1972, Top Height Increment 1973-1975 and 1976-1979. Mean Effect Means (m). Means are Unadjusted.

Season	Age at end of period	N_0	N_1	N_2	SE Treatment Mean	P_0	P_1	P_2	P_3	SE Treatment Mean
1967-1972	11	2.71	3.11	3.10	0.114	1.61	3.53	3.44	3.31	0.131b
1973-1975	14	1.18	1.55	1.44	0.136	1.36	1.42	1.35	1.44	0.157
1976-1979	18	1.31	1.75	1.70	0.261	0.69	1.82	2.09	1.75	0.302a

a $P_0 < P_1, P_2, P_3$ $p < 0.05$
b $P_0 < P_1, P_2, P_3$ $p < 0.01$

Table 7 Experiment 2. Mean Basal Area Increment (m^2/ha) 1976-1979 and 1980-1981. Main Effect Means. Means Unadjusted and Adjusted using Height Increment 1973-1975 as Covariate.

Season	Age at end of period		N_0	N_1	N_2	SE Treatment Mean	P_0	P_1	P_2	P_3	SE Treatment Mean
1976-1979	18	Unadj.	12.5	15.6	16.7	0.99a	9.6	17.1	16.6	16.5	1.15b
		Adj.	12.6	15.5	16.6	1.04a	9.6	17.1	16.6	16.5	1.20b
1980-1981	20	Unadj.	5.2	6.9	7.1	0.51c	4.9	6.9	6.8	7.1	0.59d
		Adj.	5.3	6.8	7.0	0.53	4.9	6.9	6.8	7.0	0.61d
1976-1981	20	Unadj.	17.7	22.6	23.7	1.37c	14.5	24.0	23.4	23.6	1.59b
		Adj.	18.0	22.3	23.7	1.43a	14.5	23.9	23.4	23.5	1.65b

a $N_0 < N_2$ $p < 0.05$
b $P_0 < P_1, P_2, P_3$ $p < 0.01$
c $N_0 < N_1, N_2$ $p < 0.05$
d $P_0 < P_1, P_3$ $p < 0.05$

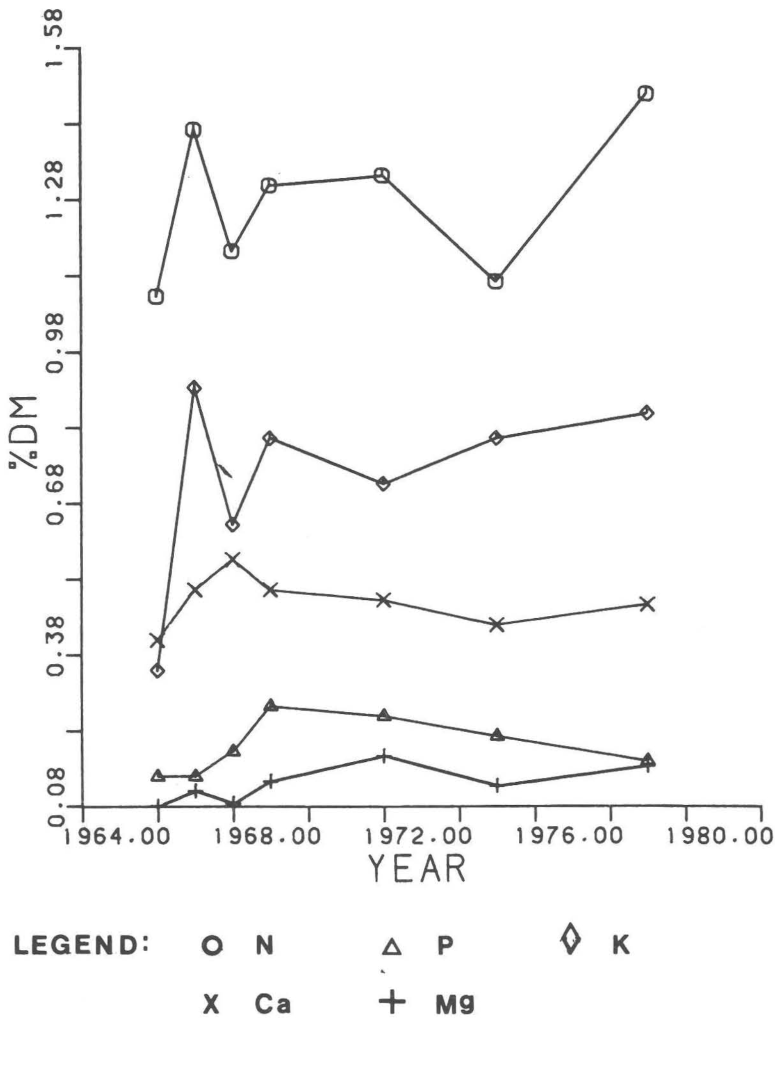

Fig 1 Experiment 1. Foliar Nutrient Concentrations (% DM), Mean of all Plots.

Table 8 Experiment 2. Foliar Nutrient Concentration 1975 (age 14 years) and 1979 (age 18 years). Lime and Fertiliser Treatments Applied 1977. Main Effect Means (% DM).

Main Effect	N 1975	N 1979	P 1975	P 1979	K 1975	K 1979	Ca 1975	Ca 1979	Mg 1975	Mg 1979
	Nutrient Concentration (% DM)									
N_0	0.92	1.28	0.21	0.17	0.81	0.81	0.41	0.62	0.11	0.16
N_1	1.07	1.44	0.20	0.19	0.76	0.81	0.38	0.64	0.11	0.16
N_2	1.05	1.68	0.21	0.19	0.77	0.71	0.38	0.58	0.12	0.14
SE Treatment Mean	0.046	0.066	0.12	0.008	0.044	0.050	0.020	0.031	0.006	0.011
		b								
P_0	0.93	1.26	0.10	0.11	0.86	0.87	0.34	0.59	0.10	0.14
P_1	0.96	1.57	0.23	0.20	0.79	0.80	0.39	0.58	0.11	0.16
P_2	1.13	1.55	0.23	0.22	0.73	0.72	0.41	0.64	0.13	0.18
P_3	1.03	1.48	0.27	0.21	0.75	0.73	0.42	0.63	0.12	0.15
SE Treatment Mean	0.053	0.076	0.14	0.009	0.051	0.059	0.023	0.036	0.007	0.013
		c	a	a						

a $P_0 < P_1, P_2, P_3$ $p < 0.01$
b $N_0 < N_1, N_2$ $p < 0.01$
c $P_0 < P_1, P_2, P_3$ $p < 0.05$

mineralisation of nitrogen and phosphorus. During the build up of the microbial population, competition for nitrogen would be severe and it was hoped that the fertiliser treatments would reduce the deleterious effects of competition on the tree crop. However, the results do not fully support this model. Levels of foliar nitrogen increased in the period 1976-1979 both in Experiment 2 where lime was applied in 1977 (Table 8) and in Experiment 1 where there was no intervention (Figure 1). Even the N_0P_0 treatment in Experiment 2 which had a mean foliar nitrogen concentration of 0.84% in 1975 showed a concentration of 1.24% in 1979. Corresponding nitrogen concentrations for the N_0P_0 treatment in Experiment 1 were 0.85% in 1975 and 1.30% in 1979.

Comparison of Experiments 1 and 2

The study was not primarily designed to test the effect of lime alone. However, it is likely that growth was in fact retarded as a result of lime application. The only true comparison to test the effect of lime is between the N_0P_0 plots in each experiment. However, variation in growth rates between plots which have received very low levels of fertiliser is often very high and this is the case with these plots making direct comparison of little value. Nevertheless, despite the stimulation produced by the fertiliser treatments in Experiment 2, top height increment over all plots in this experiment was significantly less than in Experiment 1 in the 1976-1979 seasons (Table 9). A similar trend can be seen in basal area increment, although it should be pointed out that a higher, though not significantly so, total basal area was recorded in Experiment 1 two years prior to application of lime in Experiment 2.

Apart from the increase in foliar calcium concentrations following liming (Table 8), no significant differences were recorded in foliar nutrients between experiments. While the possibility of a long-term effect of liming cannot be discounted, it seems unlikely as the lime did not become thoroughly incorporated with the peat.

Discussion

At initial spacing of 1.5 x 1.5m, a spot application of 85g of rock phosphate per tree represents an application of about 378kg fertiliser or 55kg P per ha, almost identical to the rate recommended today. The fact that the crop was in distress five years after planting is a remarkable testimony to the advantage of broadcast over spot application of fertiliser.

Table 9 Comparison of Means over all Treatments of Top Height, Top Height Increment, Basal Area and Basal Area Increment 1972-1981 between Experiment 1 and Experiment 2.

Season	Age at end of period	Experiment 1	Experiment 2	t value
Top Height				
1972	11	4.9	4.9	0.11
1975	14	6.2	6.2	0.15
1979	18	8.3	7.9	0.92
Top Height Increment (m)				
1973-1975	14	1.4	1.4	0.15
1976-1979	18	2.1	1.6	2.19*
Basal Area (m^2/ha)				
1975	14	23.1	21.6	0.56
1979	18	40.5	36.6	1.07
1981	20	47.0	43.0	1.02
Basal Area Increment (m^2/ha)				
1975-1979	18	17.9	14.9	1.85
1980-1981	20	6.6	6.4	0.29

* p 0.05

High rates of phosphate were used in the 1967 treatments, the intention being to investigate the possibility of a greater duration of response to the heavier rates. The higher rates of application often gave a slightly greater growth response but the differences were never significant and could hardly give an economic return on the increased investment. In this regard, it is rather disturbing to see that an increase in height growth of 23% over the control, as was recorded in 1976-1979 in Experiment 1, should fail to reach statistical significance. A corresponding increase in volume increment would be very attractive financially. The lack of significance is due to the high level of experimental error (coefficient of variation in this case was 33%), which was in part a consequence of the low level of replication following the division of the original experiment in 1977.

In comparison with phosphate, the response to nitrogen in Experiment 1 was small. Nevertheless, basal area in the N_2 plots in

1981 was 8m^2 per ha greater than in the No plots (Table 4), a 19% increase. This difference was far from being statistically significant. However, it follows exactly a trend established in 1975 and repeated in 1979 (data not presented), and as such appears to represent the residue of the small but significant effect of nitrogen on height increment measured in the years following fertiliser application 15 to 17 years previously.

