Ir. J. agric. Res. **17**: 315-322, 1978

LONG-TERM EFFECTS OF DRAINAGE AND LAND USE ON SOME PHYSICAL PROPERTIES OF BLANKET PEAT

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ABSTRACT

Measurements were made of moisture content at different tensions, air volume, bulk density and hydraulic conductivity of blanket peat samples from an undrained site and three other sites that had been subjected to different drainage regimes and land use. The sites were as follows:

a) A forest where the peat had been drained by open, ploughed ditches 0.3 m deep and 2 m apart.
b) The same forest where tunnel drains 0.7 m deep had been installed at 2.2-m intervals.
c) An intensively drained pasture site.

The peat in each site had responded differently and these differences are described and commented on.

INTRODUCTION

For about 20 years, research has been in progress at Glenamoy into methods of reclaiming deep blanket peat. In its raw state the peat is unsuitable for either agriculture or forestry because it is waterlogged and very deficient in all of the major and most of the minor elements necessary for the economic production of crops. Progress on problems associated with lime and nutrient deficiencies has been rapid, but the physical amelioration, i.e., drainage and cultivation of these organic waterlogged soils has proved more difficult.

Blanket peat is highly colloidal and in consequence its hydraulic conductivity, strength and proportion of drainable pores are extremely low. The main physical properties of blanket peat have already been described by Galvin (1) and measured values for Glenamoy have also previously been published by Burke (2, 3). The degree of humification or decomposition, according to the von Post scale, ranges from 5 at the surface to 9 or 10 at greater depths. Field and laboratory measurements show that the saturated hydraulic conductivity can vary from 10 mm/day to more than 100 mm/day but most values recorded were very close to the lower end of the range. In the undrained peat, volumetric moisture content is generally greater than 90% and air content seldom exceeds 4%. The saturated peat is very weak but gains strength rapidly with dewatering. Galvin (1) has shown that vane strength increases from less than 20 kPa at a moisture content by volume of 90% to about 35 kPa at a moisture content of 70% and to more than 100 kPa at 50%.

The main climatic features of the area have already been described in detail (2, 3, 4). Both summers and winters are cool and wet, the average annual precipitation (1250 mm) being moderately high. However, the dominant climatic feature is the frequency of the rainfall. At Glenamoy some rain falls on average on almost 3 out of every 4 days, with little difference between winter and summer. The frequency and amount of rainfall in combination with the adverse physical properties of the peat add considerably to problems of reclamation and utilisation.

It has been shown that, in blanket peat, a very intensive drainage system is necessary to achieve even a moderate improvement in soil moisture conditions, but there is also evidence that drainage once started dries the peat progressively for a number of years (4). The net effect of installing 0.75-m deep drains at 4.5-m intervals is to lower the average watertable by 0.15 to 0.2 m. In order to achieve this intensity of drainage at an economic cost, two special ploughs were developed – the tunnel plough (5) and the gravel plough (6). At present it is considered that the tunnel plough is more useful for forestry and pasture, and that the gravel plough is better suited to semi-intensive agriculture.

It had been observed that the physical appearance of the peat had changed on sites which had been drained about 15 to 20 years ago and which had since been utilised either for pasture or for forestry. The purpose of the work reported in this paper was to measure some of the changes that had taken place in the physical characteristics of the blanket peat in response to drainage and land-use practices.

EXPERIMENTAL

Site description

Samples were taken from four locations as follows:

a) A forest site, planted with Sitka spruce on an area where the peat had been drained by shallow, open ploughed ditches 0.3 to 0.4 m deep and 2 m apart.
b) The same forest where tunnel drains, about 0.7 m deep, had been installed at 2.2 m intervals.
c) A grazed pasture where the original drainage system was subsequently supplemented by gravel drains.
d) An undrained site near the forestry block.

The forest sites, (a) and (b), were drained and planted in 1961 by the Forestry Division of the Department of Lands, now the Forest and Wildlife Service of the Department of Fisheries. Subsequent investigations showed that, while timber production was about the same for all drainage treatments, the trees growing on the tunnelled ground had very superior root systems (7). It was also observed that the character of the peat in this area had changed from a waterlogged to a well-aerated, moist, friable condition.

