SPRUCE REGENERATION ON WET FOREST SITES

by

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ABSTRACT

Wet site improvement was examined on three soils in a Scottish Border Upland forest; peaty podsol, peaty gley, and deep peat. The area was hand-drained and turf-planted with Sitka spruce in 1928-1932. The growth and distribution of natural seedlings in 0.1 acre clearcut gaps were used as an index of preferred growing conditions.

The seedlings were rooted in the superficial, well-aerated organic horizons, mainly in spruce litter from the overwood. Roots did not penetrate to the old *Molinia* peat below. Aeration values, measured as Redox, Oxygen diffusion rate, and available pore space, decreased rapidly with depth. Preferred microsites were small depressions and the base of cut stumps. These moisture conserving conditions indicate an intolerance of drought stress during the short dry periods in the growing season. On two dates during the 1968 season seedling relative cell water content (R.T.) approached limiting levels estimated in a laboratory test. Seedling numbers decreased but height growth increased across the gaps from the stand to the gap centre. These are responses to a) vegetation competition and b) light. Best height growth occurred in the north half of the three circular gaps sampled. Mortality among the 1968 germinants is to a large extent attributable to a drought/heat complex in the surface organic horizons.

Examination of sulphide distribution in the top ten inches of soil indicated that seedling roots are exposed to anaerobic and possibly toxic conditions repeatedly for short periods during the growing season on the peat and peaty gley soils. A fluctuating water table improves aeration and flushes away these reduction products. The influence of draining and tree growth in the study area has lowered the water level, increased water table fluctuation, and raised soil aeration status in comparison with an undrained unforested control sample, and has provided a variety of seedbeds suitable for spruce germination and seedling survival. Differences in soil moisture, aeration status and seedling growth were revealed between the three soil types.

Tubed nursery seedlings were sensitive to a test range of depth to water table and aeration levels in fibrous peat. Aeration levels on modern ploughing patterns for deep peats compared favourably with the test levels. Rooting of windblown trees which were observed on the study area indicates that on shallow peats there is rooting down to the mineral soil within one rotation after site improvement.

The silvicultural implications of these assessments are discussed with regard to afforestation programmes and to regeneration of spruce for the second rotation, in the face of a major wind stability problem on wetlands.

I hereby declare that this thesis is the result of my own work and has been composed by myself. The contributions of others are acknowledged below.

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INTRODUCTION

Current demands for timber in the face of an increasing world land hunger are forcing the forest manager to consider the possibilities of economic forest production from previously "unplantable" sites and from "non-productive" forested areas. These problem sites include high elevations, exposed slopes, thin rocky soils, barren sands, and wetlands. Production potential on wetlands is high and where these occur at lower elevations in accessible locations, some sort of site improvement is usually already in operation. Initial efforts to bring wetlands into forest production had their origins in agricultural practice and the fertile mineral soils were first to be improved. Rigg and furr cultivation of mediaeval times is an example (Booth, 1965).

On most wetlands in the Northern Coniferous Forest zone the mineral soil is capped by a more or less deep layer of organic matter. Where this layer has formed under oxygen deficient conditions and excess moisture, peat develops with a high proportion of raw relatively undecomposed plant remains. Zehetmayr (1954) recognises two depth classes: shallow peat, 6-24 inches, and deep peat, more than 24 inches. Lines and Neustein (1966) consider more than 12 inches accumulation is peat, but report that the Geological Survey of Great Britain used 24+ inches, and the Soil Survey 12 inches. For the purposes of this study depths as shallow as 6 inches are considered to be peat because of their anaerobic nature. Peat may form on fairly steep topography because of a high precipitation/evaporation ratio, or on plane topography with impeded drainage and in depressions where drainage water accumulates. The rate of peat formation for a given physiographic situation is controlled by a number of factors including temperature, moisture levels and pH, on which the microbiological activity of the soil depends. Vast areas of peatland extend across Canada, the north of the United Kingdom, Scandinavia, Finland, Poland and the U.S.S.R., where the growing season is not long enough to permit efficient breakdown of plant remains. At lower latitudes higher temperatures are offset by excess moisture and lack of aeration. In the United Kingdom Zehetmayr (1954) indicates the 40 inch isohyet as defining areas where peat forms, with the exception of local depressional peats which may occur in lower rainfall areas.

The large forested areas on wetlands in Canada and the U.S.S.R. have been considered as a forest reserve until very recently. The pressure on land in the European countries has relegated recent afforestation and the expansion of the coniferous forest estate to sites marginal for agricultural use. A well-developed technology now exists in peatland forestry. Many of the original trials are nearing the end of the first rotation and the information so far produced is being re-invested in current peatland afforestation practices. With the increasing demands for dimensional timber, for wood pulp, and the chemical products of wood utilisation, it is not surprising that wet forest sites which were previously avoided, are now to be considered potentially productive. New extraction methods, more efficient transport systems and more complete utilisation of the product make the returns on the necessarily higher investments in peatland forestry more attractive. Increased transport costs make long haulage distances from distant forest areas less attractive and the wetlands close to processing plants and markets are first to be improved for forest growth.

TREE GROWTH AND STABILITY ON WETLAND SITES

Two early aims of wet site improvement for forest growth were removal of excess water by lowering the water table and the provision of a well aerated planting site. The combined aim was to increase effective rooting depth. To these aims must be added the suppression of vegetation competition. These three are now foremost in current wet site improvement practice. The history and development of planting on peatlands is summarized by Zehetmayr (1954) for the United Kingdom.

For adequate forest growth the problems of the peat substrate are associated with water table manipulation and aeration. The need of the forest crop is for increased rooting depth to exploit a larger volume of peat, to improve the stability and maintain an economic growth rate. Many of the early attempts at peatland forestry failed because the planting techniques were those used for well drained sites. Thus the benefits of drainage, effective to a few inches depth from the peat surface, were offset by notching the transplant down below the layer of improvement. It was not until turf planting was applied to these areas that promising results were obtained and it was with the introduction of Sitka spruce that headway was made, Zehetmayr (1954). The adoption of the Belgian spaced-turf planting method (Stirling-Maxwell 1910 and 1913) with hand draining led to the development of ploughed drains with planting on the ribbon of turf. Zehetmayr (1954) accords to Anderson in 1925 the initiation of slicing the turf to align the roots in a sandwich between turf and original peat surface. By 1939 the Forestry commission practice for peatlands had developed to more closely spaced hand-cut drains, and tractor drawn ploughs were tried which produced a long ribbon of planting turf alongside the drains. The early peat plantations of Sir John Stirling Maxwell at Corrour responded to addition of 2 oz. of phosphate per plant which helped the early problem of planting check (Anderson 1967). After 1948, development with new machines was rapid and a variety of ditch sspacings, depths and turf patterns became available. Planting check (Binns 1959) and heather check (Handley 1963, Weatherall, 1953) were continuing problems. Binns (1959) showed how the application of phosphatic fertilisers increased growth rates of Sitka spruce transplants and raised the amount of available nitrogen. Larger turfs increased the rate of nitrogen mineralisation and provided a greater volume of aerated peat. Handley (1963) examined the possible antagonism of fungi associated with <u>Calluna</u> and spruce seedling roots. Basic slag and ground mineral phosphate are still generally used to aid the recycling of nutrients in drained peats.

Stability of spruce stands on improved wetlands has been examined by Fraser (1966, 1967) and Fraser and Gardiner (1967). A response to drainage and to drain intensity is shown by Fraser (1966) through deeper rooting and lowering of the water table. Table A is reproduced from Fraser's reports.

TABLE A *

MEAN ROOT DEPTH IN INCHES ON FIVE MAJOR SOIL TYPES FOR ELEVEN SPECIES STUDIED

Soil type / Species	Samples	Brown earth	Peaty podsol	Surface water gley	Peaty gley	Deep peat
	19	34.3				
Sitka spruce	4		26.1			
	7			17.7		
	17				16.5	
	6					25.5
Norway spruce	6	34.9				
	3			20.3		
Douglas fir	1	37.1				
Japanese larch	1	38.2				
	1		25.4			
European larch	1	35.8				
	1		28.1			
Scots pine	1		22.2			
Lodgepole pine	1		24.3			
Western Hemlock	1	18.2				
Lawson cypress	2	27.0				
Red alder	1			35.1		
Grand fir	1	33.6				

Superficial rooting continues to be the major problem in wet site forestry (Fraser and Gardiner 1967). With an increasing proportion of the coniferous forest estate on wetlands, a windblow problem on

* reproduced by the courtesy of the author (Fraser 1966)

these sites becomes of national concern. Recent examples from January 14-15, 1968 in the United Kingdom, Denmark and Germany involved more than 50 million cubic feet of merchantable timber (World Wood Review 1968). Fraser and Gardiner (1967) classified peatlands in an attempt to develop a windblow hazard rating. Peaty gley soils and deep peats yielded rooting depths of less than 30 inches for mature trees. The tree-pulling studies, they report, show a high hazard on surface water gleys, peaty gleys and deep peats. Stem lengths are unlikely to exceed 50 feet on exposed sites and 60 feet if less exposed, before suffering severe windblow. Typical root forms and resulting windblow on a peaty gley soil are illustrated in Figures 1, 2 and 3. Natural spruce forests on peat show a drainage response although the general growth pattern is one of densely spaced shallow-rooted, stunted trees (Kayll 1960, Horton and Lees 1961). Cold wet soils provide a poor nutrient cycle (Huikari 1955). The species which grow on peatlands generally have some root adaptation which permits them to adjust to the high fluctuating water table: Jeffrey (1959) and Wagg (1967) describe the multilayered root structure of white spruce, Picea glauca Moench Voss, in response to a rising water table and a plate-like rooting form in response to a fixed high water table. Black spruce Picea mariana (Mill) BSP competes successfully on wet sites by prolific root grafting and sprouting, and by layering of basal branches on well-aerated micro-sites (Kayll 1960, Horton and Lees 1961). By a prolific and widespread seed-fall, broadleaved species such as birch

Figure 1.

Shallow Sitka spruce rooting at Ae Forest

Figure 2.

Windblow at Ae Forest

Figure 3.

Windblow of a drainside tree

Betula pubescens and B. papyrifera and by root sprouts Populus balsamifera L., are able to take advantage of favourable micro-sites, and the poplars and birches are components of many peatland forests. Day (1957) examining Sitka spruce in natural forests in British Columbia reports that seedlings were to be found on peaty areas only on those micro-sites raised above the surface of the bog and where there was lateral water movement or a fluctuating water table. Huikari (1966) and Heikurainen (1967) describe a significant improvement over a wide age and diameter class range in the growth of Scots pine, Pinus sylvestris L. and Norway spruce Picea abies L. Karst. to drainage of forested swamps.

REGENERATION

The first response to removal of the overwood is a rise in the water table and a re-invasion of ground vegetation, especially grasses and rushes, (Holstener Jorgensen 1967, Bay 1965). A rotation under a drainage regime together with the effects of tree rooting alters the physical properties of the peat. Peat drying, shrinking and cracking occurs, (Binns 1959, Hooghoudt 1950). The substrate for seedling growth in the second rotation is therefore quite changed from that of the afforestation project.

Nevertheless the aerated planting turf produced in current ploughing practice produces adequate establishment rates for transplants. Addition of fertilisers provides a growth increase to take advantage of the few growing seasons of vegetation suppression resulting from turf inversion. An abundance of natural seedlings in windblow gaps, along roads and logging racks suggests that a seedbed condition has been created within the rotation which is receptive to Sitka spruce germination and survival. Features of that regeneration are a high population beneath the stand in the absence of vegetation competition, few seedlings in the open and a markedly clumped distri - bution. Absence of established seedlings in the numbers observed among recent germinants points to considerable seedling losses during the early years following germination.

WET SITE CHARACTERISTICS

Climate

The build-up of organic matter is associated with a precipitation/evaporation ratio greater than unity and a precipitation distribution which is more or less even throughout the growing season. Number of days with rain for this period is high. Kononova (1961) points out the importance of temperature on the rate of humus build-up. A rise of 10°C, she reports, at low basal temperatures can increase microbiological activity two or three times. Above 60% of peat moisture capacity, activity falls off. Where there is increased precipitation in the winter months, the soil is re-wetted and the trees reduce transpiration, evaporation rate falls with reduced temperatures and the water table rises.

The distribution of rainfall and mean monthly temperature records for a hill station in the Border Uplands are shown in Table 1.

TABLE I

RAINFALL, TEMPERATURES, AND RAINFALL DISTRIBUTION FOR ESKDALEMUIR

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Rain inches	5.9	3.8	3.7	3.7	3.8	4.0	4.8	5.6	5.5	5.3	5.8	6.4	58.3
Temperature °C	1.1	1.5	3.7	5.9	9.1	11.4	12.9	12.6	10.9	8.0	4.5	2.4	7.0
Percentage Days with rain	77.0	69.6	63.5	62.7	56.7	57.8	64.3	67.7	67.8	73.3	72.6	73.3	67.2
Parkgate, Gubhill Rainfall	6.7	4.1	3.6	3.3	3.5	3.3	4.6	4.7	4.8	6.1	5.7	5.9	56.4

These records are typical of border upland wet sites as the records from Parkgate, Gubhill in the Forest of Ae indicate.

Topography

A transect of rolling topography in the Scottish Border Uplands provides examples of a variety of wetland peat types. Physiographic peatlands form where topography and soil combine with climate to form basin moor (Fraser 1933). Topography on this type is flat or depressional and these are water receiving sites. (Figure 5). Climatic peatland forms on a variety of topographic situations where precipitation and temperature levels combine to allow peat accumulation even on steeply sloping terrain, (Figure 4) - blanket peat (Fraser 1933)

Figure 4. Blanket peat, Scottish Border Uplands

Figure 5. Basin peat, Flanders Moss

Soil

Peat forms over a variety of soils where vertical drainage is impeded. Iron pans, indurated iron rich layers, and massive clays often underly peats. These layers prevent drainage of surface moisture, reduce aeration, prevent root penetration, and may lead to continued peat build-up. The peat types on basin moor and climatic moor have distinctive textures which present physical problems to rooting and drainage. Fraser (1933) list 3 main types with 10 varieties. He assigns aeration status to them thus: high - surface amorphous; moderate - fibrous, fragmental, shallow dark; pseudo fibrous - low.

The fibrous peats do not shrink and crack on drying to the same extent as the black, well humified and amorphous peats.

Lines and Neustein (1966) condense these classes to

1. Pseudo-fibrous - low aeration and high shrinkage
2. Fibrous - high aeration, low shrinkage
3. Amorphous - low aeration, high shrinkage and cracking

and include the peaty gleys and peaty podsols of Fitzpatrick (1964) as problem soils on wetlands. The peat because of its origin (species), structure, texture (colloidal nature) and level of humification determines the response to drainage and a base level of productivity to which fertilisers have to be added to achieve economical production returns. Thus the forest planner quickly comes to recognise peat types whose production potential can be anticipated.

A *Molinia* peat is superior to a *Calluna/Eriophorum* or *Sphagnum* peat in broad productivity terms. A basin peat with a high *Molinia* content is indicative of good aeration just as *Juncus* content on blanket hill peat indicates a site flushed by lateral water movement. Information on past production of forests on peat may be available from buried and preserved stumps.

The low aeration status of some soil types severely limits rooting since the waste products of respiration are not removed, oxygen supply to the roots is restricted and toxic substances remain in the rhizosphere. Pearsall (1950) lists methane, hydrogen sulphide metal sulphides and phosphine as occurring under anaeraobic conditions in wet soils. Crawford (1967) and Fulton and Erickson (1964) assessed ethanol in the xylem to relate root failures to alchohol build-up in roots under waterlogging. Poor growth responses to low aeration levels are recorded by Letey *et al* (1964) for a variety of annuals. Oxygen diffusion status in organic soils is examined by Poel (1960) and Armstrong (1967) to explain bog plant distribution. Hydrogen sulphide levels in peat have been assessed quantitatively by Armstrong (1967) and qualitatively by Urquhart (1966).

WET SITE IMPROVEMENT TECHNIQUES

Water Table Manipulation

The effect of modern drainage techniques on the water table level is rapid. During the early months of drain consolidation, high water volumes must be handled. With outlet drains of adequate size the run-off following heavy precipitation can be easily led away -but proper drain alignment is vital if erosion and drain scouring are to be avoided.

The effect on water storage capacity of modern drain intensity is in some doubt. Bay (1965) and Boulter (1964) record water storage capacity for drained and undrained peats in the U.S.A. The drained peat acts as a better sponge than undrained and waterlogged peat. However the work of Hooghoudt (1950) in Holland shows that shrinking, cracking and irreversible drying of peat after draining can result in a loss of storage capacity compared with the undrained conditions. The upper horizons of the amorphous peat become an irreversibly drier layer of black sealed crumbs on top of a water-logged layer. The waterholding capacity of this layer is reduced by draining. These effects depend on the peat type since draining may improve storage capacity of a fibrous peat but will reduce that of an amorphous peat if irreversibly dried. Where precipitation and number of rain days are high however, drying seldom advances rapidly enough to produce water storage and run-off problems. Generally, the water storage capacity of drained peats is improved. Water table levels falling by as much as 50 cm. are recorded by Heikurainen (1964) and Paavilainen (1966) in Finland while comparable rates in U.K. are reported by Zehetmayr (1954), Henman (1963) and Lines and Neustein (1966). The early work of MacDonald (1945) on the Lon Mor and reported by Zehetmayr (1954) reveals a drying effect which extends only a few inches from the drain side and down from the peat surface on certain pseudo-fibrous peat types.

Current practice tends towards more intensive draining and the maintenance of as complete a forest cover as possible (Lines and Neustein 1966). Thus a typical forest drainage project in U.K. utilises deep (24 inch) cultivation to provide the planting turf, with 36 inches deep cross drains every 100 feet. A step is cut into the side of high turfs to allow plant roots to be placed in the aerated layer between turf and peat surfaces. For maximum local removal of surface water the ploughed furrows run downhill. Cross drains are aligned more or less diagonal to the contours to collect run-off and to drain the deeper soil horizons. Current drainage patterns on hill peats are shown in Figures 6, 7 and 8 and 9. A single mould-board plough is used in this illustration providing a high planting turf and increased local drainage. This plough or a deeper mouldboard may also be used for cross-draining. As the intensity of open drains increases a large proportion of the surface area becomes unavailable for planting and the risk of instability of drainside trees is increased. A variety of underground or mole drains have been tried especially at the Glenamoy Peat Research Station in County Mayo, Ireland. These have a slit which is kept open by filling with gravel leading to an underground tunnel or perforated plastic pipe. A variety of machines are now available for the formation of this drain type but the effect on water table levels is not yet known. Provision of a planting turf is not part of this machine operation.

Figure 6. Ploughing, single mouldboard.

Figure 7. The single mouldboard plough

Figure 8. Single mouldboard plough in raised position; tractor fitted with wide tracks.

Figure 9. Wet site improvement on blanket peat showing pattern of cross-drains and access rides.

Planting site improvement

From the Belgian turf methods first employed on peatlands in this country in 1910 by Sir John Stirling Maxwell came the thin sliced turf of Anderson (Zehetmayr 1954) who placed the roots in the well aerated sandwich between turf and peat surfaces. The effect on growth rates was immediate, but the early workers were quick to observe that rooting was restricted to the turf. The windblow that followed often involved a whole line of trees as the turf was simply overturned. On exposed locations the spaced turfs dried, cracked and eroded exposing a stilt-like structure of superficial roots. Under conditions of excessive drying, fissures and voids (Binns 1959) developed in deep peat which reduced root anchorage.

The provision of an aerated planting site is necessary for establishment of spruce on wet sites. Turf planting provides such a rooting medium above the water table. The upturned turf suppresses competing vegetation. Site improvement techniques, draining, fertilising, and sheltering are also of benefit to the competing vegetation, so there is an immediate response of luxuriant growth of bog species especially the heathers, grasses and rushes. The upturned turf is therefore an important part of the control of competition for rooting space, light and nutrients.

The top of an upturned turf is not necessarily the preferred or "safe site" (Harper, Williams, and Sagar 1965) that random seeding might select and it presents problems in exposure because of its position above the surrounding ground level, Rennie (1956). The stepped turf which developed from the need to put plant roots in the aerated sandwich with high turf patterns may be a better example of a "safe" site.

EFFECTS OF AMELIORATION TREATMENTS

Short term

Water table response to draining is rapid, aeration of the planting turf occurs and the moisture content of the rooting zone decreases. The large volumes of water handled by the drains lead to erosion of the drain network and the filling-in of drains. The first three years following treatment often lead to as much as a $\frac{1}{3}$ loss in drain depth (Granfield, 1965) (Lines and Neustein 1966). The roots respond to initial site improvement by spreading along the turf ribbons. It is not until later that they ramify across the space between turfs or beneath ploughed furrows. The roots faithfully follow the aeration gradient and will extend up the gradient or across it but seldom down into the undisturbed peat. A few growing seasons following drainage the onset of peat drying and shrinkage can be seen and surface cracking is evident. Along drainsides the level of lateral water movement can be detected and distinct textural horizons are revealed. The bare peat -surface once cracked and locally dried can be colonised by vegetation more demanding than the first sedges and mosses. Figures 10, 11 and 12 illustrate this on basin peat at Flanders Moss. Since the cracks

Figure 10. Peat cracking in a double mouldboard furrow

Figure 11. Peat cracking with drying of algal colony.

Figure 12. Peat cracking after heavy rain.

stay open after re-wetting an important local drainage effect develops.

Short term effects of forest drainage were most encouraging to the early workers and the need for deeper drains and more intensive spacing was not immediately apparent. The progressive drying effects and the scope of long term changes in peat after draining are only now evident and are reviewed below.

Long term effects

Inspection of older spruce stands established on drained peats shows a particular form of microtopography. That is, the ground surface dips gently between stems. A network of superficial supporting roots is evident and the buttress of the stems is exposed. This is caused by peat shrinkage. A close inspection of the organic soil horizon shows that there are fissures and voids which often permit a hand and arm to be thrust among the tree roots. The whole root system is felt to swing as the trees are moved by wind and this action may pump mineral soil onto the peat surface. Steel rods anchored to the mineral soil below drained peats have metered shrinkage of 6 inches in the first 10 years.

The irreversible drying of peat with accompanying shrinkage was examined by Binns (1959). His work on forested peatland in Scotland indicated shrinkage ratios of 20% on ovendrying at 87°F and a marked degree of irreversible drying was achieved. He also pointed out that irreversible drying was sometimes difficult to detect in the field since the root network held up the peat and shrinkage then led to formation of voids beneath. Hooghoudt et al. (1960) theorise that irreversible drying may be caused by a number of reactions. Waxes and resins from the organic matter may effectively seal off peat particles. The cells on the outside of the peat may collapse on drying to form a varnished seal. On gley soils with high iron content, the peat particles may be coated with iron oxide during drying. The net effect is to change the peat structure to a crumby aggregate of hard black particles which do not rewet. These are easily eroded by wind and water and often break off from the planting turf to expose the superficial tree roots. Frost movement of irreversibly dried organic horizons is a serious effect during seedling establishment. Amorphous well decomposed surface peat layers are most susceptible to this erosion.

On the other hand, the improvement of structure, the cracking and fissuring of drying peat, leads to a progressive and important local drainage effect. The horizontal layering of organic horizons is broken up and effective rooting depth is steadily increased. Binns (1962) compares the mineralisation rate of a variety of turfs which give an encouraging indication of long term benefits. He reports greater mineralisation of nitrogen on large turfs which is accentuated by the addition of phosphatic fertilisers.

EFFECTS OF TREE CROP

Lowering of the water table

Early prescriptions for drain intensity took into account the drying effect of a tree crop. The "biological pump" as it was known was expected to take over much of the load from drains. This assumption was reasonable in the light of felling experience on wetlands when removal of the canopy or 'pump' resulted in a rise in the water table. However, this did not always occur and where drain maintenance has been neglected, rapid soil re-wetting has followed. It is difficult to separate the components of the water cycle in wetlands. The tree cover increases transpiration and interception of precipitation to give increased evaporation. The ground cover is protected from the sun and surface evaporation decreases. The surface conditions are cooler and more humid. However the work of modern researchers shows that the water table rises rapidly in response to felling. Heikurainen (1967) records 40 cms. rise following clearcutting or thinning. Wilde et al. (1953) record a rise of 14 inches following cutting of aspen in Wisconsin. Craib (1929) and Binns (1959) warn of over-draining where the overwood can contribute to drought mortality of natural regeneration during tension periods of short duration.

Vegetation suppression

One of the aims of wetland ploughing is the suppression of vegetation at the planting site. From canopy closure the stand fulfils this role. In the intervening period, up to 16 years, vegetation suppression depends on a variety of site factors, the planting spacing, and the degree of cultivation. Until canopy closure occurs weed control using herbicides may be necessary to combat the luxuriant growth of competing vegetation which results from site improvement treatments. Growth of heathers, especially Calluna vulgaris and Erica tetralix can be important growth checking factors (Handley 1963). Mature stands of Sitka spruce are associated with a clean forest floor and a carpet of mosses especially Plagiothecium spp. Into openings in the canopy however, come the components of the original ground cover, with some indicators of site improvement such as ferns, rushes and finer grasses.

Windblown gaps larger than 1/20 acre are quickly colonised by a vigorous growth of grasses, rushes and small herbs as increased light and abundant moisture stimulates their growth. This provides a further problem for second rotation regeneration establishment. It points to a need for canopy control for vegetation suppression.

NATURAL REGENERATION

A feature of the windblown gaps, recent fellings, and heavy thinnings in Sitka spruce on wetlands is the appearance of natural regeneration. Stand treatment studies for tree growth improvement, regeneration trials of several species, and of establishment methods including broadcast and spot seeding are reported by the Forestry Commissioners. In his summary, Wood (1966) indicates that greater attention should be paid to this regeneration and a study of its status undertaken. Professor Bonnemann (1967 pers. comm.) of Göttingen University notes the appearance in Germany of natural regeneration of spruces on wetlands which is an embarrassment to a local forest management committed to artificial regeneration.

Sitka spruce stands visited by the writer in U.K. and Germany to review regeneration status all supported a well-stocked (more than 33% by milliacre quadrats)[1] population of natural seedlings. These appear to be vigorous and by the time they reach 6 years old are well established. The overwood is able to sustain ground conditions on wetlands which are receptive to spruce seeding. A preferred location for seedlings is on forest roadways which provide a mineral soil seedbed but this is apparently because of a combination of factors such as light, temperature, vegetation competition and possibly ease of observation. Some of the conditions favourable to natural regeneration of Sitka spruce were studied at Bangor University by Howells (1966). He stresses the relative importance of a moisture conserving substrate and found litter seedbeds lacking in this aspect.

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1. Milliacre stocking represents the percentage of 1/1000 acre surveyed quadrats with at least one seedling.

DISCUSSION AND SUMMARY

The amelioration techniques currently in use in wetland forestry result in forest growth improvements. The treatment aims are: lowering of the water table, provision of a well-aerated planting site, and vegetation suppression. Ploughing provides the necessary inverted turf and cross draining lowers the water table and intercepts surface run-off. The use of modern tractors pulling heavy ploughs combines the several aims of treatment in one operation pass. The planting site is uniform and extends along long lengths. Planting of the area is thus simplified and a high rate of planting can be achieved. Variability in peat depth and the nature of the underlying mineral soil on blanket hill peat demands a more careful site survey. Modification to standard equipment includes tines to break up subsoil layers of iron pans and iron humus podsols. Draining to the first mineral soil horizon is often sufficient to intercept lateral water movement between the organic and mineral soil horizons. Below this level, it may be more difficult to manipulate water in the mineral soil.

Draining peat lands produces rapid short-term effects. Changes in water table level, moisture content, water storage capacity and planting site aeration are immediate. Tree growth responses are encouraging. Provided the drain layout is efficient, short-term disadvantages such as erosion can be avoided. The long-term effects are less well known and understood. Without proper maintenance, drains slough off at sides and corners and fill with litter. Re-wetting will occur which may kill newly developed roots, and windblow, especially of drainside trees, becomes a greater hazard. Wind stability on drained peat lands is disappointing. The roots remain superficial and where deeper rooting is stimulated the effective rooting depth may be reduced by surface shrinking. Binns (1959) suggested that drains might be allowed to degrade to offset over-drying effects. Although the water table may be lowered by as much as 36 inches, the tree roots seldom get below 18 inches because of the impermeable nature and poor aeration status of some peats.

Regeneration of spruce for the second rotation on drained wetlands may be a particular problem where shallow peats have shrunk to a thin layer over impermeable mineral soil horizons. Site treatment must then be directed to the improvement of rooting in the mineral soil layers. Specialised equipment may be necessary to handle wet sites after a rotation of drainage and tree cover.

The tree crop is more or less effective in adding to the draining and drying processes on improved wetlands. Ground vegetation is suppressed from canopy closure to first formation of gaps in the canopy. Then invasion is rapid and reflects the original component vegetation together with more luxuriant growth and some indications of improvement, especially fine grasses and less tolerant herbs. Before vegetation colonisation and soon after stands are 30 years old, an abundant population of natural seedlings is commonly observed. This indicates a distribution of suitable germination sites and a promising potential for restocking, provided survival and growth rates are maintained. Day (1957) has discussed Sitka spruce in the light of its performance throughout its natural distribution in the Pacific Northwest. Natural regeneration occurs on bogs where rotten wood provides a seedbed raised above the water table yet in capillary contact with it. Seedling were also noted on disturbed soil where upturned wind-blown roots provided a receptive seedbed.

The necessity for wet site afforestation and the improvement of productivity on forested wetlands is an expression of pressure on land-use in the Northern Coniferous Forest Zone today. In the United Kingdom in particular this has led to the development during the last 30 years of a highly specialised technology for wetland afforestation and particularly the utilisation of peat for forest growth. The aims of site improvement techniques remain the same as at the outset of this effort.

These treatments together with the application of phosphatic fertilisers are sufficient to maintain vigorous growth of Sitka spruce and Lodgepole pine provided other site factors such as climate and topography, especially elevation, are not limiting. Early growth rates can be maintained by subsequent addition of fertiliser but older stands are susceptible to windblow because of the exposed nature of the sites available for forest use and the shallow rooting of the trees. Some of the long term effects of drainage of peat such as irreversible drying, shrinking, and cracking do not always improve the rooting effectiveness as might be anticipated and surface erosion of peat, exposing roots and reducing effective rooting depth, is a serious problem. Rooting is often restricted to the aerated ribbons of planting turf and roots extend only slowly to the peat below the turfs.

Regeneration of existing spruce stands on wetlands is a current problem since the early plantations on peatlands, though not yet mature, are being blown down. This windblow is now being intensively studied and a variety of hazard ratings have been developed based on examination of blown stands and on tree pulling studies on a soil type range. Knowledge of these dangers and advances in treatment techniques for afforestation have led to further confidence in successful amelioration of wet forest sites. However the basic problem is still effective rooting depth, and this study is an examination of some soil factors limiting rooting and satisfactory seedling growth on peat, the demonstration of their effect under controlled conditions and an assessment of current site improvement patterns in the light of these limitations.

OBJECTIVES

There were three main objectives of this investigation. The first was to examine the response of natural spruce seedlings to wet site improvement and to assess aeration conditions limiting root growth and penetration. The seedlings provide an index of preferred conditions assuming that seedfall is even. An examination of their survival, growth and distribution on a variety of seedbed types was planned.

The second objective was the study of seedling performance under controlled conditions on a range of peat moisture and aeration regimes which would encompass the known range of conditions on the potentially more productive hill peat soils.

Thirdly the investigation was to examine conditions for transplant growth created on current operational trials of peatland afforestation, on basin peats to determine the distribution of the known "preferred" sites under this extreme of the wet site situation.

A final objective is to examine the silvicultural implications of these seedling responses to wet site improvement. Regeneration for the second rotation and current afforestation techniques are considered.

To meet these objectives three study areas, shown in Figure 13, were selected. Natural seedlings were examined at the Forest of Ae on blanket hill peat. Current peatland afforestation on deep basin peat was surveyed at Flanders Moss and to a lesser extent at Eddleston Moor Peat Demonstration Area.

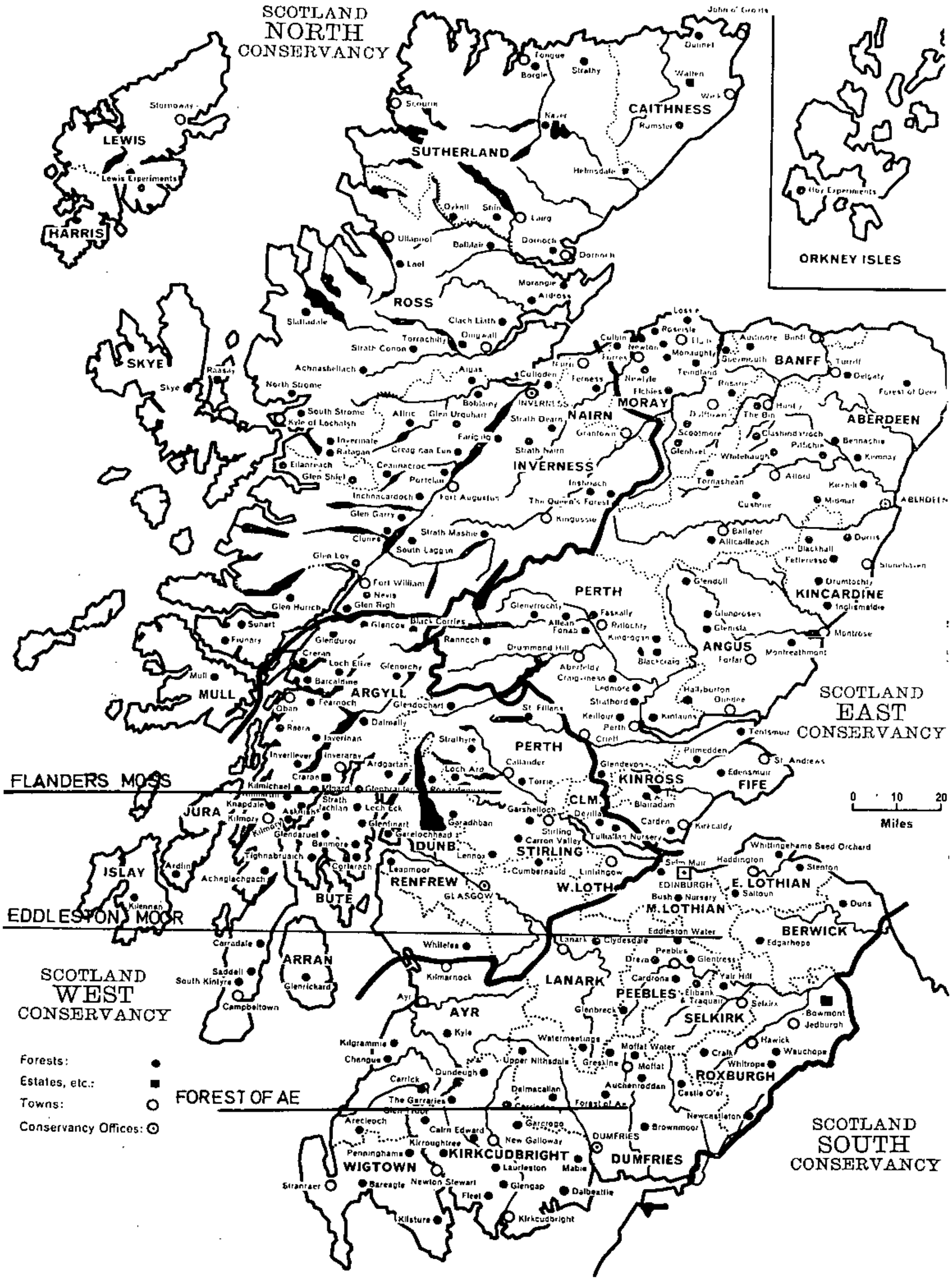

Figure 13 Study area locations

SITE SELECTION FOR REGENERATION STUDIES

Regeneration of Sitka spruce in Windblown gaps

A feature of Sitka spruce stands planted between 1920 and 1930 on spaced turfs on wet soils is endemic wind throw at age 30-35 and at about 45 feet in height. To investigate the severity of repeated small windblows in certain forest compartments thought to be at risk the Forestry Commission Research Branch initiated a series of studies. These comprised two main lines: to establish windthrow hazard ratings based on stand development and soil type, and to assess the severity of the initial blow on the potential for further spread of the damage area.

It was soon apparent that shallow rooting and low resistance to windblow were features of the peaty sites especially peaty gleys and deeper peats, (Fraser and Gardiner 1967). Small openings in the forest cover involved a greater perimeter at risk per unit area and perimeter trees were susceptible to further windblow from prevailing winds as well as storm winds, (Neustein 1968).

The problem of restocking windblown gaps was examined at the same time and openings in the forest of regular size were created to study these aspects of the problem. The Forest of Ae in the Scottish Border Uplands and Redesdale Forest in Northumberland were selected for this purpose. The growth of planted stock in 4 gap sizes, i.e. 0.1, 0.3, 1 and 10 acres, is measured periodically. A well distributed population of natural regeneration of Sitka spruce was soon evident. A feature of the natural regeneration was its vigorous growth, needle size, and healthy colour.

