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THE EFFECT OF AFFORESTATION ON CARBON AND NITROGEN IN THE SOIL AT GISBURN: A PILOT-STUDY

by

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FOREWORD

The work described here was carried out on the forest plots at Gisburn, situated in N.W. England, half-way between Lancaster and Skipton. These experimental ½ acre (0.2 ha) plots were planted in 1955 to study the effects which different tree species - both as monocultures and in 2-species mixtures - would have on soils and vegetation as the stands develop. It is a joint experiment between the I.T.E. and the Forestry Commission.

Although the site is somewhat more fertile than many of those currently being planted in upland Britain, it is in other respects fairly typical of many forest areas: the soil is a very obviously gleyed clay (humic gley, predominantly surface-water type), and the site is subject to moderate to severe exposure (elevation being about 275m) with resultant windthrow problems.

The changing soils and vegetation have been monitored at intervals since the experiment's inception. Recently, more intensive studies of decomposer activity and nutrient release - especially that of N and P - from soil organic matter have emphasized the importance of studying the latter material. This initial study, was carried out by a visiting Danish research worker in a relatively short period of 2 months or so. It represents the start of what, it is hoped, will become a much more detailed comparison of organic matter dynamics under the different forest stands at Gisburn.

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INTRODUCTION

The amount and distribution of soil organic matter are largely determined by climate, geological material and vegetation type. Although climate probably is of major importance in determining the amount of soil organic matter (Table 1), these factors are closely interrelated. Together they create a characteristic pattern of decomposition and a characteristic distribution of organic matter in the profile. Therefore the soil profile may be considered as an expression of the decomposition history at the site (Goksøyr 1975).

Table 1 Amount of Carbon in different ecosystem-types. (Data from Schlesinger 1977).

Ecosystem type	kg/m^2	CV%
Tropical forest	10.4	44
Temperate forest	11.8	35
Boreal forest	14.9	53
Temperate grassland	19.2	25
Tundra & Alpine	21.6	68

The distribution of carbon in the profile can be very different at different sites, and a classification of profiles into type-profiles has been made. Type-profiles are valuable as a conceptual framework, but the practical use of type-profiles can be limited as many profiles occurring in nature may be difficult to assign to a distinct type.

A change in vegetation type may result in a changed soil profile, but often this change takes place very slowly. Nevertheless, where the change in vegetation type is drastic, changes in the soil profile may be recognizable after a relatively short time period (e.g. Miles 1978, Nihlgård 1971, Ovington 1954 & 1956).

Studies of changes in soil organic matter pools induced by a change in vegetation type have often considered situations where soil organic matter is accumulating. When the change has been a decline in soil organic matter, many studies have considered cases where natural soils have been converted to arable soils. Fewer studies have examined situations where soils high in organic matter have been afforested resulting in a decline in the detritus pool (e.g. Pyatt & Craven 1979).

The present study examines the impact of afforestation on carbon and nitrogen in a surface-water gley/peaty gley soil. It is thought that afforestation of this soil type will result in decreased water-logging, whereby decomposition is enhanced, introducing a decline in the soil organic matter pool. The Gisburn plots offer the possibility of studying the general effect of tree planting as well as the effect of different tree species. Besides the reduced water content of the soil, afforestation introduces a different distribution of the input of dead plant material to the soil. Under grass vegetation more than 50% of the input may occur belowground, whereas the main input from a forest vegetation originates from above-ground production.

Finally there will be a change in the quality of the litter reaching the ground accompanied by a change in initial decomposition rates.

EXPERIMENTAL

Three stands in Block II (2B: Pine, 2C: Alder, 2L: Spruce) and an open grass-covered area between Block I and Block II were selected for the study. The grass-covered plot was chosen as a reference plot as it was thought to represent the original vegetation type at the site, and the tree stands were selected in order to cover the most extreme situations available. The Spruce stand was closed and dense with a very sparse ground vegetation, whereas the Pine and the Alder were rather open stands, both having a ground vegetation predominantly of grass.

During the period from 20 to 30 of October 1980 two pits were excavated within each plot. A profile was examined at each end of the squared pit (1m x 0.5m). The position of the profiles are shown in Figure 1. The pits had an average depth of 60cm, and were placed on the terraces representing the original ground level (Figure 2b). Sampling was probably inadequate to cover the likely within-plot variability, and the results must be interpreted with due caution. Nevertheless, the study provides - it is hoped - useful preliminary information on organic matter distribution.

