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The Progress of Deep Peat Afforestation in the North-West

LIAM CONDON, B.AGR.SC.

THE afforestation of deep peat is an aspect of forestry practice with which many foresters are perhaps not very familiar. As a soil-type it is regional in its occurrence and as such does not therefore come within the compass of every forester's activities. Literature on the subject has for the most part been devoted to description and interpretation of experimental projects on peatlands and moorlands. Such work as carried out by Steven (1929), Frazer (1933), Tansley (1939) and Zehetmayr (1954) has, however, proved invaluable in determining sound basic principles applicable to large-scale operational activity in the field. It may be of interest to many therefore to read of what progress has been made in this sphere and of what techniques are being adopted in order to ensure the successful afforestation of this difficult and, in a forestry sense, comparatively unknown soil-type.

The observations recorded here are based on a study of plantations laid down on the blanket-bog regions of south-west Sligo and west and north-west Mayo. The work encompassed by the study was initiated in 1952. In the meantime further areas have been developed annually. The 1952 plantings are now approaching the thicket stage. There is therefore available for study a complete series of age-classes throughout the establishment phase of the rotation. First-hand information on all relevant factors can be availed of to create a composite picture based on factual evidence. It is the primary purpose of the study therefore, to record all relevant data and facts for the purpose of creating such a picture. Having done so, it is further intended to present an interpretation of the significance of the facts observed and the data recorded in so far as they are considered relevant to the establishment of an appropriate sylvicultural technique for the future treatment of deep peat areas.

Peat Classification and Type.

The region as a whole, in which are located the following State Forests, Ballycastle, Glenamoy, Glenisland, Lough Talt, Nephin Beg and Nephin Mór, is characterised by the occurrence of vast expanses of peat of climatic origin. Adopting Frazer's classification it is predominantly of the "blanket-bog" type, with some local development of "basin-peat". In referring to classification, the following extract from Zehetmayr is considered particularly relevant. While referring specifically to north of England and Scottish Highlands it is very descriptive of conditions in the north-west and it is therefore quoted in full:

. . . . "There remains the blanket moss or blanket bog types which cover huge areas to a varying depth and which is the chief concern of this Bulletin. Within this type there are often local developments of basin peat, originally formed in lochans, lochs, or lakes which give rise to areas of deep peat varying in size from pockets a few yards across to great bogs hundreds of acres in extent. Also easily recognisable in blanket bog areas are the knolls typically underlain by moraine, but also on occassion by rock, where the peat rises locally and becomes thinner and tougher. Between these extremes lies peat neither basin nor knoll, which is divided in this work into slopes and flats, the distinction having considerable importance in forestry as effecting the drainage and the exposure. The phenomenon of flushing must also be mentioned here. If peat is traversed by drainage water the composition and vigour of the vegetation alter, even though the seepage water is extremely poor in nutrients. These five features of the blanket bog basin, knoll, slope, flat and flush are constantly referred to in the description of the experiments as a means of defining the site" . . . .
In the north-west the peat deposits vary in depth from 12 ins. to 18 ins. on the "knolls" to 24 ft. or more on the "basins" and "flats". They are predominantly pseudo-fibrous in character with the exception of the "knoll" peats which are distinctly fibrous, and some molinia flushes which may exhibit amorphous characteristics. In this predominance of the pseudo-fibrous form they do not conform with Frazer's classification based on the predominance of a particular vegetation element, viz. *Tricophorum,* pseudo-fibrous; *Calluna/Eriophorum,* fibrous; *Molinia,* amorphous. Many of the *Eriophorum* and *Molinia* dominated peats of the north-west have the distinct gelatinous consistency of the true pseudo-fibrous peat. It is worthy of note that it is on these pseudo-fibrous types that the maximum response to ploughing is evident. The *Eriophorum* dominated slope or flat is particularly noteworthy in this respect.

Vegetation.

The major vegetation communities are dominated by *Molinia, Calluna, Eriophorum* or *Tricophorum, Erica cinerea, Myrica gale, Juncus squarrosus, Erica tetralix; Narthecium* and *Carex* species are secondary constituents. There is local occurrence of *Juncus articulatus, Pteris aquilina* and *Sphagnum.* A characteristic of many of the north-west peats is the occurrence in varying quantities of *Schoenus nigricans.* It's significance as a constituent of the vegetation communities is not fully understood. Suffice to say, however, that where it is abundant the suitability of the site for Sitka spruce is considerably enhanced.

