Nutrient Status of Boglands and their Microbiology with regard to Afforestation

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An early idea that the soil type which developed in any area was determined primarily, if not solely by the climate, though abandoned generally, still holds very true as far as peats are concerned. Not only is the formation of peat dependent upon climatic conditions but also the nutrient status within the different peats is influenced to a large extent by climate and topography. It can be said, that the great factors influencing the level of fertility of virgin peats are (a) climate and topography (b) the microflora.

In discussing the effect of climate and topography on the nutrient status of virgin peats it is interesting to consider peats as fen and bog peats instead of the more usual division into raised and blanket bogs. Fig. 1 will illustrate this type of classification, which is dependent upon moisture source during peat formation.

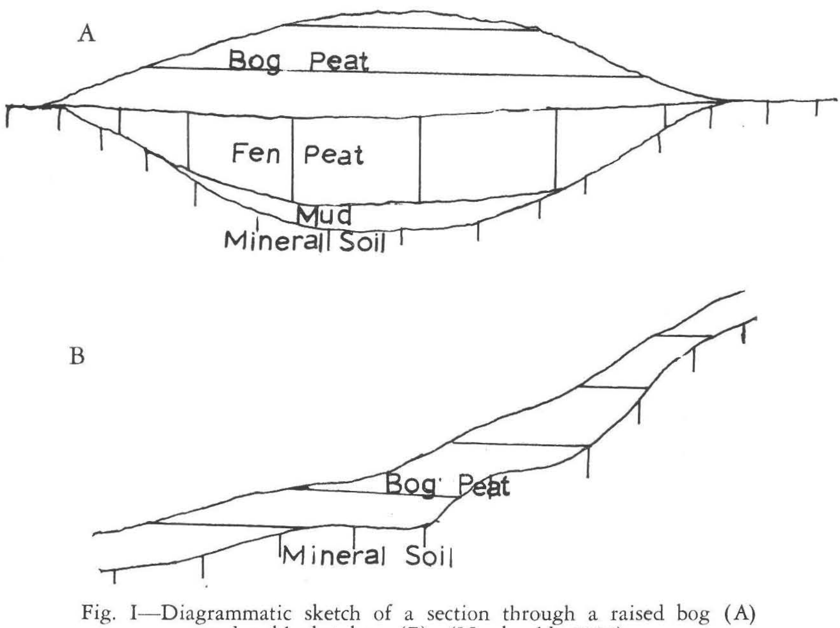

Fig. I—Diagrammatic sketch of a section through a raised bog (A) and a blanket bog (B). (Newbould, 1958).

The formation of both fen and bog peat is primarily due to the presence of excess moisture, but whereas the vegetation of the former is favoured by a combination of soil and rain water the

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latter is solely dependent upon rain water for its additional nutrients. Table 1 therefore will serve to indicate the potential difference in the nutrient status of these two types of peat by reason of this difference in the water source.

TABLE 1.

Approximate Concentration of some Inorganic Ions in Rain and Lake Waters

	Rain Water (p.p.m.)	Lake Water (p.p.m.)
Calcium	1.00	21.00
Phosphate (P_2O_5)	0.04	0.46
Potassium	0.30	2.30
Nitrogen (NH_4)	0.70	0.96
Nitrogen (NO_3)	0.30	0.15
Magnesium	0.50	7.00
Sulphate	3.00	6.10
Chloride	5.00	19.00
Sodium	0.60	12.00

Where bog vegetation is dependent upon a mixture of rain and soil water any raising of the bog surface will alter the balance, until the surface vegetation becomes entirely dependent upon direct rain water. This leads to the formation of bog peat rather than fen peat with the resulting increase in dryness, acidity and poverty of mineral nutrients. The change in the type of peat formed becomes obvious when examining a profile consisting of fen and bog peat (Table 2).

Thus in fen peat because of the base rich conditions the production of plant material is probably greater, but the breakdown of carbohydrates and proteins and the subsequent utilisation of the end products by decreasing the organic content of the peat, increases its relative ash content, which is added to by mineral colloids and particles in suspension. In contrast, where acid conditions prevail, as in bog peat, the peat is often very fibrous and frequently has an ash content below 2% of the dry weight. In both cases the nett result is an impoverished medium for plant growth.

Anaerobic, waterlogged conditions prevail with a resulting restriction upon microbial numbers and activity. This does not prevent the growth of plants and a type of microflora adapted to that environment, but it does prevent the growth of fungi, actinomycetes, and aerobic bacteria capable of rapidly decomposing plant residues. The obligate and facultative anaerobic bacteria favoured by these conditions are capable of attacking only some of the organic residues leaving the other constituents to accumulate. Thus on fen type peat bogs, fungi and aerobic cellulose decomposing bacteria are found at or just below the surface but they diminish rapidly. Actinomycetes are also found in abundance at the surface. The acid sphagnum bogs contain an abundant flora of acid bacteria, largely anaerobic, which increases with depth (Table 3).