The effect of fertilisers in Experiment 1 has been to temporarily increase the growth rate in the treated plots. A continuing long-term response is not to be expected. The fact that Yield Class was greater than in the untreated plots at the end of the experiment tells us merely that a real increase was obtained and that as a result the crop is closer to maturity. Rather than consider the effect of the fertiliser in terms of an increase in Yield Class, it is more appropriate to compare treatments in terms of their relative stage of development (Everard 1974, Miller 1981). Thus, at year 18 the top height-age relationship indicates that the control plots in Experiment 1 are Yield Class 10. Top height averaged over all phosphate treated plots was 8.8m, the height a Yield Class 10 crop would achieve at 24 to 27 years. Expected top height increment in a Yield Class 10 Sitka spruce stand of top height 8.8m is about 48cm per annum (Edwards and Christie 1981). Annual leader length in the phosphate treated plots 1976-1979, was considerably greater than this (55cm). Assuming that top height increment does not fall below the level commensurate with a stand of Yield Class 10 at that stage of development, the rotation has been shortened by a minimum 6 to 9 years and this is the most sensible criterion of successful fertiliser treatment.

Applying lime to this crop holds little promise of success. Growth in comparison to the unlimed plots of Experiment 1 was, if anything, slightly retarded by the lime. The influence of the lime and fertilisers on the peat will be dealt with in a later paper but the effect of the lime on peat pH was small. There was an increase in pH of the forest floor from pH 4.5 to pH 7.0 in some plots, but the lime proved to be poorly mobile and its influence was not seen below 5cm in the peat. Lime may produce beneficial results after a number of years (Dickson 1984), or if it can be fully incorporated with the peat (Dickson 1977), but this is of course impossible in an established crop. Even when incorporation is possible, the evidence suggests that the lime should be worked into the peat several years before planting (Dickson 1977).

Foliar analysis in 1979 did not indicate a deficiency of nitrogen in either experiment. Despite the fact that applied nitrogen has been shown to be beneficial in the early years on low level blanket peat

(Carey M.L., Personal Communication) and essential on high level blanket peat (Dickson and Savill 1974), there is no evidence that additional nitrogen will be required on this site to maintain growth. The gradual decline in foliar phosphorus concentrations, however, suggest that a further application of this element might well produce a growth response.

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Long-term study of Sitka spruce

(Picea sitchensis (Bong.) Carr.)

on blanket peat

2. WATER-TABLE DEPTH, PEAT DEPTH AND NUTRIENT MINERALISATION STUDIES

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ABSTRACT

Depth to water table was monitored during two growing seasons, peat depth changes over a 15 year period measured and nitrogen and phosphorus mineralisation studies conducted in a fertiliser and lime experiment on a pole stage crop of Sitka Spruce (*Picea sitchensis* (Bong.) Carr) on oligotrophic blanket peat. The original fertiliser experiment, a nitrogen and phosphorus factorial was established in 1967 and in 1977 it was subdivided, one part receiving no further treatment (Experiment 1) with lime and further applications of nitrogenous and phosphatic fertilisers being made to the other (Experiment 2). When the two experiments were treated as one, mean depth to water table was linearly related to growth parameters. The best relationship was obtained with basal area. However, there were marked differences between experiments and significant differences in water table depth were recorded between treatments in Experiment 2, where fertiliser induced growth differences were also measured, but not in Experiment 1 where the 1967 treatments were no longer producing growth increment differences.

Peat subsidence has occured in the experimental plots at an average rate of 1.2cm per year. In shallow peat situations experimentation on peat-soil mixing should be initiated to test long-term effects.

Levels of mineral nitrogen were depressed in forest floor samples from limed, fertilised plots. Neither total nitrogen concentrations nor mineral nitrogen levels showed any evidence of a residual effect of fertilisation. Plots treated with phosphate in 1977, by contrast had markedly higher extractable phosphorus concentrations than material from Experiment 1.

INTRODUCTION

Depth to water-table was monitored, peat depth changes measured and nitrogen and phosphorus mineralisation studies conducted in a long-term Sitka spruce (*Picea sitchensis* (Bong.) Carr.) fertiliser and lime experiment on oligotrophic low level blanket bog. There is an annual water surplus (rainfall minus evapotranspiration plus deep seepage) of 660 to 760mm in the region. The ability of tree crops to increase depth to water table has been established on this site type under a mixed species forest tree shelterbelt (O'Hare 1972) and under plantation conditions in the present experiment (Farrell and O'Hare 1974). In the latter study, measurements were made in 1969-1970 when the crop was 8-9 years old. In this paper results of measurements made in the period 1981 to 1982 are reported. The purpose of this investigation was to review the results of the earlier study in the context of increased crop growth and under the influence of additional experimental treatments applied in 1977 to 1979. Most of the experimental plots were thinned about midway through the measurement period and the influence of thinning on depth to water-table was examined.

The peat depth measurements were made at the initiation of the experiment in 1967. The measurements were repeated in 1981 and the differences are reported here.

Forest floor and peat samples were taken from four of the experimental plots and mineralisation rates of nitrogen and phosphorus were measured in an incubation study over a 189 day period.

EXPERIMENTAL

The experiment was located in a Sitka spruce crop, on oligotrophic, low level blanket bog at Glenamoy State Forest in north-west Co. Mayo. The climate of the area is extreme maritime, annual rainfall averages 1,400mm distributed over 270 days. The wind climate is very severe with gales in almost every month. Details of the natural flora and afforestation procedures when the crop was established in 1962 have been reported (Farrell 1985).

The original fertiliser experiment, established in 1967, was divided in two in Spring 1977. In two of the original four blocks no further treatments were applied (Experiment 1). In the other two blocks (Experiment 2), all plots received an application of 8 tonnes of ground limestone per ha in addition to further applications of nitrogen and phosphorus. Treatment details are summarised in Table 1.

In August 1969 one slotted PVC drainage pipe, 7.0cm diameter 1.6m long, was installed in a bore hole at the centre of each plot. The method of installation has been previously described (O'Hare 1972). Depth to water-table was monitored in these bore holes in the 1969-1970 period as previously reported (Farrell and O'Hare 1974). They were examined, missing caps replaced etc. in 1981 and

Table 1. Summary of Treatments Applied in Experiment 1 and Experiment 2 (kg nutrient ha^{-1}). All treatments applied in springtime.

Year	N_0	N_1	N_2	P_0	P_1	P_2	P_3
1967[1,2]	0	132	264	0	55	110	220
1969	0	132	0	0	0	0	0
			Experiment 1				
1977/ 1979			No further treatments applied.				
			Experiment 2				
1977[3,4]	0	75	75	0	35	70	105
1978	0	0	75	0	0	0	0
1979	0	0	75	0	0	0	0

1 N applied as sulphate of ammonia; P as ground rock phosphate.
2 Sulphate of potash (42% K) was applied to all plots at 125kg per ha and copper sulphate (25% Cu) at 11kg per ha.
3 N applied as calcium ammonium nitrate; P as superphosphate.
4 All plots limed at 8t ground limestone per ha.

measurements were conducted at approximately biweekly intervals between May 1981 and June 1983. A probe was used to measure peat depth at one point at the centre of each plot in spring 1967. The same procedure and measurement point were used in winter 1981. On the latter occasion, forest floor thickness at each measurement point, which was negligible in 1967, was deducted from the measured depth.

Samples were collected from forest floor (01 and 02 horizons) and peat to 10cm depth for nitrogen and phosphorus mineralisation studies in April 1981. Samples were taken at 30 points in each of the plots of the N_0P_2 and N_2P_2 treatments in both Experiment 1 and Experiment 2. On returning to the laboratory, samples were deep frozen (–18°C) until required. In order to prepare material for study, samples were allowed to thaw and dry until suitable for sieving through a builders screen. They were then dried further until moisture content was estimated to be slightly below that at 60% of field capacity. Moisture content was determined on samples taken immediately before bagging. Samples for field capacity determination were also taken at this time. Field capacity was determined on the sand box under 100cm suction. These samples were analysed in duplicate for total N by distillation procedure following micro Kjeldahl digestion and for total P, K, Ca, Mg, Na, S, A1, Si, Mn, Fe, Cu, Zn and Cl by X-ray fluorescence spectrophotometry.

The incubation experiment ran for 189 days with four replicate samples removed for pH and extractable nitrogen and phosphorus at 0, 7, 21, 63, 126 and 189 days. pH was determined on fresh material in a 1:1 peat-water slurry. Extractable nitrogen fractions (NH_4^+ and $N0_3^-$) were determined by distillation of a M KCl extract of fresh material (equivalent dry weight 2.5g, 100ml M KCl, shaken for 1 hour followed by centrifugation at 2000rpm and filtered through a Whatman No. 42 filter paper). Extract solutions were frozen until the time was suitable for determination. Extractable phosphorus was determined by the ascorbic acid procedure after shaking 1g dried ground peat with 50ml 1.5 M H_2S0_4 in a 100ml centrifuge tube followed by centrifuging and filtering.

Results and Discussion

When both experiments were analysed together, the linear regressions of mean depth to water table on top height at the end of the 1979 growing season, on basal area at the end of the 1981 season and on basal area increment in the 1980-1981 season were all significant. Depth to water table was calculated for the whole measurement period and separately for each year and growing season. The best relationship was obtained between mean depth to water table during the second (1982) growing season and basal area at the end of the 1981 season and the results of this analysis only are presented (Figure 1).

There were marked differences in water table variation between Experiment 1 and Experiment 2. Values for the growing seasons only are presented here. Calculations based on the full calendar year showed very similar trends, but treatment differences, although having generally the same level of significance, were less pronounced, in absolute terms, than in the growing seasons. Within Experiment 1, which was untreated in 1977, no significant difference in depth to water table was observed between plots grouped according to the original treatments (Table 2). This corresponds with the absence of treatment effects on growth increment during the period of water table measurements (Farrell 1985). In Experiment 2, the phosphate treatments significantly increased depth to water table ($p < 0.01$) over both growing seasons (Table 2). In addition, an effect of nitrogen was observed during the first (1981) growing season.