For each profile the thickness of the horizons were measured, and a short description of the horizons were made in the field. The two upper horizons (F, A_1(5)) were sampled by cutting a block out of the horizons with a sharp knife. The size of the block was measured in the field. Samples from all other horizons were collected by gently pressing a squared metal frame (5x5x5cm) into the freshly exposed horizon. Litter samples (L) were collected from the soil surface. In stands with ground vegetation, only leaf-litter originating from the trees was included in the litter samples.

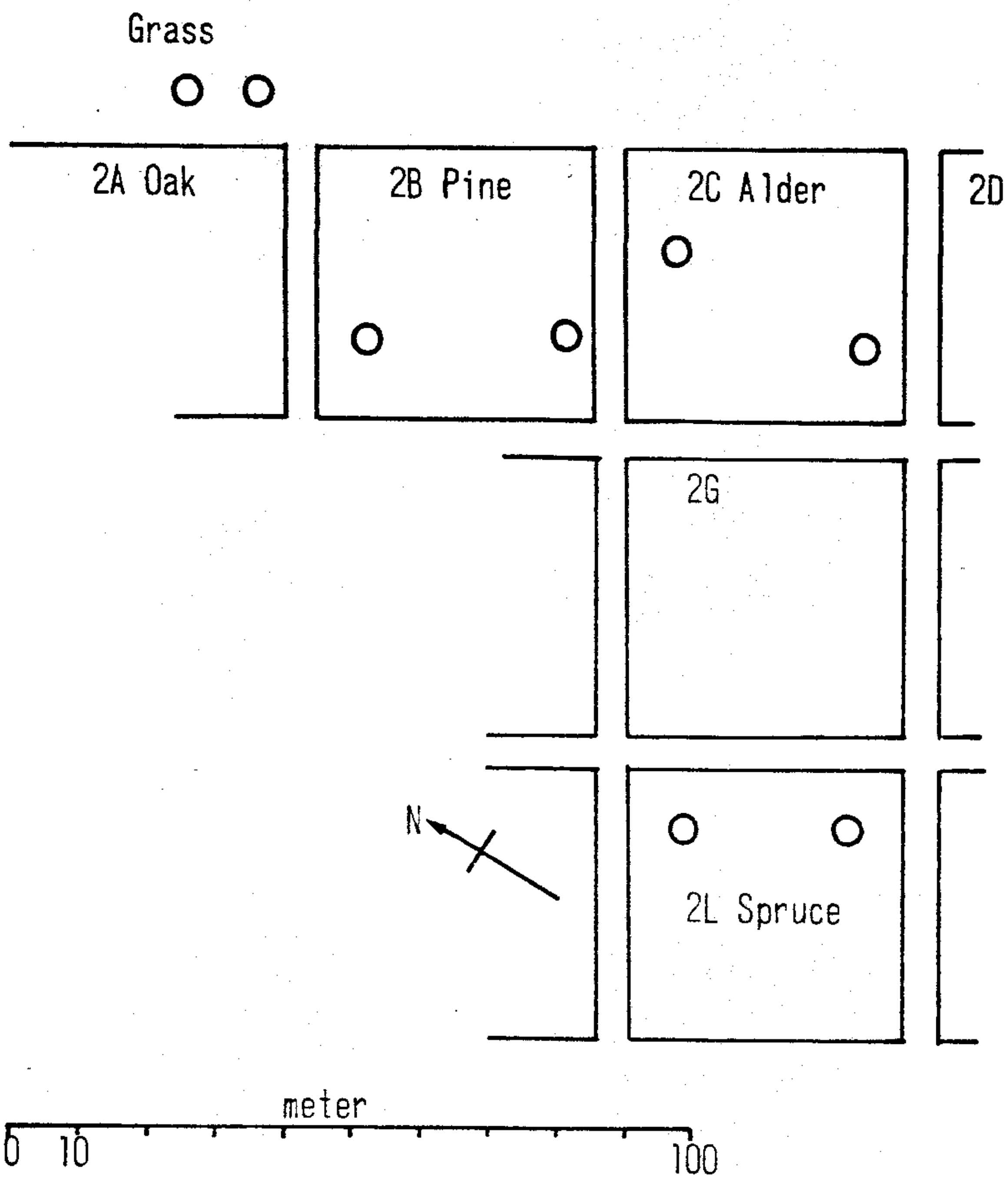

Figure 1. Approximate positions of the examined profiles in Block II.
Positions of pits indicated by circles.