Nutrient Status.

Analytical data covering the various peat types of the region are unfortunately not available. Table I below, indicating the chemical analysis of a pseudo-fibrous *Eriophorum/Schoenus* peat at Glenamoy, gives however, an indication of the trend of fertility in peat. For purposes of comparison, in Table II is shown an analysis of a "raised bog" *Polytrichum/Sphagnum* taken from a profile at Cloncreen, Co. Offaly. (Walsh & Barry 1958).

TABLE I

Depth (cms.)	% H_2O	pH	% N	% Ash	P(s) P.P.M.	Ca(s) *	K(s) P.P.M.	% Decom-position	Density grams/ c.cm.
0–20	91.2	4.6	1.44	2.4	16	4	177	38	0.80
20–50					2	3	22		
50–100	93.8	4.5	1.20	1.2	4	4	50	47	0.91
100–150	93.0	4.6	1.08	1.2	0.5	3	33	46	0.91
150–200	92.5	4.8	1.00	2.6	0.5	3	56	44	0.90
200–250	92.2	4.8	0.84	2.6	0.5	3	83	38	0.87
250–300	91.0	5.0	0.72	2.6	0.5	3	61	59	1.04
300–350	90.1	5.1	0.76	12.6	0.5	2	45	57	1.03

TABLE II

0–20	93.7	4.5	1.36	1.9	17.0	4	130	14	0.40
20–50					7.5	5	88		
50–100	94.2	4.6	0.92	1.4	2.0	4	77	10	0.35
100–150	95.0	4.3	0.72	1.0	3.0	4	67	8	0.34
150–200	95.1	4.5	0.76	1.0	0.5	3	33	5	0.36
200–250	94.5	4.7	0.76	1.2	0.5	3	33	8	0.36
250–300	93.3	4.7	0.80	2.4	0.5	3	33	48	0.80
300–350	92.7	4.6	0.72	1.6	0.5	3	27	40	0.79
350–400	92.8	4.8	0.72	1.8	0.5	3	17	35	0.60
400–450	91.2	5.0	1.64	3.8	0.5	4	22	38	0.78
450–500	90.2	5.3	1.40	5.0	0.5	6	12	51	0.82
500–550	91.4	5.2	1.68	6.0	0.5	7	33	58	0.92
550–600	90.1	5.5	1.44	19.2	0.5	8	27	42	0.80

* Calcium Value 2 = 400 P.P.M.
" " 3 = 600 "
" " 4 = 800 "
" " 5 = 1,000 "
" " 6 = 1,500 "
" " 7 = 2,000 "
" " 8 = 2,500 "

By way of contrast the figures hereunder indicate the amounts of some of the major elements present in some Co. Sligo agricultural soils :

(a) pH 6.3
Calcium 5,000 lbs. per acre or 2,500 P.P.M. (value No. 8)
Phosphorus 30 " " " 15 "
Potassium 150 " " " 75 "

(b) pH 5.5

Calcium	5,000 lbs. per acre or	2,500 P.P.M.	(value No. 8)
Phosphorus	15 ,, ,, ,,	7.5 ,,	
Potassium	300 ,, ,, ,,	150 ,,	

(c) pH 5.7

Calcium	1,200 lbs. per acre or	600 P.P.M.	(value No. 3)
Phosphorus	3 ,, ,, ,,	1.5 ,,	
Potassium	200 ,, ,, ,,	100 ,,	

A level of less than 5 P.P.M. of phosphorus is regarded as deficient.

It is quite apparent even from a superficial study of the Tables that the nutrient status of the Glenamoy profile is extremely low in respect of the major elements necessary for plant growth. Nevertheless it is evident in the field that tree-growth amongst certain species will respond significantly to fertiliser application of as little as 1 cwt. per acre. As yet in field practice, fertiliser application has been confined to dressing with Phosphate (Ground Mineral Phosphate or Basic Slag). It is not unreasonable to hope therefore, that applications of other major and even minor elements can bring about equally significant responses and in the long run perhaps widen considerably the choice of species for peat afforestation.