Mean depth to water table over the whole measurement period was 46.7cm in Experiment 1 and 45.4cm in Experiment 2,

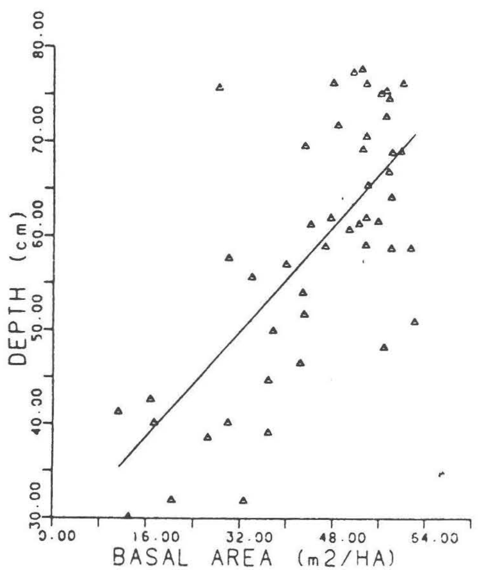

Fig 1 Regression of Depth to Water Table (cm), mean of 1982 Growing Season, on Plot Basal Area (m^2 per ha), 1981.
$Y=27.50+0.6992X$. $F=45.96$ ($p<0.01$).

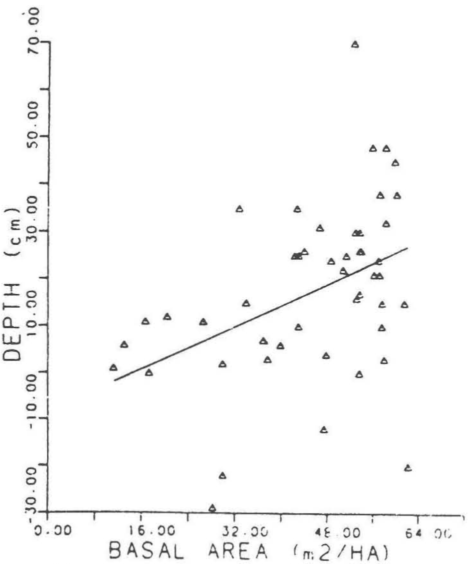

Fig 2 Regression of Decrease in Peat Depth (cm), 1967-1981, on Plot Basal Area (m^2 per ha), 1981.
$Y=-8.249+0.5689X$. $F=9.87$ ($p<0.01$).

Table 2 Mean depth to water table during 1981 and 1982 growing seasons.

Main Effect	Main effect means. Depth to water table (cm) 19-5 to 24-9 1981 Expt. 1	Expt. 2	8-4 to 23-9 1982 Expt. 1	Expt. 2	2-4 to 24-9 1970* Expts. 1 and 2 Combined
N_0	47.3	42.1	60.7	54.8	40.8
N_1	51.0	47.7	63.0	60.2	40.3
N_2	44.3	50.4	55.0	60.2	37.8
SE trt mean	4.44	1.99	4.64	2.43	1.62
		a			
P_0	35.6	27.2	46.9	37.6	36.6
P_1	54.2	51.1	65.5	64.0	42.6
P_2	49.8	53.6	62.3	65.1	39.8
P_3	50.5	55.0	63.4	66.9	39.6
SE trt mean	5.13	2.3	5.35	2.80	1.88
		b		b	c
Overall Mean	47.5	46.7	59.4	58.4	39.5
Mean Weekly Rainfall (mm)	26.3		18.3		24.4

a $N_0 < N_2$ $p < 0.05$
b $P_0 < P_1, P_2, P_3$ $p < 0.01$
c $P_0 < P_1$ $p < 0.05$

*Taken from Farrell and O'Hare (1974).

considerably greater than in 1970. Water table depth during the 1981 growing season averaged 7.6cm more than in the 1970 season (Table 2). In 1982, water table depth was, on average, deeper than in 1981, 19.4cm deeper than in 1970. This was despite the fact that thinning was carried out in the early summer of 1982. A decrease in water table depth in peatland forests has been measured, in other studies, following thinning (Heikurainen and Päivänen 1970). However, rainfall was less in 1982, a mean of 18.3mm per week in the growing season. This compares with 26.3mm per week in 1981 (Table 2). In addition, the line thinning procedure adopted left an almost inact cover of cut trees and fresh slash on the felled lines which probably intercepted a significant proportion of the incoming precipitation.

Before establishment of the original experiment in spring 1967, mean peat depth in the experimental plots was 2.93+0.85m. In the winter of 1981 it was 2.75+0.77m. The mean difference of 18cm was significant ($p < 0.01$) and represents an average subsidence of 1.2cm per year. This subsidence can be attributed in part, to drying of the peat brought about by increased evapotranspiration of the vegetation and in part, to peat decomposition. There was no difference in subsidence between Experiment 1 and Experiment 2. Regression of decrease in peat depth on crop basal area (1981) over all 48 plots was significant (Figure 2) although the degree of association was low (17.7%).

In the mineralisation study, the data represent the net production of mineral nitrogen and phosphorus, that is the quantities released from organic matter which are surplus to the requirements of the microbial population. In the forest floor, where large quantities of nitrogen are stored in organic compounds unavailable to plants, net nitrogen mineralisation was greater in material from Experiment 1 than from Experiment 2 (Figure 3). This was despite the fact that no fertilisers had been added to the Experiment 1 plots since 1969, whereas the plots in Experiment 2 had received lime and phosphorus in 1977 and in the case of the N_2 plots, nitrogen in 1977-1979. It is safe to assume that lime, which increased forest floor pH to 6.9-7.0 (Table 3), stimulated microbial activity. The immobilisation either of nitrogen in forest floor or of added nitrogen, as a consequence of increased microbial activity has been frequently reported (Zöttl 1960, Viro 1963, Nömmik 1968, Adams and Cornforth 1973, Carey and Farrell 1981). In the limed plots, a greater proportion of the mineral nitrogen was recovered as nitrate (Table 4), which is more mobile and easily leached from the soil, than as ammonium, which dominated in the samples from Experiment 1. This too accords with previous experience (Carey and Farrell 1981).

In the peat, the effect of lime is less obvious. The pH of the surface peat (0-5cm) and total calcium at both depths have been increased by liming (Table 3). Nitrate makes up a larger proportion of total mineral nitrogen than in Experiment 1 (Table 4). Nevertheless, net mineral nitrogen levels, while exhibiting a definite upward trend with time, showed no clear treatment differences, except towards the end of the incubation period, when the N_0 plots yielded greater quantities of nitrogen than the N_2 plots across both experiments (Figure 3). At 5-10cm, the upward trend was again obvious, but differences between treatments were even more obscure than in the surface peat (Figure 3).

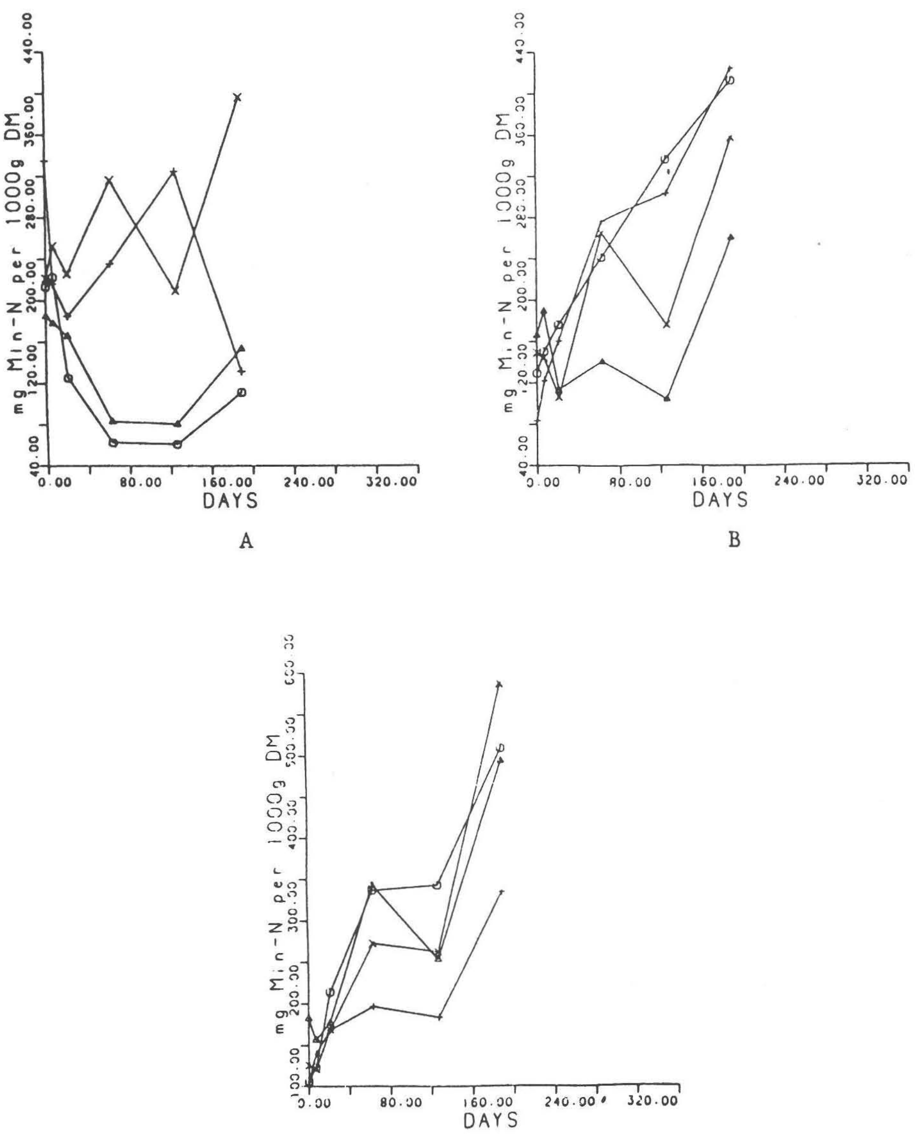

Fig 3 Net Nitrogen Mineralisation in (a) Forest Floor (b) Peat 0-5cm and (c) Peat 5-10cm. Treatments: Experiment 1, N_0P_2+, N_2P_2 X; Experiment 2, N_0P_2 0, N_2P_2 Δ

Table 3 Chemical composition of peats used in N-P mineralisation studies.