The pasture site, (c), was originally an experimental area where, since 1963, the effects of several types of drain had been monitored to test their suitability in deep blanket bog. The actual site from which the samples were taken was less intensively drained at the outset, but supplementary gravel drains were installed about 5 years before sampling. This site has been in continuous pasture since 1964 and, for most of the time, was grazed with light stock – sheep and 1½-year-old cattle. More recently, it has gradually become firm enough underfoot to carry heavier animals in summer and the peat is now very firm and compact at the surface but becomes less consolidated and wetter with increasing depth.

Sampling

The sites were sampled in dry weather in late summer 1977. In all sites samples were taken at the following depths: 0.15, 0.3, 0.45 and 0.6 m. In addition, samples were taken from the surface of the pasture (0 to 30 mm) and at 0.9 m in the tunnelled area, i.e., about 0.3 m below the present bottoms of the tunnel drains. The surface samples were taken from the pasture as it was apparent that this layer had been made very firm and strong by the hooves of the grazing animals. Similarly the 0.9 m samples were taken in the tunnel-drained forestry site as it was apparent that some drying of the peat had taken place well below the tunnel inverts. The surface samples from the pasture were taken by cutting out the required samples with a knife and subsequently trimming them to size in the laboratory. The other samples for moisture, air volume and bulk density determinations were taken in cylindrical rings 80 mm in diameter and 40 mm high. The samples for hydraulic conductivity were extracted in cylinders 72 mm in diameter and 100 mm in length. Samples were taken in triplicate for moisture, air volume and bulk density determinations. The samples for hydraulic conductivity were single samples.

Methods of analysis

Moisture, air volume and bulk density: Weights of core samples at field moisture condition and after slow saturation under vacuum were recorded for the subsequent determination, after drying, of moisture content. The samples were then placed on a sand table and reweighed following application of tensions (H_2O) of 0.2 m for 8 days and 0.6 m and 1.4 m each for 14 days. Although none of the samples reached equilibrium after the time intervals selected, the rate of water loss had become very small and the dewatering was considered sufficiently advanced for the purpose of the investigation. All cores were finally oven-dried to constant weight and the moisture contents of all the samples determined on a fresh volume basis. In calculating the air volume or drainable porosity at the three tensions employed, the specific gravity of the peat was taken as 1.3, after Galvin (1). Bulk density was expressed as dry weight per fresh unit volume.

For these calculations also the volume of the original sample was used as the total sample volume in all cases. This can lead to some difficulties in the interpretation of data because some shrinkage takes place in the peat as dewatering proceeds. Thus some of the "air-filled porosity" is in reality a reduction in the total volume of the sample. The alternative is to measure the actual volume of each peat sample everytime equilibrium is reached on the sand table. Because of the difficulties and the possibility of error inherent in these volume measurements and also because shrinkage was not excessive at the tensions used, it was decided to use the simpler system and base all calculations on the original volumes.

Hydraulic conductivity: The constant head method was used to measure hydraulic conductivity. In the laboratory, the peat cores were removed from the cylinders and, to prevent leakage along the walls during measurement, were dipped in molten paraffin wax at a temperature greater than 100°C. At this temperature, water along the outside of the cores was boiled off and the wax penetrated to a depth of about 1 mm, thus forming a perfect seal around the perimeter. Subsequently the cores were repeatedly dipped in cooler molten wax until a firm wall of wax was formed. Finally a flange of wax was built up around the top edge of each core to permit a constant head of water to be maintained.

The cores were pre-saturated and measurements, under constant head, were continued over several days. With this technique, hydraulic conductivity decreases with time. Almost all of the cores had extremely low conductivities and the calculations were based on the minimum time necessary to give results.

RESULTS AND DISCUSSIONS

Results showing air-water relationships, bulk density and values for hydraulic conductivity are presented in Tables 1, 2 and 3. Unless stated otherwise, all values except those for hydraulic conductivity are the mean of three measurements. Single samples were used for hydraulic conductivity determinations. The data show that the peat has responded differently both to drainage systems and to methods of utilisation.

The air and water content at sampling, and the water content at saturation, are indicative of the large differences that have developed between the different treatments. In the undisturbed and undrained peat, water content at sampling was 86% and air content was 7% at the 0.15 m depth (Table 1, A). In the peat with shallow open drains under forest, the corresponding values were 80 and 13%. At the other depths the values were almost identical for the samples from both sites. These values indicate that the forest has had a drying effect on the surface layer of peat.