These sites at Ae and Redesdale were among several visited in 1966 during a preliminary survey of suitable areas to study wet site amelioration effects. The following brief notes were recorded during the survey:

Corrour - Inverness-shire.

Seedlings were rooted in raw spruce humus and underneath were voids caused by peat shrinkage during the last rotation.

Lennox - Stirlingshire.

Very heavy grass competition in gaps. A massive blue clay lay under the shallow peat. Rooting was restricted to organic matter.

Moorburnhead - Roxburghshire.

Regeneration stocking increased from stand margins, then decreased because of smothering in grass competition.

Canonbie Estate - Dumfries-shire.

Regeneration was noticeable in groups on exposed mineral soil from roadways and upturned roots.

Kershope - Northumberland.

Regeneration was rooted in surface peat layers below which (14 in.) was a massive gleyed stony clay.

Newcastleton - Roxburghshire.

Regeneration was rooted in organic matter below which (9 in.) was an indurated iron rich layer.

Kielder - Northumberland

Regeneration was rooted in spruce litter below which was a gley and at 12 in. a complete thin iron pan.

Ae - Dumfries-shire

Regeneration was rooted superficially on a wide variety of peaty soil types. On some soils windblown trees had peeled off the peat layer down to mineral soil, in other cases the roots held and the stems snapped.

To compare regeneration status at these sample locations a north-south transect was used across "typical" or interesting areas. Stocking levels in excess of 30% by $\frac{1}{4}$ milliacre quadrats were normally encountered. Seedling numbers per acre based on these samples are exaggerated since the unstocked areas are not included. A stocking of more than 1,000 established plants per acre is indicated although the seedlings have a markedly clumped distribution around "preferred" micro-seedbeds.

The primary response of the natural seedlings was apparently to insolation since vigorous growth occurs along roadsides, logging racks and in windblown gaps. Growth and vigour of seedlings is in accord with the observations of Fairbairn (1967) and Howells (1966) who recorded increased growth of Sitka spruce seedlings up to 70-100% of full insolation.

Increased insolation on wet sites involves higher ground temperatures, evaporation rates and more rapid drying of the rooting medium. Locally the microseedbed is constantly changing in moisture status. Microtopography becomes important under these conditions. Hollows are cold and wet, ridges are hot and droughty, (Harper, Williams and Sagar 1965, Howells 1966). However sufficient safe sites are available to produce the regeneration establishment which was observed at all locations.

Day (1963) discusses the importance of microseedbed types in relation to adverse microclimatic factors. His findings for spruce seedlings on the east slopes of the Rocky Mountains are an extension of the more basic relationships established by Harper, Williams and Sagar (1965). Harper et al used seeds of annuals to examine microtopography in pots. They rated each surface according to its texture or roughness and qualified "safe sites" for the experimental species. These were associated with rough textures unless evaporation was limited. Day's assessment of natural spruce seedlings showed that under severe climatic conditions germination was best on such moisture conserving sites as rotten wood, and mixed mineral and organic soils; also that cool slopes and the shade of stumps, stones and logs were favoured sites for good survival and growth.

If an even seed fall is assumed then the subsequent distribution of natural seedlings reflects the arrangement of "safe sites" for growth. Further, the growth of the seedlings can be used as a phytometer (Clements 1924) or index of site conditions. The well-established seedlings observed in the forest areas visited during the early stages of this investigation presented a most useful guide to favourable conditions for spruce growth on wet sites and it was decided to use this method to assess the effects of amelioration treatments in established forests.

Information supplied by the Forestry Commission Research Branch (Neustein 1966 pers. comm.) indicated that the weed-free seedbed beneath dense Sitka spruce stands on blanket peats provided an adequate substrate for germination but insufficient light for subsequent growth. The seedlings became well established only in gaps and at a rate which pointed to immense losses during the first 4 growing seasons. Studies were initiated in 1966 to monitor these survival rates (Neustein 1968) and the early results of that survey are utilised in this investigation. The potential of these populations of natural seedlings is now being examined by the Forestry Commission Research Branch in the light of a wind-firm rotation of only 40-50 years. MacNeill (1962) discusses this potential with regard to the very serious vegetation competition which can be observed in gaps in the existing spruce canopy. His assessment is that "presence of natural regeneration may be nothing more than an absence or weakness of competitors".

Survival and subsequent growth is another matter. It is not the object of this investigation to assess the possible use of natural regeneration in Sitka spruce forests on wetlands but it would be a serious omission to overlook the very high stocking levels encountered.

At the Forest of Ae and on a variety of soil types a series of circular clear-felled gaps was created for the Research Branch, Forestry Commission, in Sitka spruce stands, which had been turf planted in 1928-1932 on wet upland sites on shallow blanket peat. Experimental establishment was completed in 1962, drains re-opened, and re-planting with a variety of promising wet site species finished. Windblow studies began. A healthy population of natural Sitka spruce seedlings followed good seeding in 1963, 1964 and 1966. By 1966 advance growth of Sitka spruce seedlings, stimulated by canopy opening and drainage began to interfere with routine measurements of planted Sitka spruce. It was noticeable that the natural seedlings looked more vigorous than the transplants.

The Ae sites at 700-950 feet a. s. l. have an annual precipitation of more than 55 inches. This has ensured that the local Silurian soil material is capped with a layer of peat from 6 to 24+ inches.

The windblow hazard survey carried out on the Ae forest soils showed that the problem was exacerbated on peaty gleys when rooting depths were severely restricted. On peaty podsols maximum rooting depths of 25.8 inches were recorded, on peaty gleys 12.5 in. maximum and on deep peats 23.0 in. maximum.

These were indicated by the following vegetation types.

Soil	Bare ground vegetation	Vegetation changes under forest cover
peaty podsol	*Molinia cearulea* *Calluna vulgaris* *Nardus stricta*	Mosses esp. *Plagiothecium* re-invasion of Juncus spp. in gaps and along rides
peaty gley	*Molinia caerulea* dominant	Mosses esp. *Plagiothecium* *Sphagnum palustre.* In gaps slow invasion of *Juncus*
basin peat	*Juncus effusus* *Sphagnum palustre* *Polytrichum commune*	Mosses, as above

Pyatt (1965) in the Ae forest study and Fraser (1967) at Kielder forest note that ploughed and drained land had more resistance to stem pulling and that rooting was significantly deeper on drained areas.

STUDY AREA SELECTION FOR SEEDLING ROOTING RELATIONSHIPS

Natural seedlings were found in abundance on these three wet soil types and gaps were selected at Ae (figures 14 and 15) which allowed comparison of seedlings under the spruce canopy and in the open, and in gaps not confounded with fertiliser application treatments.

Figure 14. 0.1 acre circular gap, Ae Forest.

Figure 15. Natural seedling of Sitka spruce on a stump-base micro-site.

The constraints were:

Sitka spruce at the second growth stage of development.

Natural regeneration at an established development stage.

Wetland soil types representative of wet site improvement efforts to date.

Uniform coupe size to allow valid comparison of growth responses.

No treatment other than draining, turf planting and canopy opening size.

Three 1/10 acre circular gaps therefore were selected in 40 year old Sitka spruce stands, turf planted in the Forest of Ae in 1928-1932, and on peaty podsol, peaty gley, and deep peat soils. The selection of these gaps was followed by that of an area outside the forest which was undrained and unplanted. Here it was hoped to establish datum levels for soil moisture and aeration. A description of the areas follows.

1. Gap C13 On peaty gley soil 15" peat over gritty clay

Stand: 50 feet high, P1928
130 sq. ft. basal
area/acre.

Soil:*

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* Soil horizon nomenclature follows:

The Soil Survey of Great Britain, Department of Agriculture and Fisheries for Scotland, 1967.

Horizon	Depth	Description	
L	0-1 ins.	spruce litter, moss roots.	
F	1-2 ins.	decomposing litter with fungal mat.	black/brown
H	2-11 ins.	well decomposed greasy peat.	black
A_{2g}	11-12 ins.	narrow mixed O. M. /M. M.	dark brown
B_{1g}	12-13 ins.	abrupt change to gritty stony layer with bonding of heavy clay.	grey/yellow
B_g	13-22 ins.	predominantly grey mottled gritty clay. Blocky	grey/blue
C_g	22+	predominantly red mottled gritty clay merging at 30 inches with shattered bedrock	yellow/brown

Vegetation: Grasses predominant. 100% ground cover.

Birch Betula pubescens	
Oak Quercus intermedia (2 seedlings)	
Calluna vulgaris	abundant
Vaccinium myrtillus	sparse
Chamaenerion angustifolium	occasional
Juncus effusus	
J. conglomeratus	
J. squarrosus	
Galium saxatile	
Deschampsia caespitosa	
Molinia caerulea	abundant
Agrostis spp.	
Polytrichum spp.	

2. Gap C3 on peaty podsol. Peat, 7-8 inches over weak iron rich podsol.

Stand: 54 feet high, P. 1931
200 sq. ft. basal area/acre

Soil:

Horizon	Depth	Description	
L	0-½ ins.	shallow needle layer	
F	½-1½ ins.	decomposing litter, matted	black/brown
H	1½-8 ins.	old Molinia peat, greasy	black/brown
A_1	8-9 ins.	diffuse humus stained silty layer.	brown
A_2	9-11½ ins.	bleached sandy gritty layer	grey/black
B_{1h}	11½-13 ins.	diffuse humus stained clayey	black
B_{2t}	13-25 ins.	red stained gritty clayey, massive-blocky with gritty lenses and old root channels	red/brown
G	25-36 ins.	blue mottled compacted stony clayey	grey/blue
C	36+	shattered bedrock	grey/yellow

Vegetation: Grasses predominant, 95% cover with bare peat patches.

<u>Deschampsia caespitosa</u>	
<u>D. flexuosa</u>	abundant
<u>Molinia caerulea</u>	many clumps
<u>Eriophorum angustifolium</u>	in old drain channels
<u>Vaccinium myrtillus</u>	sparse, on drain spoil
<u>Juncus articulatus</u>	occasional
<u>Galium saxatile</u>	densely matted carpet
<u>Polytrichum spp.</u>	in open
<u>Plagiothecium spp.</u>	under stand

3. Gap C9 on deep peat. Peat, 15-36 inches over heavy gritty clay.

Stand: 45 feet high, P. 1929
140 sq. ft. basal area/acre. North of stand blown out to 40 sq. ft. in 1968.

Soil:

Horizon	Depth	Description	
L	0-½ ins.	sparse needles roots and leaves	
F	½-1½ ins.	raw humus in matted layers	black/brown
H	1½-19½ ins.	black greasy peat, more brown and fibrous lower down. Strong smell of H_2S	black
B_{1h}	19½-20½ ins.	black stained layer. clay	black
B_{2g}	20½-36 ins.	blue/grey mottled massive clay with gritty lenses	blue/grey
C_g	36+	blue stained shattered bedrock	blue/yellow

Vegetation:

Birch
Rowan
Vaccinium myrtillus
Chamaenerion angustifolium
Erica cinerea
Potentilla erecta
Galium saxatile
Molinia caerulea
Deschampsia caespitosa
Polytrichum commune on drain spoil
Plagiothecium under the stand

Stations were selected at 1 chain intervals along the 4 chain control transect and water table bore holes established every ½ chain. Brief notes on these samples appear below:

North.	Soil	Vegetation		
Station 1	Peaty podsol	_Nardus_	-	_Molinia_
" 2	Peaty gley	_Molinia_		
" 3	Peaty gley	_Juncus_	-	_Molinia_
" 4	Peat	_Sphagnum_	-	_Eriophorum_
" 5	Peaty podsol	_Molinia_	-	_Tricophorum_

North-south sample transects were established across the centre of the three gaps. At the centre and at ½ chain intervals from it, sample stations were set up to monitor soil moisture, aeration and water table levels. Seedlings were examined along the 2 chain transect lengths on a strip 5 links wide to provide 40 ¼ milliacre quadrats. The three gaps selected for the study of soil moisture and aeration characteristics provided, within a

Figure 'B'

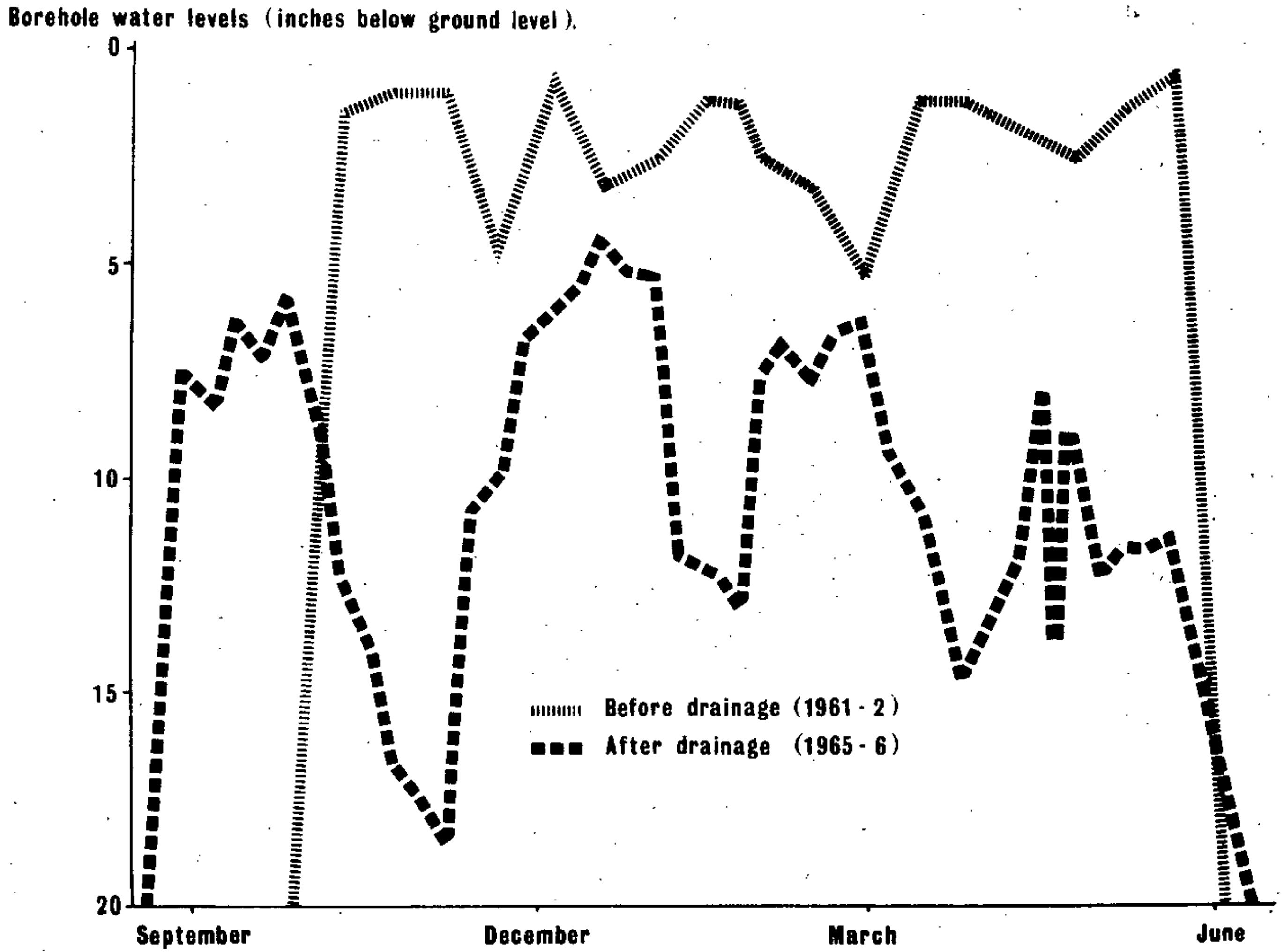

Figure 2. Mean borehole water levels before (1961-62) and after drainage (1965-66) for Halwill Experiment 5. The total rainfall during the period shown in the two years was respectively 39.5 ins. and 42.5 ins.

small area, a range of wetland situations with a high growth potential. The control area served as a datum to indicate improvement attained by the original attempt at wetland improvement and afforestation. Thus four soil moisture regimes were sampled.

ASSESSMENTS

WET SITE CHARACTERISTICS ON THREE SOILS.

A major part of the assessment of wet site improvement for spruce vegetation was concentrated on the three soil types at Ae. It was planned to sample key soil factors over a growing season to give some account of conditions for spruce seedling growth and to help explain seedling rooting responses to wet soil conditions. Throughout the 1968 growing season from April to September, soil conditions were monitored and climatic records maintained. These were: Soil moisture content, depth to water table, aeration levels, and distribution of sulphides. Available pore space was assessed to support soil aeration studies at one period of measurement. Rainfall, relative humidity and air temperatures were recorded during the summer.

Soil Moisture Content

Introduction.

In a review of pertinent literature, Cope and Trickett (1965) list 95 references on the measurement of soil moisture. It is not surprising therefore that many works relating plant growth response to soil moisture use a wide range of methods.

To a great degree this work is associated with soils at the dry end of the moisture scale and with high soil moisture tensions. Thus Livingston and Ohga (1926) followed the summer march of soil moisture by repeated weighings of porous porcelain containers filled with water which were allowed to come into equilibrium with the soil, re-weighed, recharged and replaced. These "soil points" had lost 85% moisture when spruce "wilted". Craib (1929) followed soil moisture gravimetrically and demonstrated that moisture stress induced by the overwood can contribute to drought mortality of natural regeneration during tension periods of short duration. Soil moisture content in the critical 0-0.85 atmosphere range can be measured using tensiometers, an advance on soil moisture points (Scofield 1945). Scofield compares gravimetric measurement from fixed volume samples, electrometric potential of plaster of Paris blocks and tensiometers. He concludes that the tensiometric method appears to be the most accurate and the most sensitive for measurement of available soil water within the optimum range of plants although limited to tensions less than 1 atmosphere. However many workers have found electrical resistance a satisfactory method provided good contact could be maintained with the soil (Fraser 1957) and that there are not high concentrations of soluble salts (Marshall, 1959). A gravimetric method is described in the recent work of McQueen and Miller (1968) for extensive surveys involving large sample numbers. Standard treated filter papers are allowed to come to moisture equilibrium with soil in sealed containers at 20°C. From the wet weight of the calibrated papers the soil moisture content is calculated.

In peat soils there are some basic problems associated with moisture assessment. Peat at 15 atmospheres still retains over 100% moisture by weight (Binns 1959) and reports such as that of Heikurainen, Paivanen and Sarasto (1964) discuss soil moisture response to groundwater table in terms of 400-500% moisture content. The importance of the volumetric expression of water content of organic soil is stressed by Boelter and Blake (1964) because of the high moisture retention properties of peat. The wet volume basis is recommended because of the shrinkage of peat on drying.

Methods

At the outset of this examination high tensions were not anticipated and a method was selected by which rapid comparison could be made of soil moisture status in the rooting zone of natural seedlings and between sample stations. A soil core was extracted at each of five stations in the windblow study gaps and along the control transect. The known rooting zone of seedlings was sampled. This core was trimmed to fit and placed in a 3-inch deep porous porcelain battery cup, with a minimum disturbance to the horizons within the core. A wire gauze cap was fitted to the cup to prevent rain splash. The cups were then placed back in the sample holes flush with the surface and left for a week to reach equilibrium with the moisture of the surrounding soil. At weekly intervals throughout the summer these containers were lifted, weighed and replaced. At the conclusion of the study they were removed and weighed oven-dry at 105°C. From this value the full summer range of soil-moisture was calculated. The method assumes that there is good contact between cup and surrounding soil and that the porcelain allows free transfer of moisture. Sampling in the usual way beside the cup containers confirmed that these values were in close agreement. By the end of July some of the samples felt loose in the containers and they were replaced to maintain good contact.

TABLE 2

SEASONAL MARCH OF SOIL MOISTURE CONTENT

(based on % wet bulk volume)
(5 stations per transect)

Date	Peaty Podsol	Peaty Gley	Peat	Control
April 11	55.33	60.77	64.10	-
April 18	68.89	61.05	69.33	72.58
April 25	61.97	66.17	68.50	73.65
May 2	70.22	66.03	72.86	75.36
May 9	64.06	69.16	75.87	76.19
May 16	69.21	71.91	71.72	73.05
May 23	61.59	64.41	68.51	66.83
May 30	60.89	63.56	67.82	65.50
June 6	59.27	61.11	65.91	64.47
June 13	57.46	56.58	58.57	59.43
June 20	51.46	50.41	55.28	54.54
June 27	65.17	69.62	67.62	65.18
July 4	54.22	61.30	65.69	70.48
July 11	70.60	72.97	69.81	75.65
July 18	65.75	66.67	62.67	72.22
July 25	62.09	61.87	60.44	69.11
August 1	58.13	56.38	52.16	62.86
August 8	64.87	41.71	40.51	52.95
August 15	65.62	63.87	56.42	60.76
August 22	72.06	71.81	67.11	66.89
August 29	61.27	60.80	58.22	62.76
September 5	66.22	65.84	61.88	65.57
15 Atmos.*	30.72	31.7	31.66	38.49
	$\bar{X}$ 63.02	62.91	63.68	66.95

* 15 Atmospheres tension was applied in the laboratory pressure membrane apparatus to fresh field samples.

Analysis of variance for moisture content.

Source of variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Dates (V)	21 (V-1)	15631.9027	744.3763	7.8490**
Soils (B)	3 (B-1)	873.3862	291.1294	3.0698**
Interaction	63 (V-1)(B-1)	3960.8285	62.8703	0.6629 NS
Residual (for K determinations)	352 (BV(K-1))	33382.5744	94.8369	
Total	439 (BVK-1)	53848.6938		

Results

Soil moisture levels are presented in Table 2 showing values based on wet volume. Values approaching 15 atmosphere tension level are underlined. In Figure 6 mean monthly levels for the three soils, are presented together with other soil moisture and aeration characteristics. Throughout the summer the descending order of moisture status is: peaty podsol, peaty gley, peat, control transect; except in the midsummer months of June and July when the highly humified peats of the top 3 inches in peaty gley soil and the peaty podsol retain more moisture than the deep peat, and on June 27, more than the control transect.

The analysis shown in Table 2 confirms that moisture content varied significantly between soils and date of measurement and not between sample stations with soils. The range of moisture content

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* $P \leq 0.05$
** $P \leq 0.01$

This and the following like analyses are used to illustrate the distribution of variation between sources but do not necessarily provide precise estimates of the variance.

is important when water table fluctuation and subsequent aeration are considered. The values for the summer months are shown in Table 3.

TABLE 3

MOISTURE CONTENT RANGE
(% wet volume)

Soil types		April	May	June	July	August	Sept./ Oct.
Peaty podsol	Max	68.89	70.22	65.17	70.60	72.06	70.41
	Min	55.33	60.89	57.46	54.22	58.13	66.22
	Range	13.56	9.33	7.71	16.38	13.93	4.19
Peaty gley	Max	66.7	71.91	69.62	72.97	71.81	71.08
	Min	60.77	63.56	50.41	61.30	41.71	65.84
	Range	5.40	8.35	19.21	11.67	30.10	5.24
Peat	Max	69.33	72.86	67.62	69.81	67.11	69.65
	Min	64.10	67.82	55.28	60.44	40.51	61.88
	Range	5.23	5.04	12.34	9.37	26.60	7.77
Control	Max	73.65	75.36	65.18	75.65	66.89	75.65
	Min	72.58	65.50	54.54	69.11	52.95	65.57
	Range	1.07	9.86	10.64	6.54	13.94	10.08

The greatest fluctuation in moisture status occurred in August and was most evident on the peaty gley. The control transect remained consistently wet. The range of soil moisture values for the peaty gley soil during a droughty period at the beginning of August is associated with the following weather records(table 4) from a station in the centre of the gap on the peaty gley soil. The Stevenson screen containing a thermohygrograph and the rain gauge were set at ground level.

TABLE 4

Date	Rain in.	Temperature °F 14.00 hrs.	Relative humidity 14.00 hrs.	Moisture Content % (vol.)
July 25-29	Trace	-	-	-
August 1	Trace	63.5	52%	56.38
August 5	0.0	67.0	60%	
August 8	0.0	67.0	65%	41.71
August 12	0.0	57.0	80%	
August 15	0.55	57.0	58%	63.87
August 19	1.1	-	-	
August 22	0.2	56.0	90%	71.81
August 26	0.05	58.0	80%	
August 29	0.0	51.0	88%	60.80

This period reduced moisture content on all soils. By the end of the growing season the high moisture levels were re-established.

As the growing season progressed, soil reduction/oxidation products were precipitated on the porous pot surfaces. Thus orange red stains were to be found at better drained stations and deep blue and black stains on the control transect. At the north station on the deep peat sample, a strong blue/orange brown mottled pattern developed in response to a high, slightly fluctuating water table. The short time required for this gleying to develop is indicative of the intensity of such pedological processes.

Water Table Level

Introduction

Water table levels and fluctuation are a useful guide to wet site moisture regimes. In many wet site situations on hill peats this water table is a perched system close to the surface. In a few instances and usually on basin peats, it is true ground water. However, it is this superficial waterlogged layer, maintained by heavy precipitations and lateral water movement, that creates the rooting problem. Bore holes allow easy observation of changes in water level. Rutter (1955) used batteries of tubes driven down to various depths with a basal cavity punched a few inches further down, a piezometer. He noted that the deeper the hole, the higher the water rose, because the deep tubes tapped a higher potential and an associated lateral water flow from up-slope. Rutter recalls Child's (1940) comment "Water in a pit rises too high when rising and too low when falling". Similar differential responses are recorded by Leibundgut and Dafis (1963). There is rapid response with low water tables but slow response where high levels are maintained by lateral flow after rain stops. Bore hole observations form the basis of the studies by Huikari (1966) Heikurainen (1964), Holstener-Jorgensen (1967) and Fraser (1967), who have described water table responses to drainage intensity and forest cover type. Fraser's results are representative of the experience of the investigations and an extract is presented in Figure B (p. 45a) by courtesy of the author. A fluctuating water table is shown by Rutter (1955) to play an important role in flushing away toxic substances in the rooting zone. Hydrogen sulphide is very water-soluble and would be readily removed from the rooting zone. Webster (1962) confirms that fluctuation of the water table would be sufficient to remove excess H_2S and CO_2 and thus improve root respiration status. Joint research by the Forestry Commission Research Branch and the Macaulay Institute for Soil Research (Fraser and Taylor 1967) reports height growth response and survival rate increase with depth to a fixed water table.

Heinselmann's study (1961) of black spruce growth on a raised bog system in Minnesota showed that site index was significantly correlated with water table fluctuation. His findings illustrated that levels of oxygen, assessed by water table fluctuation and lateral water movement, have more influence on tree growth than depth to water alone.

Methods

At each of 5 stations on the three soils and at 10 stations along the control transect, 30 inch long, $1\frac{1}{2}$ inch inside diameter, plastic pipes were inserted in auger holes. The pipes were perforated along their length with small $^3/16$ in. round holes to allow them to tap water from all layers down the soil profile. In some cases and especially on the peaty podsol it was not practical or possible to insert the pipes below the upper horizons of the mineral soil and a maximum penetration of only 19 inches was achieved at one station on the peaty gley. All pipes extended well below the rooting zone of Sitka spruce on these soils. Using a metal tape, the distance to water level was recorded at regular intervals through the season and normally twice weekly.

Results.

Maximums, minimums and ranges of water table levels are shown for each month of measurement in Table 5. The figures are for the centre station in each gap.

Fluctuation of water table is least on the deep peat and control areas, greatest on the peaty gley. Water table level is lowest on the peaty podsol and always more than 22 inches, highest on the control area and never lower than $9\frac{1}{2}$ inches. Of the 10 control stations; 3 had surface water tables for at least some period during the summer. This did not occur on any of the drained plots. Despite the low water table level on the peaty podsol, soil moisture contents in the surface rooted organic layers remained high because of the highly humified amorphous peat horizons and the pattern of precipitation.

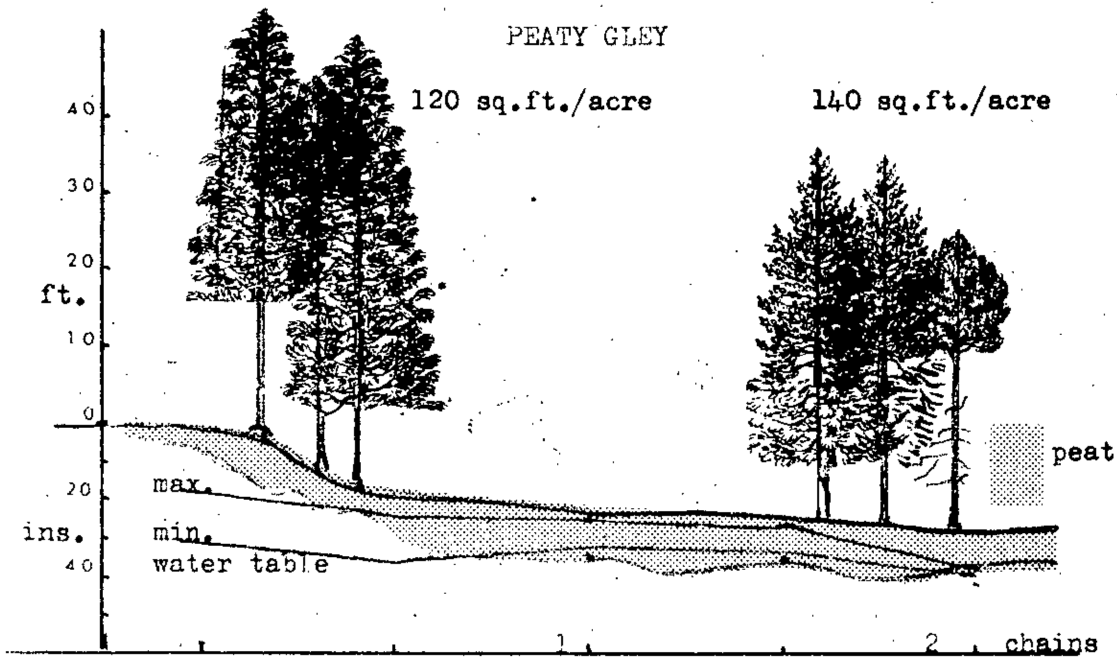
TABLE 5

DEPTH TO WATER APRIL - OCTOBER 1968

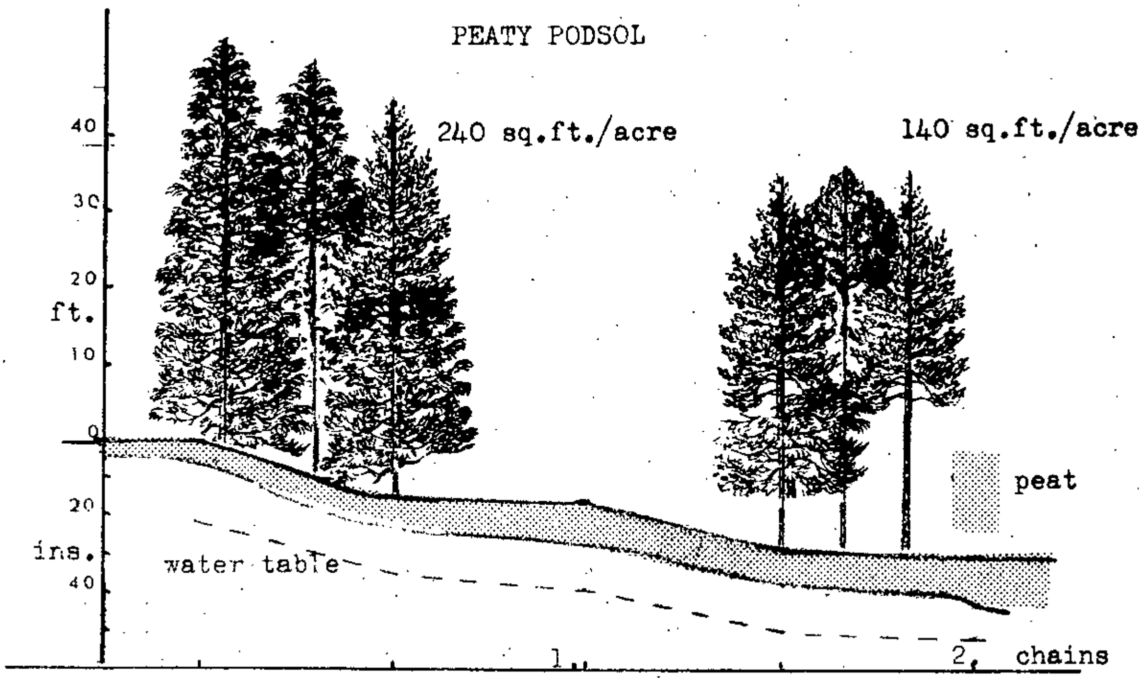
Date	April	May	June	July	August	September/October	
Rainfall	2.17	3.85	1.19	2.68	1.85	3.64	3.15
Peaty Gley							
Max.	7.0	7.0	8.0	8.0	18.0	9.0	6.5
Min.	6.5	4.0	6.0	4.0	3.0	2.5	5.0
Range	0.5	3.0	2.0	4.0	15.0	6.5	1.5
Peaty Podsol							
Max	22+	22+	22+	22+	22+	22+	22+
Min.	22+	22+	22+	22+	22+	22+	22+
Range							
Peat							
Max.	13	14½	16	15	17	14	15
Min.	10	11½	13	12½	14	13	14
Range	3	3	3	2½	3	1	1
Control							
Max.	5	5½	7	6½	9½	5½	6
Min.	1½	1½	5½	2	3½	2	4
Range	3½	4	1½	3½	6	3½	2

Variation in depth to water table and soil moisture content across the gaps is apparent in Figure 16. On the peaty podsol and peaty gley sites conditions are generally drier beneath the stand. The south stand station on the peaty gley in particular was located within 18 inches of a drainside and this is reflected in lower moisture levels. The peat site on the other hand illustrates the influence of topography since the north and south stand locations were moisture receiving sites with a consistently high water table. The north gap sample at the stand margin on deep peat was also beside a drain. Some indication of these physiographic effects is given by the profiles in Figure 16.