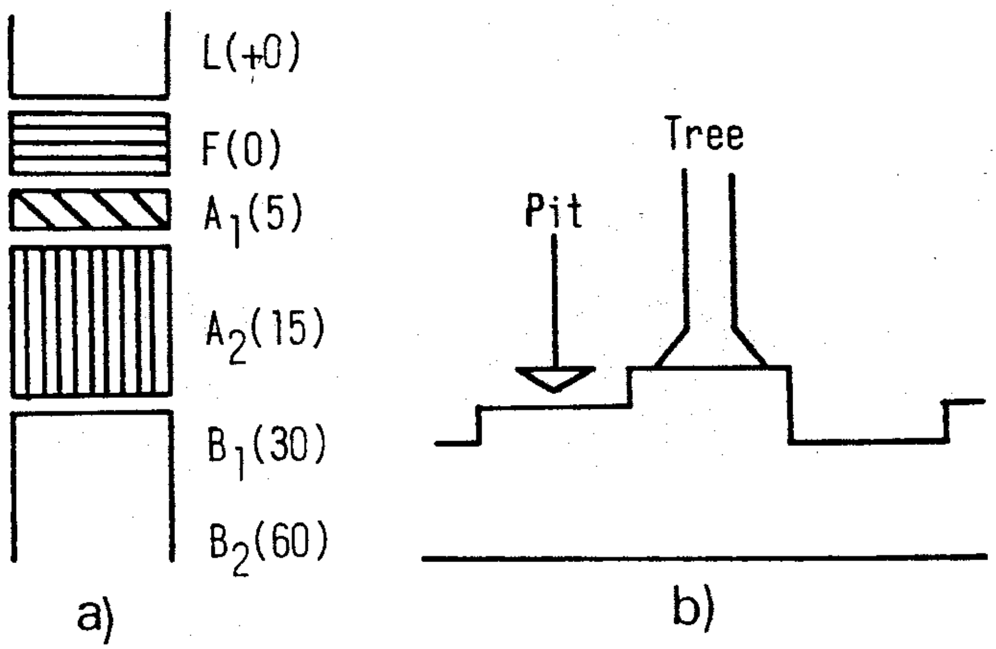

Figure 2. The structure of the profile under Grass (a)) and position of pits in relation to micro-topography (b)). Horizon designation are explained under "General profile description".

