Studies on marginal farm ecosystems in upper Teesdale

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STUDIES ON MARGINAL FARM ECOSYSTEMS IN UPPER TEESDALE.

by

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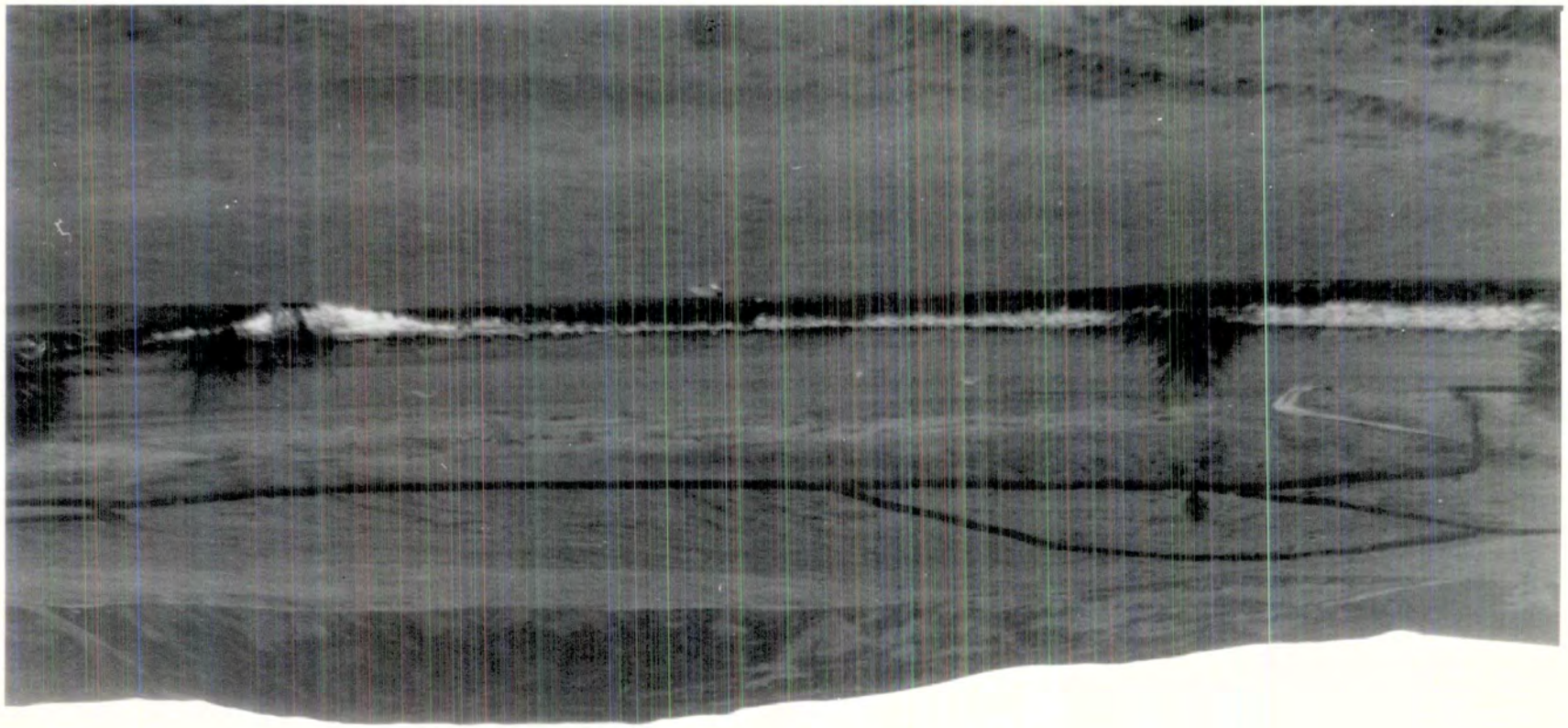
Being a dissertation submitted in accordance with the regulations for the award of the degree of Master of Science at the University of Durham. September 1969.

FRONTPIECE.

The Experimental Area From The Durham Bank Of The Tees.



CONTENTS

INTRODUCTION.

"The chemical elements of which plants are composed are each involved in intermeshing and mutually dependant cycles of assimilation and return to the enviroment. Knowledge of these cycles is the key not only to the scientific understanding of the factors which determine the character of vegetation but also to the effective use of forest, pasture and wilderness which is becoming an increasing practical necessity under present conditions."

G.F. Fogg, Editors Forward to Production and Mineral Cycling of Terrestrial Vegetation. (1967).

This work was undertaken to gain basic knowledge relating to the nutrient budgets of four distinct natural vegetation types which, subject to management, constitute a typical marginal farm system in the Northen Pennines.

The literature on the productivity and nutrient cycling of arable crops and pasture (good farm land) is legion. Similar work on forest ecosystems is now quite extensive, Robin & Bazilevich (1967), while there are some detailed studies which have been made into specific vegetation types, Heather Moor, Allen (1964), Robertson and Davies (1965), Wet Heaths, Loach (1966), Molinia Grasslands, Loach (1968), and Mire Ecosystems, Tamm (1954) and Malmer (1958). In comparison little or no work has been carried out on marginal farmland of the type to be discussed in this work.

The aim of this investigation was to describe and delimit the major soil types of the area, to gather data which, within the limits of the time available, could form the basis of nutrient cycles for each farm subsystem, in an attempt to explain the pattern of vegetation and the 'limits' imposed on the farmer.

The research programme consisted of nine parts:

1) Description of the major soil types, their drainage and aeration characteristics.
2) Chemical analyses throughout the soil profile for calcium, sodium, potassium, magnesium, nitrate, phosphorus, total alkalinity and pH.
3) Analysis of nutrient input in rainfall and output in drainage water.
4) Estimation of nutrient in fertilizer.
5) Estimates of the change in biomass (crude estimate of net production).
6) Construction of stylised nutrient cycles for each of the sites.
7) Analysis of the standing crop for the above minerals, and hence the mineral flux into and within the vegetation.
8) Phytometric study of the potential of each soil type using three crop plants in greenhouse conditions.
9) Floristic analysis of the on-site vegetation.