Some aspects of the tabulated results as shown in Table I are worthy of further consideration :

(1) *Moisture Content:* It will be noted that to a depth of approximately 12 feet in the profile, moisture content is over 90%. This is a very significant factor in ground preparation. 90% Moisture Content is a stagnation level in which tree roots will not survive. Drainage therefore must be so intensive that moisture content in the upper layers can be reduced to a degree where healthy root growth and penetration can be promoted.

(2) *pH.:* Acidity level is not considered a very significant factor for species now in use on peat. Further investigation may indicate the desirability of liming in order to get satisfactory results with other species.

(3) *Nitrogen:* It will be noted that Nitrogen content is extremely low at all levels. This would seem to indicate that perhaps spectacular results could be obtained by adjustment of Nitrogen status. In view of the importance of Nitrogen as a basic and fundamental element in plant growth, this presents a line of investigation which is well worthy of consideration.

The possible effects of liming on nitrification, particularly on nitrogen fixing plants such as alder might also be investigated with advantage.

(4) *Phosphate:* This is critically low at all levels, except in the top 6 ins. to 8 ins. where the highest concentration of available P_2O_5 exists. After ploughing, however, the transplant is planted in a zone carrying

only 2.0 to 2.5 parts per million of this very essential element. Hence the immediate and significant response to phosphate application. Lack of phosphate application on peat means virtually complete absence of growth.

(5) *Calcium and Potash:* Levels are not significant as far as is known to performance of species now in use. Experimentation with new species may bring these elements, particularly calcium, more into the picture in years to come.

(6) *Decomposition and Density:* Comparison with the "raised bog" figure is revealing. Response of various peat types to ploughing may well reveal a distinct relationship with these two factors. The degree of aeration and consequent physiological and chemical activity may be influenced to a considerable extent by both.

Climate.

High rainfall combined with low insulation and high humidity, being the three factors most associated with peat formation, are the dominant meteorological elements of the region. The Table below indicates graphically statistical information on the meteorological complex. Figures quoted are taken from meteorological records for Glenamoy. They are average figures for 1958. Where appropriate, records from other stations are quoted for comparison. Again it must be stated that records are only readily available in respect of conditions at Glenamoy. As this is situated on the north Mayo coast a maritime influence is reflected on a number of the elements recorded. They may not therefore be applicable to the region under study as a whole. They are, however, indicative of climatological trends in the region. In fact, conditions at other centres would probably reflect an improvement in respect of most elements.

Element	**Records**							
	9 A.M.		3 P.M.		9 P.M.		MAX.	MIN.
Air Temperature	*Wet °F*	*Dry °F*	*Wet °F*	*Dry °F*	*Wet °F*	*Dry °F*	*at 9 a.m.*	*at 9 p.m.*
	42.27	49.75	49.32	52.44	46.91	48.33	51.47	44.23
Relative Humidity	84.64		79.72		80.75			
Soil Temps.	2″	4″	3″	2″	4″	8″		
	48.92	48.34	49.89	53.23	49.65	45.25		
	1′	2′	4′					
	49.84	49.93	50.10					

Frost	No. of days per annum with temp. 32°F or less=25
Rainfall	Mean Annual = 48.41 inches
Sunshine/Day	2.99 hours

	9 a.m.	3 p.m.
Wind Velocity	22.94 m.p.h.	17.38 m.p.h.

		Dublin	Malin Hd.	Blacksod	Valentia	Gale Force Beaufort	Gale Force M.P.H.
Gale Frequency	No. per annum	7	43	117	5	8	over 42
	Mean over 10 yrs.	29	40	66	26	6 to 7	28 to 35

	Equivalent in Inches of Rainfall per Annum	
Evapo-Transpiration	Undeveloped Bog Surface	Grass Sward
	10″	15″

Exposure.

As far as tree-growth is concerned the most extreme element indicated above is that shown by the data relative to gale frequencies. It is apparent that the region as a whole is subject to severe gales and that therefore exposure can be severe. Prevailing winds are from the south-west, but some of the severe gales may be from the north-west. Land shelter to seaward is therefore a factor of considerable importance in determination of degree of plantability.