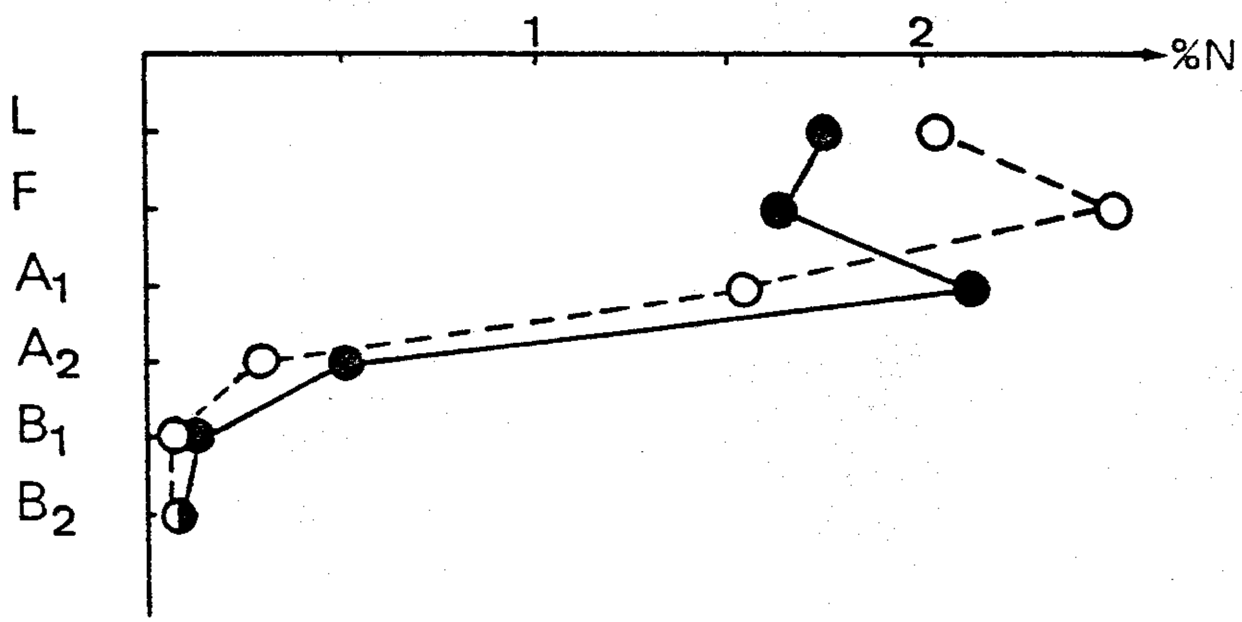

Figure 3. The distribution of nitrogen (% d.w.) in the profile under Grass (closed circles) and under Alder (open circles).

Bulk density, total nitrogen, and organic carbon-content were determined. Before being analysed, litter samples and samples from the F horizon were milled through a 0.7mm screen. All other samples were sieved through a 2mm screen. Determinations of nitrogen and carbon were carried out by the Chemical Section at Merlewood (Kjeldahl-N, organic carbon after the titrimetric method of Kalembasa & Jenkinson 1973).

GENERAL PROFILE DESCRIPTION

A general picture of the profile in the examined plots is shown in Figure 2a. The following horizons were recognized (thicknesses being given in Table 2):

L: Surface litter, where litter components are easily recognizable and not fragmented. Samples were collected around the pit (Grass plot) or in the middle of the stands. For tree-covered plots four subsamples were pooled to give one sample.

F: This horizon includes fragmented litter and grass roots on plots where ground vegetation was present. The structure of the horizon resembles a mat, interwoven with tillers and roots. Nitrogen-fixing root-nodules were present under Alder, but these were carefully avoided during sampling.

A_1: This horizon is black in colour, and resembles the H-horizon of a mor profile. Only a few cm thick, it has a rather sharp boundary upwards to the F, whereas the boundary downwards to A_2 could be indefinite. This horizon was not recognized in the Spruce plot on the day of sampling, but on a later occasion it was seen to be present, although it appeared very thin (less than 1cm).

A_2: The bulk of the organic matter in the profile is located in this horizon. It is a dark-grey/black colour, and has a very uniform appearance and thickness (c.18cm) within and between plots; the horizon has a sharp boundary towards the underlying clayey sub-soil. For these reasons, P.A. Stevens (pers. comm.) has suggested that it represents a former cultivation layer. The main visible difference between plots was the higher amount of grass-roots occurring in the grass-covered plot.

B_1 and B_2: These horizons represent the inorganic sub-soil on which the organic layers are situated. Two samples were taken from the sub-soil, one at the top five cm (B_1), and one in the bottom of the pit (B_2). The horizon consists of clay intermixed with sand, and has a blueish or greyish/white appearance. Roots were present under Grass and Alder, whereas tree-roots were absent under Spruce and Pine.

HORIZON THICKNESS

The mean depths of the horizons are shown in Table 2. When horizons from different plots are compared, the F - and A_1 -horizons are seen to be the most variable, whereas the A_2 show only minor differences between plots.

Table 2 Horizon thickness (cm), mean values (with standard deviation).

Horizon	Grass		Alder		Spruce		Pine	
F	7	(0.8)	4	(1.3)	2	(0.5)	6	(2.4)
A_1	4	(0.8)	2	(0.5)	20	(3.1)	3	(0.8)
A_2	17	(1.7)	18	(2.6)			18	(1.3)
Depth of organic layers, n=4	27.5	(2.9)	24.8	(2.2)	21.8	(3.4)	26.8	(3.0)

Total mean of all plots, n=16: 25.2 (3.5)cm

The total organic layer (F, A_1, A_2) has a mean depth of 25cm. The lowest value was recorded under Spruce, whereas the highest values were found under Grass and Pine.

BULK DENSITY

Only small differences were obtained in bulk density between the different plots (Table 3).