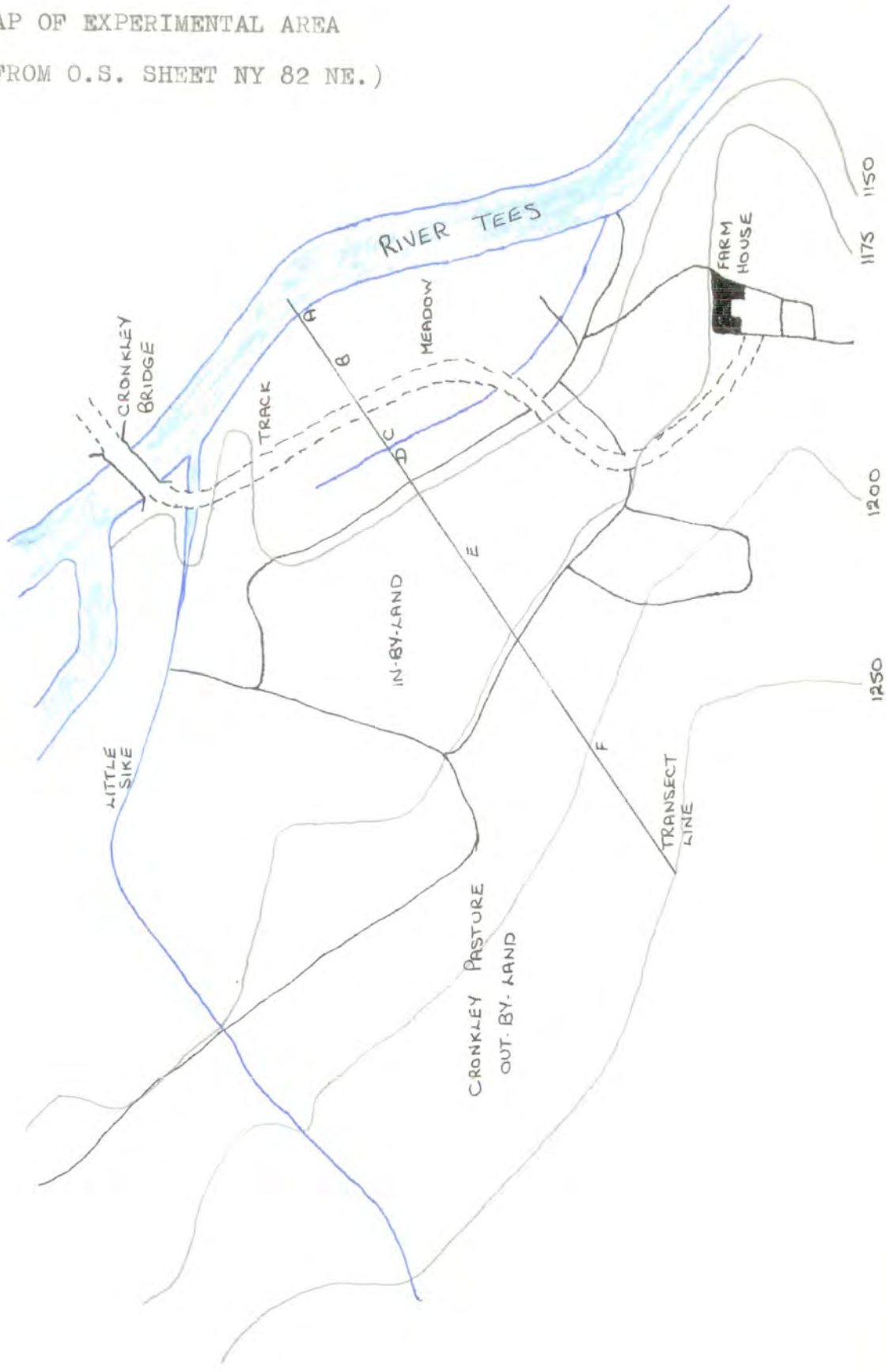
The methods used for these analyses are presented in Appendix 1.

THE EXPERIMENTAL AREA

Fig. 1

MAP OF EXPERIMENTAL AREA

(FROM O.S. SHEET NY 82 NE.)



THE EXPERIMENTAL AREA.

The experimental area is shown on the map Fig. 1. and is located below Cronkley Scar in North West Yorkshire, it consists of the meadow, in-by-land and out-by-land (Cronkley pasture) of Cronkley farm (G.R. 863289), which is part of the Upper Teesdale National Nature Reserve.

The farm is typical of those in the area, and indeed of those in most upland areas of the North Pennines. Sheep are the main farm animals with some cattle and a few ponies. The management system of this farm involves the use of the in-by-land as rough, but enclosed grazing. The grazing pressure however, is not constant as although there are animals in the area for most of the year, during the summer months the bulk of the stock is turned on to the Fells, to be returned to the in-by-land and meadow in the autumn. The flocks are over-wintered in these areas with supplimentary feeds of hay which is grown on the flatter parts of the meadow during the summer months when the area is completly cleared of sheep. To maintain this hay crop the meadow is fertilized and limed regulary.

The meadow, which is the only level part of the area see Fig. 2, proved to be of different geology to the surrounding area in that the soil here is alluvial in nature, being deposited by, and marking the previous