Elevation.

Plantable limits are governed to a large degree by the exposure factor. In a region, however, which is characterised by low mountain ranges (under 2,000 ft.) and wide valleys, interspersed through open plains, plantations have been established at elevations varying from sea-level at Glenamoy, to 750 ft. at Nephin Beg and 900 ft. at Nephin Mór. These do not necessarily represent the maximum heights attainable. It is unlikely, however, that much planting will take place at elevations in excess of 1,000 ft.

Site Classification and Plantability.

Any attempt at assessment of plantability must necessarily be proceeded by some form of site classification. The term "deep peat" is almost as wide in its interpretation as a definition of a soil-type as is "mineral soil". It is necessary, therefore, at the outset to break down this broad class into some appropriate sub-classification. The sub-classification adopted here is prompted to a large degree by the phrase recorded above under Peat Classification, viz. "These five features of the blanket-bog, basin, knoll, slope, flat and flush are constantly referred to in the description of the experiments as a means of defining the site." (Zehetmayr). These physical features are readily recognisable in the terrain under study and it is now apparent that they possess characteristic patterns of plantability. It is also possible to co-relate these recognisable physical features to a common pattern of vegetation dominants. On this basis, therefore, is devised the following sub-classification of the class "deep peat".

(1) Molinia *basins and flushes:* These carry strong *Molinia* with very often, vigorous *Schoenus nigricans* dominant to *Eriophorum* and weak *Calluna. Carex* species and *Narthecium* are also present. In pronounced flush conditions *Juncus articulatus* can be a dominant constituent. They occur, as the title indicates, in basins which have been enriched by drainage waters from adjoining slopes or on concave slopes which are similarly enriched. Peat depth is considerable and peat may show amorphous characteristics.

(2) Eriophorum *flats and slopes:* These areas carry *Eriophorum* with weak *Schoenus nigricans* dominant to *Molinia, Calluna; Narthecium* and *Carex* species also occur. *Tricophorum* may be found but normally it is not abundant. It can, however, be locally dominant where slightly convex configuration is developed. They occur as vast flats and slopes. Configuration is generally concave but never sufficient to create flush or basin conditions with consequent enrichment by drainage waters. Peat depths can be extreme, particularly on the flats. (Depth in excess of 24 feet has been noted). Peat type is predominantly pseudo-fibrous. Amorphous characteristics may, however, be exhibited at lower levels of the profile. When this is turned up by ploughing difficulties in planting can arise.

(3) Calluna *slopes:* These are found where gradient becomes moderate to steep and therefore peat depth is not great. They carry vigorous *Calluna* dominant to *Molinia* and *Eriophorum. Erica tetralix* and *Tricophorum* may be found on the poorer variants, but pockets of bracken may also occur. Peat is definitely fibrous. Such slopes are often boulder-strewn and are therefore unploughable.

(4) Calluna *knolls:* These carry weak *Calluna* with *Erica tetralix* and *Tricophorum* and some *Eriophorum.* They are generally found interspersed through flats and gentle slopes (as described in sub-class 2) and display, as is indicated in the title, a distinctly convex configuration. Peat is shallow, fibrous and tough and solid rock or compacted glacial debris may be very near the surface. In this respect they conform closely to the "black" soils of south-west Scotland as described

by Macdonald (1953). As such they are very intractable and unrewarding afforestation sites.

(5) Tricophorum *knolls:* These occur generally on mountain summits or exposed knolls. They carry *Tricophorum* dominant to *Eriophorum, Molinia* and sparse weak *Calluna.* The inherent combination of low fertility with severe exposure render them totally unsuitable for forestry purposes.

In the light of experience now gained, the following assessment of plantability is suggested. It must be appreciated, however, that in assessing plantability of any of the above types in the field, due regard must be taken of factors of the locality. Subject to these factors being favourable the assessment beneath is presented.

