Depth of Water Table in a *Picea Sitchensis* Fertilization Experiment on Blanket Peat

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Abstract

Depth to water table was measured at weekly intervals over a one year period in each plot of a N/P factorial, Sitka spruce (*Picea sitchensis* (Bong.) Carr.) fertilization experiment on deep peat in western Ireland. The relatively rapid adjustment of water table levels to changing precipitation patterns suggested that no extreme deficits occurred in the peat during the growing season. While tree growth was increased by both N and P fertilizers, depth to water table was significantly increased only in the phosphate-treated plots. These plots showed consistent water table depression, particularly during May and June when weekly rainfall levels were at a minimum. The greatest depression was recorded at the lowest level of added phosphate. This curvilinear response, which may reflect a complex evapotranspiration effect of components of the tree stand, persisted late in the growth season when the linear response had disappeared. It is difficult to evaluate the long term effects of tree growth on this peat. Information is needed on the relationship between peat moisture content and water table depth and on the optimum moisture conditions for tree growth on this site.

Introduction

This paper is concerned with the water using powers of forest crops in an area of water surplus. At Glenamoy, Co. Mayo, in the blanket peat (1) area of western Ireland, there is an annual water surplus (rainfall minus evapotranspiration plus deep seepage) of 660 to 760 mm. Effective drainage of this low permeability peat requires 1 m deep drains at 5 m intervals (6). In a comparative study, depth to water table at Glenamoy was greater under a mixed species forest tree shelterbelt than under grassland (13).

This investigation was initiated in 1969 in a N/P fertilization experiment on Sitka spruce (*Picea sitchensis* (Bong.) Carr.) at Glenamoy (5). Water table levels were examined under the conditions of differential productivity created by the fertilizer treatments.

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Experimental

The experimental plots were located on blanket peat at Glenamoy State Forest, situated at Glenamoy in north-west Co. Mayo. The climate of the area is extreme maritime; annual rainfall is 1,400 mm, distributed over 270 days. The wind climate is very severe with gales in almost every month. The *Schoenus nigricans* L. association dominates the natural flora (12). Principal species include *Schoenus nigricans* L., *Molinia caerulea* Moench., *Eriophorum angustifolium* Honck., and E. *vaginatum* L. The top 50 cm of peat has an ash content of 2.5 per cent and humification 5 to 6 on the Von Post scale (18). Bulk density (wet basis) ranges from 0.95 g per cc at the surface to 1.01 g per cc below 30 cm; air filled pore space after drainage was 5 per cent to 8 per cent by volume at the surface and the hydraulic conductivity of undrained peat was about 1 cm per day (3).

Preliminary drainage to 1 m depth was carried out at 31 m spacing in 1954. Prior to afforestation in 1962, the area received double mouldboard ploughing producing an 18 cm deep drainage channel and two continuous lines of planting turves. The area was planted to Sitka spruce at 1.5 m $\times$ 1.5 m spacing in 1962. The trees received a spot application of ground rock phosphate per plant at planting. The fertilization experiment, 48×0.03 ha plots, was installed in 1967. A randomized block design was employed with four levels of ground rock phosphate (0, 55, 110, and 220 kgP/ha designated P_0, P_1, P_2 and P_3 respectively) and three levels of sulphate of ammonia (0, 132, and 234 kgN/ha designated N_0, N_1, N_2) in factorial combination, replicated four times. Sulphate of potash (42 per cent K) was applied to all plots at 125 kg/ha and copper sulphate (25 per cent Cu) was applied at 11 kg/ha. All fertilizers were applied broadcast, without incorporation, in April 1967. In 1969, the 132 kgN/ha sulphate of ammonia treatment was repeated on those plots which had received it in 1967.

Depth of peat measured in 1967 ranged from 1.0 m to 4.4 m in the experimental plots, with a median depth of 3.0 m. Moisture content ranged from 85.2 per cent to 91.2 per cent by weight with a mean of 88.8 per cent.