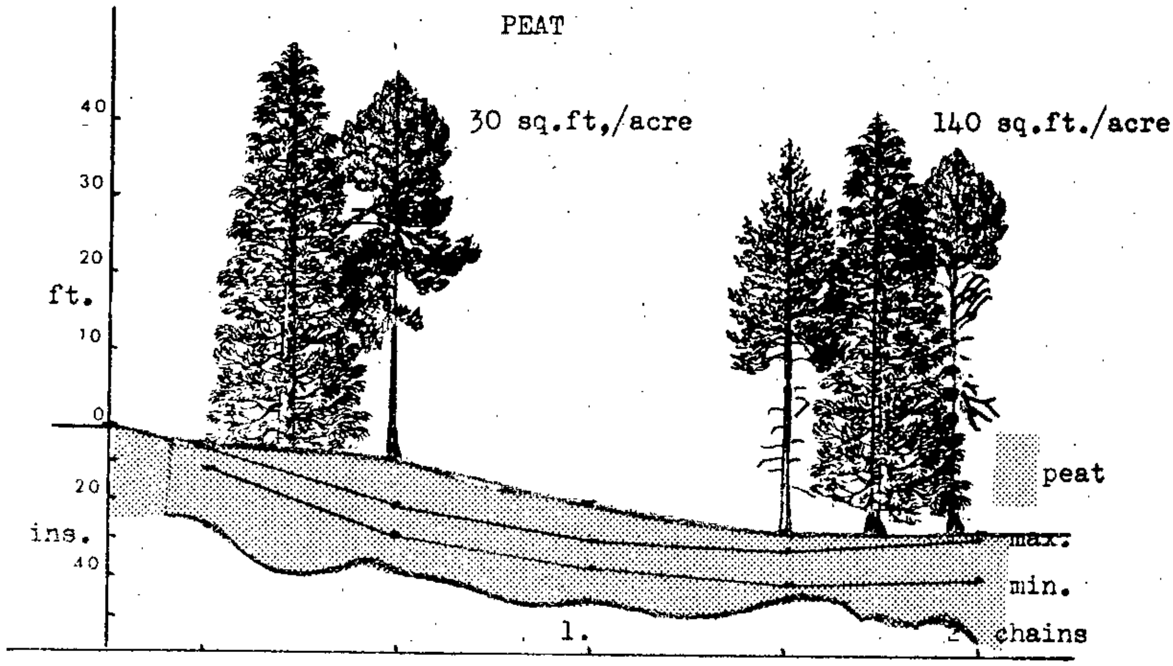
Figure 16



April							Rain 2.17 ins.
	pH						
	mV						
Water	tb	16+	14.6	6.9	6.3	15.3	Mean ins.
MC.	%	55.79	67.78	69.79	70.21	50.74	
May							Rain 3.85 ins.
	pH	3.3	3.6	3.6	3.6	3.4	
	mV	930	660	650	650	610	
Water	tb	16+	11.2	6.3	7.0	14.6	Mean ins.
MC.	%	68.06	68.28	69.02	76.70	57.69	
June							Rain 1.19 ins.
	mV	560	590	580	570	600	
Water	tb.	16+	17.0	7.3	7.9	15+	Mean ins.
MC.	%	63.57	59.84	53.18	68.97	51.60	
July							Rain 2.68 ins.
	pH	3.3	3.9	3.8	3.8	3.5	
	mV	570	670	535	600	410	
Water	tb	16+	12.0	6.6	5 8	15+	Mean ins.
MC.	%	65.12	65.95	71.19	75.09	51 18	
August							Rain 1.85 ins
Water	tb.	16+	17+	10.2	7.7	15+	Mean ins.
MC	%	66.95	63.86	62.86	67.71	43.21	
September							Rain 3.64 ins.
Water	tb	16+	11.1	6.3	5.0	15+	Mean ins.
MC	%	67.14	72.54	65.56	75.87	48.10	



April							Rain 2.17 ins.
	pH						
	mV						
Water	tb	23+	18+	22+	18+	23+	Mean ins.
MC.	%	60.32	57.73	67.19	64.98	50.74	
May							Rain 3.85 ins.
	pH	4.4	3 9	3.6	3.5	4.4	
	mV	720	690	760	810	660	
Water	tb	23+	18	22+	17+	23+	Mean ins.
MC.	%	60.26	60.63	74.03	68.83	62.22	
June	pH						Rain 1.19 ins.
	mV	630	610	585	640	595	
Water	tb	23+	18+	22+	20+	23+	Mean ins.
MC.	%	51.34	53.97	64 92	60.44	61.03	
July							Rain 2.68 ins
	pH	4.4	3.9	4.1	4.1	4.0	
	mV	370	420	380	570	580	
Water	tb	23+	18+	22+	20+	23+	Mean ins.
MC.	%	64.96	58.69	67.10	60.80	61.82	
August							Rain 1.85 ins.
Water	tb	22+	17	22+	20+	23+	Mean ins.
MC.	%	63.94	52.29	70.35	77.68	60.73	
September							Rain 3.64 ins.
Water	tb	23+	17	22+	20+	23+	Mean ins.
MC.	%	68.10	58.57	73.65	67.46	63.33	



April							Rain 2.17
	pH						
	mV						
Water	tb	2	17½	11½	8	3½	Mean ins.
MC.	%	71.48	58.68	70.16	66.35	70.16	
May							Rain 3.85 ins.
	pH	5.8	3.9	3.6	3.7	3.9	
	mV	340	640	650	620	500	
Water	tb	1½	16	13	6½	3½	Mean ins.
MC.	%	75.78	55.94	73.90	56.03	74.79	
June							Rain 1.19 ins.
	pH						
	mV	570	730	750	720	720	
Water	tb	3	18½	14½	7½	7	
MC.	%	74.52	35.72	63.89	66.66	68.42	
July							Rain 2.68 ins.
	pH	5 7	4.0	4.1	4.0	3.9	
	mV	590	550	540	580	350	
Water	tb	2	16	14	6½	5½	Mean ins
MC.	%	74.84	47.51	67.54	66.80	67.34	
August							Rain 1.85 ins
Water	tb	3½	18	9	8	7	Mean ins.
MC.	%	66.80	36.92	58.73	71.14	61.05	
September							Rain 3.64 ins
Water	tb	2½	7½	14	7	5.5	Mean ins.
MC.	%	73.33	40.00	69.05	63.50	63.50	

Seasonal mean, maximum, and minimum water table levels are incorporated in the gap profiles presented in Figure 16 and the water table records for the summer are presented in Figure 17 along with distribution of sulphides.

The amount of fluctuation on the peaty gley site is indicative of a constantly changing moisture and aeration status. The rainfall pattern ensures that the surface horizons are almost always wet.

Available Pore Space

Introduction

Russel (1949) reports that the percentage of air filled pores is a more reliable criterion of soil aeration than bulk density. It is useful for predicting the rate of gas diffusion through the soil and can be used for moisture content determination if a density of 2.60 gm./cc is assumed for mineral soil. Organic matter has a bulk density closer to 0.24 (Bay 1965). The gas-filled pores in peats are likely to have low oxygen concentrations. However it is in this portion of the soil that root respiration takes place and an estimation of free pore space in the rooting zone is a valuable assessment of aeration.

Reynolds (1957) found that Scots pine root growth was related to the effective pore space in the top 10 cms. of mineral soil with controlled high water table and a variety of compaction treatments.

Paavilainen (1966) relates root penetration of Scots pine to pore space in peat. He points out a very sharp drop in free pore space at about 10-15 cm. during the growing season which thus forms a severe limit to the rooting zone. The very high available pore space means that surface droughts may also be damaging. The maximum water table reaches above the level of mean root penetration.

Methods

Cores were extracted close to the soil moisture and water table level stations in each gap and along the control transect using a cylindrical sampler and liners. The cores were cut into three 105 cc. portions and placed singly in their retaining rings into an air pycnometer. Free pore space was determined using the loss of pressure from a fixed head of mercury. The corer allowed three samples down the profile to 7 inches to be extracted with one insertion. It is important that disturbance of the sample be minimised. Since the samples were transferred direct from the corer to the air pycnometer nearby, this requirement was satisfied.

Results

The available pore space down the rooting profile is presented for the three soils and for the control transect in Table 6

TABLE 6

% AVAILABLE PORE SPACE IN ROOTING ZONE FOR 3 SOILS (July 1968)

	Depth 0-1.3	1.3 - 2.6	2.6 - 3.9 inches
Peaty podsol Station			
1	18.0	16.0	15.75
2	36.0	24.5	12.0
3	34.0	28.5	11.0
4	29.5	16.6	18.5
5	60.0	16.0	40.5
Peaty gley			
1	32.0	23.5	18.0
2	17.0	17.0	15.5
3	27.5	15.0	12.5
4	65.0	30.0	15.0
5	39.5	27.0	13.0
Peat			
1	1.5	16.0	18.5
2	66.0	22.0	6.0
3	17.0	6.5	10.5
4	15.5	11.0	0.0
5	15.5	20.5	5.0
Control			
1	27.5	14.5	7.0
2	42.0	17.5	9.0
3	13.5	16.5	8.8
4	0.0	19.0	0.0
5	23.5	15.5	32.0

Analysis of variance

Source of variation	Degrees of freedom	Sum of squares	Mean Square	F
Depths	2	2523.4072	1261.7036	8.0109 **
Soils	3	1198.6435	399.5478	2.5368 **
Interaction	6	279.1984	46.5331	0.2955 NS
Residual	48	7559.9400	157.4987	
Total	59	11561.1891		

Treat. Means

Depth

1	29.03
2	18.66
3	13.42

Soils	Mean
peaty podsol	24.50
peaty gley	25.14
peat	15.43
control	16.40

S.E. 2.8062

Differences in pore space between depths and soils are highly significant. The main difference between the three drained soils and the control transect values occurs in the third level or 3.0 - 4.0 inches down. In all cases the available pore space at this third level is extremely low and indicative of a low gas diffusion rate. Pore space in level 2 for the deep peat is low and station 1 reflects a permanently waterlogged situation which had a maximum water table depth of 6 inches and minimum of zero during the season.

Distribution of Sulphides

Introduction

Sulphates are reduced to sulphites and to sulphides by a large group of bacteria including the obligate anaerobes. These are operative at low oxygen concentrations and can tolerate low pH levels. The oxygen deficient medium is further reduced by facultative anaerobes to give fermentation end-products such as methane. The anaerobic peat rooting medium of wetlands reduces growth in a variety of tree species (Huikari 1955). Some species perform adequately only because root adaptations avoid the anaerobic layers (Kayll 1960). Toxic effects of sulphides are discussed in rice culture by Pearsall (1950) and Mitsui (1955). Pearsall examines the fall-down disease of rice "AKI-OCHI" caused by H_2S toxicity and records methyl sulphide as a toxic product of anaerobic fermentation. Webster (1962) illustrates the effect of H_2S and CO_2 on Molinia caerulea. He assesses H_2S concentration in peat water by mixing with an iodine solution and back-titrating with sodium thiosulphate. Presence or absence of H_2S can be demonstrated by shaking bubbles of gas from Molinia roots in lead acetate solution which turns dark in colour. Webster found that bog plants were distributed in accordance with the reduction status of the soil and Molinia did not root where H_2S was present. Armstrong (1967) used a polarographic technique with a dropping mercury electrode to record, in the field, concentrations of dissolved H_2S. Also in field studies of sulphide distribution in the upper layers of basin peats, Urquhart (1966) used silver plated copper sheets inserted into the peat profile. Black-brown staining of silver sulphide took place after several hours exposure and the pattern was photocopied. The plates were then cleaned and re-used. Urquhart showed that Molinia and Eriophorum roots protected the silver plate from staining indicating that oxygen was actively diffusing from the roots to the peat. Armstrong (1967) confirms this diffusion with a platinum micro-electrode technique. While Urquhart did not quantify the staining, intense stains after short exposure indicates high sulphide concentration and poor aeration. To compare sulphide distribution as a aeration index in the spruce rooting profile, and between locations, the method of Urquhart was adopted.

Methods

Strips of silver, 12 inches long, 0.5 inch wide and 0.04 inch thick were used. They could be repeatedly cleaned without loss of silver surface area. To determine a suitable exposure time the plates were first inserted along a peat/podsol integrade investigated by Franklin (1962) at Boghall Glen near Edinburgh. At this site on a north slope, physiography, soil and lateral water movement result in a change from a podsol to a peat through iron humus podsol, gley and peaty gley, within a distance of 1 chain. An exposure time of at least 4 days was required in November to establish a pattern of H_2S staining for the iron humus podsol and 2 days for the peaty gley. This experience was confirmed on other hill peat sites before sampling began at Ae. Exposure for short intervals of only 3 hours was required at Flanders Moss in July 1968 on basin peat. No change in response with season was observed at Ae in 1968. This aspect of the method must be more carefully investigated before any quantities can be assigned.

Three days' exposure at Ae was found to be most suitable. At weekly intervals a silver strip was inserted to 10 inches depth at each soil moisture station. On removal, the plates were gently rinsed with water and photocopied to obtain a permanent record of the staining pattern. The plates were then cleaned with a "Scotchbrite" mild abrasive scouring pad before re-inserting. Since the stains were distributed down a 10 inch strip, it was possible to get a comparison between layers down the rooting profile. These records were continued from April to October.

Results

The seasonal march of staining distribution is presented in Figure 17 with water table fluctuation for the corresponding stations. Control samples are included for each soil type. The photocopy for each station each week has been placed in chronological order to illustrate the changing conditions from April to October. The photocopies were all contact prints, 12 inches long.

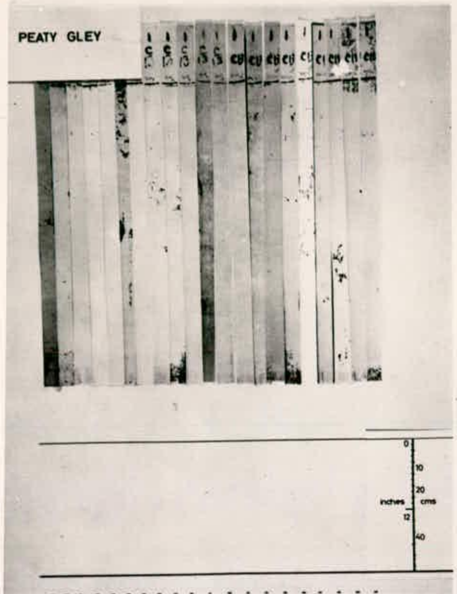
The scale refers to depth to water only. A marked variation in the levels at which sulphides occur is evident on soil types and between dates of assessment. Stations on the deep peat and control samples consistently show intensive staining. The stations on the peaty podsol show no staining other than a few intense spots. Generally, seedling roots did not extend into the layer of staining. If a rooting zone of 3 inches maximum depth is assumed however, there are locations on the peaty gley and peat site where extremely anaerobic conditions pertain for short periods during the growing season. These may be sufficient to affect root extension. The response to rainfall is immediate and a few days with a consistently high water table is sufficient to produce heavy staining. A fall in water level quickly reduced stain intensity. Double layers of stained bands occur on several occasions. It is difficult to account for such separate zones of bacterial activity which are so discrete in their effect. However the small spots appearing on the peaty gley and peaty podsol plates also indicate localised activity.

Intensity of staining was recorded in each stained area or band using a transparent dot grid. From first appearance of staining after a rise in the water table there is a gradual intensification of stain throughout the sulphide-rich layer.

The presence of sulphide staining is only generally associated with a drop in aeration levels as indicated by the

Figure 17. Silver sulphide staining/depth to water table for the peaty podsol sample and a comparable control station.

Figure 18. Silver sulphide staining and depth to water table for the peaty gley sample and a comparable control station.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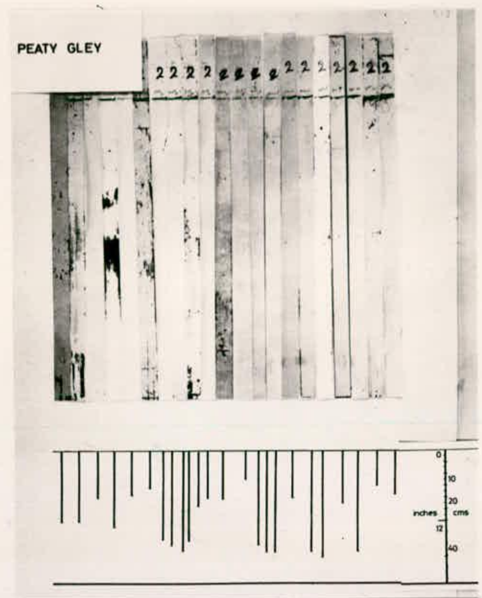
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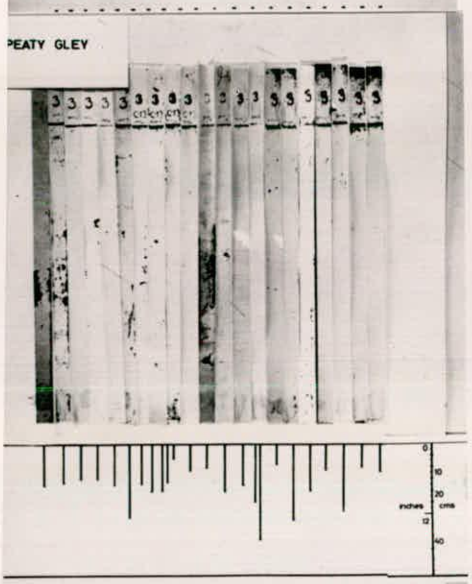
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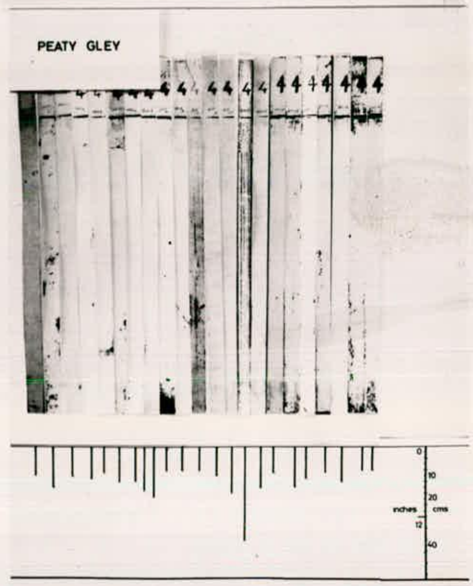
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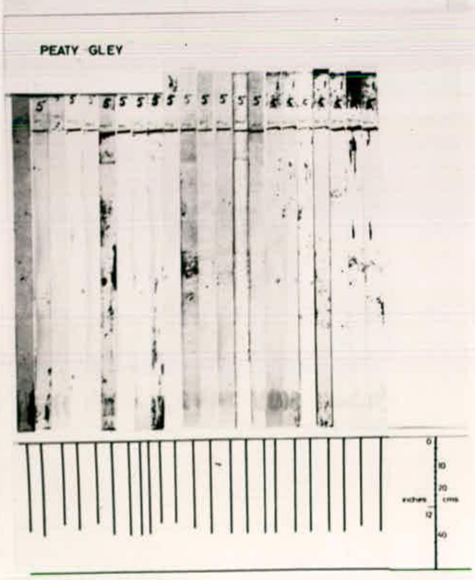
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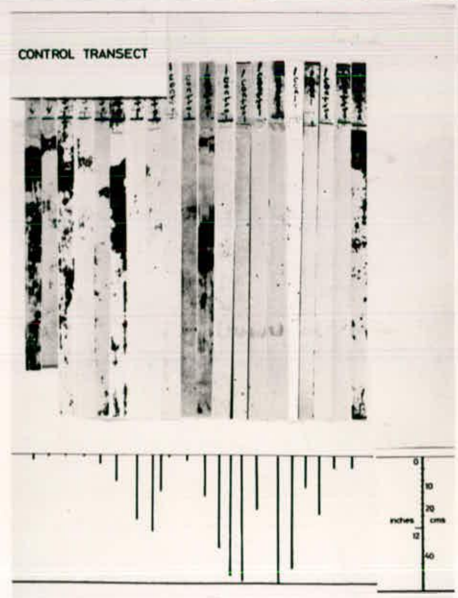
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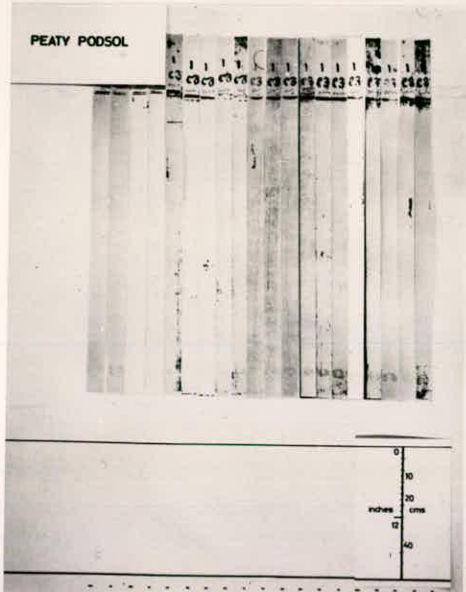
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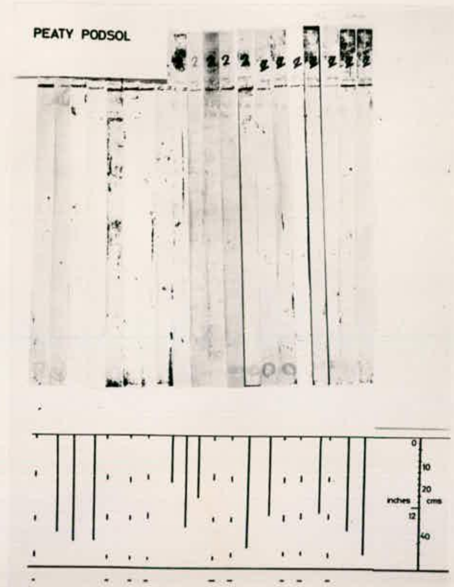
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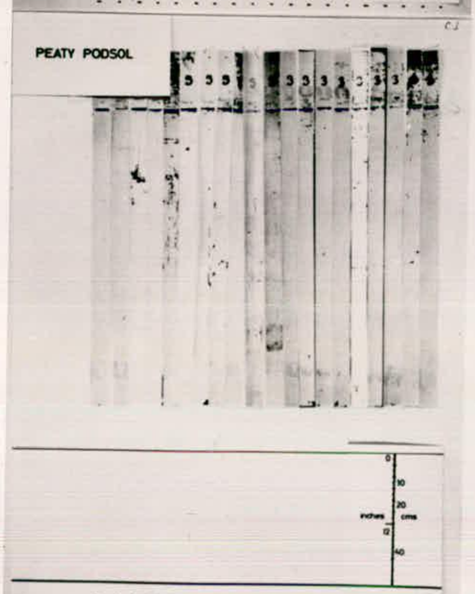
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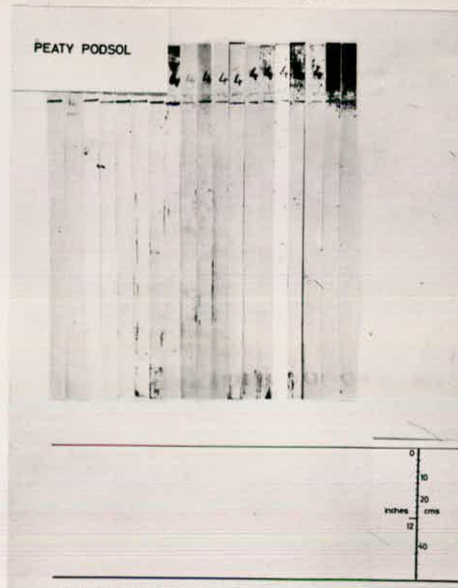
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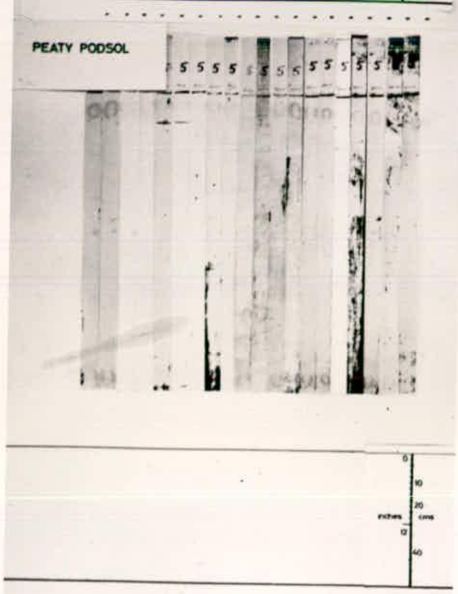
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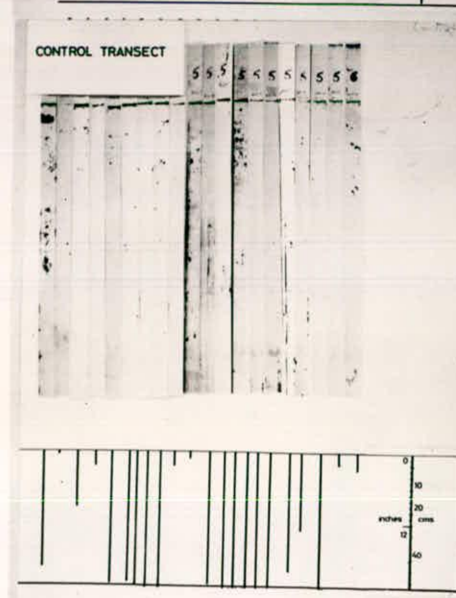
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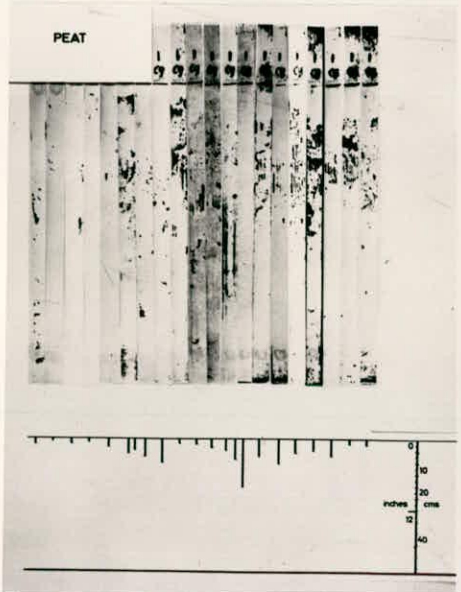
Figure 19. Silver sulphide staining and depth to water table for the peat sample and a comparable control station.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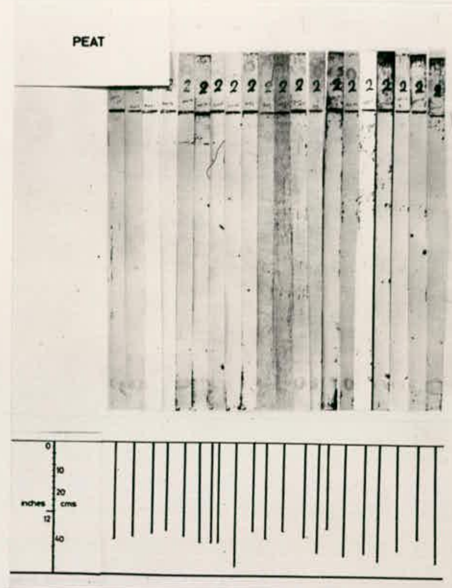
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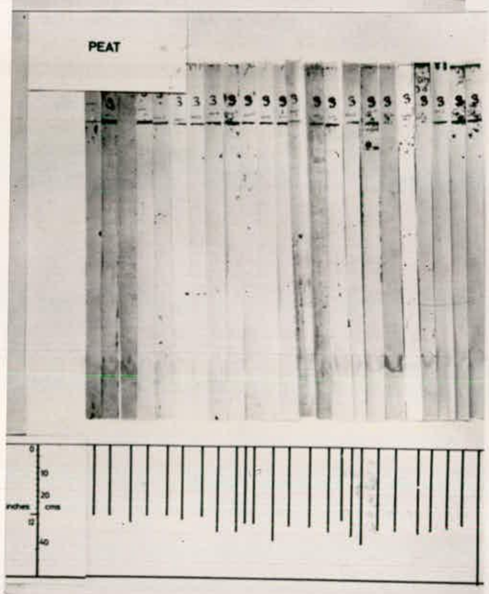
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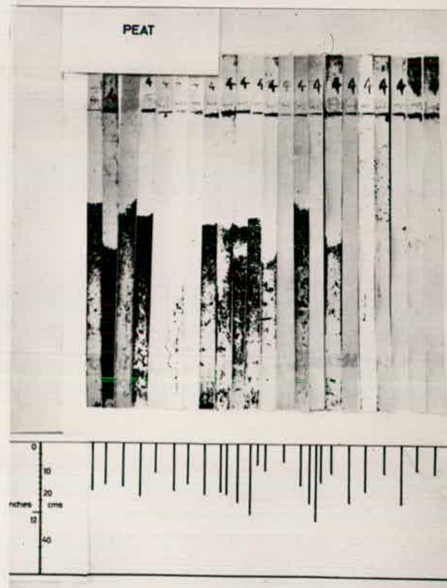
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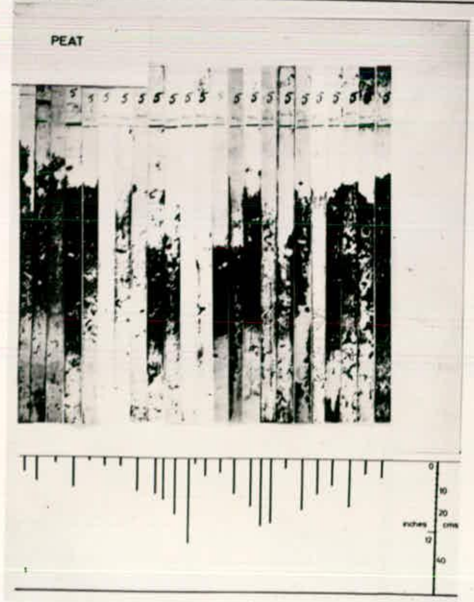
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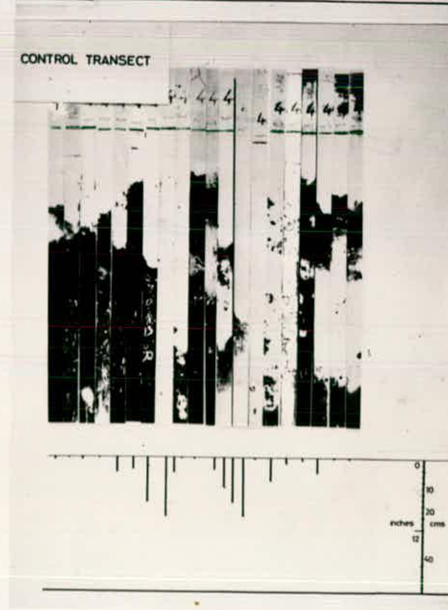
CONTROL TRANSECT
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REDOX and ODR aeration profiles. At the stations with a consistently high water table and high level of staining, aeration levels fall. Thus the peaty gley soil produced consistent staining at only one station. The deep peat showed regular staining throughout the growing season on three out of five stations. A similar pattern occurred on the control transect between soil types and at an increased intensity.

TABLE 7

SULPHIDE STAINING * INTENSITY IN PEAT SOILS
(Peat Station 5)

DATE	RAINFALL Inches	DEPTH TO WATER TABLE Inches	LEVEL OF STAIN inches	INTENSITY
May 23	0, 05 0. 0	5½	Diffuse stains 2-10	10%
May 30	0. 35 0. 0	6	0-4 4-10	15% 67%
June 6	0, 2 0, 0 Dry	7	4-10	70%
June 13	0, 1 0. 0 Dry	9½	3-10	80%
June 20	0, 0 0, 02 Dry	14½	No stains	-
June 27	0. 32 0. 61 Raining	1[illegible]	Light stains 3½ - 10	17%
July 4	0. 18 0. 07	3	Spotty stains 1½ - 10	30%
July 11	0 07 0. 52 Raining	2½	Dense stains 4 - 10	92%
July 18	0. 48 0. 02	6	Dense stains 2 - 10	80%
July 25	0, 05 - Dry	8	Patchy stains 2 - 10	80%
August 1	- - Trace	10	Dense stains 2 - 10	90%
August 8	- - Dry	11½	Dense stains 3 - 10	84%
August 15	- 0. 55 Rain	11	Dense stains 2½ - 10	86%
August 22	1, 1 0. 2 Rain	1½	Dense stains 3½ - 10	70%
August 29	0. 65 0. 0 Dry	8½	Dense stains 2-6 + 7-10	80% + 50%
September 5	0. 51 0 05	6	Dense stains 2 - 10	96%

* Presence of Sulphide stains was confirmed using an X-ray spectrometer which illustrated the sulphur and silver frequency peaks.

Fluctuation of the water table as illustrated in Table 7 has an influence on the distribution of sulphide in the profile. After a dry period from May 30 to June 24 the water table is raised, by more than an inch of rain, to 1 inch from the surface; staining re-appears and steadily intensifies.

Aeration

Introduction

The earliest workers in forest wet site improvement were influenced by a realisation that "oxygenation" must be increased if tree roots are to grow in peat (Zehetmayr 1954). Differences between growth of plants notched into undisturbed peat and those on top of turfs were noted. The initial growth rates, however, were not maintained on all but the most fertile fen peats and flushes. Fertilisers, lime at first, and then phosphatic compounds were soon tried. Through their use satisfactory growth rates were resumed and it became difficult to assess the relative importance of nutrition and aeration. A more careful examination of the turfs by Binns (1962) revealed that larger, or higher turfs, with presumably better aeration, gave a higher mineralisation rate for nitrogen, and increased transplant height growth.

The activity of the hydrogen ions in reduction, and of oxygen ions in oxidation, measured as a electrical potential between a noble metal cathode and a calomel anode was used by Brown (1934) to characterise the aeration status of soils. The amount of these reducing and oxidising agents determines the direction in which a number of soil reactions will develop and affects microbiological activity. A high potential corresponds to high aeration, a low potential to poor aeration. The state of oxidation/reduction equilibrium in soil can be metered by the activity of the electrons at the cathode (reduction) and at the anode (oxidation) causing a small current to flow when the electrodes are joined by a wire (Cottrell 1963). This reduction - oxidation potential or REDOX has been used to assess aeration status in soil and to estimate whether the soil reactions will tend towards reduction (water-logged state) or oxidation (well aerated state). REDOX values are adjusted according to temperature and pH.

When applied to the rooting zones of crop plants it became apparent that aeration levels measured by REDOX explain growth variation of several species. Reynolds (1957) reviews some of the aeration studies and notes that aeration is controlled by soil factors such as structure, pore space, moisture content and depth to water table. He confirms that aeration levels at waterlogging lead to CO_2 toxicity and lower nutrient uptake at low oxygen concentrations. Pearsall (1950) associated high REDOX levels with healthy growth of rice. Above 350 millivolts conditions were aerobic and below this value, anaerobic.

Products on either side of these levels were

350+	350-
Carbon dioxide	Methane
Nitrate	Ammonia
Sulphate	Sulphide
Phosphate	Phosphine

Van Raalte (1944) discusses the ability of rice to improve its rhizosphere with oxygen transported to the roots where a higher REDOX was recorded than that in the surrounding soil. Huikari (1955) also measured higher REDOX near roots of birch, Scots pine and spruce seedlings in peat.

Response of plants to soil aeration levels is demonstrated by a number of workers. Leyton and Rousseau (1958) recorded growth differences for Norway spruce, Sitka spruce, black spruce, Scots pine and Jack pine under a variety of 0_2 concentrations in solution, with a limiting level of 10%. Oxygen was bubbled down glass tubes to the waterlogged roots. In its absence roots died within 2 days. McKeague (1965) compared aeration levels, (REDOX), with water table levels in 3 dry soils. He concluded that levels below 200 m V indicated reduced soil, a somewhat lower level than Pearsall's. Brown, Carlisle and White (1966) used 350 m V at pH 5 as the boundary between oxidising and reducing conditions in a study of Scots pine on peat. Reducing conditions on a Calluna-Sphagnum-Eriophorum site began only 7 cms. down the profile. Poor aeration they concluded limits nitrogen availability.

Pierce (1953) followed REDOX levels across a transect with natural forest cover in Ontario and related aeration status to cover type e.g. aspen, alder, black spruce,open swamp, alder and aspen. The aeration levels also correspond to dissolved oxygen in ground water samples, specific conductance, hardness and pH. Deficiency of dissolved oxygen and low REDOX were associated with a slow tree growth rate.

Quispel (1947), Pearsall & Mortimer (1939), Pearsall (1950) and Mitsui (1955) found low REDOX associated with reduction products. Reducing conditions lowered yield and root penetration. Gore and Urquhart (1966) relate REDOX values to aeration in the root zone of Molinia caerulea and Eriophorum vaginatum. They note that REDOX in peat is low. Root penetration was inhibited when added sulphate was rapidly reduced to sulphide. Reducing conditions were tolerated better by Eriophorum than by Molinia. Studies by Bonner and Ralston (1968) make use of REDOX values under high water table conditions. By incubating forest soils the role of anaerobic micro-organisms in the activation of REDOX systems is demonstrated. They conclude that REDOX changes are not the response to oxygen supply alone. Gore and Urquhart (1966) further point out the particular usefulness of this aeration index in organic soils.

The sensitivity of bog species and especially Molinia *caerulea*, to aeration is indicated. This agrees with the observations of several foresters, (Fraser 1933) Anderson (1961), and it may be considered an indication of aeration/fertility status. The importance of the assessment of aeration in considerations of oxygen supply and CO_2 removal is stressed by several workers. Rutter (1955) explains that growth of *Molinia* with a fluctuating water table is improved. The special characteristics of flush type vegetation were sampled by Poel (1960) using a polarographic technique which employed a platinum cathode and a Calomel anode across which a small potential was applied. The resulting current is proportional to the rate of oxygen supply to the electrode surface. This estimate of oxygen delivery was correlated with *Molinia-Nardus* vegetation cover on a hilltop, *Calluna* moor, flushed hill areas, and low lying swamps. Letey et al (1964) explain the theory simply:

> "When a certain electrical potential is applied between a platinum electrode inserted in the soil, and a reference electrode, oxygen is reduced at the platinum surface. The electric current flowing between the two electrodes is proportional to the rate of oxygen reduction. This, in turn, is related to rate of oxygen diffusion to the electrode. The oxygen diffusion rate (O.D.R.) can therefore be calculated from the measured electric current... Although the result of the measurement is an electric current, results are customarily expressed in terms of soil ODR in units of grams per square centimeter per minute".

A platinum wire electrode is chosen to represent a root and the O.D.R. is based on the exposed surface area of platinum.

Thus:

$$O.D.R.^{*} = \frac{i \times 10^{-6} \times 60 \times 32 \times 10^{8}}{4 \times 96,500 \times A}$$ and it is

calculated by dividing the current (i) by the electrode area in sq. cms. (A) and multiplying by a constant. Letey et al (1964) also provide full details of techniques and illustrate growth response of plant roots and shoots to aeration levels.

The technique was also employed in the aeration studies of Packham, Willis and Poel (1966), Williamson (1964) and Armstrong (1965).

Armstrong favours O.D.R. based on the electrolytic reduction of dissolved oxygen at the surface of the platinum micro-electrode, and stresses that the measured current is proportional to O.D.R. only in the plateau region of the current/voltage relationship. In acid peats he found this voltage to be lower (0.48V) than that used by Poel (0.8V) and points out that beyond this potential, i.e. the plateau level, rise in current corresponds not to oxygen but to reduction of ionic hydrogen to hydrogen gas. Examples are shown in the accompanying diagram (Figure 22). Armstrong points out that rate of oxygen supply may be more important to plant growth than oxygen concentration.