Sub-Class 1: This is land which is fully plantable after either manual or mechanical preparation. The latter is of course more desirable. Sitka spruce is the ideal and invariable choice of species. On such types it is a rapid grower and should form canopy quickly. Phosphate application is normally practised, but may not be essential on the more "mineralised" flushes. Species other than Sitka spruce have not been tried to any extent. Scottish experiments have shown, however, that *Tsuga heterophylla* has distinct possibilities on this peat type. Bushy type growth is characteristic of its earlier development, but where canopy has closed growth has increased rapidly (Zehetmayr). *Picea omorika* has as yet only been tried in experimental plots in the northwest. It is therefore premature to reach any conclusion on its performance. Experience in Britain has indicated that it may have a limited application on peat, particularly in areas subject to severe frost. *Alnus incana* is a possible hardwood variant which may play a significant part in the silviculture of deep peat planting. It has proved the best of various alders tried in Scottish experiments.

Sub-Class 2: Excellent crops are produced on this type after ploughing. Manual preparation is feasible but results are less satisfactory. Manuring (with G.M.P.) is essential for all species on this type. Present selection of species is Sitka spruce with mixtures of *Pinus contorta* up to 50%. On the better types (where *Molinia* is more dominant) the response to ploughing is so significant and spectacular that one is tempted to question the presence of *Pinus contorta* as a crop constituent. Nevertheless an intimate admixture of a proportion of *Pinus contorta* is probably desirable silviculturally. The deeper rooting tendency of the *Pinus contorta* will tend to create more amenable soil conditions for Sitka spruce and will also tend to act as a stabiliser. Species other than Sitka spruce and *Pinus contorta* have not been tried to any extent, but again *Tsuga, Picea omorika* and *Alnus incana* may in time prove to have appreciable potentialities on this sub-class.

Sub-Class 3: This type is difficult as a rule in so far as due to steepness of slope or boulder-strewn condition ploughing is not feasible.

Where ploughing is possible excellent crops of *Pinus contorta* can be established. Manuring is very essential. Even with manual preparation good results can be obtained with *Pinus contorta.* Where *Calluna* is vigorous and almost pure, *Abies nobilis* or *Abies nobilis/Pinus contorta* mixtures are possible. In bracken pockets Japanese larch or *Pinus radiata* will produce satisfactory results. Red oak or mountain ash are possible hardwood introductions for silvicultural purposes on this type. Birch has not proved at all satisfactory in this respect.

Sub-Class 4: If ploughable and provided factors of the locality are favourable this type can produce fair *Pinus contorta* after manuring. If not ploughable however, it borders on unplantable. Results after manual preparation are very unsatisfactory. No alternative species has been tried on the type. It is unlikely, however, that any other would give more satisfactory results.

Sub-Class 5: This type is considered totally unplantable.

In referring to *Pinus contorta* in the above context no differentiation has been made as between 'coastal' and 'inland' varieties. Both varieties are present in the north-western plantations. As yet, however, no specific assessment of their potentialities can be made. The typical upright habit and 'one year's needles only' characteristic is apparent in the 'inland' type. The 'coastal' on the other hand is strong and spreading and carries 2 to 3 years' needles. Both varieties may ultimately fulfil a function relative to their own characteristic habit of growth. It could well be visualised that whereas in Sub-Class 2, *Pinus contorta* is planted in intimate mixture with Sitka spruce, the 'inland' type would be the desirable choice, whereas in Sub-Class 3 where it is desired to effect early elimination of *Calluna* competition, or in Sub-Class 4 where a pioneer species is called for, the 'coastal' type could well be the appropriate selection.

Preparation of Ground.

Ploughing with Cuthbertson plough, single-mould board or double-mould board has been resorted to in all locations where ground conditions permit. Where this is not possible, manual distribution of turves for mound planting must be resorted to. Direct notching or pitting into virgin bog is never practised in peat afforestation.

Drainage.

In addition to opening existing watercourses (very often these only appear as sinuous narrow flushes), cross-drains have been created obliquely across the ploughed ribbons at intervals of from 1 to 3 chains apart. While this may appear to constitute intensive drainage, in practice it is necessary in order to maintain satisfactory growth, to deepen alternate ploughed furrows after 2 to 3 years. Effective uniform lowering of water-table levels is therefore not achieved by the basic system of drainage which has hitherto been practised. It must be appreciated and emphasised that a system of drainage which cannot produce the appropriate lowering of water table level AT AN ECONOMIC PRICE is not worth considering. For this reason the supplementary manual drainage which must be undertaken with the basic system now in vogue must be regarded as a heavy monetary imposition which should be eliminated if at all possible. (This point is further discussed hereunder).