TABLE 2.

Mineral Constituents of Peat Types

(Walshe and Barry).

(*a*) *Raised Bog (Bog and Fen peat)*

Depth cms.	H_2O %	N %	Ash %	P p.p.m.	Ca p.p.m.	K p.p.m.	Decomp. %	pH
0-20	94.25	1.58	2.8	15.50	4.0	205.0	14	4.60
20-50				6.24	4.5	106.0		
50-100	94.75	0.96	2.3	1.75	3.5	75.0	24	4.65
100-150	95.40	0.88	2.3	2.15	4.5	72.0	16	4.60
150-200	95.20	1.04	2.4	0.75	4.0	29.0	14	4.80
200-250	94.75	0.78	2.16	0.50	4.5	33.0	13	5.00
250-300	94.15	0.80	2.6	0.50	3.5	25.0	17	5.00
300-350	93.80	0.92	2.6	0.50	4.5	24.5	37	5.15
350-400	93.60	1.20	3.2	0.50	4.5	19.5	35	5.40
400-450	92.80	1.42	5.1	0.50	6.0	24.5	31	5.70
450-500	92.50	1.42	5.1	0.50	6.5	25.0	40	5.70
500-550	93.35	1.70	6.4	0.50	7.5	25.0	40	5.80

(*b*) *Blanket Bog (Bog peat)*

Depth cms.	H_2O %	N %	Ash %	P p.p.m.	Ca p.p.m.	K p.p.m.	Decomp. %	pH
0-20	92.8	1.33	2.30	10.00	3.90	124.0	35	4.70
20-50				3.25	3.70	30.75		
50-100	93.4	1.44	1.60	2.30	3.60	36.00	42	4.70
100-150	92.7	1.12	2.46	0.50	2.60	36.60	43	5.00
150-200	92.4	1.08	2.70	0.50	3.00	33.00	44	5.00
200-250	92.2	1.08	2.70	0.50	3.00	39.00	45	5.16
250-300	91.4	0.98	2.70	0.50	3.00	31.30	53	5.26
300-350	91.2	0.70	7.70	0.50	2.30	27.00	55	5.20

TABLE 3.

Microbiological Activity in two Peat Profiles

(Waksman 1929)

(*a*) *Fen Peat*

Depth cms.	Bact. and Actinomycetes	Actinomycetes %	Fungi	Aerobic Cellulose	Nitrifying Bacteria	Anaerobic Bacteria
Surface	6,000,000	90	105,000	++	+++	+
30	350,000	40	250	+	++	++
45	450,000	25	175	0	++	++
60	40,000	20	150	0	+	++
75	35,000	25	33	0	+	++
90	20,000	15	0	0	0	++
120	110,000	2	0	0	0	+++
150	500,000	0	0	0	0	++++

(*b*) *Acid Sphagnum Peat.*

Depth cms.	pH	H_2O %	Aerobic and Facultative	Acid resisting Anaerobic Bact.
Surface	4.05	92.7	100,000	+
7.5-20	3.95	92.6	220,000	+
20-30	3.85	92.6	1,600,000	++
30-40	3.86	92.9	3,500.000	++
45-60	3.73	93.6	2,100,000	+++
60-75	3.90	93.6	1,500,000	+++
20-150	4.47	93.4	2,000,000	+++

+ Designates a few; ++ a fair number;
+++ abundance of microorganisms; ++++ numerous.

Because of this restriction upon the microflora a one sided decomposition is accomplished, the nature and extent of which is influenced to a large extent by the nature of the bog vegetation itself. The differences in chemical composition, shown in Table 4, illustrate this influence of vegetation upon the chemical composition of the resulting peat.

TABLE 4.

Organic chemical composition of peat types

(Waksman 1929)

Depth cms.	Ether sol. Fraction	Hemi Cellulose	Cellulose	Lignin	Crude Protein
(*a*) *Carex Peat.*					
12	0.66	10.31	0	38.35	22.48
18	1.10	8.95	0	50.33	18.72
160-180	0.49	7.02	0	57.82	14.81
160	0.78	7.51	0	42.10	19.81
Lake-Peat	0.67	12.14	0	33.25	19.38
Bottom Peat	0.36	5.92	0	15.62	9.81
Woody Material	1.54	8.15	6.12	65.02	5.37
(*b*) *Sphagnum Peat*					
1-10	1.76	26.30	16.43	19.15	3.97
15-20	2.53	25.51	13.33	22.23	4.04
20-30	2.45	25.51	16.23	25.43	5.72
90-120	2.97	22.68	12.07	25.83	5.53
150-180	3.63	15.78	10.84	35.75	13.15
240-270	2.60	5.93	3.20	52.79	13.44
270-330	2.73	4.78	2.70	54.94	12.07