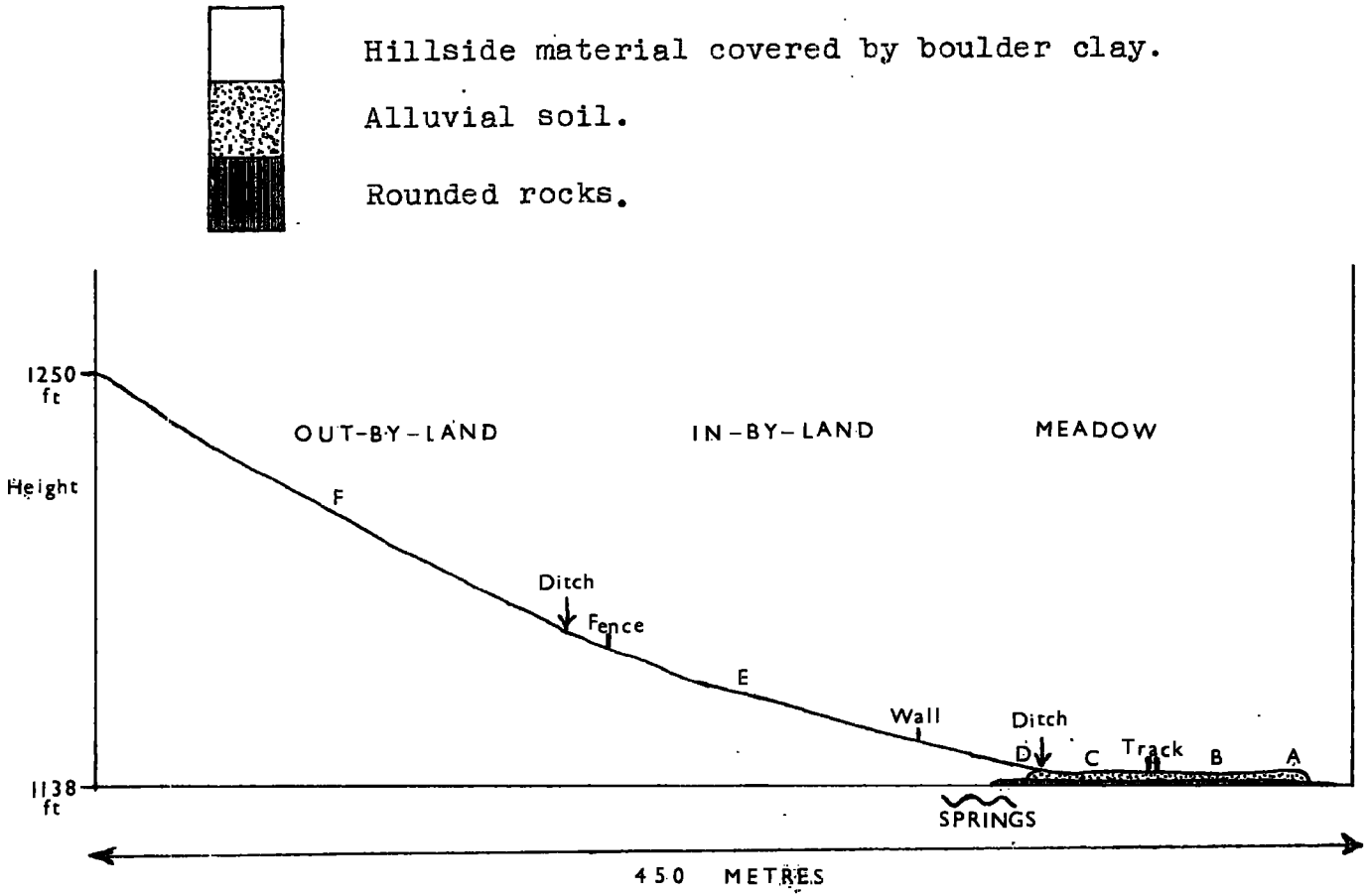


Figure 2.

PROFILE OF THE TRANSECT LINE.

position of the River, which has now receded to its present course.

The soil depth varies between about 30 and 40 cms. and overlies the rounded rocks which at one time formed the River bed. Towards the southern end of the meadow the ground rises steeply, see Plate 1., and it is on this raised ground that the farm house is situated. To the West of the flat part of the meadow the ground begins to rise, see Fig. 2. This break of slope, well within the meadow, signifies a change in geology which occurs at this point. The boulder clay which is found further up the hillside starts to become apparent. Although, in this area, its true extent is masked due to the presence of numerous springs. These have eroded the clay, and in the hollows thus formed, peat deposits up to 1 m. in depth have developed, and these areas support mixed flush communities.

Drainage of this very wet area has been attempted and a ditch takes off much of the water from this area directly to the river. Previous to the construction of this ditch the water probably drained through the sandy soil and flowed to the river in the rocks below the level of the meadow soil.

Above the wall marking the edge of the meadow the ground of the in-by-land rises fairly steeply. The soil consists of weathered boulder clay overlaid by

PLATE 1.

The Meadow Looking Towards The South.

a layer of humus rich material, with many small rocks standing out above the surface. The out-by-land beyond is separated from this part of the farm by a wire fence and a drainage ditch, Plate 4a. The soil is similar to that of the in-by-land, peat covered boulder clay, with many half buried rocks which are more obvious being of a larger size than those of the in-by-land.

SITE SELECTION

and

SOIL SAMPLING

SITE SELECTION.

The selection of soil sampling sites took place in late November 1968, and the position of the six original sampling sites A,B,C,D,E & F is shown on the map Fig. 1 and the profile Fig. 2. The choice of these sites was taken after consideration of several superficial factors such as floristic character, land usage, and a wish to work at sites representitive of the full range of major soil types in the experimental area. The transect line shown on the map Fig. 1 was chosen on the bases of the above criteria as it appeared to cross all the major vegetation types and land use boundaries of the area.

SITE A is shown in Plate 2a and was situated at the extreme North East of the transect line and consisted of an area of the meadow in the immediate vicinity (within 2 metres) of the present course of the River Tees.

The other sites B,C,D,E, & F were situated progressivly more South Westerly along the transect line.

SITE B is shown in Plate 2b and was in the centre of the flat meadow between the river, and the track of the Pennine Way which crosses the meadow.

SITE C was again in the meadow but was on the other side of the track, between it, and the ditch marking the

PLATE 2a

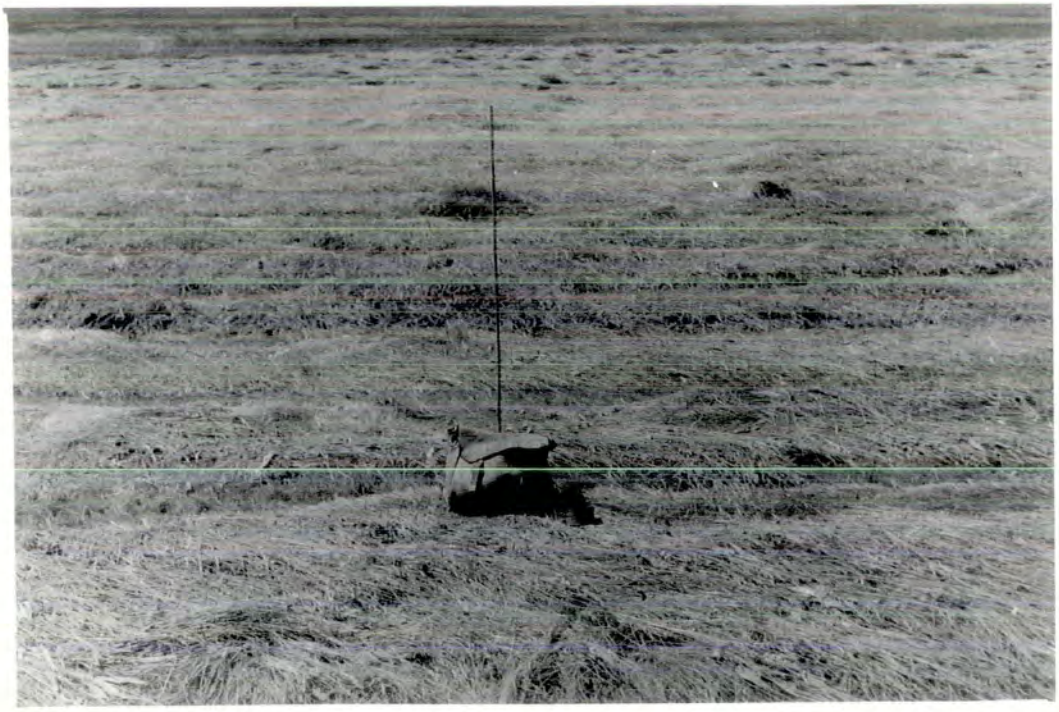
The Riverbank.