TABLE 1: Air-water relationships of peat samples (means of three samples)

Sampling depth (m)	Water content (% vol) At sampling	At saturation	Air content (% vol) At 200 mm (H_2O)	At 0.6 m (H_2O)	At 1.4 m (H_2O)	As sampled
A. Undisturbed – undrained						
0.15	86.5	93.6	10.7	19.9	29.4	7.0
0.30	88.1	94.0	11.2	23.3	36.1	5.9
0.45	92.1	94.8	11.7	28.0	42.6	2.7
0.60	92.7	94.7	14.2	29.7	40.7	2.0
B. Forestry – open drains approx. 0.3 m deep						
0.15	79.9	92.6	12.1	16.3	23.8	12.6
0.30	89.6	94.1	9.8	13.2	23.2	4.3
0.45	89.7	93.6	10.4	20.5	33.9	3.8
0.60	91.5	94.0	8.0	20.9	35.6	2.5
C. Forestry – tunnel drains approx. 0.6 m deep						
0.15	36.7	92.2	23.3	31.6	51.0	55.6
0.30	54.0	90.6	12.3	28.0	31.9	36.5
0.45	56.8	91.9	14.4	30.2	35.2	35.1
0.60	75.1	92.2	10.0	19.8	32.3	17.1
0.90	88.9	91.9	3.3	5.3[a]	15.2[a]	3.0
D. Grazed pasture – drained approx. 0.6 m deep						
0.03	68.6	83.1	6.2	7.9	13.5	14.5
0.15	80.7	91.4	5.3	6.9	17.1	10.7
0.30	84.8	93.3	8.3	11.9	29.8	8.5
0.45	85.0	90.6	6.5	8.2	13.3	5.6
0.60	86.8	91.5	5.2	7.3	17.5	4.7

[a]Mean of two samples

The increase in air-filled pores at sampling from 7% in the undrained area to 13% under the shallow-drained area shows that tolerable conditions have been created for the tree roots in the top layer of the peat. An air-filled porosity of approximately 10% is considered to be about the minimum at which plant roots can thrive (9). At a depth of 0.3 m there was no appreciable difference in air-filled porosity between the two sites – 6% in the undrained peat and 4% in the peat under the forest. It was also observed that the tree roots had not penetrated to this depth and this lack of roots had inhibited the type of profile development which occurred in the tunnelled area as will be seen later. The increase in air-filled porosity in the root zone indicates that while the trees are removing water from this zone, the proliferation of roots there provide reinforcement which prevents the peat from general shrinkage. Instead, shrinkage is localised and the result is increased air-filled porosity. As will be seen later this effect is much more pronounced in the tunnelled area.

It is apparent from Table 2 that there is a slight increase in bulk density at all depths in the peat under the shallow-drained forest when compared to that in the undrained area. Similarly there is a corresponding apparent reduction in hydraulic conductivity (Table 3). Both of these factors indicate that the forest is having a dewatering effect on the peat mass even at depths considerably below the root zone. By reducing porosity, the resulting shrinkage increases bulk density and reduces hydraulic conductivity.

When the peat in the tunnelled drained area was analysed it was seen that dramatic changes had taken place to the maximum depth sampled, i.e., 0.9 m. On this site the moisture content at sampling (Table 1, C) was relatively low at all depths to the tunnel bottoms, and even 0.3 m below the drain it was lower than at shallower depths in both undrained bog and in shallow drained bog. The well-aerated conditions of the peat to a depth of 0.6 m on this site at sampling (last column of Table 1, C) is attributed to the proliferation of roots which acted as reinforcing strands and reduced the general shrinkage or consolidation that would otherwise have taken place. It appears that as moisture was withdrawn by evaporation the peat matrix was held in position by the roots, thus localising shrinkage and preventing general subsidence. The process is also evidenced by the high value for drainable porosity to the 0.45 m depth at all tensions (Table 1, C), bulk density (Table 2) and hydraulic conductivity (Table 3).

TABLE 2: Bulk density of peat samples (kg/m^3)

	Native vegetation	Forestry		Grazed pasture
Sample depth	Undrained	Open drains at 0.3 m	Tunnel drains at 0.6m	Drains at 0.6 m
30 mm	–	–	–	219
0.15 m	85	97	101	112
0.30 m	79	78	123	87
0.45 m	67	84	105	122
0.60 m	69	78	102	110
0.90 m	–	–	105	–

TABLE 3: Hydraulic conductivity of peat cores (mm/day)