		% D.M.										Mg. g^{-1} peat			
EXPERIMENT 1															
Treatment N_0P_2	pH	N	P	K	Ca	Mg	Na	S	Cl	Si	Al	Mn	Fe	Cu	Zn
Forest Floor	4.5	1.46	.098	.085	.51	.16	.046	.16	.14	.20	.027	12	152	3	8
Peat 0-5cm	4.0	1.48	.050	.050	.18	.14	.041	.21	.17	.33	.045	3	256	11	4
Peat 5-10cm	3.9	1.53	.031	.037	.10	.16	.046	.28	.17	.34	.048	4	585	3	5
Treatment N_2P_2															
Forest Floor	4.6	1.70	.094	.072	.53	.17	.036	.18	.13	.19	.029	15	188	3	7
Peat 0-5cm	4.1	1.60	.042	.045	.16	.13	.034	.24	.14	.42	.044	3	560	14	5
Peat 5-10cm	4.0	1.80	.033	.037	.07	.14	.042	.30	.15	.41	.052	2	844	3	4
EXPERIMENT 2															
Treatment N_0P_2															
Forest Floor	6.9	1.17	.140	.070	3.61	.23	.039	.16	.08	.17	.036	68	322	5	10
Peat 0-5cm	4.9	1.75	.074	.059	.99	.13	.050	.26	.16	.63	.090	12	2617	13	5
Peat 5-10cm	4.0	1.92	.046	.041	.21	.12	.041	.34	.17	.45	.092	3	1563	3	4
Treatment N_2P_2															
Forest Floor	7.0	1.31	.140	.066	3.64	.24	.029	.18	.07	.14	.035	56	295	5	13
Peat 0-5cm	5.7	1.67	.070	.091	1.75	.14	.042	.25	.15	.48	.086	13	1376	13	7
Peat 5-10cm	4.0	2.15	.050	.080	.33	.11	.050	.34	.18	.57	.100	4	2279	4	4

Table 4 Nitrate content of forest floor and peat as % of total mineral nitrogen over 189 days incubation.

		Experiment 1		Experiment 2	
Forest Floor	Incubation Period (days)	N_0P_2	N_2P_2	N_0P_2	N_2P_2
	0	9.6	1.9	24.8	32.4
	7	14.4	15.0	35.6	79.9
	21	6.7	6.3	23.3	44.7
	63	10.3	9.8	7.5	38.3
	126	25.1	10.2	41.4	41.9
	189	18.6	32.2	27.5	53.7
Peat 0-5cm					
	0	57.3	5.6	22.8	14.9
	7	14.3	20.0	14.8	34.1
	21	29.0	9.9	8.2	39.9
	63	7.0	24.7	42.4	49.6
	126	8.8	0	53.1	80.8
	189	10.0	25.8	70.1	58.5
Peat 5-10cm					
	0	40.7	2.9	4.0	20.0
	7	8.1	27.1	6.4	11.3
	21	28.8	14.4	14.7	7.3
	63	8.8	2.4	6.8	19.1
	126	9.4	5.3	12.6	7.0
	189	7.1	32.9	11.8	14.5

There was no consistent pattern of phosphorus mineralisation and despite some exceptions, levels remained fairly constant through the course of the incubation. However, the effect of the 1977 application is clear in the increased levels of total phosphorus (Table 3) and extractable phosphorus, in both forest floor and peat (Figure 4).

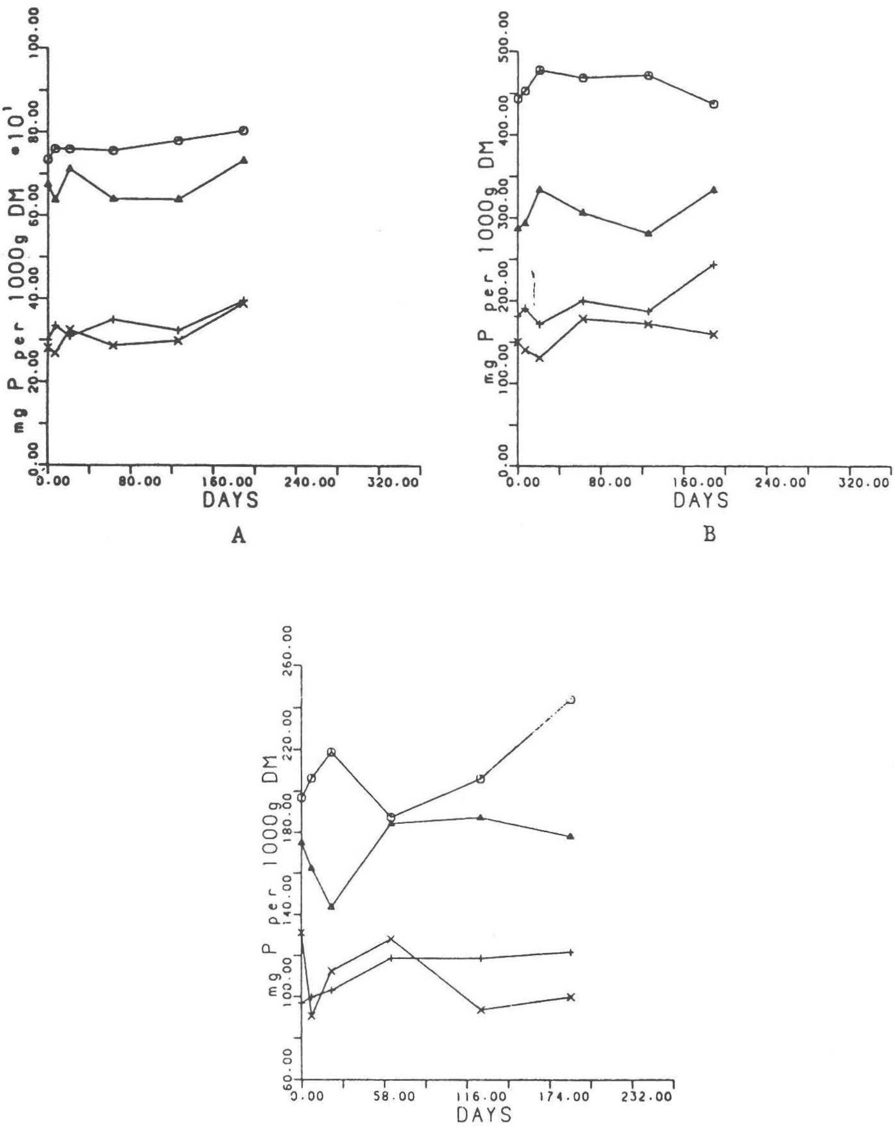

Fig 4 Net Phosphorus Mineralisation in (a) Forest Floor (b) Peat 0-5cm and (c) Peat 5-10cm. Treatments: Experiment 1, N_0P_2+, N_2P_2 X; Experiment 2, N_0P_2 0, N_2P_2 △

CONCLUSIONS

The close correspondence between growth response to fertiliser and depth to water table, recorded both in the present study and in the previous one (Farrell and O'Hare 1974), is remarkable. The relationship is probably indirect, resulting from increases in needle biomass induced by the fertiliser (Albrektson et al. 1977) with consequently increased evapotranspiration.

It is to be expected that rates of evapotranspiration from forest canopies will be high in the west of Ireland. This is because evaporation is high in areas of frequent rainfall where the canopy is almost continually wet (Jarvis and Stewart 1979). Growing season mean depth to water table of 50 to 67cm, as was reached in the phosphate treated plots in these experiments, is very satisfactory for a low level blanket peat site although it would be presumptuous to expect any significant rooting at or even close to this depth range (Farrell and Mullen 1979). Also, allowance must be made for the experimental conditions, as height differences between adjacent plots will lead to increases in aerodynamic roughness of the forest canopy surface and this will result in increased evaporation (Jarvis and Stewart 1979).

Water table depth has probably reached its maximum, as with thinning, the stand is being opened up and the point of maximum current annual increment is already past. While water table depth did not rise rapidly following thinning, as had been anticipated, there is no doubt that it is sensitive to canopy cover. As there is little reason to believe that the stand can have an influence on depth to water table which will persist after clearfelling, it may well prove difficult and costly to provide adequate drainage for the second rotation crop on low level blanket bog sites, which, characteristically have low-angle slopes and peat of inherently poor permeability. Limiting the size of clearfells may reduce the problem, but the possibility of installing widely spaced, deep drains excavated to permeable material should be explored where peat depth, drainage outfalls and the nature of the subpeat mineral soil permit.

The rate of peat subsidence presents no threat to the long-term prospects of forestry on most blanket peat sites. It may be anticipated that on shallower peats the rate of subsidence will be less. In shallow peat situations where less than 50cm of surface organic matter remains, experimentation on peat-soil mixing techniques would be desirable to test the long-term effects of such treatment on crop production and organic matter stability.

The purpose of applying nitrogen in Experiment 2 in 1977 to 1979 was to alleviate potential nitrogen deficiency which might occur, in the short-term, following a lime induced flush of microbial activity. Although a response in basal area increment to nitrogen was measured, the indications are that growth was retarded by the lime (Farrell 1985). However, it would appear that deficiency of nitrogen was not the cause of the reduction in growth. Foliar nitrogen levels increased during the period in both experiments (Farrell 1985). Measureable immobilisation of nitrogen was detected only in the forest floor. However, samples for incubation were taken four years after fertiliser application, by which time an immobilisation effect might be expected to be on the wane.

It is clear that neither in mineral nitrogen levels, (Figure 3), nor in total nitrogen concentration (Table 3), is there real evidence of a residual effect of the 1977-1979 nitrogen applications on the peat. This may not be of great significance, however, if, as has been suggested, trees fertilised with nitrogen make no demands on soil nitrogen after fertilisation has ceased, over and above those made by unfertilised trees (Miller 1981).

By contrast, the residual effect of the 1977 application of phosphate is marked and despite the decline in foliar phosphorus concentrations between 1975 and 1979 (Farrell 1985), provide some reassurance on the persistence of the phosphate response in this experiment.