(Site A)

PLATE 2b

The Meadow, Just After Mowing.

(Site B)



beginning of the hillside.

SITE D is shown in Plate 3a and was on the south of the ditch about 10 metres into the area of boulder clay and peat, and although it was in this region where the ground begins to rise, the site was on almost level ground.

SITE E shown in Plate 3b and was in the centre of the in-by-land, and as can be seen in Fig. 2 the ground here is sloping fairly steeply, at an estimated 25°.

SITE F was the most South Westerly site, and is shown in Plate 4b, it was situated about 100 yards into the out-by-land, the land here, as at site E, is sloping up to the base of Cronkley Scar, at a similar angle.

Soil cores were taken from around each of these sites to check that the depth, and appearance of the soil at the actual sampling sites was in fact representative of the area as a whole. This was found to be the case at all sites, except site D where there was considerable variation in soil type over a distance of a few metres. The reasons for the variations at this site are given in the description of the experimental area and will be discussed at greater length later. In spite of this variation site D was left at the position shown on the map Fig. 1 as in my oppinion the soil here showed the original state of the soils in

PLATE 3a.

The Seepage Area.

(Site D)

PLATE 3b.

The In-By-Land.

(Site E)

the area.

The soils from these six sites were used for the determinations of soil water, and organic matter, Figs 3 & 4 and Table 1, and for the construction of the soil profile diagrams Figs 5a,b,c,d,e & f, but sampling at sites C & E was then discontinued.

PLATE 4a.

The Ditch Between The In-By and Out-By-Land.

PLATE 4b.

The Out-By-Land.

(Site F)

SOIL SAMPLING.

The soil samples were taken from the sites using, at first, a circular, 12 cms. diameter post hole auger, and it is from these samples that the water and organic matter determinations and the soil profiles were constructed. However this method of sampling was found to be unsuitable due to:-

1) The soil from site A tended to slip from the auger before the core could be removed properly.
2) The soil cores from sites E & F tended to be difficult to break from the soil below.
3) The soil from sites E & F tended to be compacted by removal from the auger giving unreliable depth measurements.

Because of this, samples for the other determinations were taken from the side of a spade-dug pit, and it was found that at sites A & B one more sample could be taken from between the rocks at a level lower than could be reached with the auger, and at site F two more samples could be taken from the deeper boulder clay.

At each site samples were taken from each 3 inch (8cm.) zone down the soil profile and the term DEPTH CLASS suffixed by a small letter a,b,c, etc. is used throughout this work to denote these sample units.

Depth Class a	being	the	soil	taken	from	between	0 and 8	cms.
Depth Class b	"	"	"	"	"	"	8 and 16	cms.
Depth Class c	"	"	"	"	"	"	16 and 24	cms.
Depth Class d	"	"	"	"	"	"	24 and 32	cms.
Depth Class e	"	"	"	"	"	"	32 and 40	cms.
Depth Class f	"	"	"	"	"	"	40 and 48	cms.
Depth Class g	"	"	"	"	"	"	48 and 56	cms.
Depth Class h	"	"	"	"	"	"	56 and 64	cms.
Depth Class i	"	"	"	"	"	"	64 and 72	cms.

The soil samples were transported to the laboratory in sixteen ounce screw-top, glass jars, a separate jar being used for samples from each site and depth class.

DISCUSSION OF RESULTS.

THE SOIL TYPES, THEIR AERATION AND DRAINAGE.

From the soil profile shown in Figs. 5a,b,c,d,e & f, the contents of water and organic matter, Figs. 3 & 4 and Table 1, it is clear that there are four distinct soil types; A, B & C, D, E & F. The ground water flow characteristics of each being shown in Fig. 6.

Types B & C are shallow soils, composed of alluvial material overlying rounded stones typical of the contemporary river bed. They are freely draining with some crumb structure, a graded distribution of organic matter, and associated water holding capacity. Throughout the profile there are no indications of anaerobic conditions, Fig. 7.

The upper part of the profile of types E & F is very rich in organic matter, but merges rapidly into the parent material which is boulder clay. The top strata of the boulder clay have a pale colour, the typical "sad" Pearsall (1950) appearance of gleyed soil and it is largely without oxygen. In the lower depth classes the clay is stained with humic material and ferrous salts. These horizons are characteristic of the podsol type of soil which is typically formed in well drained stratae by leaching from above in regions where the rainfall is relativlly low 30 to 40 inches per annum. The soil on Cronkley is formed over impermeable clay, under high rainfall, well in excess of 40 inches a year, it has a

Figure 3.

% Organic Matter in Soil Samples From Six Sites in Cronkley Pasture.

Depth Class; a = 0 - 8cms. b = 8 - 16cms. c = 16 - 24cms.
d = 24 - 32cms. e = 32 - 40cms. f = 40 - 48cms.
g = 48 - 56cms. h = 56 - 64cms.