Planting.

Normal method of planting is by single longitudinal slit on ploughed ribbon. This is preferred to the more conventional notching because of the greater anchorage it provides. If the roots are slickly followed through by the fingers or appropriate planting tool when insertion takes place, satisfactory root dispersion can be achieved. In practice very satisfartory results are obtained by this method.

As previously mentioned, where a layer of peat showing amorphous characteristics is found underlying the surface layers of pseudo-fibrous peat and is turned up as the planting surface of the ploughed ribbon, planting difficulties will arise. This layer displays an appreciably higher rate of shrinkage than the now underlying pseudo-fibrous type. Slit planting direct on to the amorphous type layer will, when shrinkage develops, produce extensive opening of slits and loosening of plants with consequent high mortality. It is necessary therefore, to remove this amorphous layer by "stepping" down to the pseudo-fibrous. A slit is then inserted in the "step". This is known as "step" planting. This was widely practised on all types in the early days. It is now, however, completely superseded by the slit method except in the exceptional case already described.

Age of Plant.

Age and size of plants is an important consideration. Strong three-year old stock is generally considered best. Some foresters, however, have a preference for four-year old plants of all species. Care must be taken in planting to ensure that plants are firmly embedded. Insertion to a depth of 2 or 3 inches above the root collar is necessary to achieve solid anchorage.

Time of Planting.

No special time of planting has been established as being particularly desirable. It is, however, desirable to have ploughing completed at least six months in advance of planting so that initial ribbon shrinkage will have taken place. Failure in this respect may lead to considerable loosening of plants with consequent increase in plant mortality.

Manuring.

Necessity for manuring has been previously referred to. In general where manuring is required, the normal dressing is 1 oz. of G.M.P. per plant for *Pinus contorta,* 2 ozs. for Sitka spruce and for other species 2 ozs. per plant. In the earlier plantations Basic Slag was used in preference to G.M.P. In current practice, however, G.M.P. is the invariable choice. While no very obvious increase in response is apparent from G.M.P. application as against Basic Slag, it seems likely that because of the more stable form in which it is applied, the response to G.M.P. will probably be more prolonged.

Rates of Growth.

Figures quoted here are based on casual observation only, without the assistance of statistical analysis.

On Sub-classes 1 and 2 growths of 12 inches to 15 inches per annum are normal. Individuals of 18 inches or more are quite common. On Sub-class 3 a range of annual growths of from 6 ins. to 10 ins. is apparent. On Sub-class 4 growth is very slow, averaging 2 ins. to 3 ins. with occasional individuals of 5 ins. to 6 ins.

Commentary.

It is now apparent that tree-crops can be established on the various sub-classes of deep peat as described, with varying degrees of success. In the accomplishment of this, three main adverse factors have been encountered :

(i) Lack of Drainage.
(ii) Lack of Fertility.
(iii) Lack of Silvicultural precedent.

It is true to say, in so far as crops are now growing satisfactorily almost to the thicket stage, that as far as establishment problems are concerned these adverse factors have to a large degree been successfully overcome. It is equally true to state, however, that these same adverse factors will be present in greater or lesser degree throughout the entire rotation. A study therefore of their respective significance during the life of the crop is perhaps not irrelevant. Judging from experience now gained it is also relevant to consider what improvements if any, aimed at a further amelioration of these ill-effects, can be effected in current technique. In the ultimate picture all three factors are utterly interdependent and cannot in practice be considered in isolation. A perfect drainage system will not of itself produce fertility. Equally does the converse apply. Granted good drainage and adequate fertility, the lack of appropriate silvicultural "know how" can lead to abortive results. Bearing this in mind therefore the following appreciation of the individual factors is presented.