ACKNOWLEDGEMENTS

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Plantation Forestry on Cutaway Raised Bogs and Fen Peats in the Republic of Ireland

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ABSTRACT

Coniferous plantations have been established on sizeable areas of handcutaway raised bogs and modified fen peats in Ireland over the last thirty years. Whereas Scots pine and Norway spruce were used almost exclusively up to the mid 1960s, Sitka spruce has now become the dominant species because of its higher production potential (20m^3/ha+). Mixtures of Scots pine and Norway spruce were often used where competition from heather was envisaged on the handcutaway bogs.

Phosphorus and potassium application are essential on the handcutaway peat types in order to ensure good growth. There are increasing indications that copper application may also be necessary, particularly for pines and Sitka spruce. Potassium application alone is essential on the modified fen peats.

Although Scots pine grew well in the early years on many of the site types described there is increasing evidence of dieback at about 25 years of age on handcutaway sites, the causes of which are under investigation.

Machine cutaway bogs, both sod peat and milled peat, appear to have a high production potential for forestry (22-24m^3/ha). However, further research is necessary on milled peat bogs to ensure this potential is attained. The depth of peat left behind will be critical because of the highly calcareous nature of many of the underlying subsoils.

INTRODUCTION

Half of the forest estate in the Republic of Ireland, corresponding to an area of 170,000ha, is now on peatland. Although just over 80 per cent of this is on blanket bog, sizeable areas of cutaway* raised bogs and modified fen peats in midland areas have also been planted. These were acquired during the 1950s and 1960s before agricultural research showed that they had a high potential to

*The term 'cutaway' is used in this paper in preference to the term 'cutover', which is normally used in soil survey terminology to describe areas used for fuel production. This is to avoid confusion in forestry circles where 'cutover' has a different meaning.

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produce grass and certain horticultural crops, provided a proper reclamation scheme was executed. Consequently, farmer interest increased significantly in certain types of midland peat, particularly after EEC entry in 1973 when land prices rose significantly. Now, twelve years later, because of a surplus of many agricultural products within Europe the interest in peatland reclamation for agriculture is less than it was in the 1970s. Meanwhile, wood and wood products remain the second largest import after oil to the European Community, the current deficit being almost sixty million cubic metres/annum, or about fifty times that now being produced in Ireland.

Because of its moist temperate climate (unaffected by acid depositions now being increasingly linked with forest decline in Central Europe) and its substantial reserve of marginal land, Ireland is in a strong position to expand forest production in the years ahead. It is the purpose of this paper to review the experience acquired to date on the forestry production potential of cutaway raised bog and modified fen peats, two categories of sites where some of this expansion is likely to occur. Thus it is hoped to provide a more rational base for future land development.

SITE TYPES

Substantial areas of peatland in Ireland have been partially cutaway by hand for domestic fuel. The total area of cutaway raised bog comes to about 172,000ha (Hammond,1979). In addition to this about 65,000ha of raised bogs have been developed over the years by Bord na Mona for industrialised peat production.

Raised bogs are often found in close association with fen peats. Not only do the fen peats occur at the base of the raised bogs, they also occur extensively in river valleys and floodplains, poorly drained hollows and adjacent to raised bogs where the continued influence of groundwater prevented the accumulation of ombrotrophic peat. The relationship between raised bogs and fen peats is shown in Figure 1. Most fen peats can be classified as modified fens in that they have been considerably altered over the years by regional drainage schemes and reclamation.

1. *Hand Cutaway Raised Bog: Turbary Complex*

Hand cutaway raised bogs are a common occurrence in the Midlands and are referred to as the Turbary Complex. The profile consists of 30-200cm of highly acid peat materials, mainly *Sphagnum* (pH 3.5-3.8), removed from the original bog surface (strippings), resting on minerotrophic peat from the original profile. In extreme cases all of the original profile may have been removed leaving behind a variable depth of strippings from the bog surface.

Peat depths on cutaway raised bogs vary considerably depending on the original depth, the amount of peat removed and shrinkage which is influenced by drainage. Depths range between 1 and 4 metres, areas with less than 1 metre being unusual, except perhaps close to the boundary between the raised bogs and the surrounding more upland landscape (Figure 1). Frequently the microtopography is uneven. This results from the method of handcutting. Large peat blocks showing the original full bog profile occur next to deep bog holes separated by variable extents of flat areas used for handspreading.

The peat materials which remain on cutaway areas depend on the depth of peat remaining after cutting. Where it is shallow (less than about one metre) ombrotrophic peat materials are thin to non-existent and layers immediately underneath are of minerotrophic or fen origin. In the deeper peat areas the overlying peat materials consist of varying proportions of poorly humified and humified *Sphagnum*. Peat depth and drainage state are reflected in the surface vegetation but may be obscured if burning has been carried out in the recent past. However, a substantial part of typical areas tend to have *Calluna vulgaris* as the dominant species in the herb layer. Surface vegetation has been a traditional indicator for species selection in forestry in Britain and Ireland (Anderson, 1961). However, its usefulness as a tool for site assessment on cutaway raised bogs is limited. This is due to the extreme variation encountered in vegetation types and also because these may only reflect the nutritional status of the upper 30-50cm disturbed surface layers. Scrub layers where present can include *Betula* spp., *Sorbus, Salix, Ulex europaeus* and *Pinus sylvestris*. The herbaceous layer is influenced greatly by the nutrient status of the peat and drainage. Areas which tend to be dominated by *Calluna, Pteridium, Eriophorum or Sphagnum* and *Molinia* are dystrophic whilst *Phragmites, Juncus* and *Filipendula* spp. indicate more eutrophic conditions.

Because detailed soil surveys of forests have not been carried out it is not possible to give exact figures on the areas growing on Turbary Complex or indeed any of the other types described in this paper. However, it is estimated that some 7,000ha of plantations occur on the Turbary Complex comprised of many small blocks, about 10-20ha in area scattered throughout the Midlands. A typical afforested area stretches some 300-400m from close by the bog facebank/peat cutting edge to the boundary with the fen peats described in Figure 1 or occasionally beyond this to the boundary

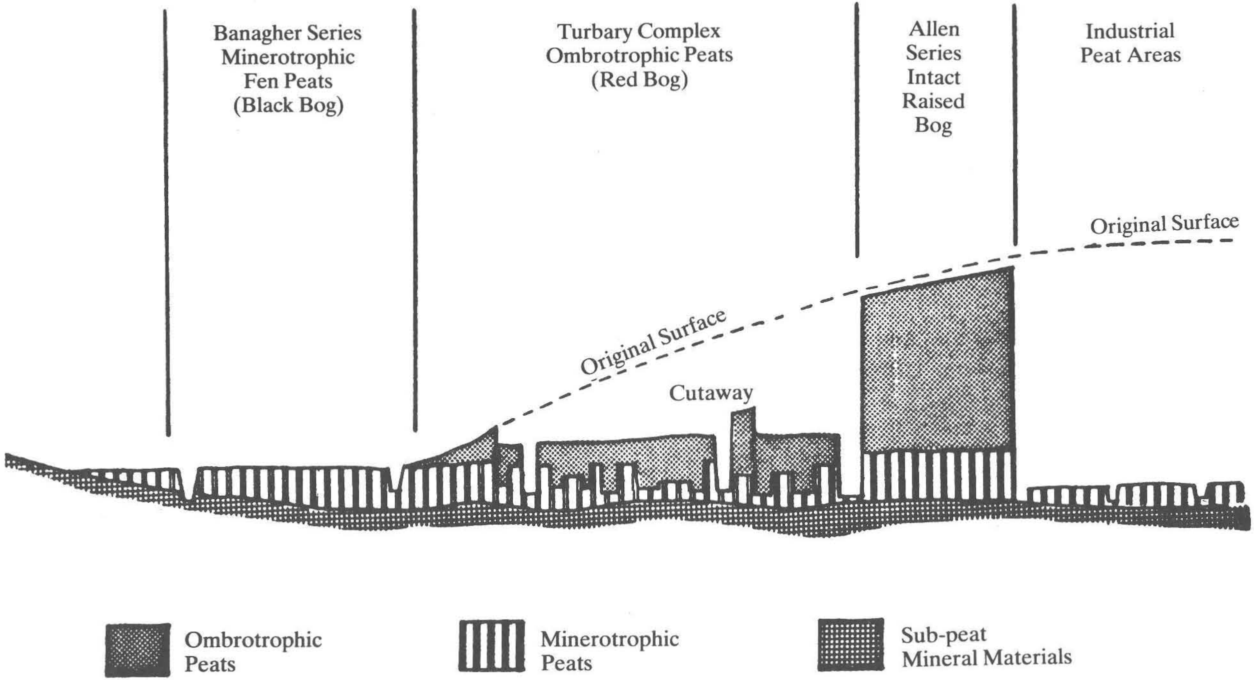

Fig 1 Schematic cross section of the typical Raised Bog landscape unit in the Midlands showing the field relationship between the drained Fen areas, hand cutaway, remnants of intact bog and the industrial peat areas.

with the mineral upland. Usually such areas were ploughed with a double mouldboard plough as an aid to tree establishment but currently mounding is being used more widely. This is likely to give better results provided the watertable is lowered through installation of main drains at some 20-30m. Mounding was successfully used on some of the wetter sites in the early 1950s where it was not possible to use heavy machinery. Midland peats are generally unsuitable for tunnel ploughing — with a few rare exceptions — a practice now recommended for some blanket peats (O Carroll *et all,* 1981).

Species Selection on Turbary Complex

In the 1950-1970 period, Norway spruce and Scots pine were the most commonly planted species on Midland peats, particularly on the Turbary Complex. Usually the species were mixed intimately or planted in alternate lines, the philosophy being that the pine would behave as a nurse species and protect the spruce from frost and at the same time help to surpress *Calluna vulgaris.* Susceptibility of the sites to late spring frosts was the main reason why Norway spruce and not Sitka spruce was planted. In recent years Sitka spruce has been planted more widely, partly because the incidence of late spring frost damage has declined but also because of its capacity to achieve higher levels of production than Norway spruce, even where it does sufer from occasional frost damage. Scots pine is seldom if ever planted nowadays, mainly because it has been replaced by the more vigorous and higher yielding Lodgepole pine, now the second most important forest tree species in the country (Carey and Hendrick, 1985). Whereas Scots pine appears capable of producing 12-14m^3/ha/annum, lodgepole pine is likely to achieve a Yield Class of at least 16-18.