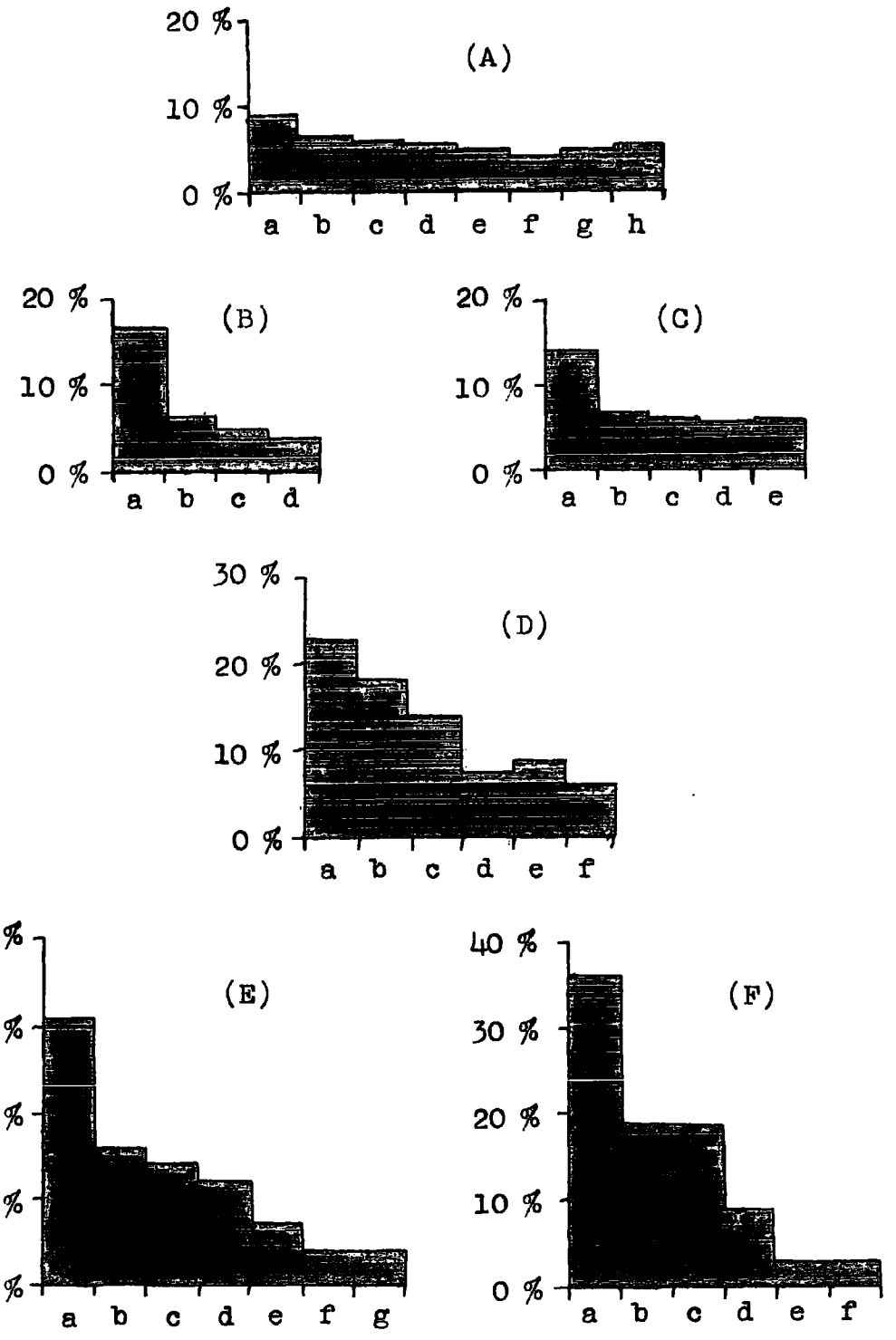
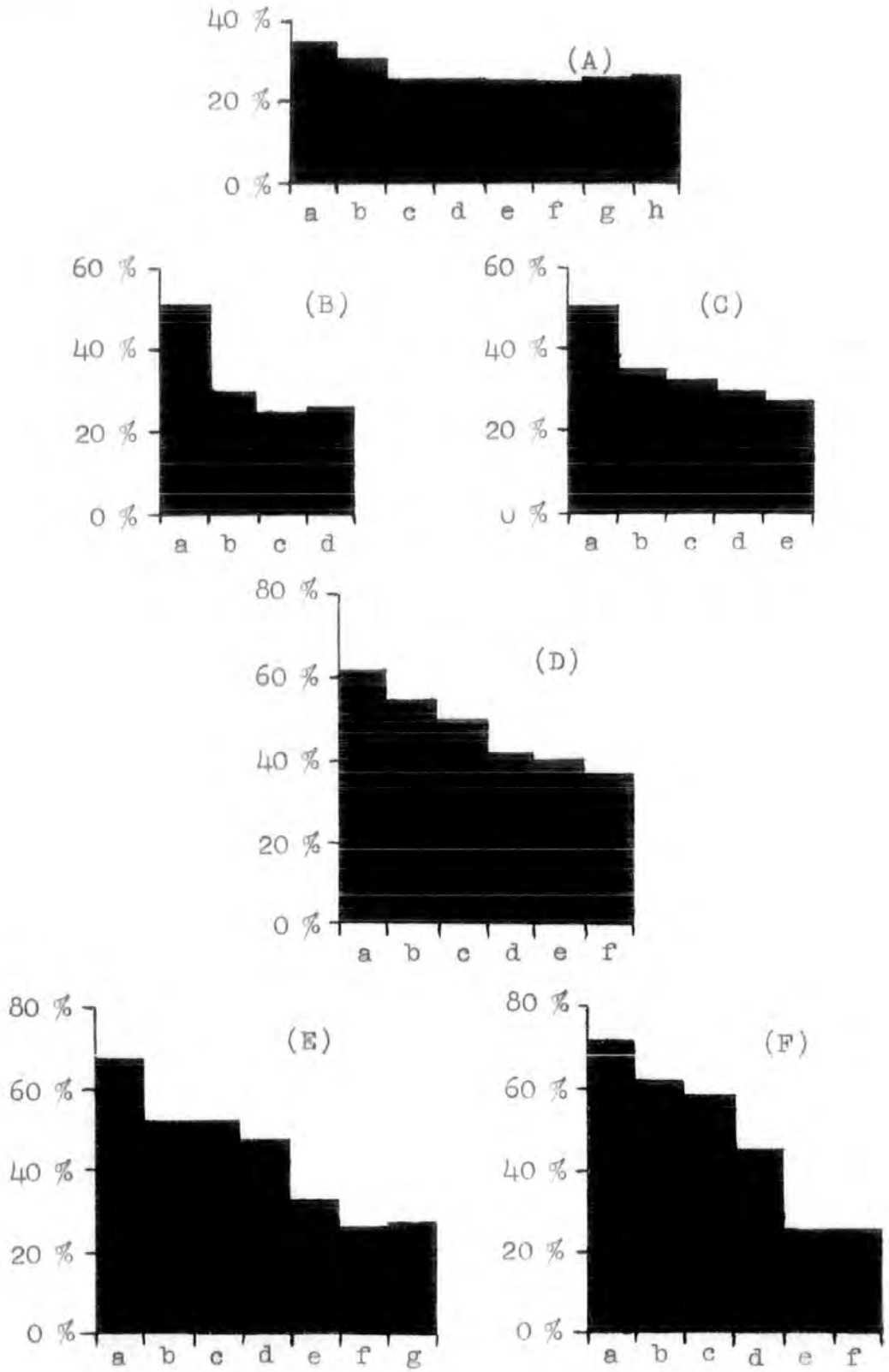


Figure 4.
% Water Content of Soil Samples From Six Sites in Cronkley Pasture.