Table 3 Bulk density (g/cm^3), n=4, mean values (with standard deviation)

Horizon	Grass		Alder		Spruce		Pine	
F	0.096	(0.025)	0.149	(0.022)	0.116	(0.018)	0.106	(0.011)
A_1	0.312	(0.037)	0.435	(0.101)	-		0.351	(0.101)
A_2	0.832	(0.104)	1.022	(0.032)	0.913	(0.047)	0.960	(0.086)
B_1	1.197	(0.095)	1.351	(0.062)	1.387	(0.077)	1.469	(0.092)
B_2	1.502	(0.136)	1.526	(0.064)	-		1.457	(0.095)

Compared with the Grass reference plot, Alder seems to have a slightly higher bulk density in the organic horizons. The bulk density of the B_2 horizon shows no difference between plots, whereas B_1 tends to have higher bulk densities under tree-covered plots. The bulk densities obtained in this study are in accordance with bulk densities measured in January 1977 by a gamma-ray transmission technique. (Forestry Commission data, unpublished).

CARBON CONTENT, NITROGEN CONTENT AND C/N RATIO

Table 4 shows the carbon content of the analyzed samples. The carbon content of the A_2 - horizon, which comprises the bulk of the organic matter in the profile, tends to be lower in plots covered with trees. Alder seems to cause a decrease in the carbon content of both the A_1 and the A_2 - horizon. For the F - horizon no clear trend is recognizable. Compared with the Grass plot, tree-covered plots, especially Pine, tend to have a lower content of carbon in the B_1 - horizon. The carbon content of the B_2 horizon shows no difference between plots.

Table 4 Carbon (% d.w.), mean (with standard deviation).

Horizon	Grass		Alder		Spruce		Pine	
	%		%		%		%	
L	53	(6.5)	59	(-)	51	(-)	65	(-)
F	52	(2.6)	48	(7.0)	46	(5.5)	55	(5.2)
A_1	30	(6.3)	21	(7.0)	-		30	(3.4)
A_2	10	(2.8)	5.6	(1.7)	6.0	(1.4)	6.3	(0.7)
B_1	1.6	(0.3)	1.0	(0.4)	1.2	(0.4)	0.7	(0.4)
B_2	0.8	(0.2)	0.8	(0.3)	-		1.0	(0.3)

Table 5 Nitrogen (% d.w.), mean (with standard deviation).

Horizon	Grass		Alder		Spruce		Pine	
	%		%		%		%	
L	1.77	(0.09)	2.04	(-)	1.45	(-)	1.35	(-)
F	1.64	(0.12)	2.49	(0.12)	1.72	(0.13)	1.79	(0.14)
A_1	2.13	(0.19	1.54	(0.49)	-		1.84	(0.19)
A_2	0.50	(0.14)	0.29	(0.04)	0.40	(0.05)	0.35	(0.04)
B_1	0.13	(0.02)	0.07	(0.02)	0.08	(0.03)	0.08	(0.01)
B_2	0.09	(0.01)	0.06	(0.01)	-		0.08	(0.01)

The content of nitrogen in the profile is shown in Table 5. Alder has a higher content of nitrogen in the F, whereas the A_1 and A_2 show a lower content than the Grass plot. This results in a different nitrogen distribution in the profile (Figure 3). From Table 5 it is further seen that tree-covered plots generally have a lower nitrogen content in the B_1 - horizon, a tendency which matches the carbon distribution.

Table 6 C/N ratio, mean (with standard deviation).

Horizon	Grass		Alder		Spruce		Pine	
L	30	(4)	29*		35*		48*	
F	32	(2)	19	(3)	27	(3)	30	(2)
A_1	14	(2)	14	(2)	-		16	(2)
A_2	20	(3)	19	(3)	15	(3)	18	(0.5)
B_1	12	(3)	15	(3)	15	(3)	10	(5)
B_2	10	(2)	12	(3)	-		12	(4)

* Composite sample of 4 subsamples

The C/N ratio was calculated for each sample and the mean value for each horizon is tabulated in Table 6. The C/N ratio for the Pine needle-litter (L) is considerably higher than the other leaf-litter types, but as nothing is known about the age of the collected litters, comparisons are difficult. The F - horizon of the Alder plot has the lowest C/N ratio, reflecting both the higher nitrogen content and the lower carbon content of this horizon. Further it is seen that the A_1 - horizon has a very similar C/N ratio in all plots.

AMOUNT OF CARBON AND NITROGEN IN THE PROFILE

The total amounts of carbon and nitrogen in the organic layers of the profile are shown in Figure 4. For each plot the amounts have been calculated for the individual profile, and data presented are mean values for each plot. Generally, the amount of carbon tends to be lower in tree-covered plots compared with the Grass plot, the strongest effect being exerted by Spruce. The trend is paralleled by the differences obtained for nitrogen.