Examining the relationship between REDOX and O.D.R. Armstrong (1966) showed that a very small diffusion rate, with

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* The factors 60 and 32×10^{8} convert the results to minutes and micrograms. 96,500 is the Faraday constant

oxygen just present, was associated with a correspondingly larger REDOX value. Armstrong and Boatman (1967) were successful in relating O.D.R. levels to growth of bog plants and the distribution of vegetation types on peat.

Several limitations or constraints to this technique are mentioned by these workers. However performance is reliable in wet soils tending to acidity, where good electrode wetting and contact is maintained, and conductivity is high. Inserting the electrode into the soil cleans the platinum surface and prepares it for measurement. Use of a silver/silver chloride reference electrode prevents mercurial poisoning of the platinum surface and this electrode is more temperature stable. The diffusion current is not affected by distance between electrodes and one reference station can be used for a series of insertions up to 2.5m. distant, (Letey et al 1964). The use of a wire electrode minimises soil disturbance at insertion and prevents local aeration. Temperature affects the diffusion current and Letey and Stolzy recommend a 1.8% change for 1°C increase in temperature.

On the basis of these considerations a method was developed and equipment assembled, to assess aeration levels in the rooting zone of Sitka spruce seedlings in situ. Where possible, both REDOX and O.D.R. were measured.

Methods

The apparatus assembled to measure aeration status consisted of the following components.

(a) Oxidation - reduction potential. An E.I.L. 30C transistorised direct-reading pH/millivoltmeter was used with a laboratory type-platinum spade electrode and a silver/silver chloride reference whose potential is 222 mV which is added algebraically to observed meter potentials, (Hill 1956).

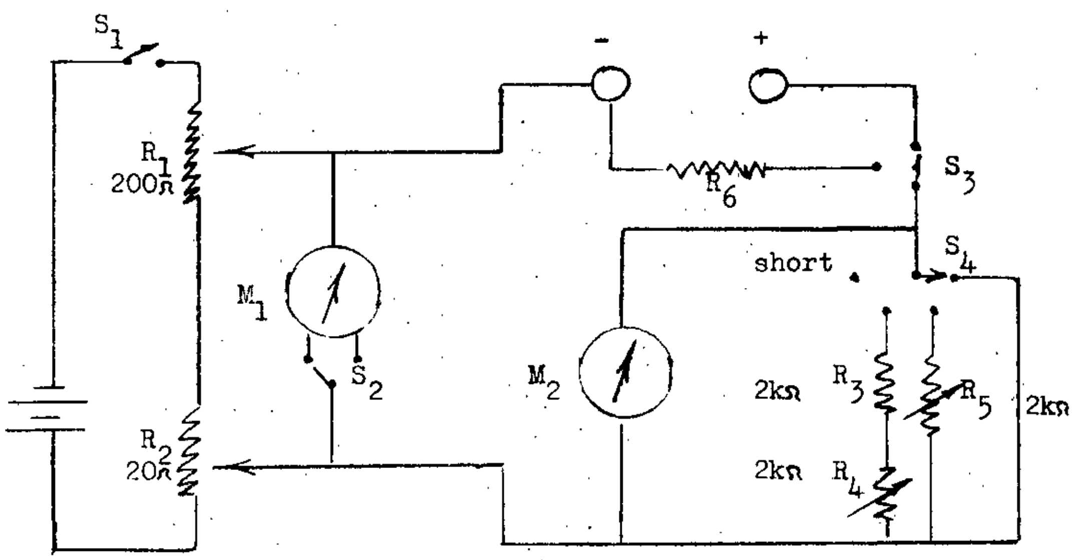
(b) Oxygen diffusion. Apparatus was assembled similar to that described by Poel (1960) and using the circuit layout shown in figure 20. The complete assembly is shown in figure 21. The platinum electrode probe consisted of a 30 inch steel rod, $\frac{1}{4}$ inch in diameter with 0.35 inches (12mm.) 18 S.W.G. thermo pure platinum wire set in to the pointed tip. The rod was marked off in $\frac{1}{4}$ inch divisions and sealed in "Araldite". Exposed surface area of platinum, allowing for the tapered point left by wire cutters, was 40 sq. mm.

The procedures adopted were:

REDOX

At each sample station at Ae the soil moisture sample pot was removed and the spade electrode pushed into the bottom of the hole, i.e. 3 in. down. The reference electrode was pushed into a small depression at the surface and irrigated with distilled water. The potential was read after two minutes. pH was then measured in the sample pot hole puddled with distilled water. A laboratory-type glass electrode and a Calomel reference were

FIGURE 20. CIRCUIT DIAGRAM - POLAROGRAPH



S_1 = battery switch

S_2 = voltmeter range switch

S_3 = electrode and ammeter range calibration switch

S_4 = micro-ammeter range switch

R_1 = 200 ohm wire-wound potentiometer

R_2 = 20 ohm wire-wound potentiometer

R_3 = 2000 ohm wire-wound resistor

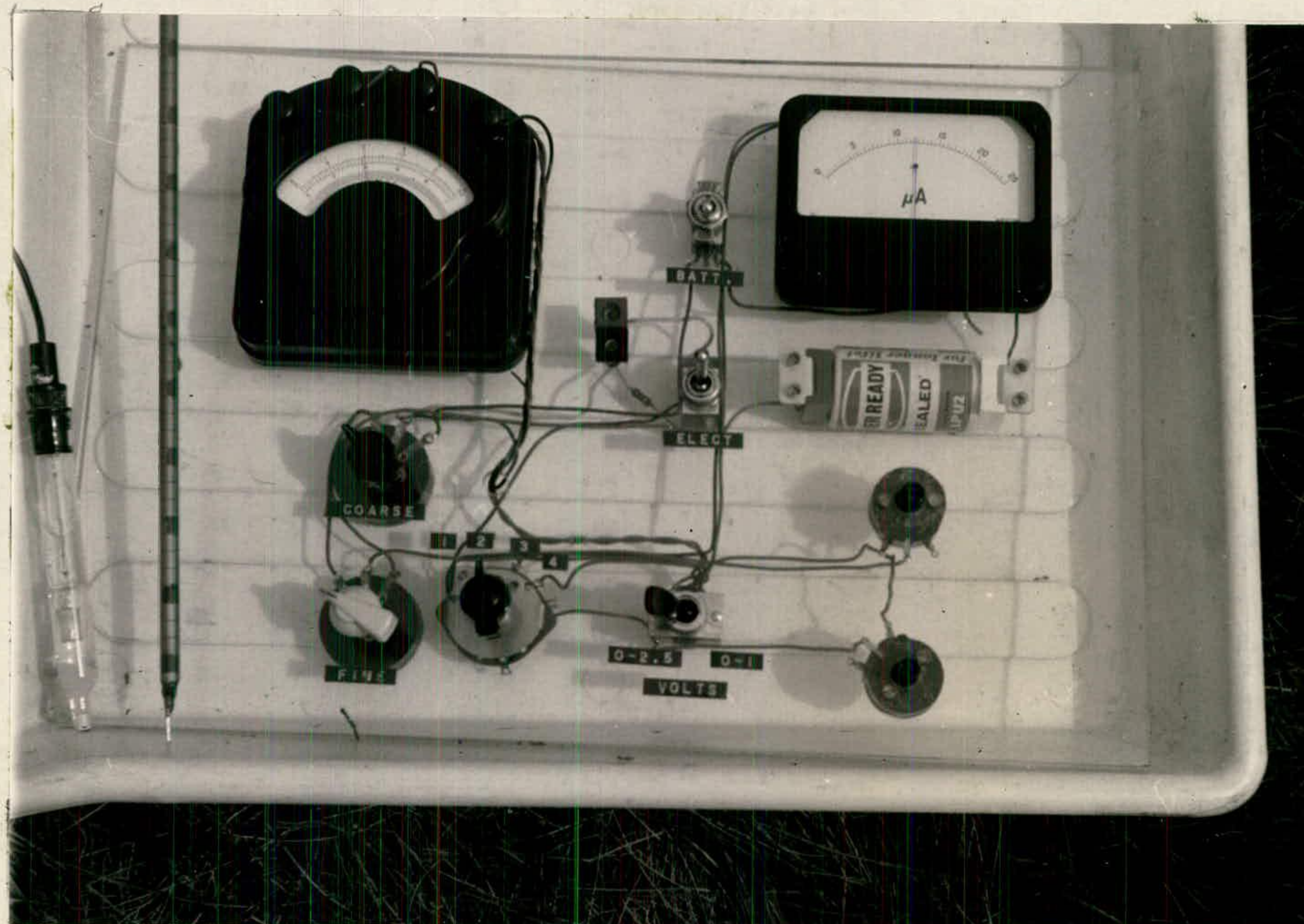
R_4 + R_5 = 2000 ohm wire wound potentiometers

M_1 = Weston voltmeter model S.61. 0-1.0 and 0-2.5 volt ranges selected by S_2

M_2 = micro-ammeter, 0-25µA, 2½ in. scale; 0-25 , 0-50, and 0-100 µA ranges selected by switch S_4 with SHORT position to protect instrument during transit

1.5V dry cell battery

Figure 21. Polarograph assembly showing platinum micro-electrode and silver/silver chloride reference.



μA
BATT.
ELECT
COARSE
1
2
3
4
FINE
0-2.5
0-1
VOLTS

used with a temperature compensator.

Oxygen diffusion

At each sample station the probe was inserted to the desired depth, (0-6 inches, in inch stages), with reference at the surface pushed into a depression and irrigated with distilled water.

Between stations the platinum electrode was rinsed with distilled water, cleaned with a 'Scotchbrite' mild abrasive pad and rinsed again with distilled water. After a few hours' use, the electrode was rinsed with Teepol non-ionising detergent, distilled water, flamed in alcohol, and again rinsed in distilled water.

At each study area the current/voltage relationship was developed to determine plateau-voltage settings. The polarograms are included in the results, however it was soon noted that plateau-voltage settings closely agreed with the findings of Armstrong (1967) and a setting of 0.5 volts was selected for all comparisons. This was adequate for the better aerated drained peaty podsols as well as for drained peat and the undrained control. Current was read after 2 minutes elapsed time.

Results

Table 8 shows pH and REDOX values at 3 in. depth for the 5 stations for each soil type and control. Several assessments were carried out throughout the season.

REDOX values rate the aeration status of the samples in the following order.

1 (high)	Peaty podsol)
2	Peaty gley)
3	Deep peat
4 (low)	Control (Undrained)

TABLE 8

REDOX VALUES AT 3 in. depth FOR 3 SOILS AT AE FOREST

		May 14		May 23		May 30	June 6	June 13	June 20	July 9	
		pH	mV	pH	mV	mV	mV	mV	mV	pH	mV
Peaty podsol	1	3.3	940	3.7	830	730	560	640	560	3.3	570
	2	3.6	660	3.7	760	700	590	635	575	3.9	670
	3	3.6	650	4.1	695	685	580	710	630	3.8	535
	4	3.6	650	3.9	750	700	570	680	570	3.8	600
	5	3.4	810	4.0	735	725	600	700	605	3.5	410
	$\overline{X}$	3.5	742	3.9	754	708	580	673	588	3.7	557
Peaty gley	1	4.4	720	4.7	685	715	590	680	630	4.4	370
	2	3.9	690	4.2	670	770	650	700	610	3.9	420
	3	3.6	760	5.0	650	750	640	690	585	4.1	380
	4	3.5	610	4.0	790	780	660	730	640	4.1	570
	5	4.4	660	4.1	675	715	640	770	595	4.0	580
	$\overline{X}$	4.0	688	4.2	694	746	636	714	612	4.1	464
Deep Peat	1	5.8	340	5.6	485	610	530	570	440	5.7	590
	2	3.9	640	3.9	725	760	685	730	660	5.0	550
	3	3.6	650	3.7	725	765	665	750	690	4.1	540
	4	3.7	620	4.3	680	730	690	720	650	4.0	580
	5	3.9	500	3.9	525	680	675	720	630	3.9	350
	$\overline{X}$	4.2	550	4.3	628	709	653	698	614	4.3	522
Control transect	1	5.1	460	5.3	460	570	615	400	500	4.5	570
	2	3.7	610	4.1	760	675	660	635	560	4.4	330
	3	4.5	545	4.7	580	575	515	630	590	4.7	515
	4	4.1	480	4.0	530	600	550	660	600	4.3	510
	5	4.0	508	3.6	700	610	570	650	590	4.0	440
	$\overline{X}$	4.3	520	4.3	606	606	527	639	568	4.4	473

Analysis of variance REDOX

Source of variation	Degree of Freedom	Sum of Squares	Mean Square	F
Date of measurement	6	509117.5000	84852.9167	15.8619**
Soils	3	168859.2858	56286.4286	5.0557**
Interaction	18	200398.2142	11133.2341	2.0812*
Residual	112	599140.0000	5349.4643	
Total	139	1477515.0000		

Treatment	Mean
1	625.00
2	670.50
3	692.25
4	610.00
5	681.00
6	595.50
7	504.00

Soils	Mean
peaty podsol	657.43
peaty gley	650.57
peat	624.86
control	569.14

S.E. of treatment means 16.3546

A just significant 'dates and soils' interaction indicates an aeration differential during the growing season.

Change in REDOX during the measurement period is significant and is most noticeable on the peaty podsol. Highest and lowest aeration levels occured on all soils at the same date of measurement. Hydrogen ion concentration did not vary significantly between dates or sites.

Oxygen diffusion rates were assessed for each soil and down the first 6 inches of the rooting zone. Values are presented as diffusion currents in Table 9. Sample polarograms appear in Figure 22.

FIGURE 22 CURRENT/VOLTAGE RELATIONSHIPS FOR PEAT DRAINAGE TRIALS

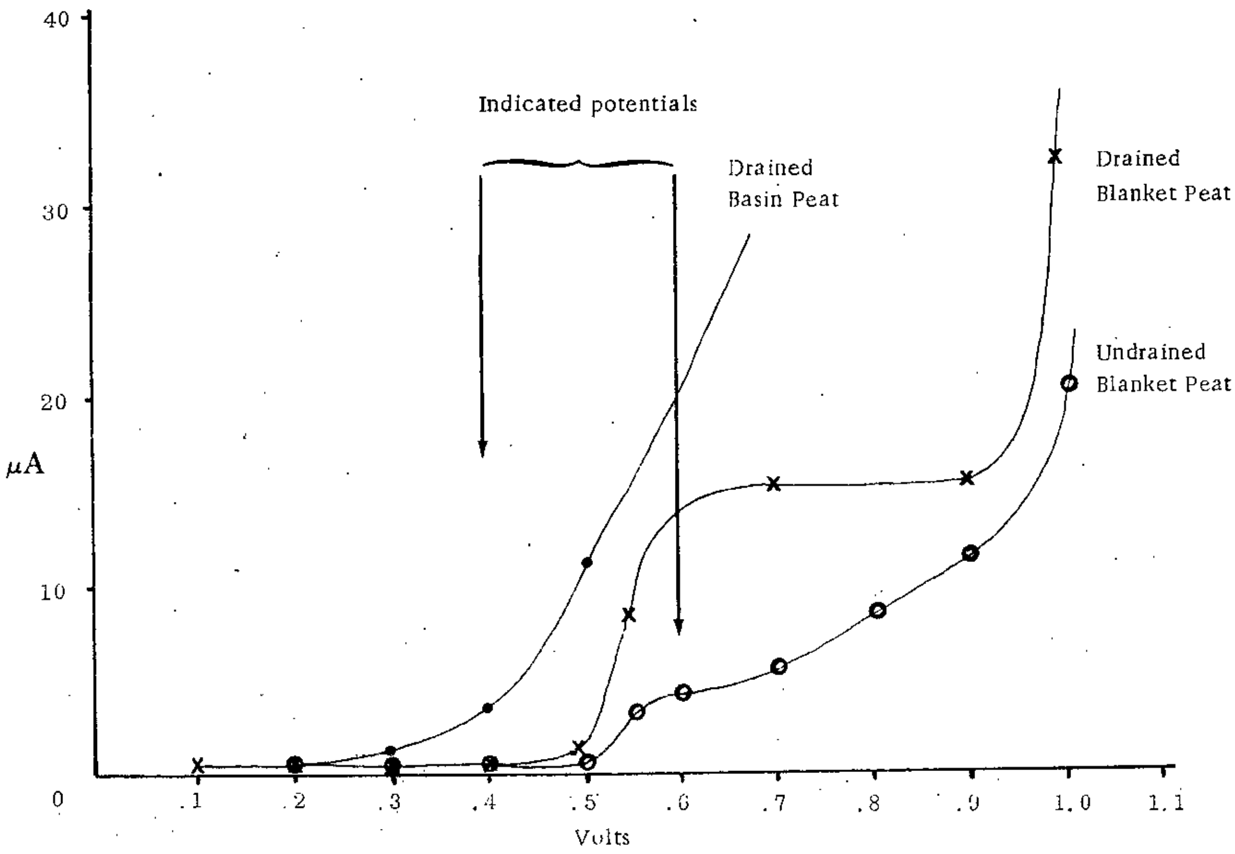


TABLE 9

DIFFUSION CURRENT PROFILES FOR 3 SOILS AT AE FOREST
(0.5V applied: µA after 2 mins.*)

Soil	Station	1 in.	2 in.	3 in.	4 in.	5 in.	6 in.
Peaty podsol	1	24.0	19.5	17.5	17.0	16.0	16.0
	2	19.5	19.0	22.0	17.5	21.0	14.5
	3	18.5	23.0	21.5	21.25	16.0	17.0
	4	20.25	28.5	27.0	20.0	16.75	19.5
	5	19.0	19.0	21.0	19.0	17.5	18.5
	$\bar{X}$	20.26	21.80	21.80	20.76	17.46	17.10
Peaty gley	1	16.75	20.25	22.5	30.0	14.5	18.0
	2	20.0	20.5	20.0	23.5	16.5	14.0
	3	19.0	16.5	19.5	16.5	14.5	13.0
	4	14.5	13.5	15.0	12.5	11.0	10.0
	5	14.0	15.0	15.0	9.0	9.0	12.5
	$\bar{X}$	16.86	17.16	18.40	18.30	13.10	13.50
Deep peat	1	15.0	11.25	5.5	9.5	5.25	6.25
	2	20.0	31.0	26.5	22.25	26.0	26.0
	3	18.0	20.5	19.5	21.0	19.25	20.5
	4	20.5	21.0	15.0	12.75	11.0	10.75
	5	12.0	10.75	10.0	9.5	9.5	9.25
	$\bar{X}$	17.10	18.96	15.70	15.02	14.20	14.58
Control transect	1	12.0	9.75	9.25	8.5	8.5	11.5
	2	7.5	12.25	10.75	10.0	10.25	10.0
	3	10.0	6.5	5.0	4.0	6.5	5.0
	4	7.5	7.5	8.5	9.0	9.5	9.0
	5	18.75	16.25	27.0	23.0	16.25	18.5
	$\bar{X}$	11.16	10.48	12.12	10.90	10.22	10.80

* To convert to µgm $O_2/cm.^2/min.$, multiply by 1.244

Analysis of variance ODR

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Depth of Measurement	5	210.4297	42.0859	1.4683 NS
Soils	3	1138.4952	379.4984	13.2397**
Interaction	15	126.0714	8.4048	0.2932 NS
Residual	96	2751.7120	28.6637	
Total	119	4226.7083		

Treatment inches	Mean
1	16.3400
2	17.0775
3	16.9000
4	15.8050
5	13.7375
6	13.9875

Soils	Mean
peaty podsol	19.57
peaty gley	16.73
peat	15.86
control	10.95

S.E. of treatment means 1.1972

Order of aeration status is

1 (high)	peaty podsol
2	peaty gley)
3	deep peat)
4 (low)	control transect

Because of the time involved in completing these measurements and the use of the equipment in other parts of the study, only one assessment using this technique was possible. Analysis of variance showed that REDOX values were significantly different between dates of measurement and between soils. Oxygen diffusion rates differed significantly between soils at all depths. Differences between depths were not significant. Mean differences between the 2 and 5 inch depths on the peaty podsol and between 2, and 5 and 6 inches for all soils were significant ($P \leqslant 0.05$).

Discussion and Summary

There has been an improvement because of draining and tree cover during the first rotation. There is significant variation in soil moisture and aeration status between the control sample and the drained forested sites and also among the drained soils.

Soil moisture status, available pore space, depth to water, and aeration of the surface rooted soil horizons are greater on the peaty podsol. During the short dry spell in August this soil retained enough moisture to offset drought stress which may have operated in the rooting zone of the other samples. Barley and Greacen (1967) and Gardner and Danielson (1964), show that unless they are well aerated, root tips are unable to penetrate soil layers of only moderate density. The soil parameters measured at Ae are all indices of penetrability although physical resistance to root penetration was not specifically measured. Records for the whole growing season have shown the significant amount of change which took place and suggest that on the drained soils tree roots may be exposed to limiting growth conditions for several periods of short duration. Monthly samples on the peaty gley during the winter of 1967-1968 recorded water table levels as low as summer minimums.

In 1968 soil moisture approached the 15 atmospheres tension level early in August. This dry period was reflected in water table levels and the associated staining patterns on the silver plates. Water table fluctuation was greater on the drained sites and controlled the intensity and level of sulphide staining. The water level was consistently below 22 inches on the peaty podsol yet the surface horizons are often saturated by the frequent rainstorms each month. Vertical drainage is obviously better on this soil type than on the peaty gley and peat soils. On all soils the available pore space decreases in the first four inches and varies significantly between sample depths and between soil types. There is highest porosity on the peaty podsol.

Sulphide distributions follow the soil moisture and aeration patterns for these wet soils. The staining pattern suggests that spruce roots may be subjected to anaerobic and perhaps toxic conditions for short periods repeatedly throughout the growing season. Aeration levels confirm the observed moisture status of the four sites. There is a significant difference in REDOX and ODR measurements between sites and between dates of measurement. ODR for the first six inch increments down the rooting zone did not vary significantly, but the records illustrate some very poorly aerated horizons at certain stations. There is an important differential between the 3-inch and 6-inch levels which suggest that ODR may be limiting for spruce rooting. These soil characteristics will be considered in the light of the seedling growth study which follows.

Further Study

Further study is suggested in several distinct problem areas: The tolerance of spruce seedlings to sulphide concentrations. Physical soil factors preventing root penetration in peats.. Permeability ratings for peats to integrate vertical and lateral water flow and to anticipate drainage responses.

NATURAL REGENERATION OF SITKA SPRUCE ON THREE SOILS

Seedling Survey

Introduction

A good seed year in 1963 in the Forest of Ae provided abundant seedfall and there was a high survival rate of the 1964 seedlings. Successful growth and good vigour of the seedlings was most apparent in the clear-cut gaps of the windblow study begun in 1961-1962. When the windblow study areas were first visited in 1966 it was decided that the distribution pattern and growth of the surviving seedlings would provide a useful guide to 'preferred' sites. A survey of regeneration status with monitoring of subsequent survival rates, using permanently marked seedlings, was planned with the Forestry Commission Research Branch Officer concerned, Mr. S.A. Neustein, (Silviculturist North). The study of the soil characteristics previously reported were to support this seedling assessement and to explain some of the variation in the population growth.

Site conditions on which Sitka spruce seedlings are successful have been examined by Day (1957), Howells (1966), and Fairbairn (1967). Conditions limiting the establishment of regeneration of associated spruces is reported by Day (1963) - Engelmann spruce), Jarvis et al (1966 - white spruce) and Sutton (1968 - white spruce). The factors summarised by Sutton are:

climate, especially drought
litter, (depth)
crown cover, (density)
site, (especially soil)
lesser vegetation
animals
seedbed
seed supply

These may combine unfavourably to prevent the successful establishment of the regeneration. Day's (1957) study shows how Sitka spruce seedlings in the natural forest are to be found on disturbed micro-sites raised above the general ground level, or on upturned mineral soil and on seedbeds cleared of vegetation competition by recent natural fires. On wet sites he found Sitka spruce on soils flushed by lateral water movement or a fluctuating water table. He concluded that this is a response to the available rooting space. Day (1964) and Sutton (1968) point out the adverse effect of a short dry spell on seedling survival. Day (1963) and Gregory (1956) discuss temperature build-up on organic matter seedbeds which leads to heat lesions on seedling stems. Peak surface temperature values reported by Day (1964) are:

humus	$43^{\circ}C$
organic matter	$38^{\circ}C$
decayed wood	$38^{\circ}C$
sandy loam	$40^{\circ}C$

while Gregory (1956) reports $45-47^{\circ}C$ on humus seedbeds in Alaska. On moisture receiving sites in Alberta, Lees (1964) showed that local and short-term flooding contributed to seedling mortality. Short periods of immersion were tolerated by white spruce seedlings, but 14 day immersions were lethal.

Seedbed studies with shading and watering regimes were carried out by Fourt (1968) and showed that shaded seedlings of Sitka spruce grow faster, but that reduction in height growth, a response to drought, is less in the open. Drought stress was associated with aphid attack and potted stock in the open and under partial shade was affected. The association of drought and attack by Elatobium abietina, reported by MacDonald (1967), further supports this indication. The deleterious effects of lack of water, shading, or fertiliser, were offset in Sutton's (1968) white spruce studies, by deep cultivation. Seedlings on cultivated seedbeds were better able to withstand limiting conditions of moisture and light. Howells (1966) records that Sitka spruce produces seed 1 year in four with no serious seed losses in the cones under stand conditions in Great Britain. Seedfall continues throughout the winter months with appreciable seedfall in March. Seed losses on the forest floor, he records, are serious. Best germination occurred on prepared seedbeds of mineral soil, while the germination rates on litter were low. Light affected growth with an increase from 0-70% of full light, and decrease from 70%-100%. Fairbairn (1967) shows increased growth of Sitka spruce seedlings from 6.25-100% full light. Germination rate, Howells found, was dependent on the moisture content of the substrate. Little short of a 'wet blotting-paper' condition was adequate for satisfactory germination. Under conditions of reduced relative humidity mineral soil was preferable to organic matter seedbeds. Howells records seedlings losses because of washing-out, lack of light, and drought on litter seedbeds.

The 0.1 acre gaps at the Forest of Ae provided the opportunity to assess a range of such conditions in the field. The Forestry Commission samples were established to monitor regeneration in four 0.1 acre gaps of which two fell within the current study area; on the deep peat and on the peaty podsol. The object of the investigation was: "To make a preliminary assessment of seedling survival on a range of micro-sites within small clearings in a Sitka spruce plantation". The results of this survey to date are included in the current work through the courtesy of the Forestry Commission Research Branch.

Rooting Depth

Methods

In December 1966 seedlings were sampled from randomly selected $\frac{1}{4}$ milliacre quadrats in the following strata on a peaty gley site at Ae:

South stand	50 seedlings
South gap margin	40 seedlings
Gap centre	50 seedlings
Drain spoil	10 seedlings

The seedlings were lifted from the soil, bagged and taken to the laboratory. Total height, root collar stem diameter, maximum rooting depth and maximum root extension were measured for each seedling. Regressions were developed for height growth, i.e.

TABLE 10

SEEDLING HEIGHT, DIAMETER AND ROOT GROWTH

Seedling height = stem diameter^{x1} + root^{x2} length + root^{x3} depth

Stand

1. All variables

$$\text{Height}(Y) = -0.[illegible]85 + 59.4X_1 + 0.017X_2 + 0.34X_3$$

	S.D.	"t" (46 df)		
b_1	8.039	7.38**		
b_2	5.390	0.32 NS	r^2	0.77
b_3	1.356	2.53**		

2. Ht/Stem diam.

$$\text{Height}(Y) = -0.51 + 76.1X_1$$

	S.D.	"t"		
b	7.025	10.834**	r^2	0.87

Margin

3. All variables

$$\text{Height}(Y) = 0.74 + 43.1X_1 + 0.15X_2 - 0.15X_3$$

	S.D.	"t"		
b_1	7.264	5.927**		
b_2	0.088	1.75 NS	r^2	0.66
b_3	0.205	0.72 NS		

4. Ht/Stem diam.

$$\text{Height}(Y) = 0.997 + 42.29X_1$$

	S.D.	"t"		
b	9.015	4.75**	r^2	0.56

Centre

5. All variables

$$\text{Height}(Y) = 0.787 + 45.076X_1 - 0.101X_2 + 0.288X_3$$

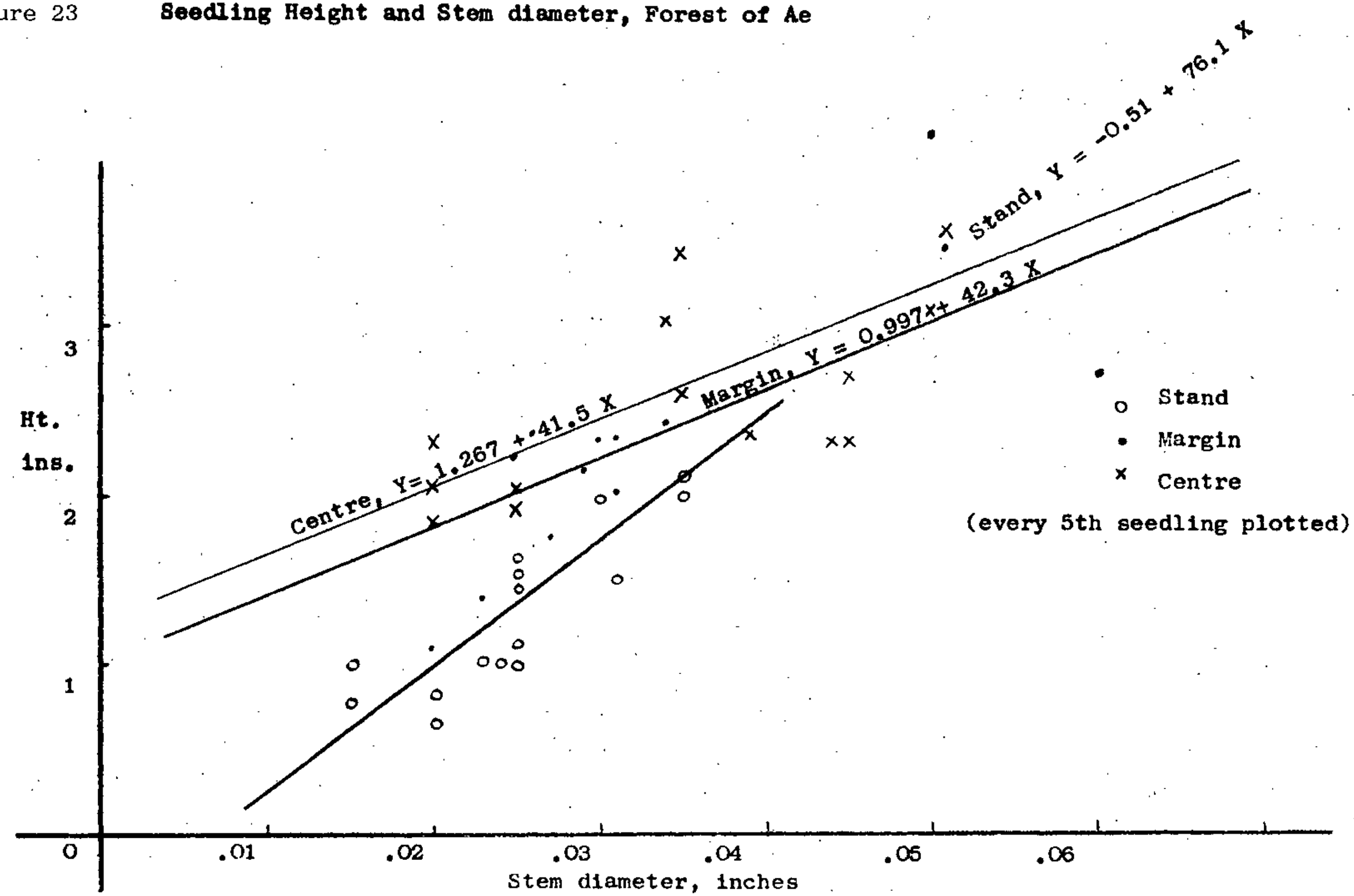
	S.D.	"t"		
b_1	9.032	4.99**		
b_2	8.081	1.252 NS	r^2	0.41
b_3	2.118	1.360 NS		

6. Ht/Stem diam.

$$\text{Height}(Y) = 1.267 + 41.478X_1$$

	S.D.	"t"		
b	1.466	2.830**	r^2	0.31

Figure 23 **Seedling Height and Stem diameter, Forest of Ae**



seedling total height in inches, and stem diameter, rooting depth and root extension. Height and stem diameter relationships were also examined.

Results

These regressions accounted for a highly significant ($P \leq 0.01$) amount of height growth variation (Table 10). The regression of height growth and stem diameter also accounted for a highly significant amount of height variation. The variance ratio was highest under the stand and lowest on the south stand margin.

Regression

When the variance ratios of the residual mean squares is estimated (Snedecor and Cochran; 10.21, 1967) it is apparent that there are significant differences in this 'F' ratio for regressions. The stand 'margin' and gap 'centre' regressions are significantly different from the 'stand' regression for seedlings sampled beneath the overwood. (Figure 23).

Residual	M.S.	Variance ratio 'F'	2-tailed test
Stand	0.081	3.50*	4.34*
Margin	0.282		
Gap centre	0.352	0.80 N.S.	

There is an increase in height growth and extent of rooting from under the stand to the gap centre. This may be a response to increasing light. Because of the wet substrate and poor aeration of the rooting zone, root growth increases laterally, rather than vertically to give increased stem diameter and height. On drain spoil with mixed organic matter and mineral soil, a substrate placed above the peat surface, vertical root penetration increases. On all sites there is a response to root extension. The roots, which cannot penetrate vertically must ramify laterally.

Discussion

Because of the number of damaged leaders which may be encountered during such a survey, the use of root collar diameter is a useful index of growth and vigour, particularly where discarding of leader-damaged seedlings would seriously reduce sample numbers.

This initial study showed a severe limitation to seedling rooting depth. The roots were restricted mainly to the litter and decomposing litter layers, horizons L and F of these peaty soils, and did not penetrate to the old Molinia peat underneath. Maximum rooting depth was 2.5 inches. Planted stock in the gaps showed a similar response after 4 growing seasons. Advance growth and regeneration from 1962 and 1963 interfered with the routine re-measurement of Forestry Commission transplanted stock, so that when some were weeded out and examined they showed a rooting depth of not more than 4 inches and a lateral root extension of up to 24 inches. Natural seedlings are supplied with adequate moisture, aeration and nutrients in the upper organic horizons of the sites sampled. The modification of rooting pattern of planted stock from vertical to horizontal orientation indicates that conditions further down the organic profile are not suitable for efficient root growth. Lateral root extension of the natural seedlings supports this observation. Of the seedlings examined for the regeneration assessment discussed below, maximum rooting depth was 4.0 inches.

Stocked Quadrats

Introduction

Stocked quadrat surveys are widely used in ecological

(Kershaw 1966) and forestry (Candy 1951, Grant 1951, and Ker 1953) regeneration assessments. Presence or absence of specimens within the quadrat boundary is expressed as a percentage for the total number examined. Area computation is possible, though subject to certain limitations because of the small area of samples involved (Ker 1953). Grant (1951) stresses the need for selection of a suitable quadrat size and the desirability of recording stocking levels based on a standard quadrat size. Thus a ¼ milliacre or $^1/4000$ acre quadrat was selected because of seedling numbers and size, and resulting stocking is converted to 1 milliacre ($^1/1000$ acre) size.

<u>Methods</u>

On a 2 chain N-S transect through the $^1/10$ acre gap centres, regeneration was sampled for the three soil types. There were therefore 40 contiguous ¼ milliacre quadrats and these are sorted in 4 groups of 10 quadrats, ½ chain sections.

N Stand
N Gap
S Gap
S Stand

A stocking tally was made in April 1968 and the tallest seedling in each quadrat permanently marked with coloured plastic ribbon. Seedlings germinating only since the opening of the study gaps in 1962 were counted.

<u>Results</u>

Stocking to Sitka spruce seedlings is presented in Table 11 for 4 strata across the transect and three soils.

TABLE 11

REGENERATION STOCKING ON THREE SOILS 1968

Position	Peaty Podsol		Peaty Gley		Peat	
	¼	1	¼	1	¼	1
N Stand	70	99	100	100	100	100
N Gap	80	99.5	90	99.75	100	100
S Gap	70	99	80	99.5	60	96.75
S Stand	20	58	70	99	90	99.75
Overall	80	99.5	85	99.7	83	99.6

Soil type

¼ = 1/4000 acre
1 = 1/1000 acre (Conversions after Grant 1951)

Overall regeneration stocking levels are very high, and represent a high seedling density per acre. There is an increase in stocking from South to North across the transect.

The distribution of age classes recorded for the tallest seedlings on each quadrat is tabulated below.

TABLE 12

	Age Class 1 - 2	2 - 3	3 - 4	4 +	Sum
	numbers of seedlings				
Peaty Podsol	6	16	5	-	27
Peaty Gley	4	13	15	5	37
Peat	7	5	11	11	34

The presence of larger numbers of older seedlings on the wetter soils may be an indication of a better germination rate and higher survival on these sites.