In August 1969, one slotted PVC drainage pipe, 7.0 cm diameter, 1.6 m long, was installed in a bore hole at the centre of each plot. The method of installation has been previously described (13). Depth to water table was measured at weekly intervals from 9 October 1969 to 8 October 1970, with the exception of one week in December 1969. This was a total of 52 weekly readings. Results are expressed on the basis of (a) the whole 52 weeks and (b) a 26 week period, 2 April 1970 to 24 September 1970, considered to approximate the growing season. Tree height measurements were taken prior to the 1967 season and at the end of each season 1967-1970. Height growth data, and mean depth of water table for the two periods were both subjected to analysis of variance. Sums of squares for N and P were subdivided using a series of mutually orthogonal comparisons. The relationship between depth to water table and precipitation in the preceding 21 day period was analysed by multiple regression techniques.

Results and Discussion

Precipitation for the year-long experimental period ending 8 October 1970, totalled 1,481 mm. Precipitation for the 26 week "growing season" period totalled 634 mm, a weekly average for this period of 24.4 mm. There was a highly significant inverse relationship between depth to water table and precipitation in the preceding 21-day period (Table 1). Precipitation in the seven day period immediately preceding water table measurement made the greatest contribution to the regression indicating a relatively rapid adjustment of water table levels to changing precipitation patterns. The rate of adjustment suggests that no extreme water deficit occurred in the peat during the growing season. Peat has a high water holding capacity. On drying, this storage capacity of the dry layers of the peat will have to be filled before penetration of subsequent rainfall to the water table is possible.

TABLE 1

Multiple regression analysis of water table depth (cm) on precipitation (mm) in the three preceding seven day periods.

Precipitation period	Regression coefficient	SE regression coefficient	t value
1-7 days before watertable measureX^1	—0.383	—0.082	4.64**
8-15 days before water table measureX^2	—0.109	—0.087	1.25
16-21 days before water table mfasure X^3	—0.141	—0.100	1.41

Analysis of variance for the regression F=10.19**

Coefficient of determination=58.1%

Prediction equation: $Y=49.32—0.399X_1$

Level of significance: *0.05, **0.01

TABLE 2

Depth to water table (cm) in treatment plots.
Means of 52 weeks and 26 weeks.

Treatment	Depth to water table (cm) 52 weeks	26 weeks
N_0	35.9	40.8
N_1	35.7	40.3
N_2	33.2	37.8
P_0	32.8	36.6
P_1	37.4	42.6
P_2	34.6	39.8
P_3	35.0	39.6
S.E. of mean	2.27	2.30
Significance of Effects		
N	NS	NS
P	NS	*
N×P	NS	NS
P components[1]		
linear	NS	NS
quadratic	*	**

Significance level: NS not significant; *0.05; **=0.01

[1] Component effects calculated after removal of P_3 level data from analysis of variance.

Mean depth to water table increased as a result of phosphate application (Table 2). The effect of nitrogen was slight, the greatest depth to water table being recorded at the P_1 level of application (55 kg P per hectare). If the data are recalculated, omitting the highest level of phosphate application, the remaining levels form an arithmetic progression. This permits the use of orthogonal polynomials to test the degree of curvilinearity in the regression of water table depth on level of phosphate application. This was done for both the mean values and for those weekly measurements which showed a significant main-effect response to phosphate in the preliminary analysis (Table 3). The results are given in Tables 2 and 3. Examination of weekly water table data shows that while the response to phosphate was consistent throughout the growing season, the effect of the fertilizers was greatest in May and June (Table 3), when weekly rainfall levels were at their minimum and mean depth to water table was at its maximum for the year. Water table depression at the P_2 level of application was most pronounced at this time also. Towards the end of the season there was little or

TABLE 3

Weekly depth to water table (cm), rainfall levels (mm) and treatment main effects during the 26 week growing season period, 2 April to 24 September 1970.

Depth to Water Table
Mean weekly rainfall, 2 April—24 September 1970—24.4 mm.
Mean water table depth, 39.5 cm.