When the amounts of carbon and nitrogen are expressed as kg/m^2/cm-organic layer, the effect of the trees in lowering the amounts of carbon is still seen, but differences between tree-species are not obvious. To examine this more closely, the amounts of carbon and nitrogen were expressed as mg/cm^2/cm-horizon or mg/cm^3. (Figure 5). With regard to carbon it is seen that the amount per cm A_2 - horizon is lower in the tree-covered plots than in the Grass plot. For nitrogen it is noted that Alder has a higher content per cm F - horizon and a lower content per cm A_2 - horizon than the Grass reference plot.

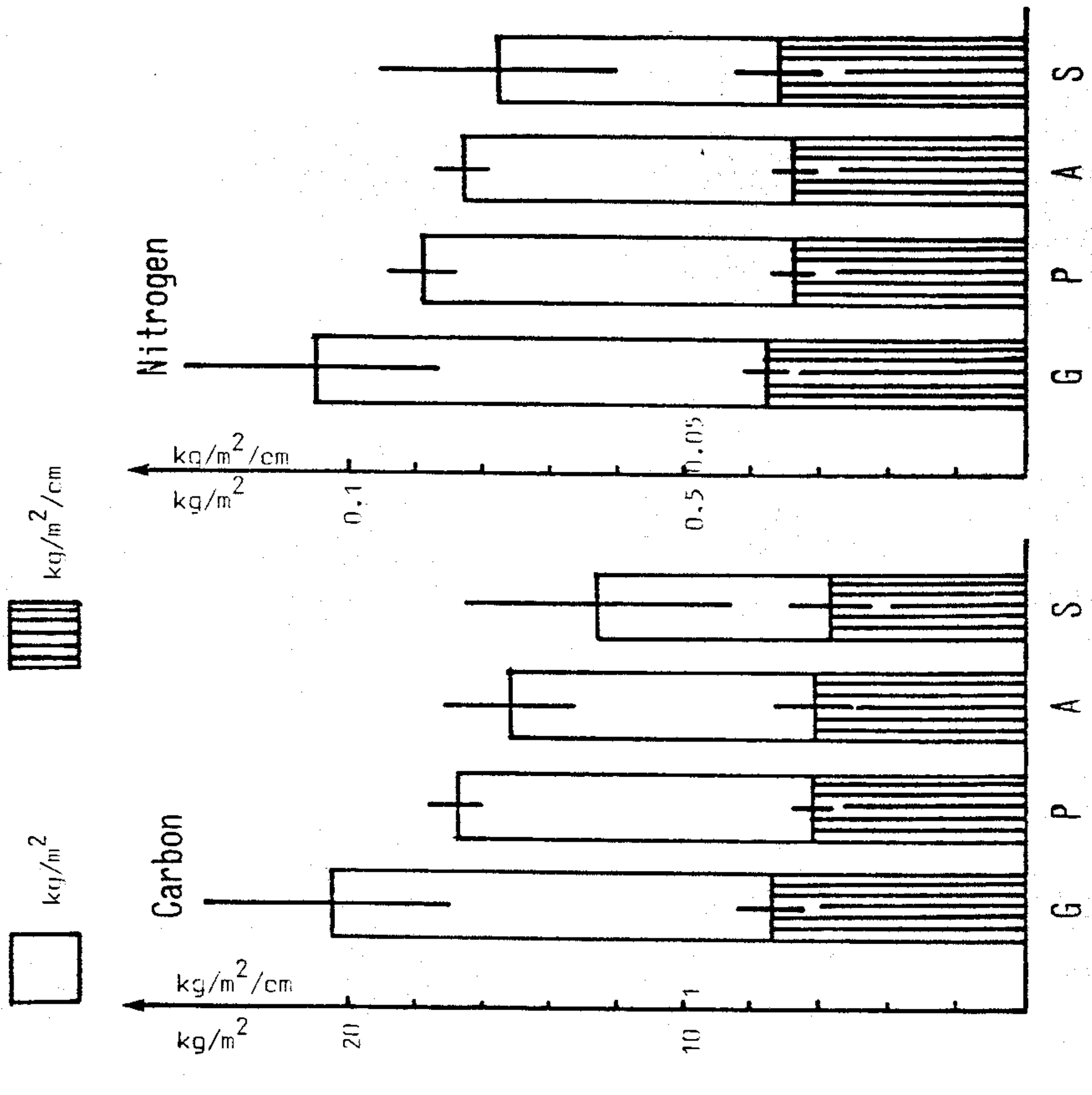

Figure 4. Amount of carbon and nitrogen in the total organic layer expressed as kg/m² and kg/m²/cm organic layer. Bars indicate ± 1 standard deviation. (G = Grass, P = Pine, A = Alder, S = Spruce).