Discussion

These regeneration stocking levels represent a substantial seedling population as a result of the creation of the small gaps in the canopy. In the first few growing seasons following cutting a suitable seedbed has existed but vegetation encroachment is rapid and within 4 growing seasons (1966) there are very few areas free from severe vegetation competition. A visual estimate of the percentage vegetation cover was:-

Peaty podsol	95%
Peaty gley	100%
Peat	90%

When this competition is sorted into three classes,

		rating
Light	- side competition only	1
Moderate	- side competition and some overtop	2
Heavy	- mostly overtop	3

the three soil types show the following degrees of vegetation competition

Table 13

VEGETATION COMPETITION

	Light 1	Moderate 2	Heavy 3
Peaty Podsol	72.5%	20.0%	7.5%
Peaty gley	62.5%	35.0%	2.5%
Peat	57.5%	42.5%	0

As the establishment period for regeneration progresses, vegetation competition becomes more severe on the drier sites. The peat site is less favourable for vegetation colonisation and seedlings there will have less competition for light and nutrients. When these competition ratings (i.e. 1, 2 or 3) are summed for positions across the gaps the following pattern emerges,

Table 14

COMPETITION RATINGS

	Peaty Podsol	Peaty gley	Peat	Total
N Stand	10	12	12	34
N Gap	20	14	14	48
S Gap	14	18	19	51
S Stand	10	12	12	34
Total	54	56	57	

Seedlings in the gap centres have strong competition from vegetation which must influence the distribution of the seedling population.

Seedling numbers and survival

Methods

Seedling numbers were recorded during the stocked quadrat survey and the distribution across the transect is shown in the accompanying figures. Four 1/10 acre gaps were sampled and two of these coincide with the deep peat and peaty podsol sites of the current study. Every third quadrat along the N-S transects was tallied and all regeneration marked with a pin and coloured plastic flag. The seedlings were divided into three populations, before 1963, 1963 to 1967, and 1968 germinants. The quadrats were inspected monthly or following major climatic events.

The study of seedling survival is being continued by the Forestry Commission Research Branch.

Results

The distribution of seedlings across the sample transects is shown in Table 15., and Figure 24.

Table 15

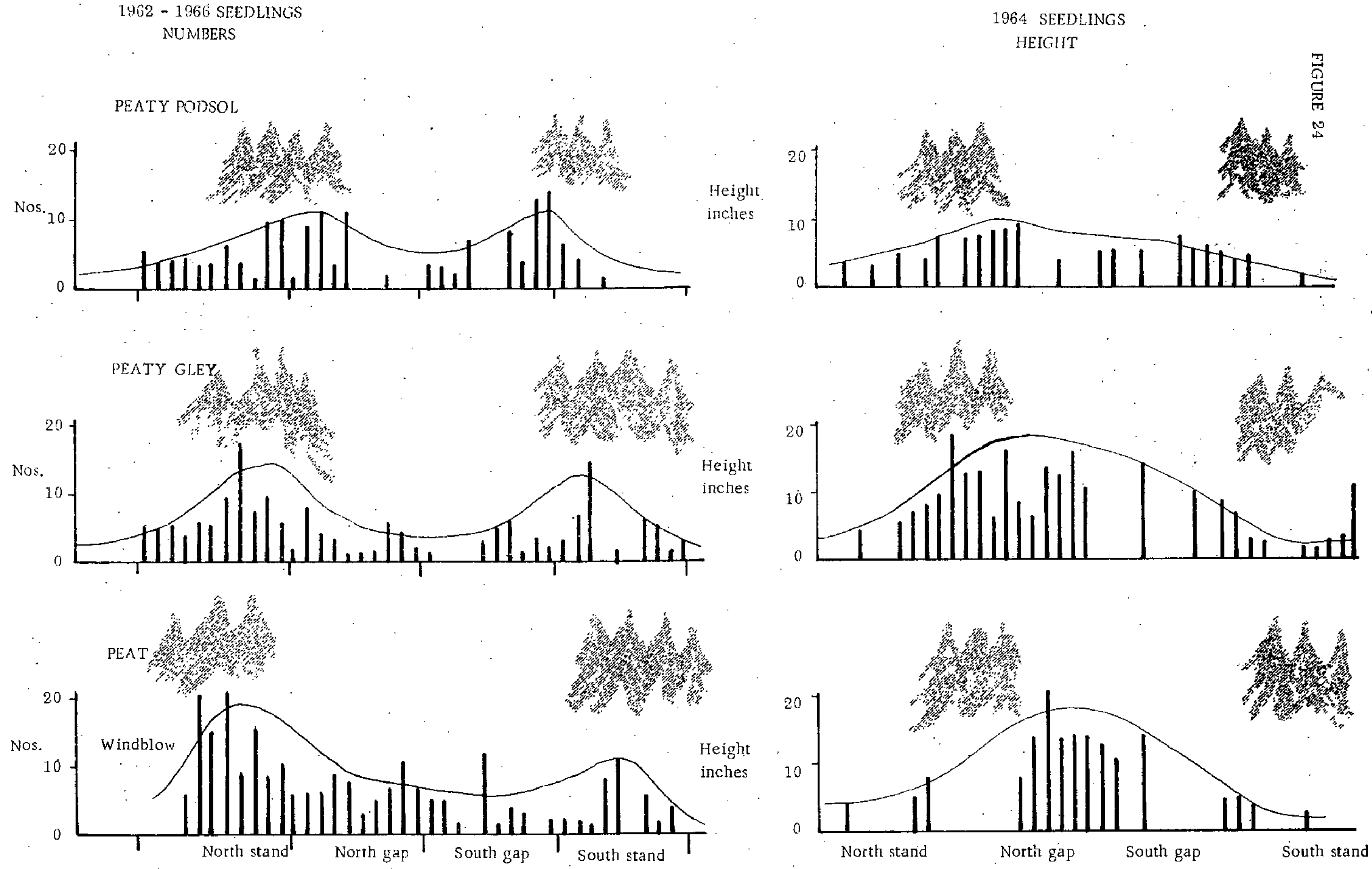
Distribution of Regeneration 1968 (1962-1967 Seedlings)

Peaty Podsol	1	2	3	4	5	6	7	8	9	10	Total
N Stand	4	3	2	3	2	3	2	3	2	3	27
N Gap	-	1	-	-	11	3	11	9	1	-	36
S Gap	13	4	9	-	-	7	2	3	3	-	41
S Stand	-	-	-	-	-	1	-	4	6	14	25
											129
Peaty gley											
N Stand	2	6	10	8	18	10	6	6	2	3	71
N Gap	2	4	6	2	2	1	1	3	4	8	33
S Gap	1	4	2	5	5	3	1	-	-	1	23
S Stand	3	2	6	7	6	2	-	15	7	3	51
											178
Peat											
N Stand	11	9	16	9	30	15	27	6	-	-	123
N Gap	7	11	7	5	3	8	9	6	6	6	68
S Gap	-	-	3	4	1	11	-	2	5	5	31
S Stand	4	1	6	3	12	-	8	1	2	2	39
											261

Seedling numbers decrease from stand to gap centre on all sites. A direct influence of competing vegetation is now apparent,. Large seedling numbers at the north stand position for the peat site may be the result of increased insolation following windblow which encroached on the gap boundary from an adjacent severely blown area.

Mortality rates recorded by the Forestry Commission

FIGURE 24


1962 - 1966 SEEDLINGS
NUMBERS
1964 SEEDLINGS
HEIGHT
PEATY PODSOL
PEATY GLEY
PEAT
Windblow
Nos.
Height
inches
20
10
0
North stand
North gap
South gap
South stand

over the period October 1966 to October 1968 have been highest in the younger seedlings germinating after 1964. This younger population has suffered the full effects of the encroaching ground vegetation especially of the grasses. In the winter months the dead grass shoots form a mat over the smaller seedlings and fungal activity was commonly observed among heavy vegetation competition.

The field research foresters record drought and aphid attack as the probable main causes of mortality with only a few deaths accorded to birds and mammals.

Both physical and biochemical facets of vegetation competition were observed especially where the vegetation was matted on top of smaller seedlings. There was loss of rigidity, yellow discolouration and a mat of fungal hyphae. The loss of seedlings because of drought and aphid attack in June 1967 was particularly interesting on these three wet sites.

Height Growth

Introduction

A clumped distribution is common to most tree species regenerating from natural seedfall (Ker, 1953). This was observed by Day (1957) among Sitka spruce seedlings in British Columbia. Since stocking levels are based on presence or absence of seedlings in the survey quadrats and seedling numbers are not necessarily recorded, something less than full stocking would provide 4000 seedlings per acre in the current ¼ milliacre quadrat assessment. Ker's (1953) figures show that the level would be closer to 50%. Since the survey at Ae was carried out when seedling numbers are high with high mortality rates during this period of seedling establishment, the tallest most successful seedling in each stocked quadrat is of particular interest. It is the seedling most likely to achieve final establishment. While a study of less successful seedlings would also provide valuable information, it was decided to carry out more detailed measurements on the tallest seedling on each quadrat to assess growth responses to site conditions.

Methods

In April 1968 the tallest seedlings on each stocked quadrat was marked with coloured plastic ribbon. At the end of the growing season the following height measurements were recorded:

Total height in inches
Leader length 1968
Leader length 1967

Results

The distribution of height growth for the 1964 seedling population across the gaps is shown in Figure 24. Maximum height development for these seedlings occurs in the gap centres and towards the north edge of the gaps. The most even distribution of this population occurs on the peaty gley soil. A height growth pattern converse to that for seedling numbers is illustrated in Figure 24. The surviving seedlings while fewer in number are taller in the gap centres and are the more likely to become well established. Leader lengths are shown in Table 16.

TABLE 16

LEADER LENGTHS ALL SEEDLINGS
(inches)

	Peaty Podsol		Peaty gley		Peat	
	1968	1967	1968	1967	1968	1967
N. Stand	1.43	1.45	2.63	2.60	2.47	2.47
N. gap	2.54	2.00	5.43	4.79	7.00	5.88
S. gap	2.32	1.96	4.39	4.25	4.14	4.36
S. Stand	1.75	1.25	1.23	0.93	1.17	0.89
	2.01	1.67	3.42	3.14	3.69	3.40

The pattern of growth across the gaps is maintained by the leader growth of the last two seasons. In September, the tallest seedling on each quadrat was lifted. The roots were washed of soil and allowed to assume their original distribution as they dried. Rooting depth measurement was then made.

The calculated regression of leader length on rooting depth supported the relationships established during the first rooting depth study in 1967. Leader length was directly correlated with depth of rooting and the resulting relationship is shown in Table 17 and in Figure 25. Mean values for stand positions within soils are shown. The regression is based on all measurements in each transect.

TABLE 17

LEADER LENGTH AND ROOTING DEPTH.
ALL SITES

Leader length (Y) = -0.454 + 2.19 X_1 (rooting depth)

Analysis of variance

Source of variation	Degrees of Freedom	Sum of Squares	Mean Squares	F
Regression	1	120.44	120.44	61.237**
Residual	48	94.03	1.9667	
Total	49	214.47		

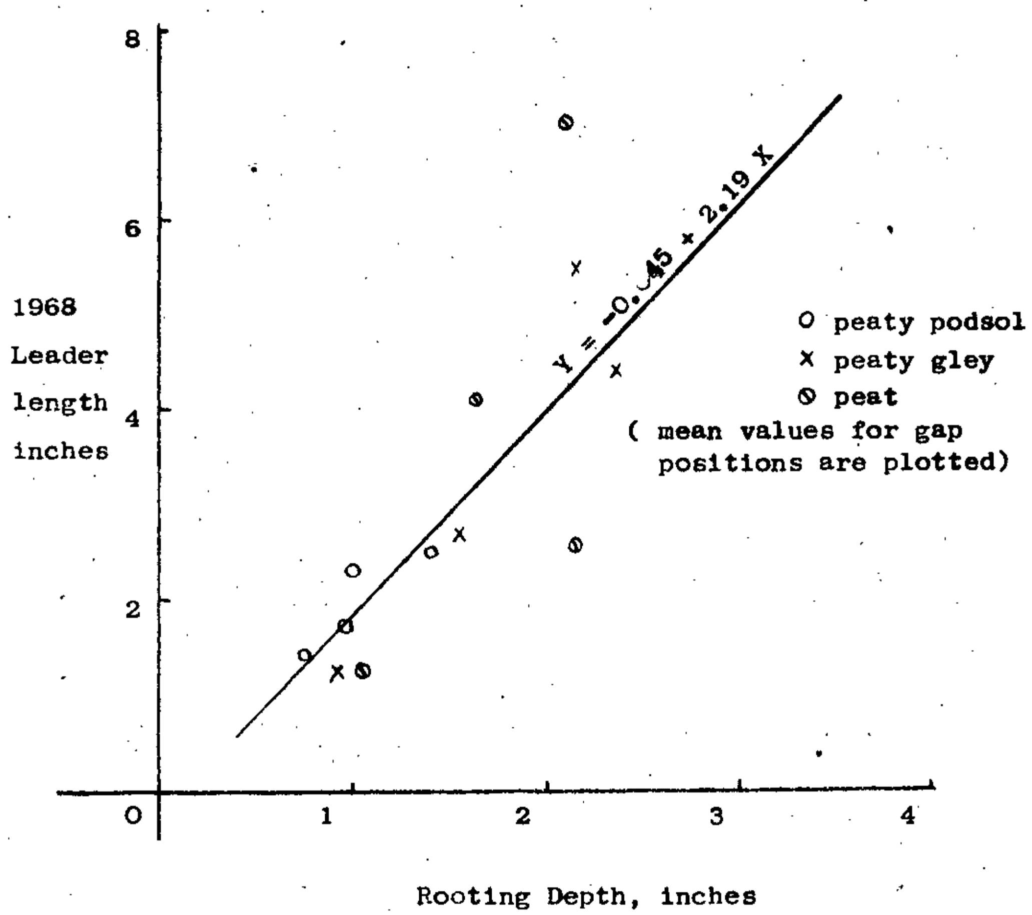
S. D.	"t"	r^2
0.2798	7.8254	0.56

The regression of leader length on rooting depth accounts for a highly significant proportion of the variation.

Light Assessment

Light measurement was made in September to examine the role of insolation across each gap transect. At each soil moisture sample station, a photometer reading of illumination in lumens was made at each corner of the quadrat frame used in the seedling surveys. Since it took some minutes to set up at each station, the full light comparison is only a general one with which to compare the station means. Results appear in Table 18.

Figure 25 **Leader length and Rooting depth 1968 seedling survey**



A high level of illumination is recorded for the north gap station for all sites. The north gap station on the peat soil is influenced by the adjacent windblow previously mentioned. Lowest insolation is recorded on the peaty podsol site where the marginal stands are denser and there are 4 residual trees within the gap.

TABLE 18

LIGHT VALUES FOR THREE CLEAR CUT GAPS AE. SEPTEMBER 1968

September 13 Light Values. Ae.

Stations round 1 metre° lumens

							$\bar{X}$
Peaty	1.	North stand	2231	2522	3395	2522	2667.5
Gley	2.	North gap	1330	2470	1995	1710	1876.3
	3.	Centre	140	110	140	140	132.5
	4.	South gap	1000	780	740	750	817.5
	5.	South stand	320	320	460	490	397.6
	1.	North stand	110	80	130	130	112.5
Peaty	2.	North gap	210	180	170	280	210.0
Podsol	3.	Centre	940	590	780	880	797.5
	4.	South gap	110	90	110	160	117.5
	5.	South stand	140	130	150	130	135.0
	1.	North stand	855	665	285	380	546.3
Peat	2.	North gap	850	650	210	320	507.5
	3.	Centre	360	560	510	540	492.5
	4.	South gap	736	552	184	184	414.0
	5.	South stand	420	380	250	120	292.5

September 18 Light Values. Ae

Stations round 1 metre lumens

			1	2	3	4	$\bar{X}$
	1.	North stand	910	780	780	500	742.5
Peaty Gley	2.	North gap	2697	2958	261	870	1696.5
	3.	Centre	485	873	873	679	727.5
	4.	South gap	485	1649	485	970	897.3
	5.	South stand	2565	2090	1520	855	1757.5
	1.	North stand	87.3	97	87.3	77.6	87.3
Peaty	2.	North gap	164.9	135.8	174.6	106.7	145.5
Podsol	3.	Centre	417.1	213.4	349.2	378.3	339.5
	4.	South gap	77.6	77.6	67.9	56.2	69.8
	5.	South stand	591.7	106.7	291	106.7	140.9
	1.	North stand	1455	1843	679	582	1140.0
	2.	North gap	582	1358	970	970	970.0
Peat	3.	Centre	582	582	679	679	630.5
	4.	South gap	485	194	388	291	339.5
	5.	South stand	97	126.1	174.6	135.8	133.4

Full light 2522 3 p.m.

Discussion

Height growth increases in response to light so that the tallest seedlings are found in the clearcut gaps. The north section of the gaps with highest insolation has maximum height growth. Height growth is correlated with root penetration, and to a lesser extent to root extension. If rooting can be encouraged in to deeper soil horizons increased height growth can be expected. Further examination of height growth patterns across the gaps would be worthwhile: however such a stratification of the current sample would not provide an adequate population of seedlings in each group and a more detailed analysis is not valid. There are real differences in height growth between soil types and between locations within soil types. Responses to light conditions and the associated vegetation competition are clearly illustrated.

Preferred Seedbeds

Introduction

The seedbeds supporting the greatest number of successful seedlings and the tallest seedlings, if they can be classified and described are a most valuable guide to suitable site preparation. This had led to a number of direct sowing trials to establish performance rates on a variety of peaty sites. Edwards, Zehetmayr and Jeffrey (1959) report trials of spot seeding on the variety of seedbeds produced by the ploughing patterns then current. Promising results were obtained on mounds in the bottom of furrows, and the sheltered step portion on ploughed ridges was better than the ridge top. Zehetmayr (1954) reports broadcast seeding over the turf profile in 1928 but the major response was to added fertiliser not microsite variation. Vegetation competition was the most important consideration after the first growing season. The pot experiments of Harper, Williams and Sagar (1965) with annual grasses illustrate the utility of a 'safe site' for germination and growth. Sites in the crevices between rough surface structured soil units were preferred by the grasses. Day (1964) discusses preferred sites for hybrid Engelman spruce and white spruce in Alberta (Picea engelmanii Parry x P. glauca Moench) Voss).

In a moisture deficient growing season Day reports that deep organic soil seedbeds are preferable to shallow organic soils or mineral soils, while rotten wood seedbeds supported the highest proportion of seedlings overall. Height growth and root extension followed a similar pattern. Shade played an important part in preferred site selection and greatest height growth and root extension occurred under light shade in Albertan conditions. Spruce occupied 96.4% shaded locations and only 3.6% open sites. Shelter was in the form of mounds, stumps, branches, shrubs, herbs and trees.

Methods

During the regeneration survey at Ae the seedbed in which the tallest seedling was rooted was recorded. This assessment was checked at the end of the growing season when the seedlings were removed for measurement. Micro-relief was assessed using a topograph, a series of pins pushed through a horizontally mounted bar, to the ground surface. The bar and stand fitted over the quadrat frame and were levelled at each quadrat. A profile of the topography along the N-S line through the axis of the tallest seedling was therefore created and the small variations in topography measured. Four seedbed types were recognised:

Spruce litter	- the L and F horizons
peat (some mosses)	- mainly F and H layer
Mineral soil	- usually on top of peat because of root pumping action or on windblow sites
Mixed	- drain spoil

Micro-relief included:

Depressions	- usually up to 4 inches deep - deeper had standing water
Stump bases	- seedling position relative to the stump
Level	-
Mound	- undisturbed mounds
Drainside	- beside drains but not on spoil
Other	- No other preferred seedbeds were encountered

Results

The distribution of the tallest seedlings and their leader length by seedbed types and micro-relief strata are presented in Tables 19, 20, 21 and 22. The quadrat survey information appears in the Appendix.

TABLE 19

DISTRIBUTION OF TALLEST SEEDLINGS BY SEEDBED TYPES

	S.S. Litter	Peat	M. Soil	Mixed	Other
Peaty Podsol	32	1	-	4	
Peaty Gley	14	19	2	2	
Peat	10	20	4	1	
Total	56	40	6	7	/109
%	51.4	36.7	5.5	6.4	

TABLE 20

DISTRIBUTION OF TALLEST SEEDLINGS BY MICRO-RELIEF

	Depression	Stump – Sheltered Side					Level	Mound	Drainsid
		≤X.	N.	S.	E.	W.			
Peaty Podsol	9	9	3	2	2	2	13	3	3
Peaty Gley	12	10	4	1	3	2	8	2	5
Peat	6	11	3	6	-	2	3	7	8
Total	27	30					24	12	16
%	24.8	27.5					22.0	11.0	14.7

TABLE 21

LEADER LENGTHS OF TALLEST SEEDLINGS BY SEEDBED TYPES (mean, inches)

	S. S. Litter	Bare Peat with moss	M. Soil	Mixed (Spoil)
Peaty Podsol	1.62	2.00	-	1.31
Peaty Gley	1.63	4.13	5.00	7.25
Peat	1.53	5.12	3.81	1.00

TABLE 22

LEADER LENGTHS OF TALLEST SEEDLINGS BY TOPOGRAPHY (mean, inches)

	Depression	Stump bases	Level	Mound	Drainside
Peaty Podsol	1.60	1.89	1.25	1.92	1.33
Peaty Gley	2.00	4.44	3.36	3.59	5.31
Peat	5.54	4.54	5.33	1.63	1.91

(Figures underlined in Table 17 indicate low sample numbers).

Most seedlings occur on bare Sitka spruce litter or peat with only a moss covering. This corresponds to the distribution with stand position and vegetation competition since these seedbeds now occur mainly on the stand margins. The somewhat sheltered site is favoured and a high proportion of seedlings occur in depressions or at the base of stumps. Mean leader growth is greatest on mineral soil but this seedbed is not well distributed and the sample numbers are small. Bare peat with a moss cover which probably developed after cutting, gives a high growth rate while the spruce litter is not capable of sustaining vigorous growth. The sheltered seedbeds give a considerably higher growth rate on all soils.

Discussion

Most seedlings grow in the shelter of stumps resulting from the 1962 cutting. They were generally rooted in the remnant of the old peat turf which formed a slope around the butt swell and this contributes to the high occurrence on the 'peat' seedbed type and the relatively high growth rate on this seedbed.

This information and that presented in the rooting depth study points to a preference for a well aerated seedbed which may be protected against the effects of drought. The stump site provides a moisture conserving microrelief between the old tree roots and shade from insolation during dry spells. The depressional microsites were associated with successful growth on spruce litter. The depressions had simply filled with this material and the microrelief was not revealed until the pins of the topograph were pushed through to a resistant datum. This also points to a well aerated layer of partially decomposed material on top of the old Molinia peat. The depression is an indication of the need for moisture conservation during short stress periods. The mineral soil and mixed spoil seedbeds though available in only widely scattered locations or along drain sides in the gap areas are nevertheless well stocked with vigorous seedlings.

The tallest seedlings per quadrat first identified in April 1968 were not necessarily the tallest at the final assessment in September 1968. In a small number of quadrats, about 10%, the current year's growth of tallest seedlings was less than another. The years of regeneration establishment seem to be a period of growth responses to a wide range of microsite factors on these small areas.

Germinant Survival 1968

Introduction

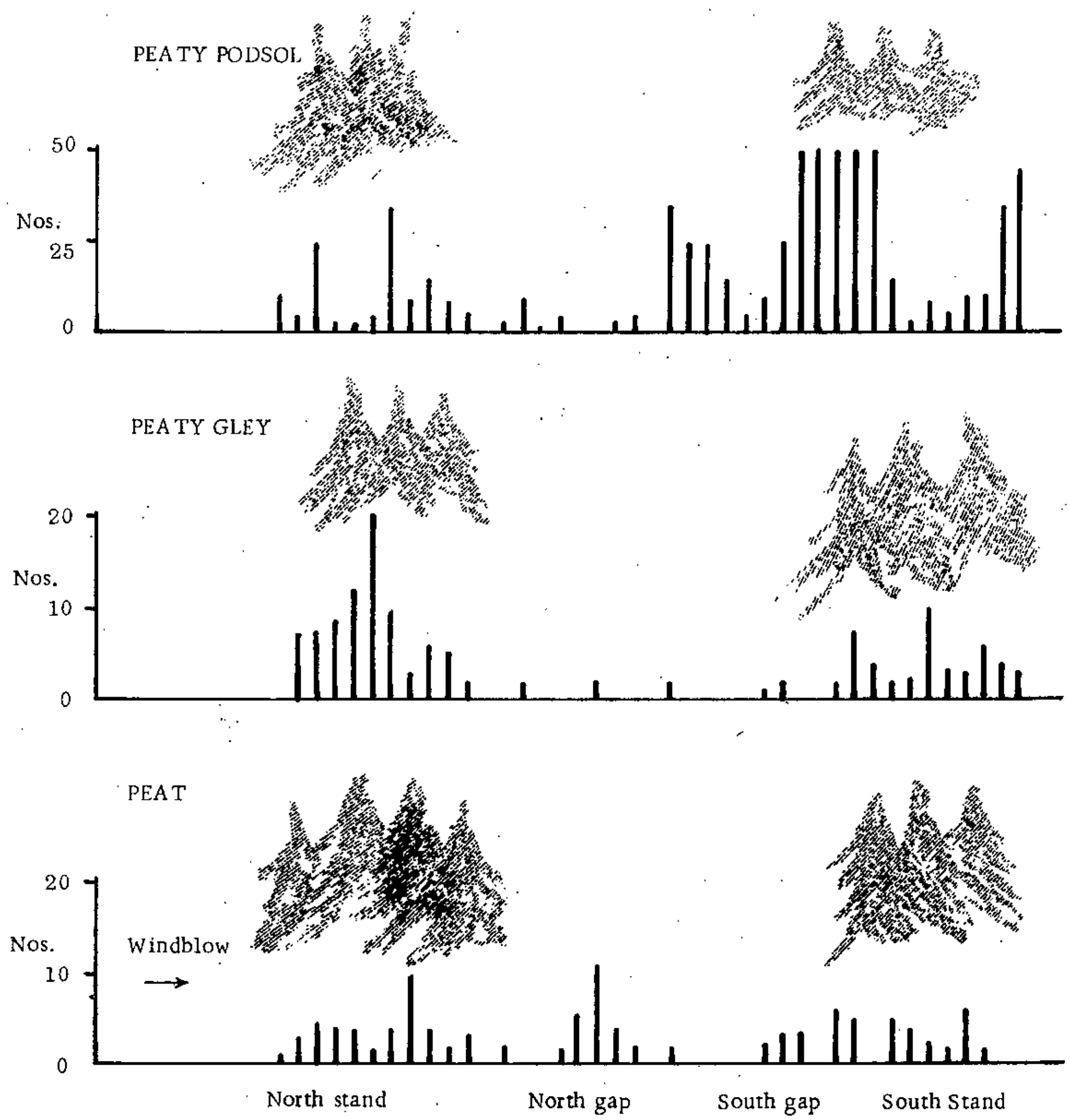
From October 1967 to March 1968 the study area was visited seven times and on each occasion seedfall was observed. Seedfall was particularly noticeable in March from windblown trees and the cone bearing branches close to the ground were seen to scatter seed. Good seedling germination was anticipated. Howells' (1966) study of germination on a variety of seedbeds showed faster germination rates on mineral soil than on spruce litter, with moss seedbeds intermediate. Final germination values, Howells reports, were not significantly different. Germination was affected by controlled conditions of relative humidity and moisture supply. Studies of germination of Canadian spruces on a variety of seedbeds underline the preference for mineral soil and mixed seedbeds, (Jarvis et al 1966, Sutton 1968).

The seedlings germinating in spring 1968 at Ae provided an opportunity to examine preferred seedbeds further and to assess first growing season mortality.

Methods

In June 1968, and after most germination was complete, the new seedlings on each regeneration quadrat were marked with a wooden toothpick. A re-tally was completed in September. Many of the seedlings had disappeared from the germination site. A few were found standing dead and others fallen down and still present.

FIGURE 26 1968 GERMINANT NUMBERS



Results

The initial and final tallies are summarised in Table 23, and shown in Figure 26.

TABLE 23

SURVIVAL OF 1968 GERMINANTS

Percent

	Soil mean	North stand	North gap	South gap	South stand
Peaty podsol	86.6	83.5	80.0	93.7	81.7
Peaty gley	76.4	91.5	34.0	50.0	53.5
Peat	98.2	92.1	72.4	100	94.1
Position mean		87.4	73.7	92.9	79.2

Since this is the sixth growing season since the gaps were felled, the pattern of seedling distribution is an index of vegetation encroachment and the availability of the 'wet blotting paper' type of seedbed. Percent losses are higher for the exposed sites towards the north gap. Survival is best on the wettest peat site and underlines the potential dryness of the superficial rooting zone.

To this information is added the summary of mortality from the Forestry Commission tally of 1968 germinants. Losses between June and November amounted to 21%. Death was attributed to a heat/drought combination, early in the development of the seedlings, because of superficial rooting. Greatest mortality occurred among seedlings beneath the stands.

C9	Peat site	4% mortality
C3	Peaty podsol	20% mortality

The Forestry Commission records confirm higher mortality on the peaty podsol.

Discussion

Mortality among the new germinants was low considering the paucity of available preferred sites as described previously. The type of damage was a brown coloured constriction at the root collar at which the seedling breaks off and often blows away. This is comparable to damage by damping-off fungi but the cause of death is most likely to be a drought/heat stress. Day (1963) describes such damage among spruce seedlings on droughty sites. Day (1963) and Gregory (1956) also refer to high surface temperature on litter seedbeds and Day (1964) describes heat lesions and bark necrosis due to this cause. The standing dead seedlings collected from this study showed no such obvious signs under the binocular microscope. The material was too badly degraded for further microscopic examination. Smothering by vegetation accounted for mortality among those seedlings not rooted on bare seedbeds. The pattern of seedling mortality will be observed by the Forestry Commission Research Branch using the permanently marked seedlings on 4 sites. Some consideration should be given to assessing seedbed surface temperature build-up.

Further Study

The further examination of the range of seedbeds sampled in the above study should be pursued Competition with ground vegetation and between spruce seedlings in clumps will lead to the establishment of dominance by particular individuals. The assessment of growth of the tallest seedlings will be followed by the Forestry Commission Research Branch programme until establishment is assured. The role of natural regeneration in restocking these forests may then be assessed. A desirable or preferred seedbed may then be adequately described and an improved assessment made of possible site preparation for regeneration for second rotation spruce stands.

Summary

Stocking of thriving spruce seedlings in simulated windblow gaps at Ae Forest was more than adequate. The small samples taken represent a considerable population of seedlings throughout the forest. Forty years of tree cover and site improvement by draining have created a range of seedbed conditions which is receptive to spruce germination and seedling survuval

The seedlings are rooted in the well-aerated surface organic soil horizons and are mainly restricted to the spruce litter layers Roots do not penetrate the well decomposed old Molinia peat.

A pattern of seedling distribution and growth across the gaps has emerged. Numbers are highest on the stand margin and

just a short distance back ($\frac{1}{4}$ chain) into the stand. Numbers are lowest but growth rates are best in the gap centres where light increases growth but vegetation competition is most severe.

Seedling survival studies carried out the the Forestry Commission Research Branch show that a drought/heat combination accounts for most losses (16%), and attack by Elatobium abietina follows drought stress.

Numbers of 1968 seedlings were highest on the peaty podsol but survival was better on the moister sites. Seedlings were generally able to survive on microsites which were moisture conserving, such as in tree stump shelter and in small litter filled depressions. Survival rate was 79%.

DROUGHT STRESS

INTRODUCTION

Relative turgidity of plant tissue is a measure of the cell water content. It is determined by weighing fresh material which is then allowed to reach full turgidity in an enclosed saturation vessel and reweighed. After oven drying to constant weight, the relative turgidity is calculated from the formula.

$$RT = \frac{\text{Fresh weight} - \text{oven dry weight}}{\text{Saturated weight} - \text{oven dry weight}} \times 100$$

(Clausen and Koslowski 1965)

It thus measures how water deficient the tissue was in comparison to the fully saturated state. Kramer (1955) points out that this assumes that the fully turgid state is optimum and desirable. It provides a simple measure of lack of cell moisture for any given set of conditions. Low levels of relative turgidity are recorded at both ends of the soil moisture scale and Bannister (1964) shows a relative turgidity response in heath plants to waterlogging as well as to drying out. Weatherly (1950) and Barrs and Weatherly (1962) present the technique in perspective using cotton leaf discs floated in water in the saturation chamber. They stress the effects of experimental technique on the results achieved and enumerate certain potential errors. The material when first weighed should be fresh, the saturation period should be as short as possible to prevent cell injection with moisture, and a constant temperature, about 20°C. should be maintained. However the technique, if carefully used, is simple and repeatable, giving consistent results. The relation of this measure of moisture stress to soil moisture tension has been the subject of several studies. Rutter and Sands (1958) used tensionmeters and gravimetric samples to relate soil moisture tension to needle turgidity in Scots pine. They outline an important diurnal variation with a minimum around 11.00 and 15 00 hours. Highest point they report was sunrise when the leaf turgor was in equilibrium with the soil moisture content. Slatyer and Barrs (1965) report that despite the variations in results because of technique:

> 'It (R.T.) has proved to be a quantitative and valuable index of internal plant water deficits, except under conditions of only slight deficit where it has been found relatively insensitive'

Pharis (1967) uses relative cell water content as an index of moisture relations of tree seedlings over a 2 year period and recorded highest levels in early morning samples, lowest in the mid-afternoon. He also established lethal levels for 4 conifers in a 1966 study. Kramer (1959) says

> 'The effect of a given relative turgidity is not the same in all species; hence the critical level probably must be determined for each species and perhaps even for each variety'

Because of drought mortality recorded in the 1967 regeneration tally by the Forestry Commission Research Branch and the obvious aphid infestation following a June droughty period, it was worthwhile to adopt some measure of drought stress for the Sitka spruce seedlings in the current study. Since it has equal application to waterlogged as to droughty conditions, relative turgidity (R.T.) or cell water content, was selected.

METHODS AND RESULTS

Three studies were conducted to examine drought stress in spruce seedlings. The first, in the field, created drought conditions around patches of natural seedlings using polythene tents. The second in the laboratory determined R.T. levels for potted seedlings dried-down to permanent wilting, and the third sampled the natural seedling population throughout the 1968 growing season to determine whether lethal levels were approached at any time on wet sites. A standard technique was developed for all studies :-

Between 11.00 hours and noon, sample seedlings were clipped at the root collar and weighed as soon as possible. In the field using bagged seedlings this was completed within 6 hours, in the laboratory within 1 hour. The seedlings were then saturated in a plastic loaf pan with a close-fitting clear plastic lid. The cut stem ends were pushed into a ¼ inch bed of clean coarse sand and the seedlings remained upright as shown in Figure 28.

These were placed in an incubator at 21°C for 30 hours. A pilot study of water uptake showed that there was little weight gained after this period. The saturated seedlings were then blotted surface dry with tissue paper, reweighed, and oven-dried to constant weight at 110°C. Needles of two age classes as well as whole seedlings were sampled and resulting R.T. levels appear in Table 24.

TABLE 24

R.T. TEST LEVELS FOR NEEDLES AND WHOLE SEEDLINGS

Sample	Current needles	Last year's needles	Whole seedlings
1	92.2	98.2	96.4
2	92.6	91.4	92.3
3	86.1	91.2	97.5
4	90.5	89.7	92.6
5	80.3	84.8	91.0
6	84.6	91.3	94.2
$\bar{X}$	87.7	91.1	94.0

The whole seedling values are not significantly higher then needles ($p \leq 0.05$).

Figure 27. Polythene tents to induce drought stress.

Figure 28. Saturation chamber for R.T. determination.

Since the tree seedlings are made up of tissue of different ages it was felt that this was a more reliable estimate of drought stress than levels in needles alone. In the saturation chambers the seedling also had to make use of a more natural water transport system than a cut needle or leaf disc. Another interesting whole seedling technique is used by Pierpoint (1967) who places the clipped seedling in a pressure vessel and records pressure at which cell sap just oozes out of the cut end, held in a soft rubber collar and exposed to the atmosphere.

1967 Field study

In August 1967 following the observation of drought stress in natural seedlings, 2 small polythene tents on wooden frames were placed over patches of natural seedlings in the gap centre and north stand locations at the peaty gley sites as shown in Figure 27. Casella Thermohygrographs recorded conditions in one of the tents and in a Stevenson screen at ground level in the open. A comparison of conditions is presented in Table 25.

TABLE 25

RELATIVE HUMIDITY AND TEMPERATURE IN THE TENT AND IN THE OPEN

Date	TEMP. °F				R.H. %			
	Tent		Open		Tent		Open	
	Max.	min.	Max.	min.	Max.	min.	Max.	min.
July 7	81.5	46.4	72	43	100	52	100	76
July 14	90.5	46.4	82	48	100	33	100	68
July 23	82.4	41.9	74	43	100	54	100	100
July 28	90.6	44.2	75	41	100	54	100	88
August 4	78.8	44.2	72	43	100	54	100	74
August 10	75.2	42.8	72	41	100	51	100	72
August 17	69.8	45.5	70	43	100	64	100	72
August 24	73.4	44.2	72	45	100	60	100	78
September 1	75.2	43.7	60	41	100	56	100	80
September 15	66.2	42.8	58	38	100	78	100	90
September 22	55.4	37.6	58	38	100	84	100	92

A small degree of drought was achieved but comparative relative turgidity levels did not vary by more than 8-16%. Seedlings in the gap centre were as able to avoid drying as those under the stand, (Table 26). At this period in the 1967 growing season, no visual symptoms of drought stress were noted.