Depth Classes as in Fig.3



distinctive down slope drainage, Fig. 6. Observations of water flow into soil pits indicated that the flow was along the clay; organic matter rich interface. It is therefore suggested that the podsol characteristics are due to lateral movement of water through the soil, so that the term podsol should not be used and these soils should be described as gleys.

Type D has a complex profile, with an horizon rich in organic matter which overlies a deposit rich in clay, the latter shows signs of gleying, and is marked by anaerobic conditions. Below this a layer of sand overlies a "fossilized meadow soil" developed on rounded stones typical of the river bed. (It is suggested that this represents the alluvial soil developed prior to deforestation of the slopes of Cronkley Fell, which was sealed and "fossilized by downwash of clay from the deforested slopes). Drainage of the soil is very poor as would be expected from the abundance of peat in this spring and seepage fed area of the meadow.

Type A soil, has a deep profile, and is poor in organic matter. There are no signs of anaerobic conditions, and the soil is freely draining, the drainage pattern being orientated towards the river. The profile is rich in course alluvial material and grades into the typical rounded stones of the river bed. It is tempting to suggest that there is regular deposition of allochthonous material by the spring floods, (which raise the water

Figure 6.

AREA OF VEGETATION KILLED BY HERBICIDE.

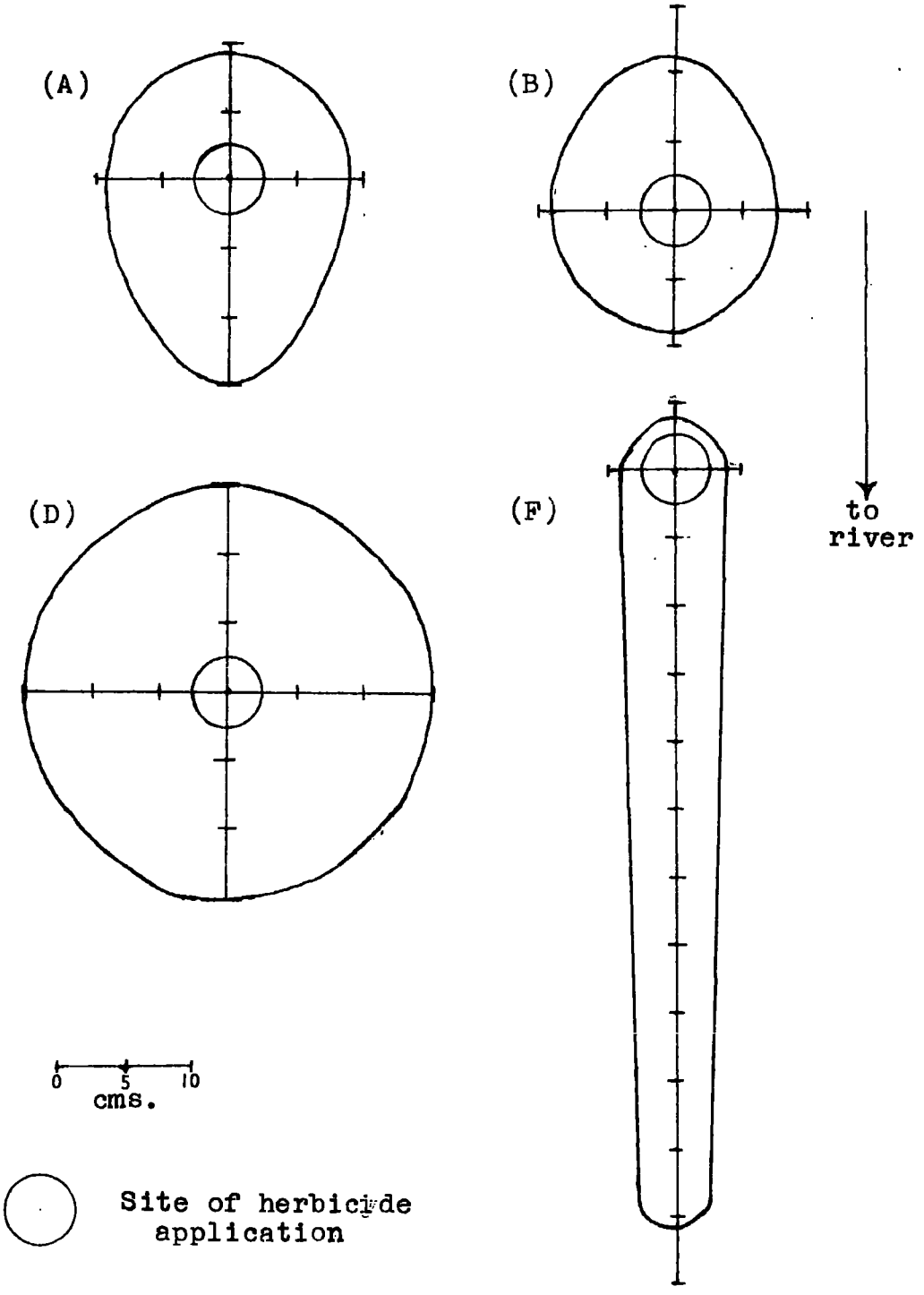


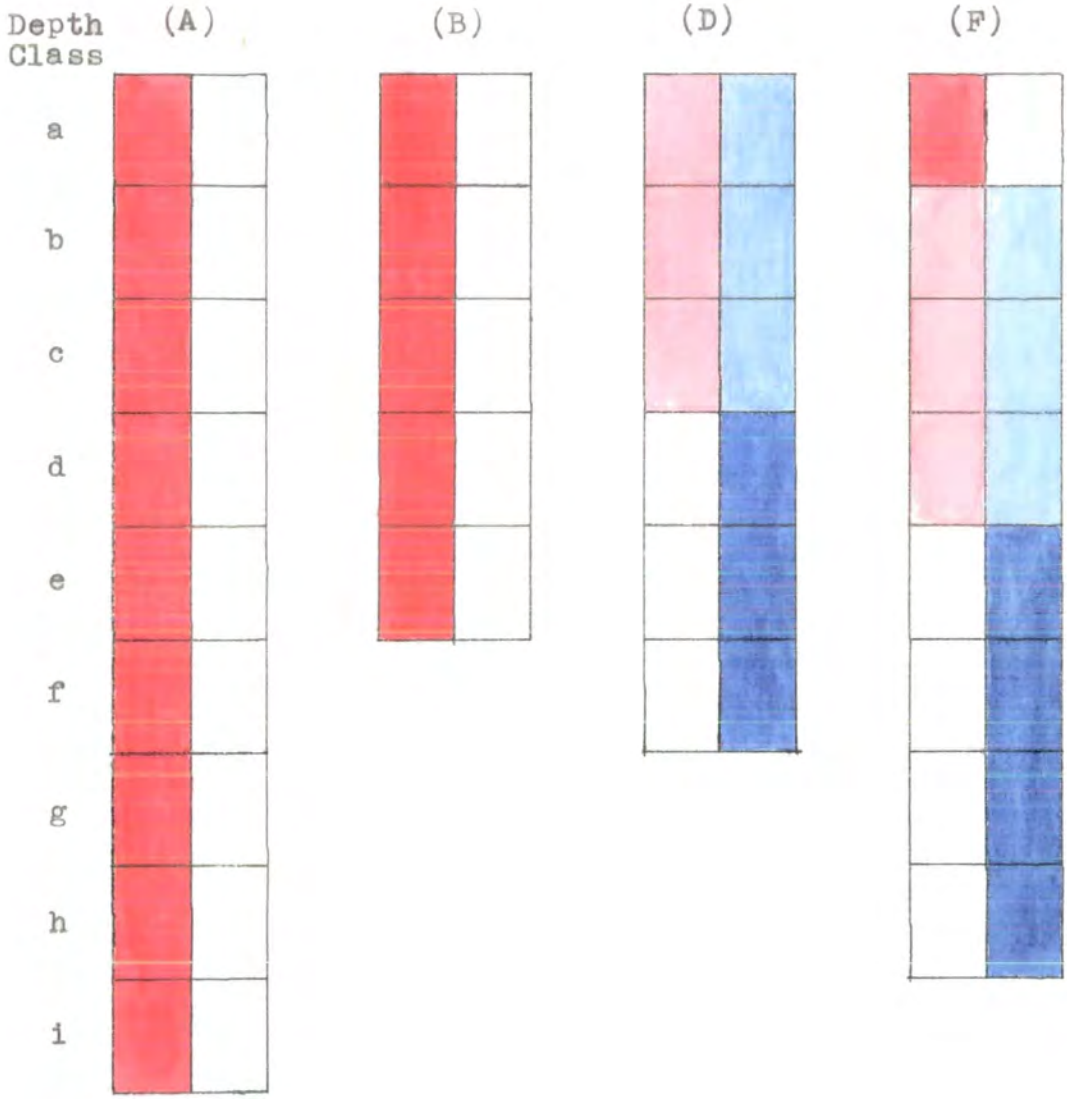
Figure 7.

Oxygen status of the soils.

Ferric iron present (Good aeration).

Ferrous iron present (Poor aeration).

Both present (Moderate aeration).



level of the river to many times its normal height Ramsden (1961).). Since it is suggested that these floods deposit material, it is reasonable to assume that soil erosion by flood might also take place. This does not seem to occur to a great extent as the roots and the remains of the above ground vegetation would tend to bind the soil and prevent this erosion. It is however suggested that litter may be lost in this way thus accounting for the low organic matter content.

Figure 5a.

SOIL PROFILE OF SITE A.

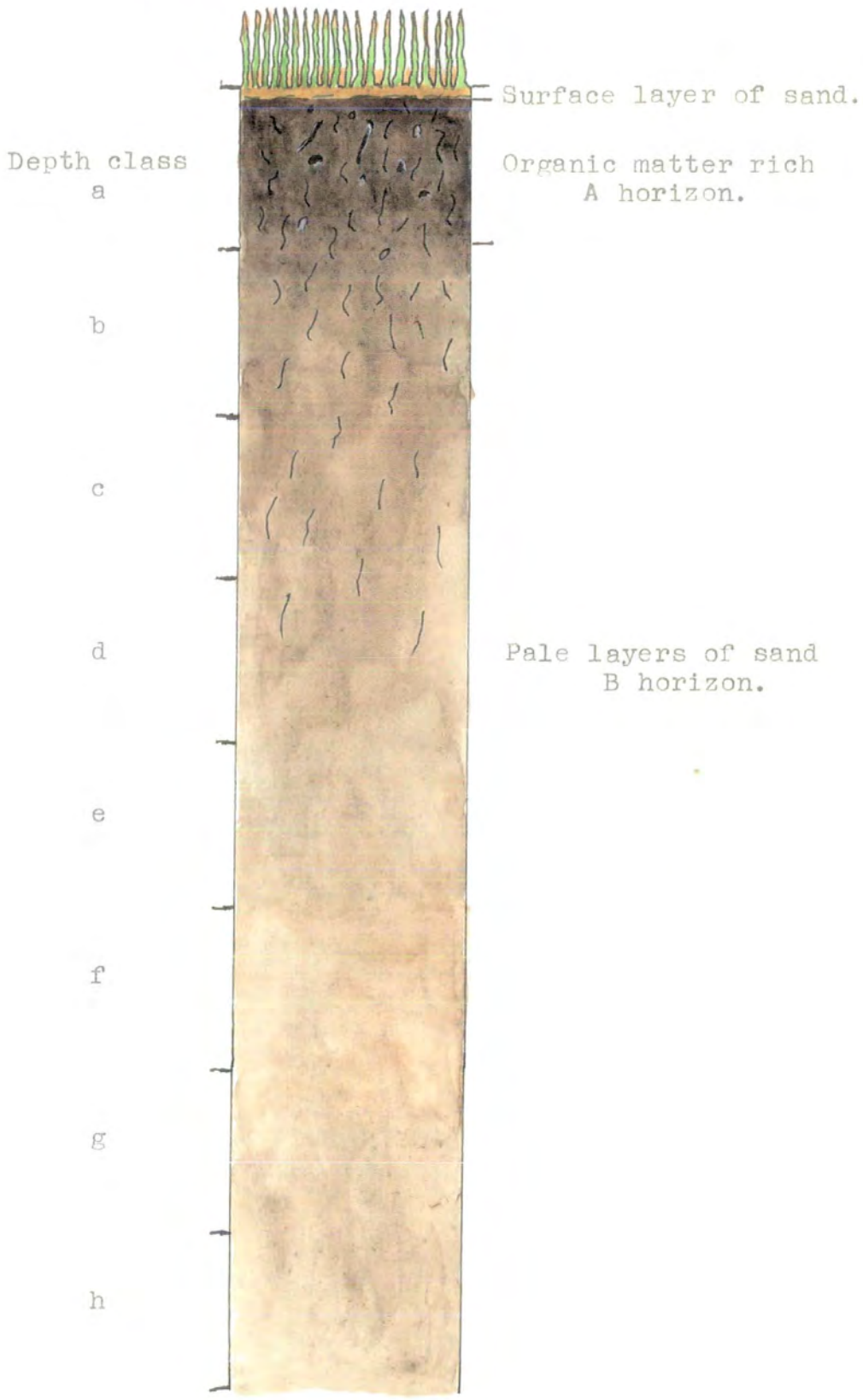


Figure 5b.