Drainage:

The achievement of good drainage is probably the most critical factor involved in the entire deep-peat complex. In the early stages stagnation can lead to severe growth check or in the extreme, to plant failure. As the crop develops, deficient drainage can at any stage cause further check. In the latter stages of the rotation widespread instability will result from high water-table levels. These are physical factors affecting the health and existence of the crop itself. Effective drainage also produces in the soil complex a number of phenomena (structure, moisture/air relationship, ground temperature, etc.) in which a favourable reaction must be obtained if the proper functioning of the physiological processes of plant growth is to be permitted. It is only by the achievement of an appropriate balance amongst these phenomena that plant nutrition can be expected to proceed with any degree of efficiency. Good drainage at all times is therefore in this instance a basic and fundamental requirement for timber production.

Appreciating at the outset that peat contains up to 94% water, the magnitude of the drainage problem becomes apparent. Realisation of the manner in which such water is held in peat—adds further to the difficulties of situation. The water content of peat is held in four distinct physical forms.

(i) Hygroscopic Moisture: This is the amount of moisture retained in an air-dried peat under ordinary atmospheric conditions. It is not available to plants and can only be removed by heating to 100°C. The percentage held in this way will vary with atmospheric conditions. There is therefore considerable variation. The following figures have been recorded, 18.4% (Mitscherlich) 42.3% (Heinrich).

(ii) Imbibitional Moisture: This represents the water absorbed by the colloidal fraction. As peat is a highly colloidal substance the percentage of moisture held in this way is phenomenal. *It is available to plants but it is highly resistant to physical movement and is tenaciously held against mechanical force.*

(iii) Capillary Moisture: When saturation of colloids is complete, excess moisture collects on the surfaces of the soil particles. In peat this is not a significant source of moisture.

(iv) Gravitational Moisture: As soil moisture increases, interparticle and intercellular spaces become saturated with water. This water is normally subject to gravitational forces. In peat, however, even where natural drainage conditions are favourable, the movement of free water within the peat is negligible.

It is apparent that moisture is held in peat in a manner which renders its movement highly resistant to ordinary physical forces. It has been observed in practice that no movement occurs towards a drain (3 ft. deep) beyond a distance of 6 ft. from the drain-edge. No significant increase in this zone of movement is effected by deepening of such a drain. A successful drainage system must therefore obviously be intensive, not in the sense as provided by deep drainage, but in an extensive sense, so that an intimate relationship is established between the root system of the crop it is intended to grow and the drainage system created. This desired intimacy of relationship between the root system of a tree-crop and an extensive drainage system can be created simply and economically by deep ploughing during preparation for planting. In practice this has many additional advantages. Normal opening of main drains will suffice to provide effective run off and dissemination of drainage water. Thus is eliminated the necessity for time consuming cross-draining over ploughed ribbons. The large ribbons turned over by deep ploughing will effect complete suppression of competing vegetation. Where *Calluna* is a constituent of the vegetation this is a very important consideration.

The extensive drainage inherent in deep ploughing would, it is believed, provide an appropriate lowering of water-table-level for a considerable part, if not all, of the rotation. Species now in use are on the whole, shallow rooting. An excessive lowering of the water-table-level would therefore serve no purpose. It must also be appreciated that when a tree-crop is established and growing vigorously, the equivalent of from 15 ins. to 17 ins. of rainfall per annum will be eliminated by evaporation. This will constitute a significant contribution to water dispersal and will influence future drainage requirements to a considerable extent. The length of rotation will also determine to a large degree the drainage requirements of the adult stages of the crop. If a pulpwood rotation is considered appropriate it may well be that drainage as suggested will meet the requirements of the final crop. If, however, on the better peat types it would seem appropriate to produce saw-log timber on a standard rotation it could be visualised that intensive drainage in depth would be necessary. This coupled with the extensive drainage of the upper layers, would serve to create conditions of periodic drought in these layers, thereby forcing the roots downwards to tap moisture supplies at lower levels and thereby increasing stability.

Fertility.