TABLE 26

R.T. LEVELS IN POLYTHENE TENTS AND IN THE OPEN

Date	Gap Centre		North Stand	
	R.T.% (basis 2 seedlings per stratum)			
	Tent	Open	Tent	Open
August 12	93.99	96.53	95.40	94.51
August 24	54.90	76.30	70.50	68.20
September 22	90.20	88.84	85.43	89.22
$\overline{X}$	86.45		86.85	

The R.T. levels from the tents and open locations do not vary other than for a short period in the week of August 21. The temperature and relative humidity differential was sufficient to reduce tent values in the gap centre to 16% below those in the open. Under the canopy in the north stand however no such differences were recorded.

Laboratory Study

Five hundred 2 year old Sitka spruce seedlings were supplied from spaced seedbeds at Bush nursery by the Forestry Commission Research Branch. They were transplanted in November to plastic trays filled with John Innes number 2 compost and stored in a cold frame greenhouse till required on January 23rd when they were placed in a light cabinet in the laboratory (Figure 29). The light schedule for the cabinet was 1000 ft. candles at the tray surfaces and an 18 hour light, 6 hours dark cycle. Water was added every second day to a photographic developing tray containing eight trays of ten seedlings. The rate was 450 ml. water to each tray after starting at field capacity. Seedlings flushed on January 29. A preliminary trial in November and December had indicated that a 14 day dry-down period would be sufficient to reach the moisture content retained at 15 atmosphere by the John Innes compound (12.1%). The moisture content had been reduced to 11.6% by fifteen days and to 8.3% by the twentieth day. Porous porcelain sample cups of soil were used to follow dry-down of the rooting compound in the seedling trays.

On each day during drying, a tray of ten control seedlings and ten treated seedlings was selected at random and the seedlings were clipped for determination of R.T. A second tray of 10 treated seedlings was selected and put on a re-watering cycle to assess recovery rates.

On the fifth day of the drydown period the newly flushed leading shoots wilted (R.T. 73.4%) but recovered on re-watering and in the saturation chambers. On the seventh day (R.T. 65.7%) the needles became brittle and lost some green colour. They soon yellowed but recovery on re-watering was satisfactory until day 10 (R.T. 40%). Needle fall began on the twelfth day (R.T. 36.3%) by which time the seedlings did not respond to re-watering. Seedling mortality assessed by recovery on re-watering is shown in Table 27 together with R.T. levels. Re-watered seedlings appear in Figure 30.

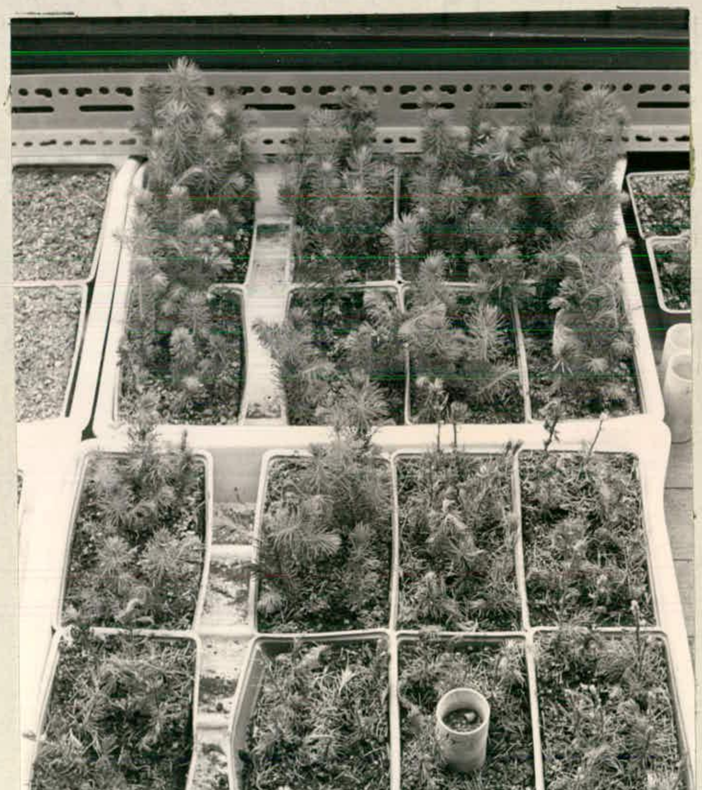
TABLE 27

SEEDLING DRYDOWN AND SURVIVAL

Day	Soil M.C. %		R.T.%		Survival %
	Treated	Control	Treated	Control	Treated (re-watered)
0	47.6	47.6	79.6	79.6	100
1	44.0	46.5	81.7	80.1	100
2	45.0	48.6	86.5	89.0	100
3	42.9	51.5	83.1	90.4	100
4	42.9	52.1	80.5	85.8	90
5	40.5	50.5	73.4	84.2	100
6	38.1	51.6	73.6	79.9	90
7	23.8	50.8	65.7	85.2	60
8	17.9	48.6	40.0	86.0	80
9	17.9	51.8	52.6	86.8	90
10	11.9	40.2	39.8	88.6	80
11	8.6	40.6	49.2	89.7	60
12	6.9	41.7	36.3	87.0	0
13	4.0	47.1	26.1	88.0	0
14	4.0	45.2	48.2	90.1	0
15	4.0	43.8	15.0	90.4	0

Figure 29. Laboratory study, light cabinet.

Figure 30. Re-watered samples from the drydown period, day 1 to day 16 are represented by the 16 trays.



The ability of the seedlings to avoid drying out in the face of very low soil moisture contents and low relative humidity (32% day - 45% night) and high air temperatures (72°F day - 56°F night) is demonstrated by these R.T. values. The limiting level reached on the twelfth day is well defined.

These levels provided a datum for field assessment in the 1968 growing season.

1968 Field Study

Each week during the field study a sample of 10 natural seedlings was taken from a peaty gley site using systematic sampling with random starts along the stand edge. During particularly dry periods additional samples were made at the north end of the transects across the other gaps and in some cases among the new germinants. The standard technique was used for R.T. determinations. Results are presented in Table 28.

TABLE 28

SEEDLING R.T. RESPONSE DURING THE GROWING SEASON, PEATY GLEY

		Location		R.T. ($\bar{X}$ mean of 10 seedlings)
		Open	Stand	$\bar{X}$
April	8	98.3	100.0	99.65
	15	75.9	92.8	84.35
	25	73.9	82.7	78.30
	29	75.5	96.2	79.15
May	6	86.9	76.9	81.91
	14	78.9	76.0	77.48
	20	79.6	75.1	77.34
	27	78.5	67.8	73.15

Table 28 (Contd.)

SEEDLING R.T. RESPONSE DURING THE GROWING SEASON. PEATY GLEY

		Location		R.T.	($\bar{X}$ mean of 10 seedlings)
		Open	Stand	$\bar{X}$	
June	3	76.8	82.8	79.82	
	10	82.9	86.0	84.47	
	13			84.3	- 10 seedlings from gap centre
				82.4 (peaty podsol)	" " " "
				82.7 (peat)	" " " "
	17	75.8	82.7	79.27	
				85.7	6 seedlings from gap centre
	24	85.3	85.7	85.48	
July	1	84.4	94.3	89.36	
	8	86.3	95.2	91.18	
	15	95.44	100.0	97.72	
	22	80.49	87.41	85.71	
	29	91.16	81.22	87.43	
	29 min	48.14	max 73.91	63.53	10 germinants from N stand
Aug.	5	89.77	84.22	87.06	
	min	56.25	max 100.0	83.15	30 germinants from N stand
Aug.	12	84.16	75.95	80.05	
	min	45.45	max 97.43	58.12	10 germinants from N stand
Aug.	20	98.18	95.87	97.02	
	min	76.4	max 100.0	93.26	10 germinants from N stands
	26	91.57	92.90	92.23	
Sept.	2	98.27	100.0	99.14	

If R.T. levels approaching 40% are considered to be in the lethal range and 50% indicative of severe moisture stress, these were approached by 1968 germinants on two occasions during the growing season. These are:

July 29 min 48.14%
max 73.91%
mean 63.53%

Aug. 12 min 45.45%
max 97.43%
mean 58.12%

Excerpts from weather records indicated a relatively short duration of dry periods leading to drought stress in the superficially rooted seedlings. No symptoms of waterlogging were recorded in the field.

DISCUSSION AND SUMMARY

It is difficult to determine the relative degree of drought avoidance and drought tolerance in plants (Levitt 1963). The ability of the plant to take advantage of relative atmospheric humidity, dew, and to change the leaf attitude, are examples of avoidance. Beyond that level the stress between root and top becomes greater and approaches the limit of tolerance.

Because of the very low moisture contents likely to occur in the surface rooting zone of the Sitka spruce seedlings sampled and their ability to thrive, it is apparent that avoidance mechanism are at work. However the attribution of mortality to a drought/heat complex by the Forestry Commission Research Branch surveyors seems to be supported by this study in 1968 and by the onset of aphid attack in 1967. The lethal level of 12 days drought with R.T. of 36% according to the laboratory determinations is merely an indication of the scale of these effects. The conditions in the light cabinet are quite remote from field conditions. The potting compost does not have the water retention capacity of peat and has quite different temperature characteristics. However, until further field sampling can be carried out under drought conditions, either in the open or under a tent, the 40-50% R.T. level is an interim guideline for moisture stress levels in young seedlings. It is in the same range as that reported by Pharis (1966) for Douglas fir, Ponderosa pine and sugar pine (43%) and by Jarvis (1968 pers. comm.) for Norway spruce (40%), Scots pine (38%) birch (40%), and aspen (54%). Kramer (1959) aptly sums up the need for such an index of moisture stress

> "Most of the controversy on this subject (transpiration/ soil moisture stress) could have been avoided had it been realised more clearly that plant processes are controlled directly by the water content of the plant and only inherently by the water content of the soil. If the diffusion pressure deficit or the relative turgidity of the leaves had been measured, it would have been possible to correlate physiological processes with the water conditions inside the plant. If, in addition, the moisture tension of the soil at various stages of drying had been known it would have been possible to correlate soil and plant water conditions with the course of transpiration and other processes. It seems that in all studies of the effects of water on plant growth, we need an accurate characterisation of plant water conditions (R.T.) as well as of soil water conditions: This is essential to indicate when water becomes a limiting factor within the plant".

SEEDLING RESPONSES TO AERATION LEVELS AND DEPTH TO WATER TABLE

INTRODUCTION

The response of tree seedlings to a variety of controlled water regimes has been studied by Richard (1959), Marshall (1931), Hunt (1951), Rutter and Sands (1958), Jarvis and Jarvis (1963), Mueller-Dombois (1964), Pharis (1966), and Sims and Mueller-Dombois (1968). Some of the measured responses to water table depth have already been discussed when field measurements of water table were presented. Generally, controlled environment studies have been conducted at the dry end of the moisture scale, (Jarvis and Jarvis 1963, Pharis 1966), but a bibliography on waterlogging of tree species (Stransky and Daniels 1964) lists 48 references. The writer conducted an experiment in tolerance of tree seedlings to flooding in 1963 (Lees 1964) in which white spruce seedlings in ttays were immersed in water and survival rates determined for a variety of treatment periods. Mueller-Dombois (1964) however adopted a technique previously used for studying grass species behaviour to enable him to test a full range of moisture regimes for tree species under controlled conditions. He compared growth responses of jack pine (Pinus banksiana, Lamb) red pine (Pinus resinosa Ait) black spruce and white spruce. A wedge of uniformly mixed soil in watertight containers provided a gradient from approximately seven inches above the water table to almost five feet above water. Seeds were sown on the slope and seedlings later thinned to even numbers for each experimental treatment level. Once the seedlings were established, routine watering stopped and responses to water table depth were assessed after 11 months. There were fully watered controls. Mueller-Dombois was able to show responses to excess moisture and also to drought. The wet site species, black spruce was noticeably intolerant of drought.

Sims and Mueller-Dombois (1968) report the third in a series of trials using the soil gradient in which the conifers were compared in competition with common grasses. Grass competition reduced the previous best growth levels on the slope.

To examine responses of Sitka spruce seedlings to a soil moisture and aeration gradient in peat, a controlled experiment was proposed based on the technique described above. A peat wedge would be prepared to give a smooth gradient from water table to a height above water which might represent overdrained conditions in a high ploughed peat turf. Because disturbance of the peat would upset aeration conditions and because of the difficulty of relating the results to field conditions, it was decided to use peat in situ. A poorly aerated peat site was chosen to ensure that limiting conditions were sampled. The following experiment was designed.

METHODS

On a moisture receiving site with deep peat in the Forest of Ae a hole was dug to mineral soil at 36 inches depth. One end was sloped at 30° from the water table level to the peat surface. The peat spoil was used to extend the slope to 18 inches above the peat surface and thus represent a planting turf. A ditch dug out to the nearest cross drain provided a spillway which kept the water level just above the mineral soil. The slope, orientated North-South was 10 feet long, 30 inches wide to the ground surface and 48 inches wide above ground to prevent excessive drying of the turf sides. The slope is illustrated in Figures 31, 32 and 33. It was completed on April 29. Because of a noticeable variation in light conditions along the slope, the hole was opened out at the south or bottom end, in a fan shape to increase insolation. Since the site was under the spruce canopy, mainly diffuse light reached the slope surface.

Soil thermometers sampled peat temperatures at 1", 2", 4", and 8" depths at two stations on the slope while 1" thermometers were placed at the bottom and top levels. Lateral water seepage and rainfall maintained a constant water level at the foot of the slope. Aeration status along the slope was assessed using the platinum micro-electrode. It confirmed that with the exception of the well-aerated layer between superimposed peat and the ground surface, a smooth aeration gradient had been created. Silver strips exposed at 4 levels indicated that sulphides were present from water level to within three inches of the surface, (Figure 34.).

On June 12, 19 rows of ten 8-week-old container Sitka spruce seedlings were dibbled into the slope at intervals of 6 inches, or 3 inches above the water, from water level to 54 inches above. The seedlings had been raised in the greenhouse at Tulliallan Forestry Commission Forest Research Branch Nursery. The 3 - inch plastic tube containers were packed with a sand/peat horticultural mixture.

A horticultural pot of John Innes No. 2 Compost was planted with 12 container seedlings and sunk into the peat at the lower end of the slope 9 inches above the water. This was to gauge the temperature and light conditions and provide a control. At the end of September after the growing season the seedlings were lifted. On several occasions during the summer, aeration levels were measured, sulphide distributioo assessed and temperature along the slope checked.

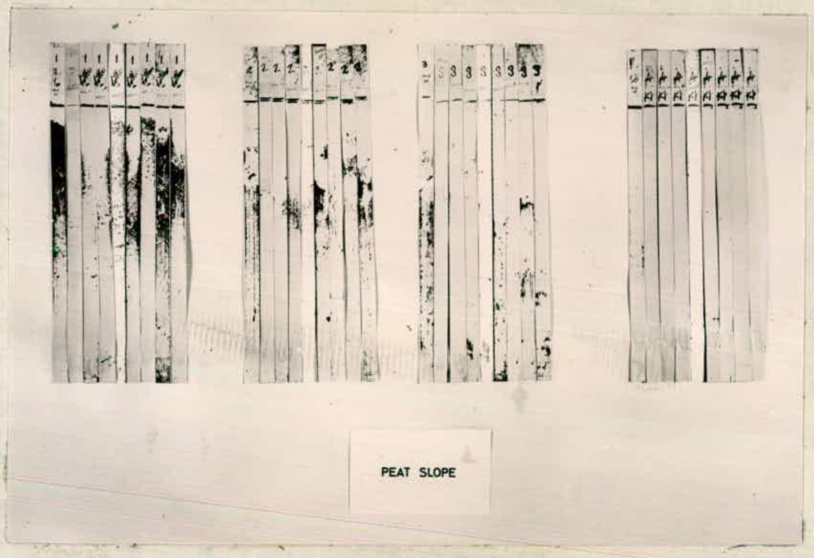
Figure 31. View down the peat slope to water level.

Figure 32. View up the peat slope.

Figure 33. The ditch which controlled water level at the foot of the slope.

Figure 34. Sulphide staining for four stations on the slope.

Foot Top



RESULTS

Growth of the seedlings appeared to follow the moisture and aeration levels quite faithfully, (Table 28).

There is an increase in aeration at the sandwich between turf and peat surface, otherwise there is a smooth aeration gradient. Analysis of total seedling dry weights and root/shoot ratios revealed that the levels were significantly different while "t" tests between individual levels showed that at the lower levels the seedlings did not develop beyond their greenhouse growth. Most of the bottom three levels' stock was dead. Further up the slope from level 8 and 20-24 inches above assumed the water table, the seedlings put on top growth and roots emerged from the containers into the peat (O.D.R. 6.22 $\mu gm\ O_2/cm^2/min$. Differences between adjacent levels then became significant. Seedlings representing each treatment level are shown in Figure 35. Growth improves markedly above the peat surface (O.D.R.11.2).

At the top of the slope the growth continued to improve, i.e. 54 inches to water O.D.R. 17 $\mu gm\ O_2/cm.^2/min$. The last row of data in Table 29 are values for the control horticultural pot which show that growth at the bottom of the slope was limited by soil moisture and aeration and not heat and light. Control temperature observations are summarised in the Appendix with the "t" tests between individual levels.

TABLE 29

GROWTH OF SITKA SPRUCE SEEDLINGS ON A PEAT SLOPE
(basis 10 seedlings per treatment level)

Level	Depth to water inches	Total seedling Wt. Ovendry grms.	Root/shoot ratio	O_2 Diffusion Current
1	0	0.013	0.479	1.1
2	3	0.018	0.254	2.8
3	6	0.017	0.250	3.9
4	9	0.027	0.180	5.8
5	12	0.026	0.181	2.8
6	15	0.039	0.313	5.3
7	18	0.025	0.147	4.4
8	21	0.048	0.154	4.9
9	24	0.032	0.374	5.0
10	27	0.044	0.360	6.8
11	30	0.037	0.249	9.1
Peat surface				
12	33	0.050	0.360	13.8
13	36	0.076	0.554	9.8
14	39	0.061	0.358	9.4
15	42	0.051	0.521	12.8
16	45	0.110	0.544	13.4
17	48	0.107	0.623	13.7
18	51	0.098	0.449	13.7
19	54	0.140	0.453	
Control				
20	10	0.596	0.491	9.0

Analysis of Variance
Ovendry Seedling weight

Source of variation	degrees of Freedom	Sum of Squares	Mean Square	F
Treatment	19	0.2368	0.0125	13.673**
Error	180	0.1641	0.0009	
Total	199	0.4008		

Root/shoot ratio (level 1 omitted)

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatment	18	3.9582	0.2199	1.792*
Error	171	20.9881	0.1227	
Total	189	24.9463		

Variation in aeration status was very small during the sampling period (Table 29$_a$).

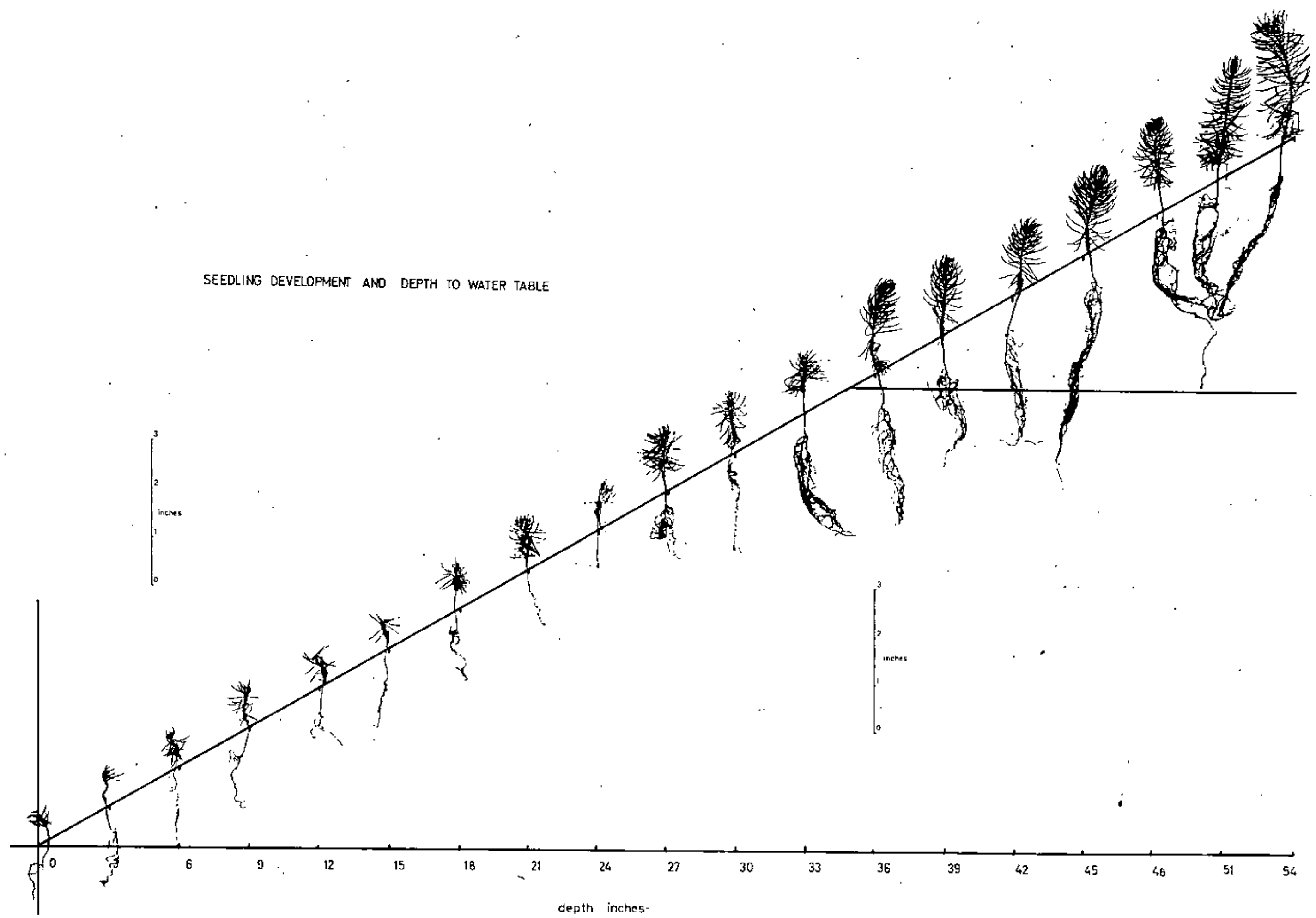
TABLE 29a

SOIL AERATION ALONG THE SLOPE

Diffusion current 0.5V applied at 3 in. depth for 2 mins.
(Basis 2 stations between each level)

Date	Treatment Level																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
June 19	1.13	2.75	3.88	5.75	2.75	5.25	4.85	4 95	5.00	6.80	9.05	13 83	9.85	12.75	13.35	13.18	12.25
July 25	2.0	2.0	2.25	3.25	2.0	2 5	3.5	3.25	4.4	3.0	10.75	11.0	10.5	12.0	12.5	16.25	17.0
August 28	2.25	2 25	2 15	4.75	4.25	3.5	4.25	5.25	5.75	5.05	8.0	10.75	10.0	7.05	13.5	10.05	11.75
October 17	3.55	3 0	3.5	5.35	5.05	5.35	5.25	6.55	6.65	7.75	10.0	9.75	10.85	11.13	9.75	11.5	12.35

Figure 35. Seedling development along the peat slope.



SEEDLING DEVELOPMENT AND DEPTH TO WATER TABLE
3
2
inches
1
0
0
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
48
51
54
depth inches-

DISCUSSION

The growth responses of these small seedlings indicate a sensitivity to moisture and soil aeration. The lower slope levels with sulphide concentrations did not provide a suitable growth medium. At a level of 20-24 inches above water and 6-10 μgm $O_2/cm^2/min$ roots just began to emerge from the tubes. Further up the slope the roots grew out into the surrounding peat. Height growth increases to a satisfactory level on the slope yet the maximum rate may not have been reached at the top. The long term effects of these conditions are not known and further testing of seedlings of varying age over several growing seasons would be worthwhile.

While the growth responses in this test appear related to aeration status and depth to assumed water level, a number of other factors must contribute to differences in treatment level. These include climatic conditions along the slope. For example light was controlled by the North-South orientation and southerly aspect of the slope in diffuse light beneath the overwood but variation in temperature and relative humidity would be operational to a small degree.

AERATION STATUS IN THE ROOTING ZONE AFTER DRAINING

INTRODUCTION

Recent afforestation of wetlands in Scotland has included large areas of basin peat where the water table is close to the surface all the year round. The cost of the intensive treatment required to improve the conditions for tree growth on these sites is partially offset by the large uniform areas of peat and the ease of machine application. To investigate this extreme of the wet site problem, sampling of aeration status was extended to a basin peat area. Flanders Moss is a raised bog on which a study of drain intensity and tree growth response is being carried out by the Forestry Commission Research Branch. An examination of aeration status was planned to determine whether conditions were being improved to the levels associated with successful seedling establishment at Ae. Experimental treatments involved a combination of turf patterns and cross-drain intensity. Turf patterns were further examined at Eddleston Moor Peat Demonstration Area near Edinburgh where recent technological methods are being tested.

METHODS

The Flanders Moss drainage intensity trials were initiated in 1964 and plots and their surrounds planted in 1965. The experiment occupies about 160 acres on Sphagnum/Eriophorum peat up to 28 feet deep over lacustrine clay. The area is 50 feet above sea level, fully exposed to east and west and the rainfall is 45-50" per annum. Surrounding the moss is arable farmland partly reclaimed in the 19th century by stripping peat from the mineral soil (Weir 1969). The central section of deep peat remains. The area was hand-drained in the 1920's to improve grouse cover. In 1964 it was drained to the following specifications.

Control	
DS/0	1 single mould board (SMB) (deep) furrow and 2 double mould board (DMB) (shallow) furrows: no cross drains
D/0	SMB furrows: no cross drains
S/100/2	DMB furrows : cross drains at 100 feet. 2 feet deep
S/100/4	DMB furrows : cross drains at 100 feet. 4 feet deep
S/50/2	DMB furrows : cross drains at 50 feet. 2 feet deep
S/50/4	DMB furrows : cross drains at 50 feet. 4 feet deep
S/2B/2	DMB furrows : cross drains at 25 feet. 2 feet deep
S/25/4	DMB furrows : cross drains at 25 feet. 4 feet deep

Two treatments using an underground drainer were included but not fully replicated. These were not sampled in the current assessment. Maximum cross-drain depth achieved in 1964 was 22". Cross-drain deepening to experimental specifications was not completed till November 1967. Treatment plots were approximately 1 acre square replicated in 4 blocks and planted with 1 + 1 Lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) The high SMB turfs were stepped. Fertiliser was applied round each tree at a rate of 118 lbs potassic super phosphate per acre. In each plot, three randomly located bore holes with perforated plastic casing have been established to meter water table fluctuation. These stations were used for soil aeration assessments; REDOX in 1967, and O. D. R. in 1968. Conditions in the undisturbed peat between the turfs were sampled at the outset.

Redox (1967)

At each water table bore hole a 3 inch core was extracted with a soil auger. The platinum spade electrode was inserted into the bottom of the 3" hole and a silver/silver chloride reference pushed into the peat surface and irrigated with distilled water. REDOX potential was read after 2 minutes. Electrode cleaning followed the method previously outlined. By changing over electrodes the same meter was used to determine pH. In 2 blocks (1 and 2) it was possible to measure REDOX before and after cross-drains were deepened to experimental specifications. There was no effect of drainage intensity on hydrogen ion concentrations and the millivolt values were not adjusted for pH.

Results

REDOX values are presented in the Appendix together with analyses of variance which were carried out by the Forestry Commission Research Branch at Alice Holt.

Drainage may have increased REDOX potentials compared with the control treatment but there are no significant effects attributable to draining intensity. Block effects are significant and indicate that the layout of the four blocks across the sample area is efficient. Two blocks lie to the south of the Blackrat Burn on a large flat and two lie to the north of the burn on slightly drier sloping terrain with evidence of severe heather burning. REDOX status is improved after drain deepening on Blocks I and II.

O. D. R. 1968

In August 1968, the area was re-visited. At the same soil sample stations duplicate readings (i. e. six per plot) of diffusion currents were recorded for three and six inch depths. The steel probe electrode was used as at Ae. The current/voltage relationship developed is shown in Figure 22. Again 0.5V was selected and the diffusion current read 2 minutes after the circuit was closed. Water table levels were read at each station.

Results

Analysis of variance was carried out for a randomised block experiment with interaction estimated.

The regression of O. D. R. and depth to water table was examined (Figure 36). The equation Y (aeration) = 5.64 + 0.476 x (depth to water) accounts for a significant amount of variation in O. D. R. as shown in Table 30.

Figure 36 Aeration and Depth to water, Flanders Moss

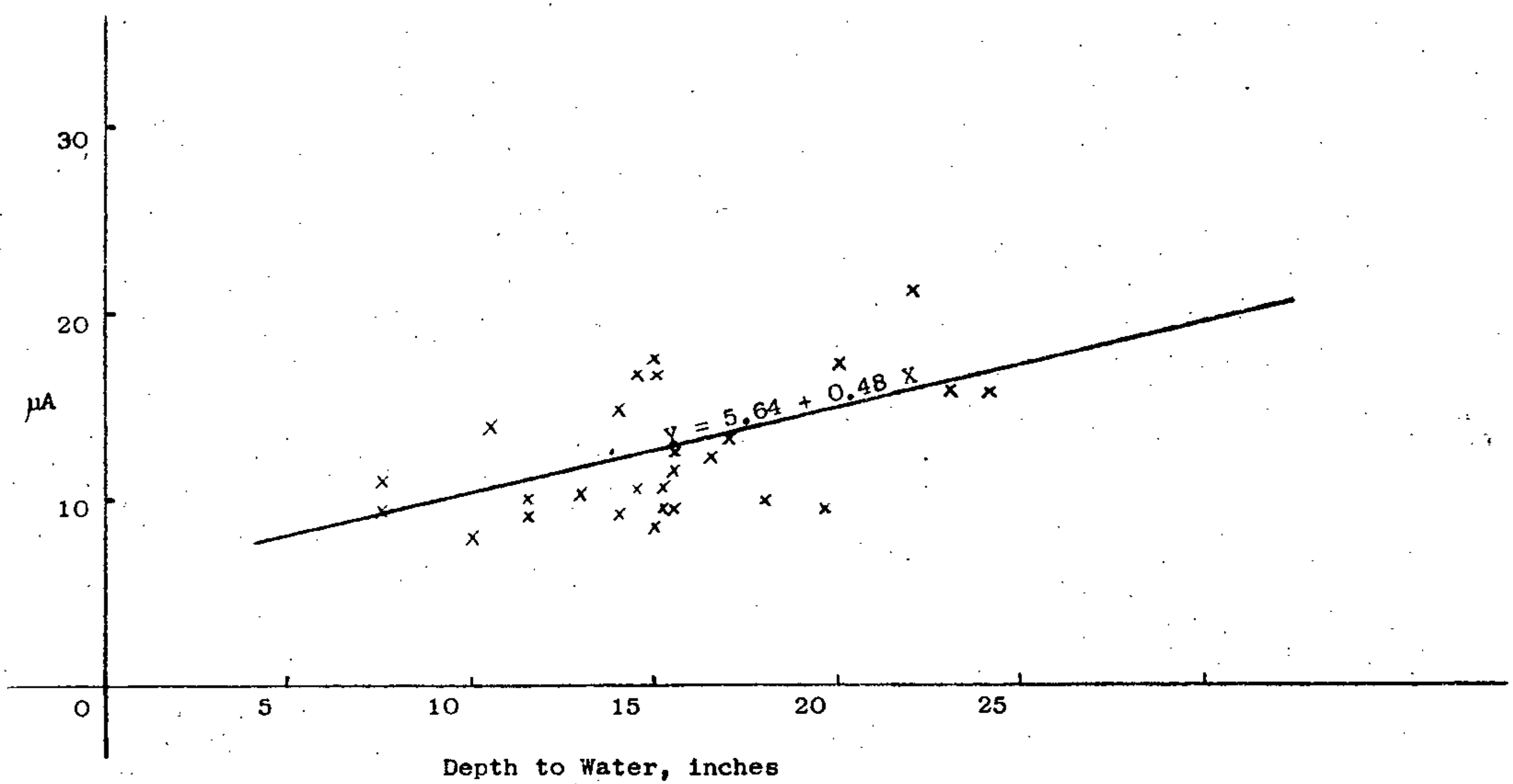


TABLE 30

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Regression	1	197.37	197.37	25.630**
Residual	48	369.63	7.7007	
Total	49	567.00		

Standard deviation 0.094 "t" (d.f. 48) 5.06** $r^2 = 0.35$

Aeration status varied significantly between the treatments and blocks. The control levels were lower than any draining treatment. Table 31 summarises the mean aeration levels for 3 and 6 inch sampling depths and presents the analyses of variance.

TABLE 31

DIFFUSION CURRENTS FOR 9 DRAIN INTENSITIES AT FLANDERS MOSS 3" down

Analysis of variance

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatments	8	865.0178	107.0022	8.4130**
Blocks	3	450.4476	150.1492	11.8054**
Interaction	24	608.8316	25.3679	1.9945**
Residual	180	2289.3688	12.7187	
Total	215	4204.6658		

Treatment	Mean	
1. Control	13.12	
2. DS/O	19.30	
3. D/O	16.26	
4. S/100/2	17.26	μA
5. S/100/4	18.14	
6. S/50/2	18.86	
7. S/50/4	17.96	
8. S/25/2	19.36	
9. S/25/4	20.08	

S.E. of treatment mean 0.7280

Table 31 (contd.)

Analysis of variance 6" down

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatments	8	711.2851	88.9106	15.3395**
Blocks	3	522.0855	174.0855	30.0344**
Interaction	24	601.4761	25.0615	4.3238**
Residual	180	1043.3167	5.7962	
Total	215	2878.3343		

Treatment	Mean
1. Control	11.02
2. DS/O	15.16
3. D/O	13.83
4. S/100/2	13.03
5. S/100/4	14.34
6. S/50/2	15.15
7. S/50/4	14.08
8. S/25/2	15.90
9. S/25/4	17.94

μA

S.E. of treatment mean 0.4914

Aeration levels fall between the 3 and 6 inch depths for all treatments. The combined use of deep (SMB) and shallow (DMB) ploughing without cross drains within the 200 foot square plots provides an aeration status equivalent to shallow (DMB) ploughing with 2 foot cross drains at 25 feet spacing but not as high as shallow (DMB) ploughing with 4 foot cross drains at 25 foot spacings. This is a very important local drainage effect. Mean height growth and total root weights for pine transplants are shown in Table 32. Water table levels and aeration response at Flanders Moss to draining may be a feature of the deep uniform fibrous peat there. Other drainage trials on pseudo fibrous peats or on amorphous peats such as those described by Zehetmayr (1954) have shown little response to drain depth per se. The Flanders Moss experiment is a good demonstration of what can be achieved with peat of a particular permeability.

TABLE 32

HEIGHT GROWTH AND ROOTING FOR 8 DRAIN INTENSITIES AT FLANDERS MOSS *

Treatment	Transplant Height (ft.)	Leader Length (ft.)	Root collar diameter (cm.)	Root Weight (grams)
DS/O	2.3	1.0	1.70	408
D/O	2.6	1.0	2.14	186
S/100/2	2.2	1.0	1.73	135
S/100/4	2.3	0.9	1.72	142
S/50/2	2.4	1.0	2.01	221
S/50/4	2.2	1.0	1.72	145
S/25/2	2.4	1.0	1.92	190
S/25/4	2.6	1.1	2.12	423

* Summary figures by courtesy of the Forestry Commission Research Branch.

The importance of aeration status with respect to rooting extent is demonstrated by these values. The D/O, S/50/2 and S/25/4 treatments are outstanding in root collar diameter though height growth response is not significantly affected but differences may be masked by a 1968 aerial fertiliser treatment.

DIFFUSION CURRENT PROFILES IN PLOUGHED TURFS

Single mould board and double mould board turfs were subjectively sampled at FlandersMoss using the probe electrode inserted to 3" depth in 10 transects across each turf profile. The results are shown in Figures 37 and 38.

Results

The profiles show that the top of the shallow (DMB) turf and the step of the deep turf (SMB) at Flanders Moss are best aerated.