Week	Date	Rainfall preceding 7 days (mm)	Mean (cm)	SE of Mean	Treatment Effects		Component[1] Effects (P)	
1	April 2	30.4	29	2.61				
2	April 9	16.7	35	2.72				
3	April 16	17.3	32	2.72				
4	April 23	44.9	25	2.47				
5	April 30	14.4	35	2.58				
6	May 8	29.2	32	2.64				
7	May 14	2.5	42	2.25	N*	P*	linear**	
8	May 21	13.8	42	2.99	N*			
9	May 29	12.9	48	2.61		P**	linear*	quad**
10	June 3	7.5	52	3.02		P**	linear**	quad**
11	June 11	7.6	56	2.83	N*	P**	linear**	quad**
12	June 18	4.6	62	2.34	N*	P**	linear**	quad**
13	June 25	34.7	52	4.26		P**	linear**	
14	July 2	45.4	40	3.05		P*	linear*	quad**
15	July 9	34.6	30	3.57				
16	July 16	19.2	41	2.72				
17	July 23	8.7	46	2.87	N*			
18	July 30	20.1	46	2.77		P**	linear**	quad**
19	Aug. 6	15.6	47	2.68		P*	linear**	
20	Aug. 13	32.2	38	4.05				
21	Aug. 20	51.5	38	2.38		P*		quad**
22	Aug. 27	2.5	46	2.32		P*		quad**
23	Sept. 3	29.5	37	3.43				
24	Sept. 10	56.4	21	2.30				
25	Sept. 17	69.7	21	2.38				
26	Sept. 24	15.5	38	2.36		P**		quad**

Level of significance: *0.05; **0.01; quad=quadratic.
1. Component effects calculated after removal of P_3 level data from analysis of variance.

no depression at the P_2 level, but the curvilinear element of the response persisted. Crop root systems, however, will respond not to the average depth to water table, but rather to the duration of water table depression. The aerobic limit (point where anaerobic conditions prevail) in peat is usually closer to the surface than the water table and responds only slowly to depression of the water table (7, 8). As the optimum depth to water table on peat soils has not been established for Sitka spruce, 40 cm was chosen as an arbitrary level for illustration of treatment effects (Fig. 1). The results (highest phosphate level omitted) follow the pattern established by the depth to water table anslyses (Table 4), the quadratic component showing a high level of significance.

The mechanism of the fertilizer effect may be attributed to increased evapotranspiration from the forest stand (including ground vegetation). It may be assumed that the effect of the fertilizers in increasing tree growth was accompanied by an increase in transpiration which would reach a maximum during the period of most active growth. While Penman (16) has warned of the effect of differences in crop height between adjoining plots on rates of

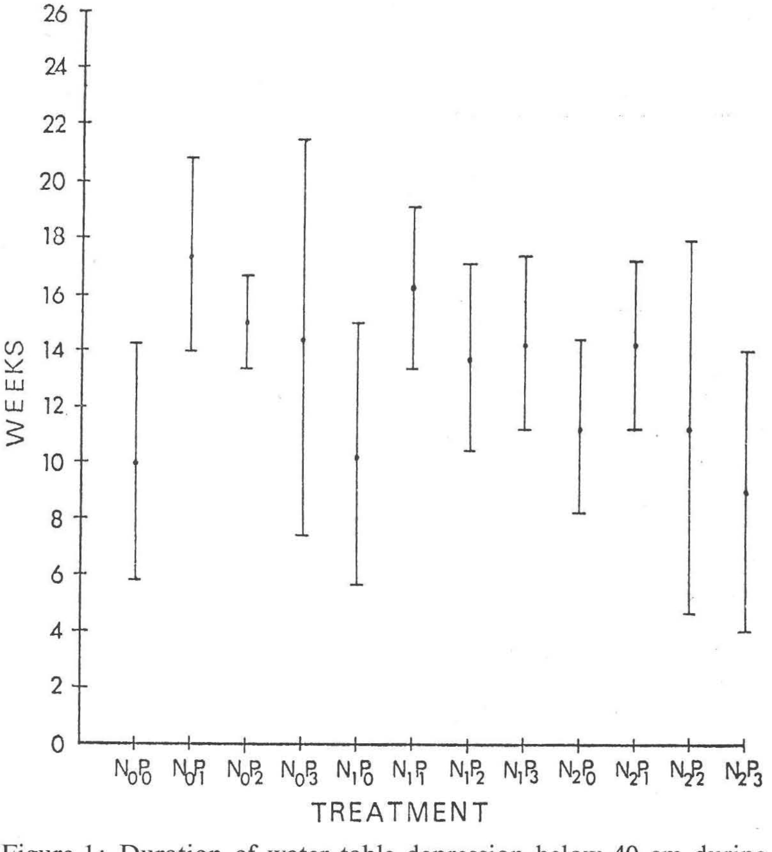

Figure 1: Duration of water table depression below 40 cm during the 26-week growing period. Mean and standard deviation for each treatment.