Probably a more important aspect of the nutrient status of peats is the availability of these nutrients to crops. In this respect, the solubility in barium acetate is one of the best indicators. On this basis it is found, that, all the potassium, two thirds of the calcium and magnesium and only the inorganic phosphorus can be regarded as freely available. The inorganic phosphorus constitutes about one third of the total phosphorus present. Perhaps the most surprising thing about the nitrogenous material in peat is its unavailability. The top layer of peat may contain 4,000 lbs. of nitrogenous material per acre yet at any one time only two pounds or less may be available for plant or microbial growth (Table 5). The organic nitrogen in peat has its origin in plant protein, but during decomposition, is converted into various forms of microbial nitrogen and presumably by autolysis partly into residues therefrom. Several theories have been proposed to account for the apparent stability of this fraction, but it now seems that the unavailability is more apparent than real and is primarily due to the absence of available carbon to support a vigorous population of microorganisms. Thus, while many groups of organisms are capable of utilising the carbon of nitrogenous complexes, such organisms have not been isolated from or shown to exist in peat. Hence the indications are, that the incorporation in peat of decomposable material with adequate additional nitrogen to meet microbial needs in decomposition, causes some ammounia to be liberated from the organic nitrogen residues, that would not otherwise become available. This may well explain why true green manuring i.e. ploughing under of immature vegetation, even in considerable amounts rarely results in anything other than a transitory effect on the supply of available nitrogen. On the other hand plant residues of lower nitrogen content incorporated into peat may result in the liberation of a greater amount of available nitrogen than can be expected from the incorporated material alone.

TABLE 5,

Total Nitrogen in lbs. per acre

(Voznyuk, S.T., et al).

Depth (cms.)	0-10	10-20	20-30	30-40	40-50
Lowland Bog (Raised-Bog & Fen)	4404	4017	4570	4833	3419
Upland Bog (Blanket-Bog)	4783	4572	4332	4783	3890

The reclamation of peat for afforestation purposes presents many problems and from a microbiological view point the most urgent is drainage. Any successful development of peatland for forestry purposes must be preceded by the establishment of an efficient drainage system, to remove excess moisture from the upper horizons of the bog. Excess moisture is itself not detrimental to plant growth, but the concomitant effect of very limited aeration adversely affects root metabolism and inhibits the activity of micro-organisms which play such an important role in the nutrient cycle. The depth and spacing of drains depends to a great extent on the nature of the peat, its permeability, and local climatic conditions. In general, where a bog has a large catchment area which brings in a large amount of soil water, the bog is subject to alternate flooding and drought. Mineral matter, carried in the soil water, forms a heavy gritty peat which sinks and allows the development of canalised water flow composed of streams running through the bog. The bog has therefore a low retentive capacity.

The hydrology of fens follows the same pattern, though the soil water may be greater in amount or richer in basic ions. Where, however, the catchment area is small and the bog is mainly dependent on direct rain water with low concentrations of minerals, Sphagnum peat is usually found. This forms a plastic colloidal peat, which floats because of the buoyancy of the Sphagnum hyaline cells (Fig. 2) and prevents any channelling of the water flow. Where these conditions are found the retentive capacity of the bog is in most instances of a high degree. This property in Sphagnum peat, together with high rainfall and humidity necessitates an intensive drainage pattern.

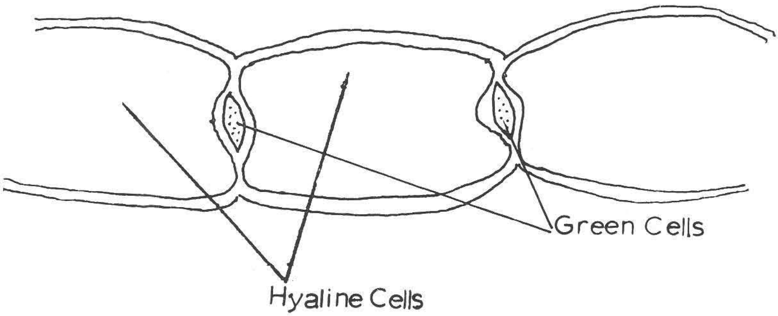

Fig. 2—Structure of Sphagnum moss.