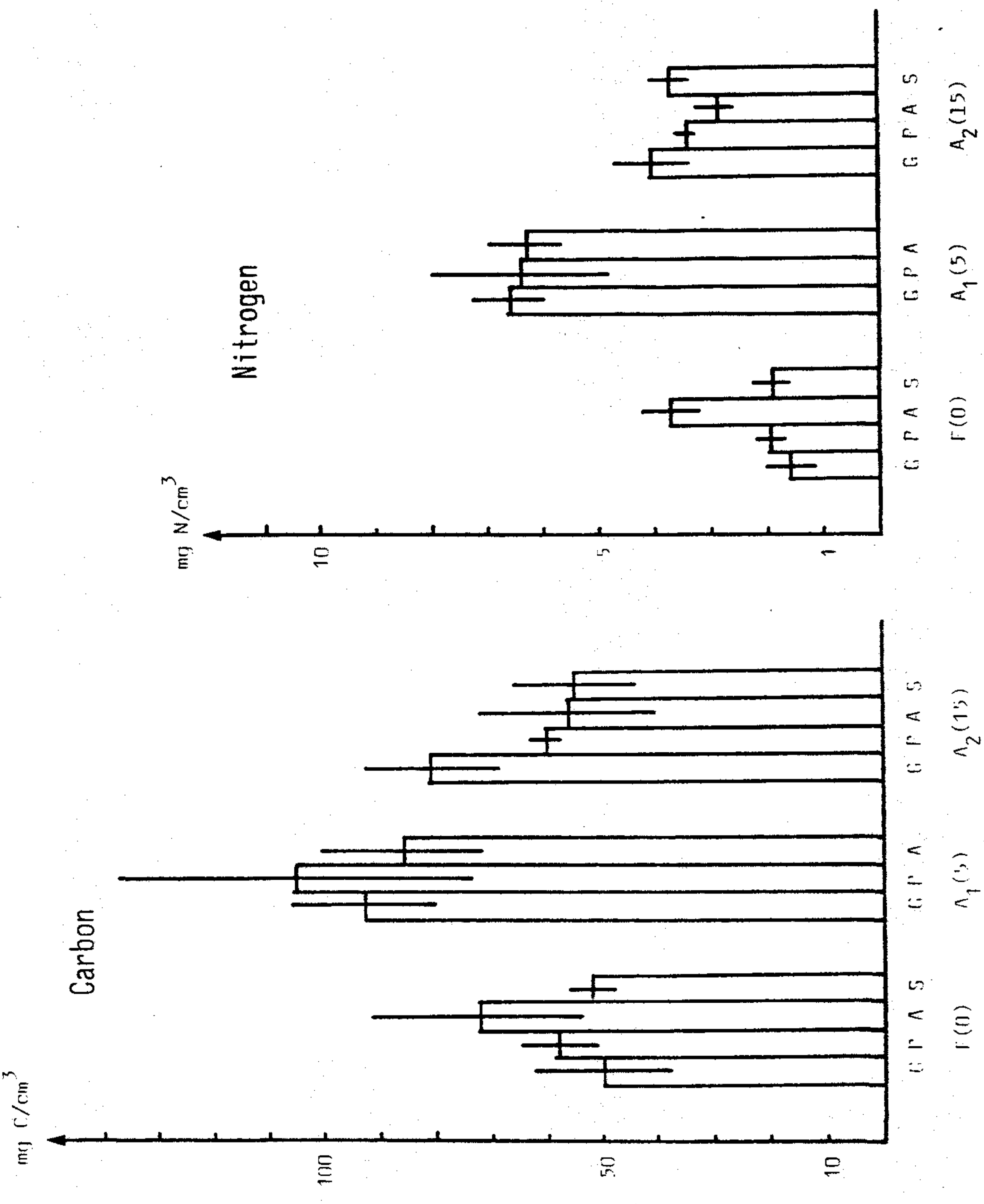

Figure 5. Carbon and nitrogen content in organic horizons (F(0), A(5), A_2(15)) expressed as mg N/cm^3.