Although Norway spruce has generally grown well in mixture with Scots pine, the production of the latter species and its quality has left a lot to be desired. This has resulted from a combination of poor provenance, squirrel damage and nutritional disorders.

Tree Nutrition on Turbary Complex

Phosphorus application is essential for at least the main coniferous species in order to ensure good establishment and growth on the Turbary Complex. This is illustrated by results from a trial laid down at Emo Forest in 1975 (Figure 2) which includes both Lodgepole pine and Sitka spruce. Projected yield classes for these species in this trial are extremely high. However, an interesting feature of the results is the decline in height growth at the higher rates of phosphorus applied. Foliage analysis of several of the Sitka spruce in the high phosphorus treatments which showed deformity, indicated that copper uptake was adversely influenced at the higher rates. In fact, part of this trial which had been split at age three years for copper sulphate application gave a significant response in height growth to copper sulphate applied at up to 20kg Cu/ha.

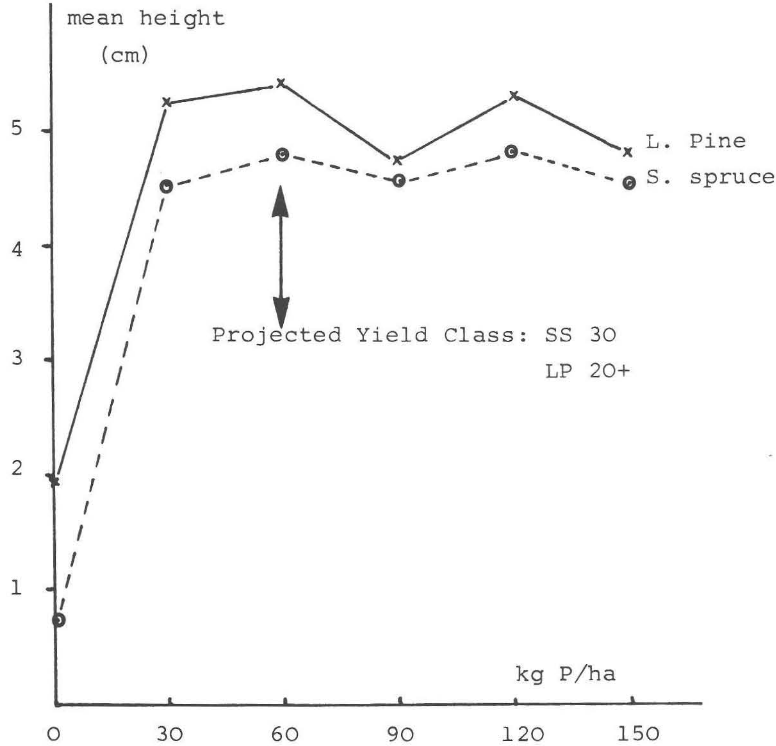

Fig 2 Emo 5/75. Effect of ground rock phosphate application on the height growth of Sitka spruce and Lodgepole pine on the Turbary Complex. Mean height age 9 years. (250kg muriate of potash applied to all treatments at planting).

Nitrogen deficiency occurs in some plantations of Sitka spruce on handcutaway bog but these are usually confined to localised areas where a deep layer of oligotrophic acid peat remains *in situ* below the disturbed and inverted original surface layer. It is often associated with the presence of *Calluna vulgaris*. The use of 2,4-D to control *Calluna* has resulted however in some side effects on the growth of trees. Its use in Athy Forest on a four year old Sitka spruce crop effectively controlled *Calluna* but resulted in severe distortion in 80% of the crop in the following year. This effect, it is postulated, is a consequence of copper deficiency induced by the short term release of nitrogen through *Calluna* kill accentuating an already chronic N:Cu ratio in the Sitka spruce crop. Subsequently the trees responded significantly in height growth to copper application, regained apical dominance but the crookedness resulting from the initial imbalance persists and will reduce considerably the commercial value of the lower 1.5 metres of the stem.

Although most midland peat soils are known to be deficient in copper for agriculture the experience so far in forestry is that this particular problem is mainly associated with the Turbary Complex. However, the problem is by no means widespread yet but there are indications that it may be more serious in the future, particularly on reforestation sites where the nitrogen:copper imbalance is likely to be greater as a result of mineralisation of organic matter and release of nitrogen following clearfelling of the first crop. Current research is aimed at achieving a better understanding of the problem and determining practical solutions. So far copper sulphate at rates of up to 60kg/ha and chelate-copper sprays (0.2-1.0kg Cu/ha) are giving promising results. Copper deficiency has also been observed in some thicket stage stands of south coastal lodgepole pine but the problem appears to be less common than in Sitka spruce.

Table 1 Effect of copper sulphate application at age 4 on the height growth of Sitka spruce. Mean height at age 6 (m).

kg Cu/ha			
0	**20**	**40**	**60**
2.56	2.90	2.69	2.69

Std. error	.09
LSD 5%	.21
Cu quad*	
Cu cub*	

Note: This is the same fertiliser trial referred to in Figure 2, the 60kg P and 150kg P/ha plots of which were split for copper sulphate application.
***Significant at 90%.**

Although the input of potassium in rainfall in the Midlands is only in the region of 2kg/ha/annum (O Carroll and McCarthy, 1973) it is interesting that young plantations of spruce and pine on the Turbary Complex do not respond to potash application. This is in contrast to the situation on the modified fen type peats — see below — where large responses in tree growth have resulted from potash application (O Carroll, 1968). This difference may be due to the exhaustion of potassium reserves on the fen peats as a result of agricultural practices and/or the higher potassium levels associated with the upper layers of raised bogs, corresponding with the distrubed upper layer on the Turbary Complex (Walsh and Barry 1958). However, most recent observations suggest that potassium stress is likely to develop in plantations growing on the Turbary Complex in or around the time of canopy closure, corresponding with age 10-12 years.

Forest Production on Turbary Complex

Production (Yield Class), measured in terms of m^3/ha/annum, is known to vary considerably on the Turbary Complex depending on species, former cultural treatment and very likely peat depth. Although few data are available on the latter so far, the indications are that Sitka spruce grows better where the peat is shallow (less than 1 metre) but exceptions to this are likely to occer. The depth of strippings may also be important.

The oldest known stand of Norway spruce, clearfelled at age fifty four years in 1979 was at Kilyon property, Donadea forest (Figure 3). This attained a Yield Class of 16. Younger stands of Sitka spruce appear to be more productive and the indications are that a yield class of at least 20 is possible (Figure 2 suggests Yield Class 30!), provided nutritional and drainage requirements are satisfied. Lodegpole pine (coastal) also generally grows vigorously. However, its form is poor due to the relatively high incidence of basal sweep, pine shoot moth and increasing evidence of deformation due to copper deficiency.

Although there are some impressive stands of Scots pine on the Turbary Complex, its maximum production potential appears to be in the order of 12-14m^3/ha/annum. Many stands have a lower yield class than this and also are of very poor quality. There is also evidence of dieback in an increasing number of areas, probably associated with a nutrient disorder of some kind. This matter is currently under investigation. Scots pine is particularly interesting from an ecological viewpoint. It is known to have grown extensively in the Midlands over the past six thousand years when peat deposits were forming. Yet it is generally assumed to have become extinct

Fig 3 Norway spruce (*Picea abies*) on cutaway raised bog (Turbary Complex) at Kilyon property, Donadea forest. The photograph was taken in 1968 when the crop was 44 years of age. Yield class 16.

(Mitchell, 1976) at some point in time during the historic period and certainly prior to its re-introduction by man, some 300 years ago (McCracken, 1971).

2. *Machine Cutaway Raised Bog: Clonsast and Boora Complexes*

Because of the activities of Bord na Mona mainly, and a number of small private operators, large areas of peatland are in the process of being cutaway mechanically. The end product, sod or milled peat, is used for combustion in generating stations or for the manufacture of turf briquettes for domestic use. The total area involved is in the order of 65,000ha, most of which is on raised bogs in the Midlands. Because Bord na Mona account for over 95% of the total operation, the discussion here centres on the areas likely to result from their activities. However, it should be borne in mind that substantial progress has been made in recent years in the development of small tractor mounted peat harvesting machines. The ground condition remaining after these operations are completed will, it is thought, be considerably different to that resulting from Bord na Mona activities.

The two harvesting systems, sod and milled peat, now differ only in the way in which the peat is extracted but previously (before 1980) also in the form and nature of the residues left behind. The net result is that the major part of the peat profile is cutaway leaving only the basal layer or layers. However, the depth of organic matter that remains depends on the topography of the underlying bog floor. In all cases a variable thickness of the lowest peat layer remains but in some exceptionally deep peat areas it can be covered by a layer of the overlying humified acid peat. The *in situ* peat in both Clonsast and Boora complexes is essentially similar. However, in the production of sod peat a 50cm layer or so of poorly humified acid *Sphagnum* peat strippings is cut from the original surface and deposited over the spread grounds prepared for peat drying, leaving a bipartite profile, a situation not unlike that described for handcutaway areas. Because it is now Bord na Mona policy to harvest milled peat from bogs formerly exploited for sod peat this bipartite profile will be the exception in the future.

FORESTRY POTENTIAL OF MACHINE SOD PEAT CUTAWAY RAISED BOGS (CLONSAST COMPLEX)

Because of the experience gained over the last 30 years at the Forest Experiment Area at Trench 14, Clonsast Bog, a considerable amount of information is now available on forestry production on machine sod peat cutaway bog. The site, with a total area of 12.9ha, is leased to the Forest and Wildlife Service by Bord na Mona. In 1955 it was considered representative of what the future situation would be like on machine sod peat bogs following completion of turf harvesting.

Site details for Trench 14 and the earlier results obtained on tree growth have been documented in previous papers (O Carroll, 1967; Carey and Barry, 1975). So far the results have been encouraging since it has been found that a wide range of conifers grow satisfactorily with a minimum of inputs. No ground cultivation is required and moderate applications of phosphorus and potassium ensure good establishment and growth. Future research may demonstrate a need for copper application for certain species. The leading species in terms of Yield Class are grand fir (24), Sitka spruce (18-24) and coastal lodgepole pine (18-20+). Other impressive species include western red cedar and western hemlock, both Yield Class 16, and Scots pine, Yield Class 14. Apart from a number of varieties of poplars that failed, the only other tested and very promising broadleaved species is the sessile oak; a small plot planted in 1971 has a projected Yield Class of 10. The best plots of douglas fir have a Yield Class of 14.