The solution of the fertility factor is primarily a matter of the application of artificial manures. It is now quite apparent that throughout the whole range of sub-classes described above, application of Phosphate is essential for successful tree growth (with the exception of some of the more mineralised basin peats). On the *Molinia* and *Eriophorum* sub-classes, for species now in general use (Sitka spruce and *Pinus contorta*), the making good of the Phosphate deficiency produces very satisfactory results. While the effect of the Phosphate is not fully understood, it is probable that apart from satisfying Phosphorus demand in itself, it also interacts with other elements and renders them more available. Satisfactory growth is at any rate achieved and is being maintained. On sub-classes 3 and 4, however, while Phosphate application is even more critical, it is not to any comparable degree as effective. Fertility therefore is decreasing down the scale of sub-classes and it would seem that artificial manuring should be stepped up accordingly. Phosphate may not indeed be the only critical deficiency in some of the lower grades. Investigation should be directed towards establishing what element or group of elements is lacking and then to what extent such lack can be made good by a simple application of individual elements or by a compound group of such elements. This latter possibility is, however, a purely theoretical concept of fertility which, as has already been emphasised, is inextricably bound up with many other inter-related factors. In these lower grades lack of fertility may not indeed be the critical factor at all.

Silviculture.

The practice of silviculture in relation to deep-peat afforestation may at the present time appear simple in the extreme. The number of species in use is limited. The variation in site types is not excessive and these are readily recognised when familiarity with them is established. Cultivation by mechanical means or by manual mounding are the recognised methods of site preparation. Manuring with phosphate is standard practice to overcome lack of fertility. Nevertheless in the absence of an established silvicultural code, particular attention must be accorded at all times to the silvicultural problems encountered. A forester must endeavour to look ahead, over and even beyond the duration of the first rotation. He must endeavour to visualise what the probable pattern of future events may be. Present practice must therefore be designed to provide solutions to silvicultural problems which may or may not arise in the future and in this respect the absence of established precedent imposes severe limitations and involves serious difficulties. The danger of instability in the pole-stage can, for example, be influenced to a considerable degree by the incorporation of perimeter bands and internal bands of hardwood species through the coniferous matrix e.g. alder through Sitka spruce, red oak, mountain ash or birch through *Pinus contorta.* An intimate admixture of deeper rooting species may also help in this respect.

The probable occurrence of a "raw-humus" problem at the end of the first rotation is another factor which must now be borne in mind. The accumulation of coniferous leaf fall on the highly acid soil conditions obtaining on peat will, it is considered, produce a substantial accumulation of "raw humus". What steps can be taken now to minimise or eliminate its ill-effects? The incorporation of hardwood species as suggested as a minimising element in the instability problem may also serve a very important function in this respect. The ameliorative reaction of the accumulated hardwood leaf fall may, over the years, assist substantially in the break down of the raw-humus accumulation. It should at least serve to reduce the quantity of ground limestone per acre, which it would seem, will inevitably be required at the start of the second rotation. "Raw-humus" is very detrimental to the establishment of tree crops and therefore must be eliminated before regeneration will be successful.

When the pole-stage is reached determination of appropriate thinning grades will test to the limit the silvicultural ingenuity of the forester. Overthinning will cause instability and possible disturbance of the critical moisture/air relationships of the soil. Underthinning in the conditions of severe exposure which prevail can give rise to serious windthrow. New techniques must be evolved for extraction of thinning produce. Conventional extraction methods by horse and wheeled vehicles will have to be replaced by appropriate self-powered track-laying vehicles.

In the adult stages of the crop serious consideration must be accorded to the method of regeneration to be adopted for the second rotation. Ploughing, as a method of ground preparation, will be ruled out. How then will such a crop be established? By conventional clear felling, with artificial regeneration? Nevertheless the balanced soil complex established and maintained by careful silvicultural practice throughout the first rotation could be utterly destroyed by clear-felling. Alternatively, should silvicultural practice in the latter stages of the rotation be directed towards creating conditions suitable for natural regeneration? If so what system will be best suited to achieve the desired result?

These, and many other problems will present themselves at various times during the rotation. There are no text book answers available. Only silvicultural "know-how", allied to appropriately directed and co-ordinated scientific research, can provide these answers.

Conclusion.

In the light of experience now gained it can be fairly stated that deep-peat afforestation is safely launched. Successful establishment of plantations has been achieved on a number of well defined peat-types. It is now apparent which are good types and which are poor types. Future development should therefore be directed accordingly. The continued maintenance of crop growth, health and vigour through to the final harvesting will present many unforeseeable and difficult problems. With careful interpretation of applicable silvicultural principles with the assistance of scientific research these problems can and must be overcome. Timber production deep-peat will then become an accomplished fact.

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