EFFECTS OF AFFORESTATION

The most readily recognized effect of Alder is the change in nitrogen distribution within the profile (Fig. 3 and 5). Alder has resulted in a higher amount of nitrogen in the F - horizon and a lowered amount in the A_2 - horizon. The higher amount in the F may be due to nitrogen-fixing nodules present in this horizon, but it should be noted that the nodules were carefully avoided during sampling. Alder tends to translocate nitrogen upwards in the profile, but the total amount of nitrogen in the organic layers are lower than in the Grass plot (Fig. 4). The lower amount of nitrogen in A_2 may result from a higher uptake-efficiency of Alder or from the higher content of roots under Grass. If the difference was due to grass roots, this effect should be more pronounced under Spruce, which has almost no ground vegetation. But the concentration as well as the total amount of nitrogen in the A_2 is higher under Spruce than under Alder (Fig. 5 and Table 5). It is therefore tempting to assume a higher uptake efficiency of Alder and, as Alder leaf-litter has the highest content of nitrogen, a higher turnover rate of nitrogen under Alder.

The change in carbon distribution follows the changes observed for nitrogen, although differences are not so clear-cut for carbon. Therefore it seems that Alder has caused an enrichment of organic matter in the F - horizon and a depletion in the A_2 - horizon.

The effect of afforestation on soil properties was expected to be most marked under Spruce. Due to the closed canopy and the evergreenness, this stand has a higher interception and a higher evapotranspiration from the canopy. (For a more detailed discussion, see Jarvis & Stewart 1979 and Pyatt & Craven 1979). This results in a reduced amount of water reaching the ground beneath the trees causing a decrease in the water status of the soil. This has been suggested by earlier studies in Block II (Howson &

Brown 1980). The dense canopy also results in a changed temperature profile with lower surface temperatures during the summer (Howson & Brown 1980).

The depth of the F - horizon has declined under Spruce, and the A_1 - horizon was absent or very thin (Table 2). This has caused a reduction in the depth of the total organic layer, and thereby contributed to the smaller amount of carbon and nitrogen under Spruce (Fig. 4). But from Fig. 5 it is seen that the amount of carbon per cm^3 A_2 - horizon, which contains the bulk of the organic matter in the soil, is lower under Spruce than under Grass. Therefore the reduced depth of the total organic layer cannot solely account for the observed difference in the amount of carbon. Differences in the amount of nitrogen per cm^3 A_2 - horizon are not obvious.

Pine exerted the least effect on measured soil properties. To some extent this may be due to an extensive ground vegetation of grass. The needle-litter of Pine has a high C/N ratio, but this seems to have no effect on the C/N ratios of the soil horizons. Pine, like Alder and Spruce tends to decrease the amount of carbon and nitrogen in the soil. The amounts of carbon and nitrogen per cm^3 A_2 - horizon are reduced too.

The general <u>effect of afforestation</u> has been a decrease in the amount of carbon in the soil profile. This trend is to some extent paralleled by a decrease in nitrogen. The decrease in the amount of carbon in the A_2 - horizon results from a lower carbon content, as the depth of this horizon is nearly similar under Grass and under tree-covered plots.

The bulk density in the top of the sub-soil, B_1, has increased under tree-covered plots and the carbon content has decreased. Under the Grass reference plot many grass-roots were observed in this horizon, whereas few roots were observed under tree-covered plots. The decrease in penetrating roots may have contributed to these changes, which may have an adverse effect on soil aeration and water dynamics.

CONCLUDING REMARKS

Several constraints are imposed on the results obtained in this study. The number and positions of the profiles clearly prevents rigid statistical treatment of the data.

When interpreting the results from this study, one more word of caution is appropriate. The examined plots in Block II are probably located in a transitional zone between surface-water gleys and peaty gleys. Although the separation of these two soil types largely depends on the depths of the organic layers, and therefore one type presumably grades into the other depending on the degree of water-logging, this could be of importance, as the Spruce plot and the Grass-reference plot lie some distance apart.

The present study shows that it is possible to register changes in the amount and distribution of carbon and nitrogen in the soil profile within a timescale of 25 years. Therefore examination of the soil profile might give valuable information on long term effects of afforestation in the Gisburn area. But a more extensive sampling will be needed. A future study should further be related to a close examination of soil water dynamics including transport processes between different plots.

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