TABLE 4

Duration of water table depression (weeks) below 40 cm during the 26 week growing period.

Treatment	Duration (weeks)	Treatment	Duration (weeks)
N_0	14	P_0	11
N_1	13	P_1	16
N_2	12	P_2	13

SE of mean = 1.76.

Significance of Effects		P Components	
N	NS	linear	NS
P	**	quadratic	**
N×P	NS		

Significance level: NS, not significant; *0.05; **0.01.

TABLE 5

Effect of treatment on tree height growth (m), 1967-70.

Treatment	Total Height 1970	Height Increment 1967-1970	Height Increment 1969-1970
N_0	2.86	1.67	0.55
N_1	2.98	1.83	0.58
N_2	3.18	1.95	0.64
P_0	2.43	1.20	0.37
P_1	3.20	1.97	0.61
P_2	3.28	2.08	0.73
P_3	3.12	2.01	0.68
	SE of mean = 0.13	SE of mean = 0.12	SE of mean = 0.0 6

Treatment Comparisons and Interaction

N_0 vs (N_1+N_2)	*	**	NS
N_1 vs N_2	*	NS	NS
P_0 vs $(P_1+P_2+P_3)$	**	**	**
(P_1+P_2) vs P_3	NS	NS	*
N×P	NS	NS	*

N_1 treatment was repeated in April 1969.

Significance level: *0.05; **0.01; NS, Not significant.

transpiration and evaporation, it is unlikely that mean depth to water table has been greatly influenced by the relatively small differential heights recorded in forest tree experiments. Height growth for the experiment (summarized in Table 5) showed positive responses to both fertilizers (5), but the data do not follow the same pattern as recorded for water table depth. Interception of rainfall and subsequent evaporation from foliage surfaces represents a major component of total evapotranspiration in forests. Figures quoted for Norway spruce (*Picea abies* (L.) Karst.) crops of about 10 m height in Britain suggest that precipitation reaching the forest floor represents 50 to 60 per cent of that in the open (14, 11). Päivänen (15) recorded an 8 cm depression of the water table resulting from the fertilization (NPK) of a 50 year old Scots pine (*Pinus sylvestris* L.) stand on peatland, which he attributed principally to increased interception by the tree crop due to increases in needle length and canopy closure. However, the distribution of precipitation on the forest floor may be quite irregular (4, 17), particularly in the present study, as canopy closure was incomplete. Ground vegetation was plentiful in the experimental plots and showed a clear quantitative response to fertilizer treatment.

It is likely that the curvilinear response to phosphate application can be accounted for by the interaction of the transpiration and interception effects of the tree and/or ground vegetation components of the forest stand. While the depression of the water table was consistently most pronounced at the P_1 level of phosphate application, the persistence of this effect towards the end of growing season suggests an active transpirational loss induced, perhaps, by the extension of the growth season of a component of the system.

The results illustrate the complexity of site response to fertilization. Annual height extension was the only measure of tree growth made in this experiment. Diameter growth may vary to some extent independently of height increment and is certainly not confined to such a sharply delimited period of growth. While both height and diameter are meaningful measures of growth response to fertilization, they are poor indices of biomass increment. The need for an integrated approach to forest fertilization has been emphasized by some workers (9, 10), who consider the fertilizer as a catalyst, increasing the efficiency of energy utilization by the tree stand, but producing a series of complex changes throughout the ecosystem. Some of these may run contrary to the aims of management. Marked reductions in peat moisture content, accentuated by fertilizer application, were recorded in a long term study of Lodgepole pine (*Pinus contorta* Dougl.) and Scots pine on peat in Scotland (2). Large cracks have developed in the peat and irreversible drying of shallow peat has occurred. The increase in depth to water table recorded in the present study will be of benefit to the tree crop in the short term, if it results in deeper rooting and improved crop stability. It is difficult to evaluate long term effects. Information is needed on the relationship between peat moisture content and water table depth on this peat type and on the optimum moisture conditions for three growth on this site.

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