Thus the results of experimental work indicate that if peats could be properly drained and then limed, the organic matter would be gradually decomposed with the liberation of ammonia. This ammonia would then be liberated to plants through nitrification, for while the acidity of peat is probably one of the factors hindering nitrification, the very wide carbon nitrogen ratio is undoubtedly the principal factor checking this process. With a wide C/N ratio the microorganisms use up most of the available nitrogen and store it in their protoplasm, therefore little is liberated as ammonia. When lime is added and the moisture content of the peat brought to agreeable proportions, conditions are made favourable for the activity of aerobic bacteria and actinomycetes and, since bacteria can get along with less nitrogen per unit of carbon consumed as energy than fungi, more nitrogen will be liberated as ammonia. With the improvement in aeration and a more favourable reaction due to liming, nitrification will take place though it may be advantageous to inoculate peats with a suspension of fertile soil as occasionally nitrifying organisms may be entirely absent. Upon draining and liming the actinomycetes become active also. Since these are thought to be the chief agents in the decomposition of the *x* fraction of organic matter and they are hindered by anaerobiosis and acidity, little decomposition of this fraaction can occur under the conditions normally found. This leads to the accumulation of lignins and nitrogenous complexes (Table 4). The effect of drainage and liming upon microbial numbers is shown in Table 6 and the importance of the presence of a vigorously active microbial population will be realised when one considers that microorganisms are involved in practically every process which takes place in the soil. Not only are microbes involved in the breakdown of organic matter but they also play an important role in such complex cycles as the nitrogen cycle the carbon cycle, and the transformation of phosphorus, potassium, manganese, sulfur, iron, zinc, copper, molybdenum, cobalt, boron, arsenic and selenium.

It now seems, however, that the addition of nitrogen salts and phosphates have practically no effect upon the rapidity of decomposition of peat because available energy and not nitrogen is the limiting factor. However a need for phosphate has been established, and a very strong positive interaction between nitrogen and phosphate has been noted. This holds true for both undisturbed bog surfaces as well as ploughed and drained peats. Some doubts have been raised as regards the advisability of using superphosphate on peats because of its possible reaction with ammonia. If superphosphate absorbs ammonia, a mixture of ammonium and calcium phosphates is formed, much of which is soluble. However it may be that this takes place more readily at a very low pH (3.0) and low calcium concentrations but not so readily at a pH of 5.0 and relative abundant calcium concentrations.

TABLE 6.

Number of microorganisms in soils of different moisture content and pH.

(Waksman, 1922)

Time of Incubation (Days)	No. of Microorganisms per gram of Soil. Waterlogged	Drained	Drained and Limed
26	1,050,000	1,935,000	233,250,000
61	533,000	1,963,000	193,624,000
88	680,000	1,450,000	143,650,000
116	415,000	1,545,000	136,725,000
150	652,000	1,760,000	49,650,000
181	1,012,000	2,796,000	22,600,000
239	910,000	2,825,000	60,330,000
291	995,000	3,320,000	101,833,000
Averages	781,000	2,199,000	117,708,000

Thus it has been clearly shown experimentally that for successful establishment of plantations on peat some form of drainage and an application of phosphate is necessary. No long term experiments with other fertilisers on peat have been reported but it is clear that although nitrogen, potassium, and other nutrients may not be limiting factors applications of these will give benefical results and they may become limiting as the plantations become older because of storage within the trees. In fact there is considerable evidence that calcium and potassium deficiencies do occur in older trees. It also seems that occasional or even annual top-dressings of phosphate are necessary even where plantations have been treated at establishment. Since as far as is known at present all the coniferous species are likely to give rise to raw humus on base-poor peats, the supply of mineral nitrogen is likely to be low, and mineral nitrogen supplied as fertiliseer is likely to become unavailable when it has been taken up by the trees and returned to the soil as litter, applications of nitrogenous fertiliser appear to be necessary also in established plantations.

The position then is that phosphate manuring, combined with other recent advances in forestry practice, results in the establishment of plantations on even the worst sites. A greater understanding of the processes of plant nutrition and the increasing appreciation of the microbiological and biochemcal principles involved give confidence that the level of fertility of peats can be improved sufficently to make afforestation of these lands a practical and profitable undertaking.

LITERATURE CITED.

Newbould, P. J., 1958. Peat bogs. In: New Biology No. 26. Penguin Books Ltd., Hammondsworth, Middx. 88-105.

Voznyuk, S.T., Korobchenko, Yu. T. and Skochinskaya, N.N., 1963. Influence of cultivation on the change in the soils. *Soviet Soil Sci.,* No. 5 (May): 12-18.

Waksman S.A., 1922. Microbiological analysis of soil as an index of soil fertility, (3) Influence of fertilization upon numbers of microorganisms in the soil. *Soil Sci.* **14**: 321-345.

——— and Stevens, K. R., 1928. Contribution to the chemical composition of peat. (2) Chemical composition of various peat profiles. *Soil Sci.* **26**: 239-251.

———, ———, 1929. Contribution to the chemical composition of peat. (5) The role of microorganisms in peat formation and decomposition. *Soil Sci.* **28**: 315-340.

Walshe, T. and Barry T. A. The chemical composition of some Irish peats. *Proc. Roy. Irish Acad.* **59** B15: 315-328.