Peat depth varies from about 50cm to about 3 metres over the length of Trench 14 (1.6km) and is now known to have a considerable influence on tree growth for a number of species. Whereas Lodgepole pine grows vigorously, regardless of peat depth, the growth of species such as spruce, fir, hemlock and larch fall off dramatically where depths are in excess of about 1.20 metres (Table 2). However, a large part of this fall off can be attributed to the greater sensitivity of these species to competition from heather, which was a problem for a number of years. Research in recent years has shown that such problems are easily overcome for spruce by using fertiliser nitrogen (Carey & Griffin, 1981).

Table 2 Relationships between peat depth and Yield Class at age 16 for a range of species growing on machine sod peat cutaway bog at Trench 14, Clonsast Bog (m^3/ha/annum).

Average peat depth (m)	Western red cedar	Western hemlock	Grand fir	Sitka spruce	Japanese larch	Lodgepole pine	Douglas fir
0.18	13	16	16	21	10	18	13
1.00	16	16	16	20	10	18	12
1.60	—	10	—	10	4	16	—
2.31	—	10	—	10	6	16	10
3.01	—	10	—	8	—	16	—

— = Yield Class not determined due to slow development.

Forestry Potential of Milled Peat Cutaway Raised Bogs (Boora Complex)

Because of the results achieved at Trench 14, it is not surprising that afforestation has become an attractive economic proposition in terms of future land use on machine sod peat cutaway bogs (Gallagher & Gillespie, 1984). However, because of the differences that exist between sod peat bogs (Clonsast Complex) and milled peat bogs (Boora Complex), indeed within a particular bog unit, care must be exercised before extrapolating results from a small experiment area which, although it appeared to be representative in 1955, is in fact now quite different to what the situation may be like in the future on Bord na Mona cutaway areas. This is because Bord na Mona have changed over almost totally to milled peat from sod peat production. The two production systems also leave behind very different drainage intensities (250m as against 15m interval drains for sod and milled peat respectively), the significance of which for forestry has yet to be evaluated.

Whereas thirty years experience exists with regard to evaluating the forestry potential of machine sod peat bogs, the situation for milled peat is far less satisfactory. In order to fill this void and obtain information on the potential of milled peat cutaway bogs for afforestation, the Forest and Wildlife Service have leased a total of 77.5ha from Bord na Mona since 1983. Most of this land (66ha) is at Lullymore in Co. Kildare, the remainder being at Turraun Bog, part of the Boora Bog Complex, west of Tullamore. Although the areas have been planted 3 years, it is premature to comment on the results. However, the indications so far are that milled peat cutaway bogs may have rather different requirements to sod peat bogs in relation to afforestation. The basic soil profile is different to that at Trench 14 in that no stripping layer of dominantly *Sphagnum* peat exists at the surface and the peat layers which remain have been undisturbed for thousands of years. This is also in contrast to the modified fen peats described in the following section, the surface layers of which have been ripened or ameliorated gradually over centuries as a result of agricultural practices. Nevertheless, the forest production potential of the Boora Complex is expected to be high, provided nutritional requirements (phosphorus, potassium and very likely, copper) are satisfied and sufficient depth of peat is left behind. This will be particularly important where the underlying subsoils are unweathered and highly calcareous (Carey & Hammond, 1970). As yet there are no conclusive data on what depth should be left after harvesting to ensure satisfactory long term growth, but a minimum of at least 50cm would seem desirable. The critical depth is likely to vary with the nature of the subsoil and tree species. There are indications that some kind of surface cultivation may be desirable in order to minimise the effects of peat cracking, shrinkage and subsoil influence.

3. *Reclaimed Fen Peats: Banagher Series*

Fen peats, most of which have been partly drained and reclaimed in the past, occur extensively in the Midlands (over 90,000 ha) and on a smaller scale throughout the country and have been referred to as the Banagher Series by Conry *et al.* (1970) and Reedswamp peat by many people involved with forestry. Whereas both terms could be correctly applied to specific situations, neither is in fact satisfactory from the point of view of describing what is a more complex soil pattern. Typically the fen peats grew and accumulated in a relatively rich minerotrophic environment, often in river floodplains or in interdrumlin flats and in the immediate environs of raised bogs (Figure 1). The profile never included a layer of highly acid ombrotrophic peat at the surface, the upper layers usually having a pH of 5.0-5.5. The complexity arises in relation to the topographical position in which the peat formed. The lowermost areas usually developed from reedswamp overlying marl deposits whereas more upland areas formed wood or woody fen peats over less calcareous subsoils. Although such differences might appear to be of little consequence for land use, they do have a considerable influence on the moisture holding capacity of the peat, the woody types being far more susceptible to drying out than those derived from reedswamp plant communities. In areas with low rainfall, such as the Midlands, this may be of significance for species selection.

The overall hydrology situation on the fen peats has been altered greatly by drainage schemes, such as those carried out on the rivers Boyne, Blackwater and Barrow catchments. In addition the soils usually show evidence of previous localised drainage, cultivation, liming and fertiliser incorporation. Old field boundaries are often discernible. The surface horizons, often containing earthworms, are usually black in colour with a crumb-like structure. Fossil wood or reed remains are evident at 30-50cm. Surface vegetation usually features grasses such as *Festuca rubra* and *Anthoxanthum odoratum*.

Forestry Potential of Fen Peats

There are about 2,000ha of coniferous plantations growing on man-modified fen peats most of which were planted during the 1950-1970 period. Initially species selection was dominated by Norway spruce or Norway spruce/Scots pine mixtures, as on the Turbary Complex. More recently plantations have consisted almost exclusively of Sitka spruce because of its greater production potential. Many of the earlier plantations did not achieve their production potential because of severe potassium deficiency and large responses in growth have been found from potash application in Scots pine and Norway spruce (O Carroll, 1968) and more recently in Sitka spruce. An interesting feature of the results from one fertiliser experiment at Derryricket property, Edenderry Forest (Table 3), is the negative effect of phosphorus application on the growth of spruce, reason(s) for which is(are) uncertain. In practice, nowadays, Sitka spruce is normally planted on this site type following application of 125kg K/ha as muriate of potash, no phosphorus fertiliser being necessary. There are suggestions in Table 3 that higher rates of potassium may be desirable, perhaps as high as 200kg K/ha. Sites have usually been ploughed in the conventional manner (DMB) but less intensive drainage/cultivation systems would probably suffice, provided the waterable is lowered sufficiently.

Table 3 Effects of applied potassium and phosphorus on the growth of Sitka spruce and Norway spruce on the Banagher series (fen peat). Mean height age 9 (m).

		Sitka spruce		*Norway spruce*	
		P0	P87	P0	P87
K0		1.48	1.40	1.21	1.40
K100		2.37	2.36	2.36	1.93
K200		2.65	3.32	2.69	2.59
K300		3.28	2.64	2.66	2.74
Standard error	0.31				
LSD 5%	0.67				

Note: K applied as sulphate of potash, P as rock phosphate. Nutrients expressed as kg/ha.

Indications are that sites planted in the early 1970s with Sitka spruce will attain a Yield Class of 18-20 compared with a range of 12-16 for Norway spruce. The lower production potential of Sitka spruce relative to that suggested earlier for the Turbary complex is perhaps rather surprising. The reason(s) for this difference are unclear. Some stands of Norway spruce in Athy and Monasterevan forests have attained a Yield Class of 20. Scots pine on the other hand does not appear to grow as well on the Banagher Series as it does on the Turbary Complex and Yield Classes of 8-10 are commonly encountered. However, there is no evidence of the dieback being experienced on the Turbary Complex, except in situations where marl is within 30cm or so of the surface. So far there is no evidence of copper or nitrogen deficiency but severe symptoms of the former have been observed at one site near Clonavoe property, Edenderry Forest, in Japanese larch and Douglas fir (Figure 4), both of which are known to be particularly sensitive to low levels of available copper but are seldom planted on fen peats. There is evidence from one site in Donadea Forest of copper deficiency being a problem for second rotation crops of Sitka spruce following clearfelling of an unthrifty crop of Norway spruce and Scots pine.

Fig 4 Loss of apical dominance and crown deformation in Douglas fir (*Pseudotsuga menziesii*) on fen peat (Banagher Association) at Edenderry Forest due, very likely, to copper deficiency. Notice unaffected Norway spruce (*Picea abies*) in background.

Discussion and Conclusions

Cutaway raised bogs and modified fen peats have a considerable forestry potential. This stems not so much from the large areas of existing plantations but rather from the extensive areas of under-used peatlands throughout the country now becoming increasingly marginal for agriculture, and the areas likely to result from Bord na Mona operations. The potential also relates to the vigorous growth patterns being recorded for certain coniferous species on some of the site types described. However, this is not to state that problems will not arise. For instance, the fall off in growth and dieback of Scots pine at about age 20-25 years on the Turbary Complex is a cause for concern. (This is in contrast to the 30 year old Scots pine still growing well at Trench 14, Clonsast). There are also indications of growth disorders in Lodgepole pine on the Turbary Complex around the time of canopy closure and difficulties have been experienced locally in establishing second rotation crops of Sitka spruce on modified fen peats. Most of the experience to date has also been based on Scots pine and Norway spruce, neither of which feature significantly nowadays in planting programmes. Whereas the performance of Scots pine has been poor, Norway spruce has been growing satisfactorily on all of the site types described and some stands have gone through a full rotation on the Turbary Complex yielding at least $16m^3$/ha/annum. Somewhat higher Yield Classes have been recorded for the species on modified fen peats and it is seldom associated with copper deficiency.