	Native vegetation	Forestry		Grazed pasture
Sample depth (m)	Undrained	Open drains at 0.3 m	Tunnel drains at 0.6m	Drains at 0.6 m
0.15	35 (6 hr)[a]	8 (4½ hr)	16630 (2½ hr)	29 (24 hr)
0.30	62 (5½ hr)	36 (6½ hr)	61 (5½ hr)	26 (24 hr)
0.60	22 (6 hr)	47 (6½ hr)	1.2 (24 hr)	1 (24 hr)
0.90	–	–	3.2 (24 hr)	–

[a]Figures in parentheses give duration of measurement

Relative to the undrained site, there is an enormous increase in hydraulic conductivity in the surface layer where roots were most plentiful, but at 0.6 m and 0.9 m there is a substantial reduction, indicating that porosity has been reduced. It was obvious at sampling that there were few if any roots at 0.6 m, although Dillon *et al* (7) have reported prolific rooting elsewhere in the site at this depth. The bulk density of the peat from this site is high at all depths to 0.9 m (Table 2). This indicates that dewatering of the peat and consequent shrinkage is occurring even below the drain bottom. Further evidence of overall subsidence is also available from the fact that although the tunnels were originally installed at 0.7 to 0.8 m, the tunnel bottoms at the sampling points now are about 0.5 to 0.6 m below the surface. These findings agree with those of Egglesman (8), who states that "... even peat layers below drains have an amount of settling."

When all the data relating to the tunnel-drained area under the forest (Tables 1, 2 and 3) are examined together, there is evidence that the tunnels have started a cycle of events which have been enhanced by the growing forest. Firstly the tunnels have provided sufficient drainage to allow root penetration and proliferation to take place. Secondly the roots, by extracting water from the peat, and reinforcing it against general collapse, have greatly enlarged the air-filled pores, and this in turn has resulted in an almost ideal rooting environment for the trees to a depth of at least 0.5 m. Below rooting depth, where the peat has also dried out, though to a lesser extent, general shrinkage has resulted in increased bulk density, a lower volume of drainable pores and reduced hydraulic conductivity.

Conditions in the pasture area differed greatly from those in the forest. The bog was very firm underfoot, and the surface was quite hard at the time of sampling. Therefore, as already explained, extra samples were taken from the top 30 mm layer or just below the surface. Values for bulk density (Table 2) were about double those found elsewhere, indicating that considerable compaction had occurred. This compaction is probably the result of two factors – intensive drying of the surface by the shallow grass roots and treading by grazing animals.

At all other depths sampled in the profile with the exception of 0.3 m, bulk density was greater than in the tunnel-drained area and about 1.5 times that in the undrained bog. This indicates that in the absence of reinforcing roots, shrinkage of the peat is much more marked. The low values for hydraulic conductivity (Table 3) and drainable porosity –for all tensions (Table 1, Part D) – provide further evidence in support of this view.

As previously stated an air-filled porosity of approximately 10% is considered to be about the minimum at which plant roots can thrive (9). At sampling, the air-filled porosity in the upper 0.15 m of the profile exceeded this value but while roots were plentiful near the surface very few grass roots were recorded at 0.15 m. Thus, while considerable compaction has occurred at and near the surface, there are still sufficient air-filled pores for healthy grass root growth.

At the 0.3 m depth the bulk density is somewhat lower than expected and the drainable porosity is higher when compared with other values for this site. There is no obvious explanation for this discrepancy but it may reflect the great variability that occurs in in pockets throughout the peat.

CONCLUSIONS

Intensive drainage has had a profound effect on the physical properties of deep blanket peat. This effect was enhanced by subsequent utilisation, but it also varied greatly depending on the method of utilisation. Under forestry on the tunnel-drained site, a very porous friable layer with ideal rooting properties developed to a depth of 0.6 m, whereas under grazed pasture considerable compaction took place especially at the surface. Although this compaction resulted in a reduction in drainable porosity there was still a sufficient proportion of air-filled pores in the top 0.15 m for healthy root development. The very firm surface layer which has developed as a result of both dewatering by grass roots and compaction by grazing animals should be capable of carrying fairly heavy stock and normal farming machinery provided reasonably good management prevails. The extent and depth to which drying out has taken place supports evidence already available that the drainage of deep blanket bog is a progressive phenomenon.

ACKNOWLEDGEMENTS

Acknowledgement is made to the Forest and Wildlife Service for permission to sample the forest sites. The assistance of P. Maloney and J. Larkin, Kinsealy, in sampling, carrying out laboratory analyses, and computing is also acknowledged.

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Received February 28, 1978