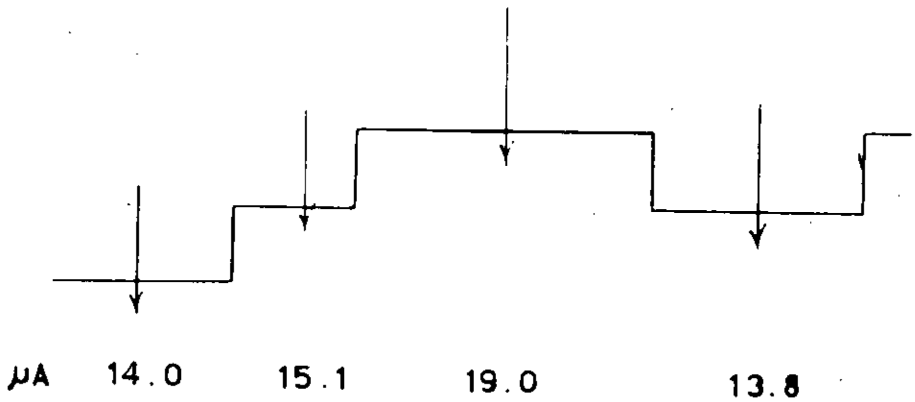
AERATION STATUS AT EDDLESTON MOOR

These aeration patterns were examined further at Eddleston Moor Peat Demonstration Area near Edinburgh. The area includes a raised bog site which fills a bowl shaped depression on top of a rounded hill, 850 ft. a. s. l. The peat type is fibrous with distinct layering down the profile in colour and texture. Deep ploughing has penetrated a predominantly fibrous red/brown horizon below which is a darker coloured anaerobic layer. The planting turfs on the area are in general well aerated. A trial of drain spacing with deep (SMB) ploughing was sampled. There are 3 blocks and 4 cross drain intensities. The most intensive, 15 foot cross drains, and the least intensive, 60 foot cross drains were sampled on each block. The centre row of 8 planting furrows furthest from the cross drains was assessed in a profile similar to that used at Flanders Moss, i. e. (1) undisturbed peat, (2) step, (3) turf top, (4) undisturbed peat. At 3 inches depth 0. 5 V potential was applied for 2 minutes.

Figure 37

DIFFUSION CURRENT PROFILE

DOUBLE MOULDBOARD TURF

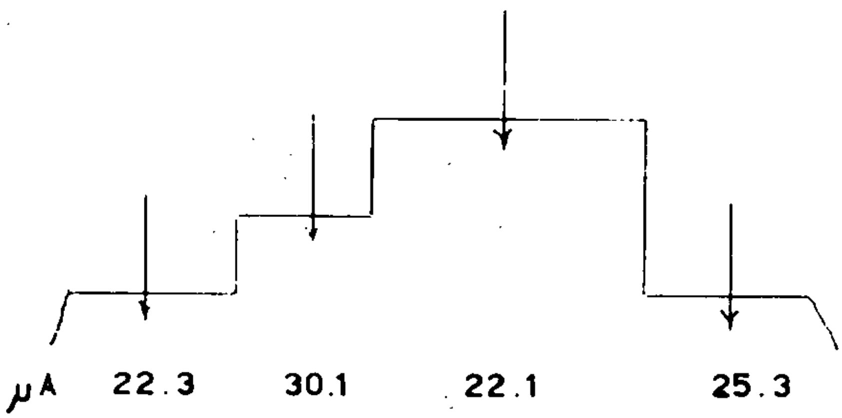


Control 12.0

Figure 38

DIFFUSION CURRENT PROFILE

STEPPED TURF



Control 12.0

Results

Analysis of variance and treatment means are shown in Table 33.

TABLE 33

AERATION STATUS ON S.M.B. TURFS - EDDLESTON

Analysis of variance — 60 foot cross drains

Source of variation	Degrees of Freedom	Sum of Squares	Mean Square	F
Treatments	3	185.7971	61.9324	6.6870**
Blocks (plots)	2	170.3127	85.1564	9.1945**
Interaction	6	363.7523	60.6254	6.5459**
Residual	84	777.9775	9.2616	
Total	95	1497.8396		

Treatment	Mean	
1	17.21	
2	18.14	
3	20.43	μA
4	16.86	

Control (not analysed) 9.5

S.E. of treatment mean 0.6212

15 foot cross drains

Treatment was N.S.

Source	d.f.	S.S.	M.S.	F
Treatments	3	58.6671	19.5557	2.1348 N.S.
Blocks(plots)	2	9.5502	4.6751	0.5104 N.S.
Interaction	6	151.4798	25.2467	2.7560*
Residual	84	769.4625	9.1603	
Total	95	988.9596		

Treatment	Mean	
1	17.77	
2	19.52	
3	19.49	μA
4	18.67	
Control	9.0	

S. E. of treatment means 0.62

Diffusion current varied significantly on the least intensive treatment between sample locations on the turfs and between the three blocks. There is also significant interaction between plots and treatments, that is, across the eight ploughed furrows. The turf top and step were always better aerated than the undisturbed peat. Non significant variation in aeration levels between stations on the 15 foot cross drain spacing may indicate that this intensity of draining has masked the micro-site differences. Further sampling at intervals from treatment would be worthwhile here.

DISCUSSION AND SUMMARY

Aeration response to modern drainage intensities on basin peats is rapid. However the best aeration levels recorded in the controlled study at Ae are encountered only at the planting site on current ploughing patterns. A diffusion current of 17μA or 21.15 $mgmO_2/cm^2/min$ is seldom reached on the undisturbed peat. Only in the ploughed turf is this level consistently exceeded. For the first years of seedling establishment at least, it is clear that rooting will be restricted to the aerated turf. Unless drain maintenance is diligently pursued, a high rate of silting will offset drain deepening and it is doubtful if rooting beyond the surface layers of the original peat can be anticipated before canopy closes.

An outstanding feature of root distribution and aeration status on this and the Ae studies is the stratification of well-aerated layers over poorly aerated strata.

Now Barley and Greacen (1967) have demonstrated that penetration powers of a root system depend not only on aeration of the root tip but the relative penetratability or compaction of successive soil horizons. Thus a well-aerated litter layer over a decomposed peat layer is not conducive to root penetration below the aerated level. Similarly penetration below the aerated sandwich between turf and undisturbed peat is not encouraged by current ploughing practice: A recent ploughing technique which provides a less stratified aeration condition was also sampled at Eddleston.

RIGG AND FURR CULTIVATION

Rigg and furr cultivation is described by Booth (1967) in the Vale of York. Basically, the spoil from widely spaced (37 feet) shallow (2 foot) drains is spread over the space between drains creating a low mound. Booth records improved tree growth on this type of topography. The result of the dumping of drain spoil over the undrained strip is a well aerated but heterogeneous layer of superimposed peat. In this material, trial planting of spruce and pine has been carried out.

Methods and Results

On Rigg and Furr cultivation at Eddleston, profiles of soil aeration (ODR) were established using the platinum micro-electrode. Random sample transects were employed and a profile determined for 4 and 8 foot drain spacings, to a depth of 12 inches. Aeration profiles are shown in Table 34 and Figure 39.

TABLE 34

AERATION LEVELS ON RIGG AND FURR CULTIVATION

Depth inches	Drains 8 Feet Apart µA	Drains 4 Feet Apart µA
1		16.0
2		15.3
3	13.0	15.3
4	15.5	7.5
5	12.5	4.5
6	10.0	6.0
8	10.0	
9		18.5
	peat surface	
10	10.5	
12	7.5	16.0

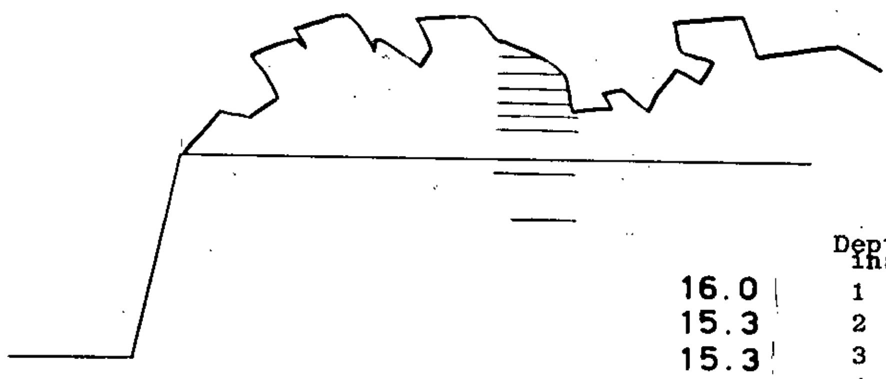
The familiar stratification of aeration status is lacking. This degree of cultivation may remove the barrier to rooting previously discussed if it can be continued down the peat profile. However the current rigg and furr profile does not provide the opportunity for continued root growth since the undisturbed peat is reached at 9 inches depth.

FURTHER STUDY

Aeration levels limiting rooting of Sitka spruce are fairly

Figure 39 DIFFUSION CURRENT PROFILE

RIGG AND FURR



μA	Depth ins.
16.0	1
15.3	2
15.3	3
7.5	4
4.5	5
6.0	6
18.5	9
16.0	12

Control 9.5

clearly defined in these small studies. The aeration relationship with time-since-treatment and seedling development stage is not examined here. While seedling roots at Ae and transplant roots at Flanders Moss and Eddleston may be restricted to the top 3 inches of undisturbed peat, the roots of older blown trees extend to at least 18-20 inches. Some progressive drying and aerating processes are obviously at work.

An assessment of improvement with time since treatment could be carried out if sufficient sample areas could be found which have been treated with a single ploughing pattern. It may be possible to prescribe drainage treatments to accelerate the aeration processes.

The characteristics of the sheltered stepped turf are discussed by Rennie (1961) for coastal locations. Its advantages in the early years of seedling establishment on peat are worthy of study as are the particular characteristics of rigg and furr cultivation.

SUMMARY

Estimation of oxygen diffusion rates as an index of aeration status showed a significant response to drain intensity and ploughed turf pattern. Different ploughs created a variety of aeration levels which are worthy of further study.

Planting sites, the top of the DMB turf and the step of the SMB are shown to be well aerated in comparison to the values established at Ae. The strict layering of aeration zones is detrimental to root penetration. Cultivation which produces a more heterogenous

aeration matrix may encourage deeper rooting and greater wind stability.

Depth to water table accounts for much of the variation in aeration and the bore holes with perforated plastic casing provide a most useful means of measuring water level and an index of drainage responses. Water table fluctuation is important as well as depth to water *per se*.

CONCLUSION

The seedling responses to wet site improvement examined in this study are associated principally with soil factors and while seedling growth may reflect many environmental factors, soil conditions play the most important part. The soil characteristics measured during this study have varied to a considerable extent between soil types and between dates of measurement throughout the growing season. Soil moisture, aeration, and depth to water table fluctuate widely on the three hill soil types, peaty podsol, peaty gley, and peat. The conditions on the basin peat areas which were sampled were much more stable and their uniformity allows a very useful comparison to be made of applied site improvement treatments.

The information on soil moisture content at the Forest of Ae reveals a significant response to draining and tree cover. The draining intensity carried out when the forest was planted in the 1920's and 30's is light in comparison with modern treatments but it has been effective in encouraging tree rooting down through 18 inches of well-decomposed amorphous <u>Molinia</u> peat to the underlying mineral soil - usually a heavy clay till. The plate-like rooting form which develops as the roots spread laterally leads to instability in the wind and the Forest of Ae has become the scene of a series of windblow studies. By pulling over trees on a variety of soil types it has been possible to classify resistance to blow by soils and by tree development stages. On peats and peaty gleys the windblown stem peeled back the root plate along the junction of organic and mineral horizons to reveal a platform of small root ends showing recurrent die-back. On peaty podsols and drier podsolic types, the roots held and the stems snapped. This information was also studied in relation to water table depth.

On the three drained and forested soil types there is evidence not only of an improvement in moisture and aeration status but of an increased fluctuation in these conditions during the growing season which was sampled. In anaerobic peaty soils water table fluctuation was seen to play an important role in flushing away reduction products of soil metabolism. Potentially toxic sulphides were detected at stations on the control, peaty gley, and peat sites but the duration and intensity of their distribution in the rooting zone of spruce seedlings on the forested samples was less than was anticipated. A rise in the water table following rain quickly restored reducing conditions and a fall in the water level appeared to flush the sulphides down the profile. The intensity of this reduction-oxidation swing is reflected in high Redox values in the sample gaps and by the appearance within only six months of gleying on the soil moisture sample containers.

Despite the effect of draining on the water table in the study plots, a high rainfall and high incidence of rainy days ensures that the surface peat layers are saturated for most of the season. Beneath the stands and in the north section of the clearcut gaps, however, the surface litter layers of the organic horizon may heat up quickly and dry out during relatively short warm spells. This was seen to have a marked influence on spruce seedling growth.

Soil characteristics assessed were: soil moisture content in the top 3 inches, depth to water table, presence of sulphides, and aeration status. The peaty podsol and the peat soils were driest and best aerated, and wettest and most poorly aerated, respectively. The peaty gley soil exhibited a marked degree of fluctuation of these values in response to climatic changes. Stations across the gaps also varied though not apparently to presence or absence of tree cover. Physiographic features such as topography and peat depth were important especially where lateral water flow kept moisture levels high after rainfall had stopped. Comparable stations selected along the control transect confirmed the relationship between these soil types.

Natural regeneration in the Forest of Ae is most evident beneath the stands where many groups of seedlings can be observed. While small seedlings abound, there is a lack of older vigorous plants. These are to be found, though not in such numbers, along roadsides, logging racks, and in windblown gaps. Some explanation of this seedling distribution is provided by the study of growth and survival along the sample transects which run from beneath the stand across the gaps of the windblow study and into the opposite stand margin. Seedling numbers drop off from stand to gap centre in response to a lack of suitable germination sites and to vegetation competition. Height growth and seedling vigour, however, respond to increased light across the gaps. The most successful seedlings were up to 30 inches tall after 6 growing seasons and interfered with routine measurements of seedlings planted when the natural seedlings were still germinants. All the natural seedlings were shallow rooted and seemed to respond to the aeration gradient set up between successive organic horizons. The root systems examined in 1967 and 1968 were all restricted to the litter and decomposed material from the spruce stand and did not penetrate the old Molinia peat. This superficial and widely spread root form however, seems able to provide adequate nutrients for vigorous growth. The planted stock suffered from the erosion of the planting turf as a result of irreversible drying. A new root system had then to be developed which closely followed the pattern of the natural seedling roots. A maximum depth of only 4 inches was recorded for 6 year old natural seedling roots. The seedlings were found mainly in small depressions in the peat surface and near the base of cut stumps. The preference for a moisture conserving seed-bed is supported by the conditions required for germination of these small spruce seeds, a "wet blotting paper" type of seedbed with close seed/substrate contact;

and also by evidence of drought stress during short dry spells in the growing season. Field observational evidence of moisture tension is in the nature of mortality among germinants, a narrow brown colour ed constriction on the stem just above the root collar. Limiting relative cell water contents (R. T.), determined in the laboratory were approached in the field in 19 68, and in 19 67, a long dry spell in June was followed by aphid attack. Drain spoil seedbeds, and mineral soil from windblown roots and from root pumping during wind-sway, allowed deeper rooting than the drained peat. Height growth was good but the distribution of this seedbed type is poor. The importance to height growth of rooting depth is shown in the regressions developed for small seedling samples. When this is considered in the light of increasing vegetation competition in the gaps it is clear that a few growing season's lack of germination following stand opening allows a vegetation colonisation to develop with which the seedlings cannot compete. Shallow rooted transplants are also at a disadvantage. Because of this the seedling growth measurements were carried out on the largest specimens in each sample quadrat, the seedling most likely to become established. Most of the stocked quadrats had more than one seedling. From first marking them in April to final tally in September, about 10% were no longer tallest in the quadrat. This effect may be more noticeable in a year following aphid attack but it points to the importance of growth and survival during the years of establishment until canopy is closed and vegetation is suppressed. To bring

TABLE 36 (CONCLUSION)

SEEDLING GROWTH AND SOIL DATA

	Seedling		Aeration		Moisture	
	Leader length inches	Rooting Depth inches	MV 3"	ODR 3"	Depth to Water	M.C. % 3"
Peaty Podsol						
North Stand	1.43	0.75	370	17.5	22+	65.4
North Gap	2.54	1.40	420	22.0	10+	52.54
South Gap	2.32	1.00	570	27.0	17+	62.86
South Stand	1.75	0.95	580	21.0	22+	60.79
Peaty Gley						
North Stand	2.63	1.55	570	22.5	15+	57.94
North Gap	5.43	2.15	670	20.0	17+	63.02
South Gap	4.39	2.35	600	15.0	7	75.24
South Stand	1.23	0.90	410	15.0	15+	44.13
Peat						
North Stand	2.47	2.15	590	5.5	4	69.53
North Gap	7.00	2.10	550	28.5	19	35.87
South Gap	4.14	1.65	580	15.0	10	58.89
South Stand	1.17	1.05	350	10.0	8.5	62.54

TABLE 3b

CORRELATION MATRICES

PEATY PODSOL

VARIABLES (n = 4)

	L.L.	R.D.	mV	0_2	W.T.	M.C.%
	1	2	3	4	5	6
	1.000	0.888	0.209	0.736	-0.837	-0.752
		1.000	-0.023	0.370	-0.500	-0.970
			1.000	0.679	-0.295	0.103
				1.000	-0.902	-0.162
					1.000	0.275
						1.000

CORRELATION MATRIX PEATY GLEY

VARIABLES	1	2	3	4	5	6
	1.000	0.933	0.945	0.197	-0.158	0.796
		1.000	0.898	0.089	-0.355	0.961
			1.000	0.480	0.084	0.777
				1.000	0.878	-0.010
					1.000	-0.480
						1.000

CORRELATION MATRIX PEAT

VARIABLES	1	2	3	4	5	6
	1.000	0.620	0.550	0.909	0.840	-0.894
		1.000	0.875	0.253	0.154	-0.290
			1.000	0.168	0.012	-0.119
				1.000	0.985	-0.984
					1.000	-0.990
						1.000

CORRELATION MATRIX ALL SITES

VARIABLES	1	2	3	4	5	6
	1.000	0.788	0.612	0.352	-0.041	-0.268
		1.000	0.676	-0.1305	-0.456	0.141
			1.000	0.201	-0.110	0.236
				1.000	0.780	-0.459
					1.000	-0.427
						1.000

Underlined values represent important seedling/soil relationships.

Because of the small sample numbers, no particular statistical significance is attached to these correlations.

together these assessments of soil characteristics and seedling growth, a series of correlations were examined. These will serve to recapitulate on the more specific relationships presented earlier. Seedling growth data were stratified by 10-quadrat units across the transects, and four soil sample stations, north stand, stand margin, south stand margin and south stand were selected to represent these strata. Soils data for the date of seedling measurement is presented in Table 35. Correlation matrices are shown in Table 36 for the three soils and for all data combined. Briefly these results illustrate the following important relationships. Rooting depth is important to height growth in the 1968 growing season and is correlated with aeration status on the three soils. Oxygen diffusion rate is related to depth to water table and variably with moisture content. On the peaty podsol, for the date of measurement, leader length and rooting depth are negatively correlated with moisture content on all soils. Gap centre locations have greater height growth and higher aeration status. Height growth and stem diameter relationships varied from beneath the stand to the gap centre. The greater slope of the regression for seedlings beneath the stand indicates that height growth in the open is greater at a given stem diameter level but that diameter increase beneath the stand will give a correspondingly greater height increase. Height growth under the stand is seen to be severely limited. Stem diameter is a useful index of vigour but under the conditions of severe vegetation competition in the gaps at Ae, height growth measurement is more important.

Seedling responses to the artificial peat gradient of aeration and depth to water table help to clarify some of the variation encountered among natural seedlings. Certain important effects are demonstrated. Aeration controls a number of bio-chemical soil processes as indicated, for example, by the presence of sulphide staining on the slope. The level at which seedling roots emerged from the tubes indicates that for a given peaty type there may be fairly well defined limits of tolerance to aeration levels. Mortality at the bottom of the slope shows that anaerobic conditions, present for a period as long as this test, (9 weeks), may be sufficient to kill new root tips. On most sample stations in the gaps, sulphides were present for much shorter periods.

Similar relationships between soil aeration and depth to water were established for the basin peat at Flanders Moss. Here a more fibrous and permeable peat type showed clear aeration responses to drain intensity, i.e. spacing and depth of cross-drains. Since the trial involves more than one plough type, results are rather confounded by cross-drain intensity and ploughing pattern. However, within the shallow ploughing treatments, deeper cross-drains remove more water and increase aeration. The combined deep and shallow ploughing seems to provide a superior local aeration effect which is reflected in root development, though not height growth, of planted stock. Reports from the 1968 rooting survey carried out for planted stock at Flanders Moss show a maximum penetration of 4 inches into the original peat surface while lateral spread along the turf ribbon often exceeds two feet. On the basin peats the roots will always be restricted to aerated organic horizons, and site treatments must aim to increase the effective rooting depth. The planting sites presently in use, ie. the top of the double mouldboard turf and the step of the single mouldboard turf are well-aerated micro-sites but aeration soon decreases with depth in the undisturbed peat. This is illustrated by the values for 3 and 6 inch depths sampled at Flanders Moss. Encouraging roots to spread down into this material may involve a greater degree of cultivation than is currently practiced. Anderson (1967) says:

> Ploughing has proved of most value on the shallow peats for turning over low ridges of peat, into which the plants can be inserted. Even then, when exposure is likely to prove severe, there may be a serious wind-throw problem in future as the stands rise. One thing seems certain and that is that tree roots cannot be compelled to descend into infertile, poorly aerated layers no matter how loose they may for a time be made, and that remains true of the deeper infertile peats. One can only marvel at the faith of those who think otherwise.

The results of this investigation suggest that we can do better than Anderson predicts provided the effective aerated rooting depth is increased. On hill peats this may imply cultivation down to the underlying mineral soil. On basin peat it implies a treatment pattern other than an aerated turf placed on top of poorly aerated peat. While nutrients required for the increased tree growth rates now demanded by investors can be added to the peat surface, the anchorage function of rooting is impaired by conditions created under the mature spruce stands sampled, and on the basin peat afforestation projects. The most useful measurements for assessing the severity of the rooting problem which are suggested by this study are:

Peat depth
Water table level and fluctuation
Presence of sulphides
Rooting depth and wind stability of older trees

This information is not difficult to collect but it should be made available before site amelioration treatments are begun. Responses following treatment should be assessed. Little is known of the progression of improvement with time from treatment and such information would be available.

FURTHER STUDY

Further study is indicated by this investigation of a variety of seedling growth relationships.

1. Physical factors limiting root penetration. Root growth in mineral soil types underlying shallow peats might be tested.
2. Tolerance of roots to sulphide distribution. A variety of intensities and lengths of exposure period will be important to the understanding of field conditions.
3. Permeability rating for peats to help determine the required drain intensity and to predict response to improvement treatments.
4. Survival rate of natural seedlings on a variety of seedbed types.
5. Aeration levels limiting spruce rooting

6. Species comparisons over a range of controlled rooting conditions such as an artificial peat gradient, or mineral soil slope.

7. Aeration status development with time-from-treatment for a range of turf patterns.

8. Investigation of complete seedbed cultivation for natural regeneration and to increase effective rooting depth of natural and planted seedlings.

9. Trials of wet site improvement following complete removal of shallow peats. A comparison of physical changes in underlying soil types after peat removal and further draining, is important.

SILVICULTURAL IMPLICATIONS

Results of these investigations have illustrated a variety of conditions which may effect silvicultural prescriptions for spruce regeneration on wet sites. Primary consideration is an assessment of water table level and fluctuation and thus aeration status. Potential response to drainage can be estimated from this assessment and from an appraisal of peat texture.

First Rotation - afforestation

There is an indication from these studies that a minimum depth to water table of about two feet should be the aim of wet site improvement. The information provided by the peat slope and study of recent afforestation on deep peats shows that greater depths to water may be desirable on fibrous peat. There is a real danger of drought stress in transplants and mortality among natural seedlings but rainfall amounts and distribution on the sample areas studied have offset these effects. Erosion of the planting turf may aggravate the drought problem if roots are exposed.

Where peat depths exceed 36 inches, spruce rooting in the first rotation is likely to be restricted to the organic horizons. Shallower peats if intensively drained are likely to permit rooting throughout the organic material and it is the top horizons of the mineral soil which are likely to limit root penetration. Peat shrinkage further reduces effective rooting depth. In the second rotation, wet site treatment will clearly involve the mineral soil underlying shallow peats. At the outset therefore it is worthwhile considering the total removal of the peat layer and improvement of the underlying mineral soil. On plane or depressional topography this might lead to a worse condition since a cavity is created which will simply fill with water. On hill peats, however, the necessary drainage effect would be achieved and physical changes in the soil to improve rooting depth might take place more rapidly in the underlying mineral soil than in the moisture retaining peat. A pilot scale trial of this site treatment would provide valuable information for foresters now considering the second rotation of spruce on improved wetlands where only a shallow peat layer remains.

Since each site improvement treatment improves conditions for competing vegetation as well as spruce seedlings, vegetation suppression becomes an increasingly important function of wet site cultivation. The trees must be given a fast start to growth so that the period to canopy closure is minimised. This may involve a return to close planting spacing on wetlands and spot rather than broadcast fertiliser applications. Since the availability of nutrients depends to a large extent on microbiological activity this should be encouraged and consideration given to the inhibitory characteristics of any herbicide treatment. The role of reduction products, such as sulphides, in restricting certain bacterial activities should be more thoroughly examined.

Modern intensive cultivation of peatland continues to rely on the aerated turf ribbon on top of relatively undisturbed poorly aerated peat. Root penetration studies show that on basin peats there is inadequate exploitation of the peat below the turf. Cultivation is indicated which will break the seal between turf and peat. Rigg and Furr cultivation is a promising advance but the tree roots may exploit only the superimposed mixed seedbed. A very hazardous rooting situation may then develop. If the original peat surface could be broken up, disced or rotovated, before placing the aerated layer of peat or the planting turf on top, effective rooting depth could be increased. Machine development may allow the cultivation and draining to be completed in a single machine pass provided the required balance between equipment flotation and drawbar-pull can be achieved. Rigg and Furr cultivation does not yet fulfil these aims. Rapid drying and shrinkage of individual small clods in the drain spoil may create an extremely shallow rooting zone if roots remain above the peat and peat turf erosion takes place at a normal rate. In summary the information provided by this investigation suggests that afforestation of wetlands should involve more complete cultivation of the proposed rooting zone and might involve removing the principal barrier to rooting and stability, the peat itself.

Second Rotation - regeneration

The behaviour of natural seedlings on hill peat in gaps in the spruce forest points to changes in wet site characteristics after a rotation under forest cover. The primary requirement for seedling establishment is a well aerated moisture conserving site, preferably sheltered from drying winds Full light is desirable after establishment and freedom from vegetation competition keeps seedling numbers high.

If advantage is to be taken of natural regeneration, small coupes or narrow strip cutting is indicated to provide an adequate seed supply and light conditions favourable to seedling growth. There is a clear possibility of rapid restocking using natural regeneration if the stand is opened up before final felling to induce seeding. Seedlings once established should quickly be exposed to full light with concurrent accelerated nutrient re-cycling. Assessment of regeneration stocking levels will indicate how much planting is required to fill in gaps in the natural seedling population and to bring plant numbers to a satisfactory level.

Drains must be maintained throughout the rotation since it is evident that the drying effect of forest cover is not sufficient to maintain the water table at low levels.

If natural regeneration is to contribute to re-stocking, the aeration and rooting studies point to a promising site treatment. That is harrowing or discing beneath the overwood, or in gaps and strips, to break up the layered orientation of strata in the organic matter horizons; i. e. spruce litter; over decomposing spruce humus; over old decomposed Molinia, or poorer grass peat; over undecomposed fibrous peat - a depth of at least 18 inches. While these successive layers may in themselves be sufficiently well aerated to permit root growth the physical resistance to root penetration restricts rooting to the superficial layers of organic matter - mainly spruce forest litter. Further, the variety of microsites created by the suggested cultivation treatment should lead to higher seedbed receptivity and a higher rate of seedling survival during the important years of establishment. A greater proportion of preferred or sheltered seedbeds would thus be created.

Where re-planting is carried out the evidence suggests the need for further site cultivation of a ploughed, disced, or rotovated type. Provision of planting turfs is not indicated since there is a real danger of drying out and erosion in the turf especially if placed over a diminishing layer of irreversibly dried peat.

In many instances the cultivation of hill wetlands for the second rotation will involve the mineral soil beneath the reduced depth of peat. The choice is again one of oomplete removal of the shallow peat or a mixing operation which will incorporate the peat with the upper mineral soil horizons. This does not create a problem on iron pan soils or indurated iron rich layers which yield to cultivation with tines, but massive poorly aerated clays in a reduced state may be a poorer rooting medium than the original peat cover. Some of the problems of machine operations under these conditions are mentioned by Neustein (1962) who describes the result of ploughing and stump uprooting as a "battlefield". This level of wet site disturbance may be no bad thing provided it is accompanied by adequate removal of water.

SUMMARY

An assessment was made of natural Sitka spruce seedlings at the Forest of Ae in the Scottish Border Uplands as an index of wet site improvement following draining, turf planting and 30 years of tree cover on hill peat.

Three soils were sampled: peaty podsol, peaty gley, and peat. There was an undrained, unforested "control" area.

Seedlings germinated satisfactorily on a cool moist substrate of spruce litter beneath the overwood and to a lesser extent further out from the stand margin.

While seedling numbers were higher closer to the stand margin because of vegetation competition and availability of germination sites, growth was best in full light in the centre of the windblow gaps sampled.

Seedling roots were restricted to the well aerated organic horizons associated with spruce litter and did not penetrate the original hill peat layers. Available pore space and aeration values decreased rapidly with depth down the rooting zone.

Seedling growth was best on the moister sites, the peaty gley and peat sample areas.

These had a higher but noticeably fluctuating water level. The peaty podsol sample area had a deep water table but surface moisture and aeration conditions were no better than on the moist sites. Conditions for seedling rooting as indicated by pore space,

soil aeration, water table and distribution of sulphides were more favourable on the drained forested sites than on the undrained, unforested control. Vegetation competition on the improved peatland was severe and its components reflected the site improvement. Response of seedlings to a gradient of soil moisture aeration and depth to water table indicated a level of about 20-24 inches to water and an ODR of 12.5 mgm $O_2/cm^2/min$ which limited root emergence from nursery containers into the surrounding peat. Maximum growth rates and oven dry weight of seedlings occurred at the top of the gradient with 54 inches to water and an ODR of 21 mgm $O_2/cm^2/min$.

Drought stress combined with heat damage seemed to contribute to mortality among natural seedlings. Levels limiting survival were investigated in the laboratory and seedlings were dried down to wilting point. The cell water contents thus determined were approached on only two occasions during weekly sampling throughout the growing season. The effect of moisture tension was most noticeable among recent germinants.

Distribution of sulphides, thought to be reduction products toxic to roots, with investigated for the three soils throughout the season. The depth to water table and water table fluctuation controlled the degree of staining on silver plates. This situation was far more changeable than anticipated, but sulphides were present in the spruce rooting zone of the seedlings for some time during the growing season on the peaty gley and peat sites. Assessment of sulphide distribution was carried out using staining on silver strips. Staining pattern varied from week to week during the growing season and reflected the wet site characteristics of the four samples: peaty podsol (spot staining only), peaty gley (fluctuating, intense stains), peat (consistent staining at some sample stations), control (less fluctuation and consistently intense stains).

Examination of recent drain intensity trials shows an aeration response to drainage and a significant difference between drainage intensity treatments on basin peat.

Aeration levels beneath the planting turf were correlated with depth to water table. Bore hole observations are a most useful index of response to drainage.

The planting positions currently used on ploughed turf patterns seem to be those best aerated across the turf profile .

Strict layering of aeration and textural levels inhibits rooting of both natural seedlings and planted stock.

Deeper rooting examined on windblow mature trees indicates that there is a progressive drying and aerating process working to the advantage of root penetration.

If natural regeneration is to be successfully utilised in re-stocking forest areas on wetlands this layering within the rooting zone must be broken up by discing, harrowing or rotovation to provide a variety of micro seedbed types which have been shown to be preferred. Afforestation programs could take advantage of more intensive site cultivation. Mixing of the upper peat layers may be beneficial in increasing potential rooting depth.

On deep peats rooting depth in the second rotation will depend on aeration levels within the peat. On shallow peats roots may be expected to penetrate to the underlying mineral soil.

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APPENDICES

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1.

Oxygen diffusion rates at the
Forest of Ae.

6 depths on 3 soils and control.