Although Sitka spruce is now the preferred species on both cutaway raised bogs and modified fen peats, the oldest crops are now only about 15 years of age, apart from those planted at Trench 14, Clonsast Bog in 1955, a site type now considered quite unrepresentative of future industrial cutaway areas. Nevertheless, indications of its production potential so far are very encouraging with Yield Classes of 18-26 being recorded for younger stands. However, as these develop and grow on past canopy closure, there is no guarantee that the problems of dieback now being observed in Scots pine on the Turbary Complex will not also occur. For this reason it is important to obtain a greater insight into the reasons for the variation being encountered between sites and species in both their relative performance and production levels. This applies not only to handcutaway areas but also modified fen peats and the different types of milled peat cutaway bogs that will result from Bord na Mona operations. The degree to which these sites are likely to dry out after canopy closure in areas with relatively low rainfall (about 900mm) may ultimately be a cause for concern and justify change of species.

Although much information is available from forest inventory records on growth rates for Midland forests, this has so far not been related to site types; this paper is merely an overview of the experience to date. More detailed soil/growth relationships are required for the main tree species in order to provide a basis for meaningful site surveys. These in turn will allow better use of the valuable land resource that is likely to become increasingly available for forestry development.

ACKNOWLEDGEMENTS

Grateful acknowledgement is extended to the many foresters who indirectly provided much useful information, in particular Mr. A. Buckley and Mr. P. Crowe. Mr. P. Dodd and Mr. E. Hendrick provided data from Inventory records and assistance on data processing.

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Society Activities

SOCIETY OF IRISH FORESTERS TOUR: 21st-23rd MAY, 1985.

NORTH CORK AREA

President: Mr. M. O'Brien
Convener: J. O'Driscoll *Leaders:* R. Griffin/M. O'Donovan

The annual study tour was based in Blarney and concentrated on the forests of Ballyhoura, Duhallow, Mullagharierk, Avondhu and Kilworth. 6.2% (46,444ha) of the land area in Co. Cork is afforested. There are 28 forest centres and a wide variety of site types. The greatest concentration of forest is on Old Red Sandstone areas. Much of this has been difficult to afforest and as a result the range of species used has been limited. Nowadays many problems have become apparent in plantations established in the 1950's and 1960's. Local hosts on this first day of the tour included, E. Fitzpatrick (Assistant District Inspector), J. Moran (Forester-in-Charge, Ballyhoura), C. O'Shea (Forester, Ballyhoura), T. Hunt (Work Study), S. Crowley (Forester-in-Charge, Doneraile), T. Horgan (Research Forester), I. Sherriff (Amenity Inspector), E Hendrick (Research, Bray), J. O'Leary (Utilisation).

The main species at Ballyhoura Forest is lodgepole pine. Many of the provenances of the species planted in Ireland were encountered. The south coastal provenances grew vigorously, but the form is usually poor and branching is rough. North coast, inland or Lulu Island provenances are much slower growing (YC 6-8) but are of good form. Most forest managers are now faced with some very difficult decisions in relation to the future management of these stands. The touring party viewed some of those areas and some of the questions which arose are as follows: Is it worth while retaining rough, south coastal crops and treating them by thinning and pruning in the hope of getting a final crop of fairly good quality trees? Should the less vigorous crops be given additional fertiliser to boost their growth rate and to produce high quality timber, on long rotations? Will there be markets for the latter type of material and will manufacturers pay a premium (estimated at £5/m^3 above current prices) for such high quality logs, in order to compensate the grower for the cost of treatment and longer rotations? In the discussion, there were almost as many differing opinions as there were participants. It was generally agreed, however, that markets should not be a problem.

A possibility in the future in the Ballyhoura region is to plant more Sitka spruce or Japanese larch or mixtures of both these two. Some good stands of these species were visited but many of the party felt that the sites on which these crops were growing were either significantly better sites initially or had been improved through agricultural use. Certainly there appears to be no question of a blanket prescription of Sitka spruce on these soils especially where peat harvesting has taken place, because nitrogen deficiency is normally a major limiting factor. Indeed, repeated applications of nitrogenous fertilisers may be necessary to get pure crops of Sitka to canopy closure stage. At present local management favour Sitka spruce/Japanese larch mixtures in the reafforestation of those poor sites. The final stop on this first day was at Doneraile Forest Park which is, at present, being redeveloped as a landscaped estate and red deer park. The great meadows and fringe belts will be retained to give the illusion that the meadows are clearings in the woodlands. The fences are sunk into the ground to give uninterrupted vistas and the oak/beech woods are being rejuvenated in such a way as to conserve the main landscaping features.

Duhallow and Mullagharierk Forests. Local hosts: J. J. Cooney (Forester-in-Charge, Duhallow Forest), A. Pfeifer (Research, Bray), T. O'Sullivan, P. Peters (Research Foresters, Brosna), J. O'Mahony (Forester-in-Charge, Mullaghareirk), D. Scannell (Wildlife). Duhallow forest was established in 1965 and consists mainly of two large blocks of woodlands. It is approximately 2,200ha in extent. The main soil type is a shallow amorphous peat over loose mineral subsoil derived from ORS parent material. In 1982 one of a series of Monterey pine trials was established at this forest, to test the resistance of various clones, to "yellows". This trial is replicated on a blanket peat and on a midland peat. It consists of 44 clones of rooted cuttings which were selected from 8-year old trees, showing apparent resistance to yellows and with sealed buds. It was designed to determine how individual trees react in different environments. Monterey pine is probably at its range limit on this site which is 213m is elevation and quite exposed. In practice the species would prefer a more fertile, sheltered site. It is not seen as a species which might replace lodgepole but might be competing for sites with more exacting species such as Douglas fir. On this site the failure rate has been high but home collected lots have shown a marked improvement in resistance to yellows.

Mullaghareirk Forest is about 2,000ha in extent. Elevation, ranges from 240-410m. The main soil types are peaty gleys and blanket peats. Much of this area, particularly the peaty gley sites, has been planted with Sitka spruce. Spacing was generally at 1.6m x 1.6m. These crops have grown vigorously (Yield Classes 20-24) and many are now being thinned. This has given rise to windthrow problems. A number of vigorous stands of Sitka spruce were visited but most discussion was provoked by a series of sample plots designed to demonstrate the effects of line thinning and no thinning upon crop development. These plots were established in 1957, received a line thinning in 1976 and were selectively thinned in 1981 and 1985. The relevant crop treatments and statistics are as follows:

First Thinning	Total Vol. Removed m^3/ha	Stems/ha	Diameter (cms.)	Mean Stem Vol. $(m)^3$	Mean Vol./ ha $(m)^3$
No thinning	Nil	3,933	15.4	0.140	524.7
1 line in 3	202.8	1,306	21.0	0.292	381.4
2 lines in 5	198.9	1,094	21.7	0.303	331.5

A wide ranging discussion on the merits and demerits of thinning crops which are liable to windthrow took place. It was admitted that a general no thinning policy is not possible because the Forest and Wildlife Service is committed to supply wood processing industries. However, it was felt that some sites should be designated as no thinning areas because of the high risk of windthrow. This might apply particularly to areas where thinning had been delayed. Removing one line in three was criticised because it appears to make plantations very susceptible to wind damage and some observers felt that it is not particularly useful from an extraction point-of-view. It was generally felt that current soil cultivation techniques such as ripping and mole drainage are advantageous in improving crop stability.

The last *scheduled* stop was to view and discuss a site which had recently been replanted following a major fire (area destroyed 325ha) in 1984. The difficulties in replanting such an area were outlined and the danger of weevil attack was discussed. There is no evidence of weevil attack at present and very little evidence of damage from this insect within the forest. All plants were carefully dipped prior to planting. Despite these facts it was felt that a significant increase in insect numbers and damage can be anticipated.

Avondhu and Kilworth Forest: Woodfab, Fermoy and Fota.

Local hosts: J. Dalton (District Inspector), D. Fitzpatrick (Assistant District Inspector), J. Greehy (Forester-in-Charge, Avondhu), M. Carey (F.W.S., Bray), T. Horgan, J. Finn (Research Foresters, Mallow), H. Maher (F.W.S., Bray), J. C. Crowley (Forester-in-Charge, Kilworth), D. J. Crowley (Forester, Kilworth), M. Joyce, M. Holly, J. Brady (Woodfab Group).

The parent rock in Avondhu Forest is Old Red Sandstone and the predominant soils derived from this are ironpan posdols and peaty podsolised gleys. Nitrogen deficiency is one of the major problems associated with the growing of Sitka spruce on these soils when *Ulex* is not present. One way of overcoming this is to use nurse species such as Japanese larch, lodgepole pine or Scots pine. In 1960 a series of mixtures were formed at Avondhu Forest to examine this nursing effect. In addition to monitoring crop parameters, rainfall amounts and chemistry are also being examined. As the thoughfall was particularly heavy on this morning there was little discussion on these extremely interesting experiments. However, it did emerge that the pH of rainfall at Avondhu is normally 5.6, whereas at Glencree, rainfall can sometimes have a pH of 3.5. An interesting factor at Avondhu is that fog and mist may account for a very significant proportion of total precipitation. At present it is difficult to 'pin-down' the actual nursing effect, but the presence of the nurse species undoubtedly enhances the availablity of nitrogen in the mixture.

In Kilworth forest the topography is typical ORS, with gently sloping hillsides interspersed by deep narrow glens. The soils are approximately 50% acid brown earth and 50% brown podsolics. Much of this forest was planted in the period 1924-34, without soil cultivation. Many of these old crops have now been felled and the question of soil preparation at reafforestation has arisen. Experimentation currently in progress indicates that cultivation (ploughing or ripping) has no effect upon growth. However, survival of Douglas fir is substantially higher following cultivation, whereas cultivation has no effect upon the survival rate of Sitka or lodgepole pine. It was suggested that this may be due to the fact that these sites may be a little too exposed for Douglas fir. The cost of replanting these sites, through the lop-and-top can be high, but cultivation loosens the soil and makes replanting easier. Local management believe that it should be possible to grow crops of Sitka spruce and Douglas fir without nitrogen additions where furze invades the site.

On the afternoon of this last day the Society were guests of Woodfab Group at their Fermoy sawmill. The group viewed the log sorting yard, the sawmill, the drying kilns and the drypack unit for the assembly of finished products. All agreed that this mill was a most impressive production unit and following refreshments generously provided by our hosts, the President expressed our gratitude to Woodfab for this opportunity to get a glimpse of this side of the forestry enterprise in Ireland. The tour ended on a high note with a most enjoyable conducted tour of Fota Estate at Carrigtoghill.

1985 Study Tour Participants

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