ANALYSIS OF VARIANCE ODR / DEPTH

PEATY PODSOL

SOURCE	D.F.	S.S.	M.S.	F
TREATMENTS	5	89.9767	17.9957	2.351 N.S.
ERROR	24	183.7160	7.6548	
TOTAL	29	273.6947		

COMPARISONS BETWEEN TREATMENT MEANS

TREATMENTS AND MEANS				STUDENT'S T		D.F.
1	20.260	2	20.900	0.3657		8
1	20.260	3	21.800	0.8801		8
1	20.260	4	18.960	0.7429		8
1	20.260	5	17.460	1.6001		8
1	20.260	6	17.100	1.6359		8
2	20.900	3	21.800	0.5143		8
2	20.900	4	18.960	1.1057		8
2	20.900	5	17.460	1.9659		8
2	20.900	6	17.100	2.1716		8
3	21.800	4	18.960	1.6230		8
3	21.800	5	17.460	2.48[illegible]2	*	8
3	21.800	6	17.100	2.6860	*	8
4	18.960	5	17.460	0.8572		8
4	18.960	6	17.100	1.0630		8
5	17.460	6	17.100	0.2057		8

ANALYSIS OF VARIANCE ODR / DEPTH

PEATY GLEY

SOURCE	D.F.	S.S.	M.S.	F
TREATMENTS	5	137.5240	27.5048	1.406 N.S
ERROR	24	469.4040	19.5585	
TOTAL	29	606.9280		

COMPARISONS BETWEEN TREATMENT MEANS

TREATMENTS AND MEANS				STUDENT'S T	D.F.
1	16.860	2	17.160	0.1073	8
1	16.860	3	18.400	0.5506	8
1	16.860	4	18.300	0.5148	8
1	16.860	5	13.100	1.3443	8
1	16.860	6	13.500	1.2013	8
2	17.160	3	18.400	0.4433	8
2	17.160	4	18.300	0.4076	8
2	17.160	5	13.100	1.4515	8
2	17.160	6	13.500	1.3085	8
3	18.400	4	18.300	0.0358	8
3	18.400	5	13.100	1.8949	8
3	18.400	6	13.500	1.7519	8
4	18.300	5	13.100	1.8591	8
4	18.300	6	13.500	1.7161	8
5	13.100	6	13.500	0.1430	8

ANALYSIS OF VARIANCE ODR / DEPTH

PEAT

SOURCE	D.F.	S.S.	M.S.	F	
TREATMENTS	5	83.3910	16.6782	0.311	N.S.
ERROR	24	1286.4120	53.6005		
TOTAL	29	1369.8030			

COMPARISONS BETWEEN TREATMENT MEANS

TREATMENTS AND MEANS				STUDENT'S T	D.F.
1	17.100	2	18.920	0.3931	8
1	17.100	3	15.300	0.3887	8
1	17.100	4	15.020	0.4492	8
1	17.100	5	14.220	0.6220	8
1	17.100	6	14.420	0.5788	8
2	18.920	3	15.300	0.7818	8
2	18.920	4	15.020	0.8423	8
2	18.920	5	14.220	1.0159	8
2	18.920	6	14.420	0.9718	8
3	15.300	4	15.020	0.0605	8
3	15.300	5	14.220	0.2332	8
3	15.300	6	14.420	0.1901	8
4	15.020	5	14.220	0.1729	8
4	15.020	6	14.420	0.1296	8
5	14.220	6	14.420	0.0432	8

ANALYSIS OF VARIANCE ODR / DEPTH

CONTROL TRANSECT

SOURCE	D.F.	S.S.	M.S.	F	
TREATMENTS	5	10.9587	2.1917	0.066	N.S
ERROR	24	800.2760	33.3448		
TOTAL	29	811.2347			

COMPARISONS BETWEEN TREATMENT MEANS

TREATMENTS AND MEANS				STUDENT'S T	D.F.
1	11.160	2	10.480	0.1862	8
1	11.160	3	12.120	0.2629	8
1	11.160	4	10.900	0.0712	8
1	11.160	5	10.220	0.2574	8
1	11.160	6	10.800	0.0986	8
2	10.480	3	12.120	0.4491	8
2	10.480	4	10.900	0.1150	8
2	10.480	5	10.220	0.0712	8
2	10.480	6	10.800	0.0876	8
3	12.120	4	10.900	0.3341	8
3	12.120	5	10.220	0.5202	8
3	12.120	6	10.800	0.3614	8
4	10.900	5	10.220	0.1862	8
4	10.900	6	10.800	0.0274	8
5	10.220	6	10.800	0.1588	8

ANALYSIS OF VARIANCE ODR / DEPTH

ALL THREE SOILS

SOURCE	D.F.	S.S.	M.S.	F
TREATMENTS	5	251.2707	50.2541	1.881 NS.
ERROR	84	2244.1133	26.7156	
TOTAL	89	2495.3840		

COMPARISONS BETWEEN TREATMENT MEANS

TREATMENTS AND MEANS				STUDENT'S T		D.F.
1	18.073	2	19.293	0.6464		28
1	18.073	3	18.500	0.2261		28
1	18.073	4	17.627	0.2367		28
1	18.073	5	14.927	1.6672		28
1	18.073	6	15.060	1.5966		28
2	19.293	3	18.500	0.4203		28
2	19.293	4	17.627	0.8831		28
2	19.293	5	14.927	2.3137	*	28
2	19.293	6	15.060	2.2430	*p≤.1	28
3	18.500	4	17.627	0.4627		28
3	18.500	5	14.927	1.8933		28
3	18.500	6	15.060	1.6227		28
4	17.627	5	14.927	1.4306		28
4	17.627	6	15.060	1.3599		28
5	14.927	6	15.060	0.0706		28

2. **Regeneration survey quadrat data for 3 soils at the Forest of Ae.**

Peaty podsol. Tallest seedling

Quad.	Stocking	Age	Height inches	Stem diam. inches	Leader '67	Leader '68	Rooted in	Topography	Vegetation comp.	Peat Depth inches	Rooting Depth inches
1	only ger	1	1	-	-	1	litter	level	1	14	0.8
2	" "	1	1	-	-	1	"	ditch	1	4	0.8
3	" "	1	1	-	-	1	"	level	1	10	0.6
4	" "	1	1	-	-	1	"	level	1	9	0.5
5	" "	1	1	-	-	1	"	1" depress	1	11	0.5
6	1	2	2	0.03	1.0	1.0	"	1" depress	1	10	1.1
7	only ger	1	1	-	-	1	"	level	1	9	0.5
8	4	3	3.5	0.05	1.0	1.0	"	drainside	1	12	0.9
9	6	3	4.0	0.04	1.0	1.3	spoil	mound	1	9	1.1
10	14	4	5.5	0.10	1.3	2.0	peat	level	1	10	1.1
11	13	4	6.0	0.08	1.5	1.3	litter	level	1	10	1.2
12	4	3	5.0	0.05	2.3	2.3	litter	level	1	8	1.2
13	9	3	7.3	0.09	3.5	1.3	litter	W stump	1	10	1.4
14	7	1	1	-	-	1	litter	level	2	11	0.6
15	3	1	1	-	-	1	litter	level	2	11	0.5
16	7	3	5.0	0.06	2.0	2.5	litter	E stump	1	13	0.9
17	2	2	3.0	0.05	0.5	2.5	litter	W stump	1	12	0.7
18	3	3	5.3	0.09	2.5	2.0	litter	N stump	1	7	0.9
19	3	3	5.0	0.07	1.5	2.5	litter	level	1	10	0.7
20	-	-	-	-	-	-	-	-	-	-	-

Peaty pedsel. Tallest seedling

Quad.	Stocking	Age	Height inches	Stem diam. inches	Leader '67	Leader '68	Rooted in	Topography	Vegetation comp.	Peat depth inches	Rooting depth inches
21	4	1	1	-	-	1	litter	level	3	10	1.2
22	1	3	4.0	0.05	1.8	o.6	spoil	S stump	2	10	0.5
23	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-
25	11	3	9.5	0.11	3.0	3.3	litter	2" depress	1	12	-
26	3	4	9.3	0.13	1.5	4.0	litter	N stump	2	6	1.8
27	11	3	8.5	0.11	2.3	3.0	litter	4" depress	2	7	1.8
28	9	3	7.5	0.14	1.5	2.5	spoil	mound	2	4	1.6
29	1	4	7.0	0.10	2.0	2.0	spoil	mound	2	M/S	-
30	1	1	1	-	-	1	litter	level	3	M/S	0.5
31	10	4	7.5	0.10	2.5	1.3	litter	2" depress	1	7	-
32	1	3	4.0	0.05	1.3	1.0	litter	2" depress	1	6	0.8
33	4	2	4.0	0.05	2.8	1.3	litter	S stump	1	6	-
34	6	3	5.5	0.07	1.8	2.0	litter	1" depress	1	5	-
35	4	2	2.0	0.03	1.0	1.0	litter	E stump	1	5	0.9
36	4	3	3.5	0.05	1.0	1.0	litter	level	1	5	-
37	4	2	2.5	0.03	1.3	1.3	litter	2" depress	1	5	0.58
38	3	3	5.0	0.05	1.5	2.5	litter	3" depress	1	7	0.85
39	4	2	2.5	0.03	1.5	1.0	litter	5" depress	1	6	-
40	5	3	3.5	0.05	1.0	2.0	litter	drainside	1	6	0.75

Peaty gley.   Tallest seedling

Quad.	Stocking	Age	Height inches	Stem diam. inches	Leader '67	'68	Rooted in	Topography	Vegetation comp.	Peat depth inches	Rooting depth inches
1	3	3	11.6	0.02	0.8	0.9	litter	level	1	13	1.15
2	2	3	1.8	0.03	0.9	0.9	litter	1" depress	1	16	1.25
3	6	3	2.3	0.03	0.8	0.8	litter	½" depress	1	19	0.77
4	7	3	1.5	0.04	0.8	0.8	litter	2" depress	1	M/S	0.58
5	6	3	1.8	0.02	0.8	0.8	litter	1" depress	1	M/S	0.99
6	2	2	1.0	0.03	0.5	0.7	litter	2" depress	1	M/S	0.60
7	-	-	-	-	-	-	-	-	-	-	-
8	15	4	2.5	0.05	0.6	0.9	litter	1" depress	1	M/S	0.65
9	7	3	2.5	0.05	1.0	1.2	litter	2" depress	1	11	0.5
10	3	4	7.5	0.10	2.2	4.1	peat	drainside	2	14	0.17
11	1	4	8.5	0.15	3.7	2.2	moss	2" depress	2	14	1.65
12	4	5	12.0	0.18	5.5	2.5	moss	1" depress	2	14	1.55
13	2	4	10.0	0.11	4.0	3.5	moss	2" depress	3	14	1.75
14	6	5	15.0	0.30	2.8	6.0	moss	3" depress	2	14	2.85
15	5	6	15.5	0.21	3.8	5.5	moss	level	1	18	2.85
16	3	5	15.5	0.40	5.0	4.0	moss	level	2	16	2.30
17	1	4	15.0	0.18	4.5	6.5	moss	level	1	10	2.95
18	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-
20	1	4	10.5	0.25	4.5	5.0	moss	drainside	1	11	2.75

Peaty gley. Tallest seedling

Quad.	Stocking	Age	Height inches	Stem diam. inches	Leader '67	Leader '68	Rooted in	Topography	Vegetation comp.	Peat depth inches	Rooting depth inches
21	2	4	16.5	0.17	6.5	5.0	spoil	drainside	2	11	1.75
22	4	4	13.0	0.18	5.0	5.0	peat	level	2	12	2.15
23	6	4	14.5	0.18	6.0	6.5	peat	N stump	1	13	1.45
24	2	4	7.0	0.15	4.0	2.0	peat	level	1	12	2.15
25	2	4	8.3	0.12	4.0	2.8	peat	W stump	1	12	2.26
26	1	4	16.5	0.18	5.0	9.5	spoil	drainside	2	M/S	1.55
27	1	4	6.5	0.19	2.0	3.0	spoil	drainside	1	M/S	1.85
28	3	3	13.5	0.16	3.8	7.0	M/S	S stump	2	12	3.10
29	4	4	13.5	0.27	4.0	4.0	peat	level	1	8	1.35
30	8	3	19.0	0.28	7.5	9.5	peat	E stump	1	8	2.65
31	2	3	10.0	0.13	5.0	3.5	peat	E stump	2	9	1.25
32	6	3	9.5	0.20	4.0	4.0	peat	W stump	2	14	1.85
33	10	4	7.0	0.16	4.0	2.0	peat	N stump	1	9	1.45
34	8	3	5.0	0.10	1.5	2.5	litter	E stump	1	11	1.45
35	18	2	3.5	0.06	1.5	2.0	litter	1" depress	1	6	1.73
36	10	6	11.0	0.22	2.0	2.5	moss	1" depress	1	11	3.25
37	6	3	4.5	0.05	2.0	2.0	litter	level	1	11	1.50
38	6	2	6.0	0.08	2.5	3.5	litter	level	1	9	0.95
39	2	2	2.5	0.05	0.5	2.0	litter	N stump	1	9	0.85
40	3	3	6.0	0.15	3.0	2.3	litter	N stump	1	6	0.90

Peat. Tallest seedling

Quad.	Stocking	Age	Height inches	Stem diam. inches	Leader '67	'68	Rooted in	Topography	Vegetation comp.	Peat depth inches	Rooting depth inches
1	4	2	2.0	0.03	0.8	1.3	litter	drainside	1	30	-
2	1	2	2.0	0.03	0.8	1.3	litter	drainside	1	23	0.48
3	6	2	2.0	0.02	1.0	1.0	litter	S stump	1	22	0.75
4	3	3	2.3	0.03	0.5	1.0	litter	mound	1	24	-
5	12	2	2.0	0.03	1.0	1.0	litter	S stump	1	26	1.10
6	-	-	-	-	-	-	-	-	-	-	-
7	8	6	6.0	0.09	0.8	1.0	litter	drainside	1	22	0.65
8	1	4	4.0	0.05	1.0	1.0	spoil	level	1	24	1.55
9	2	4	5.0	0.08	0.5	1.3	peat	drainside	1	19	2.10
10	2	3	4.8	0.08	1.8	1.8	peat	drainside	2	18	-
11	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-
13	3	5	28.0	0.51	8.0	5.5	M/S	W stump	1	25	-
14	4	2	2.5	0.03	1.0	1.5	M/S	mound	2	25	1.15
15	1	2	4.5	0.05	1.8	2.8	M/S	drainside	2	26	-
16	11	4	14.0	0.20	4.5	6.0	M/S	drainside	2	26	2.55
17	-	-	-	-	-	-	-	-	-	-	-
18	2	4	11.5	0.25	4.8	3.8	peat	3" depress	2	25	1.30
19	6	4	13.5	0.14	5.0	5.5	peat	1" depress	2	25	-
20	5	4	14.0	0.16	5.5	4.0	peat	7" depress	2	24	1.45

Peat. Tallest seedling

Quad.	Stocking	Age	Height inches	Stem diam. inches	Leader '67	Leader '68	Rooted in	Topography	Vegetation comp.	Peat depth inches	Rooting depth inches
21	7	4	14.0	0.23	6.5	4.5	peat	W stump	2	26	2.00
22	11	4	13.8	0.20	4.5	4.5	peat	S stump	2	24	2.20
23	7	4	21.0	0.31	6.0	11.0	peat	N stump	1	24	2.25
24	5	4	14.0	0.18	5.5	6.0	peat	S stump	1	28	2.25
25	3	3	7.8	0.08	2.5	4.5	peat	2" depress	2	28	2.00
26	8	6	23.8	0.66	5.0	7.5	peat	1" depress	1	28	-
27	9	7	38.5	0.85	10.5	13.0	peat	level	1	31	-
28	6	5	20.0	0.46	5.3	5.0	peat	S stump	1	30	-
29	6	6	36.0	0.95	7.0	8.0	peat	3" depress	2	18	-
30	6	6	20.5	0.65	6.0	6.0	peat	N stump	1	28	-
31	11	6	28.5	0.56	6.0	4.8	peat	drainside	1	25	-
32	9	3	8.0	0.20	2.0	3.0	peat	blow stump	1	30	1.65
33	16	4	4.8	0.08	1.3	1.3	peat	" "	1	26	-
34	9	7	14.5	0.27	3.3	4.0	litter	N stump	1	26	2.60
35	30	5	11.0	0.30	2.0	2.0	litter	level	1	33	2.55
36	15	5	10.3	0.23	2.0	1.5	litter	S stump	1	17	2.30
37	27	2	4.5	0.07	3.3	1.3	litter	mound	1	17	-
38	6	3	4.3	0.06	1.0	2.0	peat	drainside	1	17	2.30
39	3	1	1	-	-	1	peat	drainside	1	17	1.25
40	-	-	-	-	-	-	-	-	-	-	-

3. Seedling development on the peat slope.

Analyses of variance, and "t" tests between levels

Oven dry seedling weight.

ANALYSIS OF VARIANCE O.D. WT.
PEAT SLOPE

SOURCE	D.F.	S.S.	M.S.	F
TREATMENTS	19	0.2368	0.0125	13.673**
ERROR	180	0.1641	0.0009	
TOTAL	199	0.4008		

COMPARISONS BETWEEN TREATMENT MEANS

TREATMENTS AND MEANS				STUDENT'S T		D.F.
1	0.013	2	0.018	0.3481		18
1	0.013	3	0.017	0.2740		18
1	0.013	4	0.027	1.0221		18
1	0.013	5	0.026	0.9777		18
1	0.013	6	0.039	1.9331		18
1	0.013	7	0.025	0.9036		18
1	0.013	8	0.048	2.5553	*	18
1	0.013	9	0.032	1.3924		18
1	0.013	10	0.044	2.3034	*	18
1	0.013	11	0.037	1.7850		18
1	0.013	12	0.050	2.7330	*	18
1	0.013	13	0.076	4.6439	**	18
1	0.013	14	0.061	3.5700	**	18
1	0.013	15	0.057	3.2589	**	18
1	0.013	16	0.110	7.1992	**	18
1	0.013	17	0.107	6.9770	**	18
1	0.013	18	0.098	6.2882	**	18
1	0.013	19	0.140	9.3693	**	18
1	0.013	20	0.060	3.4515	**	18
2	0.018	3	0.017	0.0741		18
2	0.018	4	0.027	0.6740		18
2	0.018	5	0.026	0.6296		18
2	0.018	6	0.039	1.5850		18
2	0.018	7	0.025	0.5555		18
2	0.018	8	0.048	2.2072	*	18
2	0.018	9	0.032	1.0443		18
2	0.018	10	0.044	1.9553		18
2	0.018	11	0.037	1.4369		18
2	0.018	12	0.050	2.3649	*	18
2	0.018	13	0.076	4.2958	**	18
2	0.018	14	0.061	3.2219	**	18
2	0.018	15	0.057	2.9108	**	18
2	0.018	16	0.110	6.8511	**	18
2	0.018	17	0.107	6.6289	**	18
2	0.018	18	0.098	5.9401	**	18
2	0.018	19	0.140	9.0212	**	18
2	0.018	20	0.060	3.1034	**	18
3	0.017	4	0.027	0.7481		18
3	0.017	5	0.026	0.7036		18
3	0.017	6	0.039	1.6591		18
3	0.017	7	0.025	0.6296		18
3	0.017	8	0.048	2.2812	*	18
3	0.017	9	0.032	1.1184		18
3	0.017	10	0.044	2.0294		18

3	0.017	11	0.037	1.5109		18
3	0.017	12	0.050	2.4590	*	18
3	0.017	13	0.076	4.3699	**	18
3	0.017	14	0.061	3.2959	**	18
3	0.017	15	0.057	2.9849	**	18
3	0.017	16	0.110	6.9252	**	18
3	0.017	17	0.107	6.7030	**	18
3	0.017	18	0.098	6.0141	**	18
3	0.017	19	0.140	9.0953	**	18
3	0.017	20	0.060	3.1774	**	18
4	0.027	5	0.026	0.0444		18
4	0.027	6	0.039	0.9110		18
4	0.027	7	0.025	0.1185		18
4	0.027	8	0.048	1.5332		18
4	0.027	9	0.032	0.3703		18
4	0.027	10	0.044	1.2813		18
4	0.027	11	0.037	0.7629		18
4	0.027	12	0.050	1.7109		18
4	0.027	13	0.076	3.6218	**	18
4	0.027	14	0.061	2.5479	*	18
4	0.027	15	0.057	2.2368	*	18
4	0.027	16	0.110	6.1771	**	18
4	0.027	17	0.107	5.9549	**	18
4	0.027	18	0.098	5.2661	**	18
4	0.027	19	0.140	8.3472	**	18
4	0.027	20	0.060	2.4294	*	18
5	0.026	6	0.039	0.9554		18
5	0.026	7	0.025	0.0741		18
5	0.026	8	0.048	1.5776		18
5	0.026	9	0.032	0.4148		18
5	0.026	10	0.044	1.3258		18
5	0.026	11	0.037	0.8073		18
5	0.026	12	0.050	1.7554		18
5	0.026	13	0.076	3.6663	**	18
5	0.026	14	0.061	2.5923	*	18
5	0.026	15	0.057	2.2812	*	18
5	0.026	16	0.110	6.2215	**	18
5	0.026	17	0.107	5.9993	**	18
5	0.026	18	0.098	5.3105	**	18
5	0.026	19	0.140	8.3917	**	18
5	0.026	20	0.060	2.4738	*	18
6	0.039	7	0.025	1.0295		18
6	0.039	8	0.048	0.6222		18
6	0.039	9	0.032	0.5407		18
6	0.039	10	0.044	0.3703		18
6	0.039	11	0.037	0.1481		18
6	0.039	12	0.050	0.7999		18
6	0.039	13	0.076	2.7108	*	18
6	0.039	14	0.061	1.6369		18
6	0.039	15	0.057	1.3258		18
6	0.039	16	0.110	5.2661	**	18
6	0.039	17	0.107	5.0439	**	18
6	0.039	18	0.098	4.3551	**	18
6	0.039	19	0.140	7.4362	**	18
6	0.039	20	0.060	1.5184		18

7	0.025	8	0.048	1.6517		18
7	0.025	9	0.032	0.4888		18
7	0.025	10	0.044	1.3998		18
7	0.025	11	0.037	0.6814		18
7	0.025	12	0.050	1.8294		18
7	0.025	13	0.076	3.7403	**	18
7	0.025	14	0.061	2.6664	*	18
7	0.025	15	0.057	2.3553	*	18
7	0.025	16	0.110	6.2956	**	18
7	0.025	17	0.107	6.0734	**	18
7	0.025	18	0.098	5.3846	**	18
7	0.025	19	0.140	8.4657	**	18
7	0.025	20	0.060	2.5479	*	18
8	0.048	9	0.032	1.1628		18
8	0.048	10	0.044	0.2518		18
8	0.048	11	0.037	0.7703		18
8	0.048	12	0.050	0.1778		18
8	0.048	13	0.076	2.0887	*	18
8	0.048	14	0.061	1.0147		18
8	0.048	15	0.057	0.7036		18
8	0.048	16	0.110	4.6439	**	18
8	0.048	17	0.107	4.4217	**	18
8	0.048	18	0.098	3.7329	**	18
8	0.048	19	0.140	6.8141	**	18
8	0.048	20	0.060	0.8962		18
9	0.032	10	0.044	0.9110		18
9	0.032	11	0.037	0.3925		18
9	0.032	12	0.050	1.3406		18
9	0.032	13	0.076	3.2515	**	18
9	0.032	14	0.061	2.1775	*	18
9	0.032	15	0.057	1.8665		18
9	0.032	16	0.110	5.8068	**	18
9	0.032	17	0.107	5.5846	**	18
9	0.032	18	0.098	4.8958	**	18
9	0.032	19	0.140	7.9769	**	18
9	0.032	20	0.060	2.0590		18
10	0.044	11	0.037	0.5185		18
10	0.044	12	0.050	0.4296		18
10	0.044	13	0.076	2.3405	*	18
10	0.044	14	0.061	1.2665		18
10	0.044	15	0.057	0.9554		18
10	0.044	16	0.110	4.8958	**	18
10	0.044	17	0.107	4.6736	**	18
10	0.044	18	0.098	3.9847	**	18
10	0.044	19	0.140	7.0659	**	18
10	0.044	20	0.060	1.1480		18
11	0.037	12	0.050	0.9480		18
11	0.037	13	0.076	2.8589	**	18
11	0.037	14	0.061	1.7850		18
11	0.037	15	0.057	1.4739		18
11	0.037	16	0.110	5.4142	**	18
11	0.037	17	0.107	5.1920	**	18
11	0.037	18	0.098	4.5032	**	18
11	0.037	19	0.140	7.5843	**	18
11	0.037	20	0.060	1.6665		18

12	0.050	13	0.076	1.9109	18
12	0.050	14	0.061	0.8369	18
12	0.050	15	0.057	0.5259	18
12	0.050	16	0.110	4.4662 **	18
12	0.050	17	0.107	4.2440 **	18
12	0.050	18	0.098	3.5552 **	18
12	0.050	19	0.140	6.6363 **	18
12	0.050	20	0.060	0.7184	18
13	0.076	14	0.061	1.0740	18
13	0.076	15	0.057	1.3850	18
13	0.076	16	0.110	2.5553 *	18
13	0.076	17	0.107	2.3331 *	18
13	0.076	18	0.098	1.6443	18
13	0.076	19	0.140	4.7254 **	18
13	0.076	20	0.060	1.1925	18
14	0.061	15	0.057	0.3111	18
14	0.061	16	0.110	3.6292 **	18
14	0.061	17	0.107	3.4070 **	18
14	0.061	18	0.098	2.7182 *	18
14	0.061	19	0.140	5.7994 **	18
14	0.061	20	0.060	0.1185	18
15	0.057	16	0.110	3.9403 **	18
15	0.057	17	0.107	3.7181 **	18
15	0.057	18	0.098	3.0293 **	18
15	0.057	19	0.140	6.1104 **	18
15	0.057	20	0.060	0.1926	18
16	0.110	17	0.107	0.2222	18
16	0.110	18	0.098	0.9110	18
16	0.110	19	0.140	2.1701 *	18
16	0.110	20	0.060	3.7477 **	18
17	0.107	18	0.098	0.6888	18
17	0.107	19	0.140	2.3923 *	18
17	0.107	20	0.060	3.5255 **	18
18	0.098	19	0.140	3.0811 **	18
18	0.098	20	0.060	2.8367 *	18
19	0.140	20	0.060	5.9179 **	18

Root/Shoot ratio.

ANALYSIS OF VARIANCE Root/Shoot Ratio

PEAT SLOPE

SOURCE	D.F.	S.S.	M.S.	F
TREATMENTS	18	3.9582	0.2199	1.792 *
ERROR	171	20.9881	0.1227	
TOTAL	189	24.9463		

COMPARISONS BETWEEN TREATMENT MEANS

TREATMENTS AND MEANS				STUDENT'S T		D.F.
1	0.479	2	0.254	1.4316	P ≤ 0.05	18
1	0.479	3	0.250	1.4616		18
1	0.479	4	0.180	1.9097		18
1	0.479	5	0.181	1.8969		18
1	0.479	6	0.313	1.0601		18
1	0.479	7	0.147	2.1184	*	18
1	0.479	8	0.154	2.0718		18
1	0.479	9	0.374	0.6670		18
1	0.479	10	0.360	0.7595		18
1	0.479	11	0.249	1.4674		18
1	0.479	12	0.360	0.7583		18
1	0.479	13	0.554	0.4787		18
1	0.479	14	0.358	0.7723		18
1	0.479	15	0.521	0.2674		18
1	0.479	16	0.544	0.4136		18
1	0.479	17	0.623	0.9210		18
1	0.479	18	0.449	0.1870		18
1	0.479	19	0.491	0.0785		18
2	0.254	3	0.250	0.0300		18
2	0.254	4	0.180	0.4781		18
2	0.254	5	0.181	0.4653		18
2	0.254	6	0.313	0.3713		18
2	0.254	7	0.147	0.6868		18
2	0.254	8	0.154	0.6402		18
2	0.254	9	0.374	0.7646		18
2	0.254	10	0.360	0.6721		18
2	0.254	11	0.249	0.0357		18
2	0.254	12	0.360	0.6734		18
2	0.254	13	0.554	1.9103		18
2	0.254	14	0.358	0.6593		18
2	0.254	15	0.521	1.6990		18
2	0.254	16	0.544	1.8452		18
2	0.254	17	0.623	2.3526	*	18
2	0.254	18	0.449	1.2446		18
2	0.254	19	0.491	1.5101		18
3	0.250	4	0.180	0.4481		18
3	0.250	5	0.181	0.4353		18
3	0.250	6	0.313	0.4015		18
3	0.250	7	0.147	0.6568		18
3	0.250	8	0.154	0.6102		18
3	0.250	9	0.374	0.7946		18
3	0.250	10	0.360	0.7021		18
3	0.250	11	0.249	0.0057		18
3	0.250	12	0.360	0.7034		18

3	0.250	13	0.554	1.9403		18
3	0.250	14	0.358	0.6893		18
3	0.250	15	0.521	1.7290		18
3	0.250	16	0.544	1.8752		18
3	0.250	17	0.623	2.3826	*	18
3	0.250	18	0.449	1.2746		18
3	0.250	19	0.491	1.5401		18
4	0.180	5	0.181	0.0128		18
4	0.180	6	0.313	0.8495		18
4	0.180	7	0.147	0.2087		18
4	0.180	8	0.154	0.1621		18
4	0.180	9	0.374	1.2427		18
4	0.180	10	0.360	1.1501		18
4	0.180	11	0.249	0.4423		18
4	0.180	12	0.360	1.1514		18
4	0.180	13	0.554	2.3884	*	18
4	0.180	14	0.358	1.1374		18
4	0.180	15	0.521	2.1771	*	18
4	0.180	16	0.544	2.3233	*	18
4	0.180	17	0.623	2.8307	*	18
4	0.180	18	0.449	1.7227		18
4	0.180	19	0.491	1.9682		18
5	0.181	6	0.313	0.8368		18
5	0.181	7	0.147	0.2215		18
5	0.181	8	0.154	0.1749		18
5	0.181	9	0.374	1.2299		18
5	0.181	10	0.360	1.1374		18
5	0.181	11	0.249	0.4295		18
5	0.181	12	0.360	1.1387		18
5	0.181	13	0.554	2.3756	*	18
5	0.181	14	0.358	1.1246		18
5	0.181	15	0.521	2.1643	*	18
5	0.181	16	0.544	2.3105	*	18
5	0.181	17	0.623	2.8179	*	18
5	0.181	18	0.449	1.7099		18
5	0.181	19	0.491	1.9754		18
6	0.313	7	0.147	1.0582		18
6	0.313	8	0.154	1.0116		18
6	0.313	9	0.374	0.3932		18
6	0.313	10	0.360	0.3006		18
6	0.313	11	0.249	0.4072		18
6	0.313	12	0.360	0.3019		18
6	0.313	13	0.554	1.5388		18
6	0.313	14	0.358	0.2879		18
6	0.313	15	0.521	1.3276		18
6	0.313	16	0.544	1.4737		18
6	0.313	17	0.623	1.9812		18
6	0.313	18	0.449	0.8731		18
6	0.313	19	0.491	1.1387		18

7	0.147	8	0.154	0.0466	18
7	0.147	9	0.374	1.4514	18
7	0.147	10	0.360	1.3589	18
7	0.147	11	0.249	0.6510	18
7	0.147	12	0.360	1.3601	18
7	0.147	13	0.554	2.5971 *	18
7	0.147	14	0.358	1.3461	18
7	0.147	15	0.521	2.3858 *	18
7	0.147	16	0.544	2.5320 *	18
7	0.147	17	0.623	3.0394 *	18
7	0.147	18	0.449	1.9314	18
7	0.147	19	0.491	2.1969 *	18
8	0.154	9	0.374	1.4048	18
8	0.154	10	0.360	1.3123	18
8	0.154	11	0.249	0.6944	18
8	0.154	12	0.360	1.3135	18
8	0.154	13	0.554	2.5595 *	18
8	0.154	14	0.358	1.2995	18
8	0.154	15	0.521	2.3392 *	18
8	0.154	16	0.544	2.4854 *	18
8	0.154	17	0.623	2.9928 *	18
8	0.154	18	0.449	1.8818	18
8	0.154	19	0.491	2.1503 *	18
9	0.374	10	0.360	0.0925	18
9	0.374	11	0.249	0.8004	18
9	0.374	12	0.360	0.0913	18
9	0.374	13	0.554	1.1457	18
9	0.374	14	0.358	0.1053	18
9	0.374	15	0.521	0.9344	18
9	0.374	16	0.544	1.0806	18
9	0.374	17	0.623	1.5880	18
9	0.374	18	0.449	0.4800	18
9	0.374	19	0.491	0.7455	18
10	0.360	11	0.249	0.7078	18
10	0.360	12	0.360	0.0013	18
10	0.360	13	0.554	1.2382	18
10	0.360	14	0.358	0.0128	18
10	0.360	15	0.521	1.0270	18
10	0.360	16	0.544	1.1731	18
10	0.360	17	0.623	1.6805	18
10	0.360	18	0.449	0.5725	18
10	0.360	19	0.491	0.8380	18
11	0.249	12	0.360	0.7091	18
11	0.249	13	0.554	1.9461	18
11	0.249	14	0.358	0.6951	18
11	0.249	15	0.521	1.7348	18
11	0.249	16	0.544	1.8809	18
11	0.249	17	0.623	2.3884 *	18
11	0.249	18	0.449	1.2803	18
11	0.249	19	0.491	1.5459	18

12	0.360	13	0.554	1.2369	18
12	0.360	14	0.358	0.0140	18
12	0.360	15	0.521	1.0257	18
12	0.360	16	0.544	1.1718	18
12	0.360	17	0.623	1.6793	18
12	0.360	18	0.449	0.5712	18
12	0.360	19	0.491	0.8368	18
13	0.554	14	0.358	1.2510	18
13	0.554	15	0.521	0.2113	18
13	0.554	16	0.544	0.0651	18
13	0.554	17	0.623	0.4423	18
13	0.554	18	0.449	0.6657	18
13	0.554	19	0.491	0.4002	18
14	0.358	15	0.521	1.0397	18
14	0.358	16	0.544	1.1659	18
14	0.358	17	0.623	1.6933	18
14	0.358	18	0.449	0.5853	18
14	0.358	19	0.491	0.8503	18
15	0.521	16	0.544	0.1462	18
15	0.521	17	0.623	0.6536	18
15	0.521	18	0.449	0.4544	18
15	0.521	19	0.491	0.1889	18
16	0.544	17	0.623	0.5074	18
16	0.544	18	0.449	0.6006	18
16	0.544	19	0.491	0.3351	18
17	0.623	18	0.449	1.1060	18
17	0.623	19	0.491	0.8425	18
18	0.449	19	0.491	0.2655	18

4. Temperatures and soil moisture content along the peat slope.

TABLE 2.

SOIL TEMPERATURES ALONG THE SLOPE

Date	Top Station 1 level 18 1"	Station 2 level 15 1"	2"	4"	8"	Station 3 level 5 1"	2"	4"	8"	bottom Station 4 level 1 1"
	Temperature °C									
June 3			14.5	13.5	11.0		12.5	11.0	9.5	
4			15.0	12.5	11.0		13.0	11.0	9.5	
6			9.5	9.5	10.0		9.0	9.0	9.0	
10			14.75	12.0	10.5		12.5	10.0	9.0	
13			13.75	12.25	11.75		12.0	11.0	10.0	
17			15.5	14.0	12.75		13.75	12.0	11.0	
18	16.0	17.0	16.5	15.0	13.0	15.0	14.5	12.5	11.0	13.0
20	13.0	12.0	12.4	12.4	12.5	11.5	11.25	11.0	10.6	10.5
24	11.5	11.5	10.5	10.0	10.75	11.0	9.5	9.0	9.5	9.0
27	13.5	13.0	11.5	11.0	11.0	12.0	11.0	10.0	9.5	11.0
$\bar{X}$	13.5	13.4	13.4	12.2	11.4	12.1	11.9	10.7	9.9	10.9
July 1	16.0	15.5	14.25	13.25	11.75	14.0	13.25	11.75	10.25	13.0
4	11.75	12.0	11.0	10.75	11.0	11.0	10.5	10.0	10.0	10.0
8	11.0	11.5	11.75	11.5	11.0	11.0	10.75	10.25	9.75	11.0
11	11.0	10.25	10.25	10.50	11.0	10.0	10.0	10.0	9.75	9.5
15	12.0	11.0	10.5	10.5	10.75	10.0	10.0	9.75	9.5	10.0
18	13.0	12.5	11.5	11.25	11.25	11.0	10.5	10.25	10.0	10.0
22	15.0	15.0	14.0	13.25	12.5	13.5	13.0	12.0	11.0	13.0
25	17.0	18.0	14.5	13.5	12.5	15.0	13.25	12.0	11.0	13.5
29	15.0	14.5	13.25	12.5	12.25	12.5	12.0	11.25	11.0	12.0
$\bar{X}$	13.5	13.4	12.4	13.4	11.6	12.0	11.5	10.8	10.3	11.3

Date	Top Station 1 1"	Station 2 1"	2"	4"	8"	Station 3 1"	2"	4"	8"	bottom Station 4 1"
					Temperature °C					
August 1	14.5	16.0	13.0	12.5	12.5	12.0	11.5	11.25	11.0	11.0
5	17.0	17.0	15.5	14.0	12.8	15.0	14.0	12.50	11.5	14.0
8	12.5	12.0	13.0	12.5	12.0	12.0	12.0	12.0	11.0	11.5
12	15.5	15.5	14.25	13.25	12.25	14.0	13.0	11.75	11.5	13.0
15	12.5	12.25	11.0	11.5	10.75	11.0	10.5	10.25	10.0	10.0
19	16.5	16.0	14.0	12.5	11.25	15.0	13.0	11.5	10.0	14.0
22	15.0	15.0	14.0	13.5	12.0	14.0	13.5	12.5	11.0	13.5
26	14.5	14.0	12.5	11.75	11.5	12.5	11.5	11.0	10.75	12.0
29	12.0	11.5	11.5	11.5	12.0	11.0	11.0	11.0	11.0	11.0
$\bar{X}$	14.4	14.3	13.2	12.6	11.9	12.9	12.2	11.5	10.9	12.2
September 2	14.5	14.0	12.5	11.5	11.0	12.5	11.5	10.5	10.25	12.25
5	13.0	12.5	11.5	11.0	11.25	11.25	10.5	10.5	10.5	11.0
13	13.0	13.0	13.25	12.5	11.5	12.5	12.25	11.5	11.0	12.0
16	12.0	12.0	11.0	10.5	10.5	10.5	10.5	10.0	9.5	10.0
19	9.0	8.5	8.5	9.0	10.0	8.5	8.75	9.25	9.75	8.5
24	12.5	12.0	10.5	10.0	10.25	11.0	9.5	9.5	10.0	9.5
26	13.0	13.0	12.5	11.5	10.0	11.5	10.5	10.0	9.0	11.0
$\bar{X}$	12.4	12.1	11.4	10.9	10.7	11.1	10.5	10.2	10.0	10.6

TABLE 25

FIELD SOIL MOISTURE CONTENT AND 15 ATMOSPHERE MOISTURE CONTENT ALONG THE PEAT SLOPE
(2 samples per level 3" cores)

Level	Field M. C. % wet vol.	Field M. C. % O. D. weight	15 Atmos. M. C. % wet vol.	15 Atmos. M. C. % O. D. weight
1	68.87	633.3	45.40	411.8
2	65.00	720.7	36.04	397.0
3	68.97	689.7	44.14	430.2
4	67.40	456.3	46.54	343.1
5	71.83	754.6	18.50	317.2
6	60.14	426.6	34.55	-
7	62.07	652.9	23.15	412.1
8	65.63	717.1	38.47	423.3
9	62.7	573.2	43.04	415.9
10	63.87	516.6	44.10	368.6
11	63.24	493.9	48.73	377.9
12	64.03	491.1	46.30	351.4
13	65.80	616.2	25.50	-
14	68.97	841.1	35.90	438.6
15	64.30	702.5	40.86	460.2
16	70.40	534.9	56.46	428.8
17	61.57	449.1	34.80	272.4
18	58.87	524.3	36.36	315.2

5. Redox values at Flanders Moss 1967

Forestry Commission Research Branch Analysis.

Appendix 5

REDOX Potential 3" depth. **Flanders Moss 1967**

Means

O(control)	243.75		
DS/O	330.00		
D/O	277.25		
S/100/2	265.00		
S/100/4	312.00	Standard error	33.52
S/50/2	277.50		
S/50/4	267.00		
S/25/2	297.50		
S/25/4	247.00		

Analysis of Variance

Source of Variation	Degrees of freedom	Mean square	F ratios observed	0.05	0.01
Blocks	3	65414.73000	14.56	3.01	4.72
Treatments	8	3320.07500			
Error	24	4493.46670			

Experiment mean	279.667
Standard deviation	67.033
Coeff. variation	23.97

Redox Potential, after drain deepening.

Means

O(control)	310.00		
DS/O	342.00		
D/O	374.00		
S/100/2	337.50		
S/100/4	316.00	Standard error	36.46
S/50/2	332.00		
S/50/4	360.00		
S/25/2	328.00		
S/25/4	343.50		

Analysis of Variance

Source of Variation	Degrees of freedom	Mean square	F ratios observed	0.05	0.01
Blocks	1	2990.20	1.12	5.32	11.26
Treatments	8	807.60			
Error	8	2659.35			

Experiment mean	338.111
Standard deviation	51.569
Coeff. Variation	15.25