SOIL PROFILE OF SITE B.

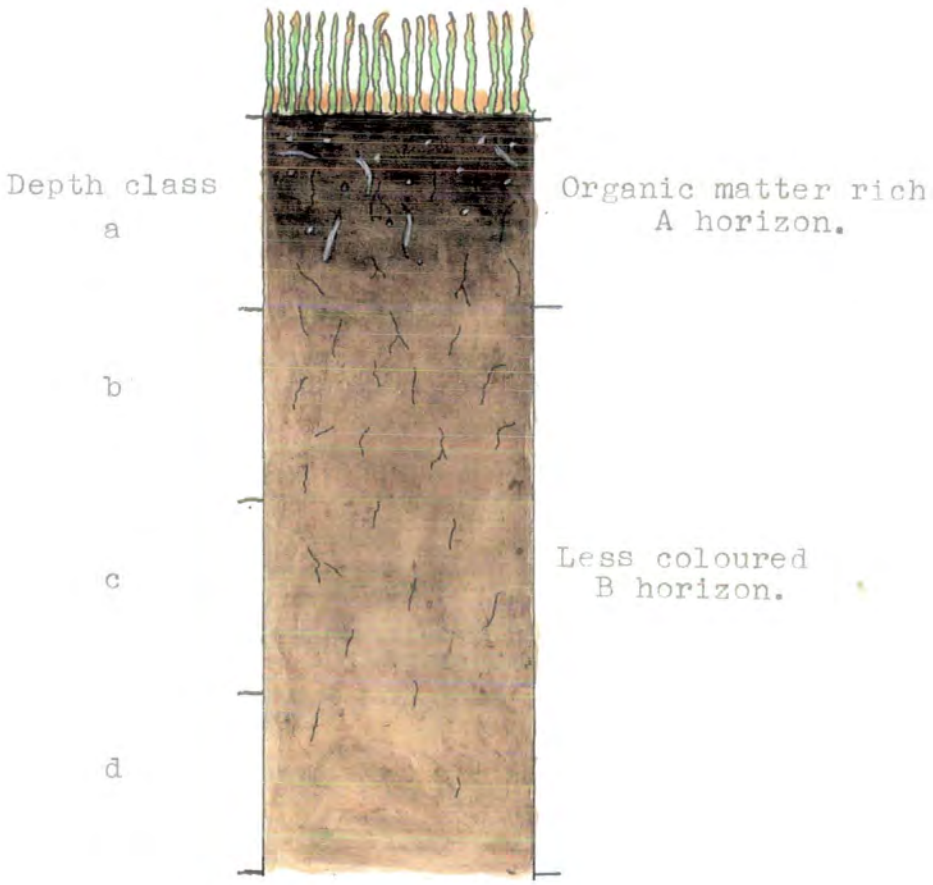


Figure 5c.

SOIL PROFILE OF SITE C.

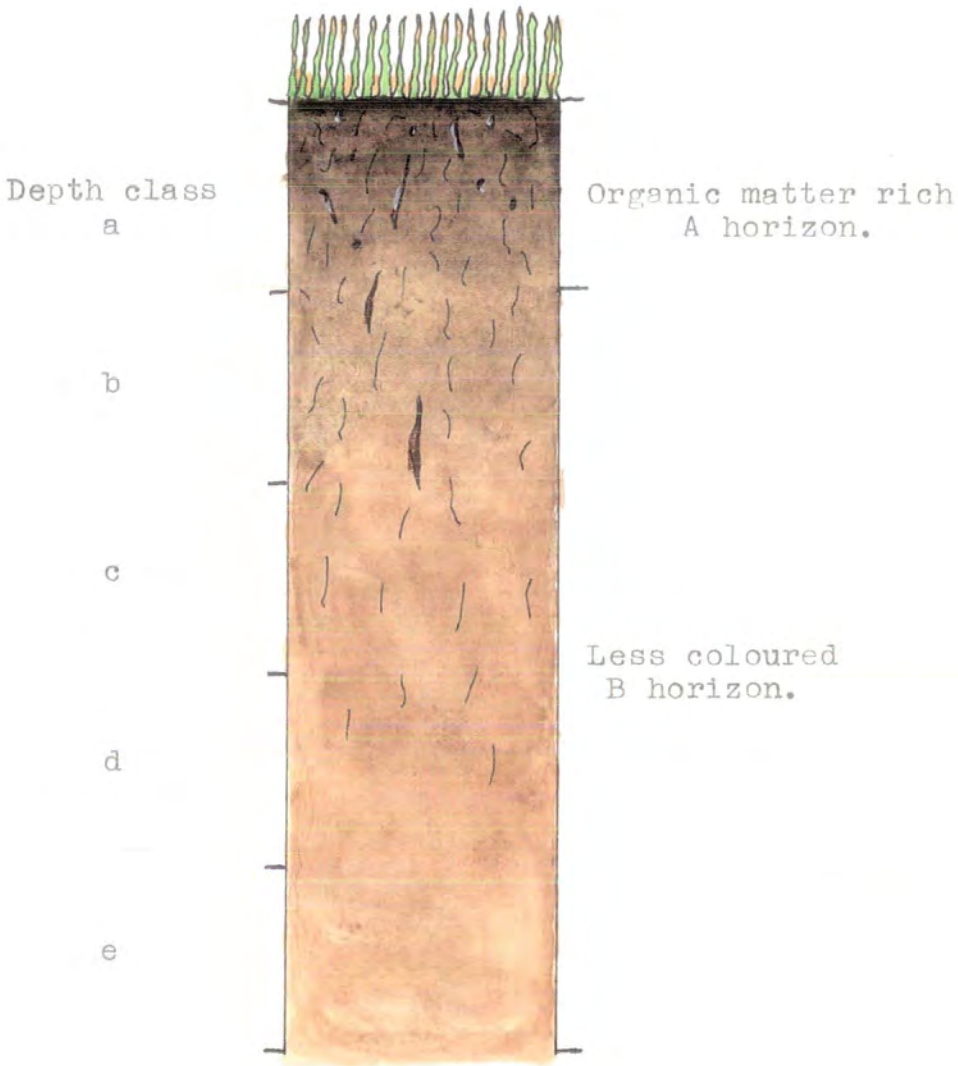


Figure 5d.

SOIL PROFILE OF SITE D.

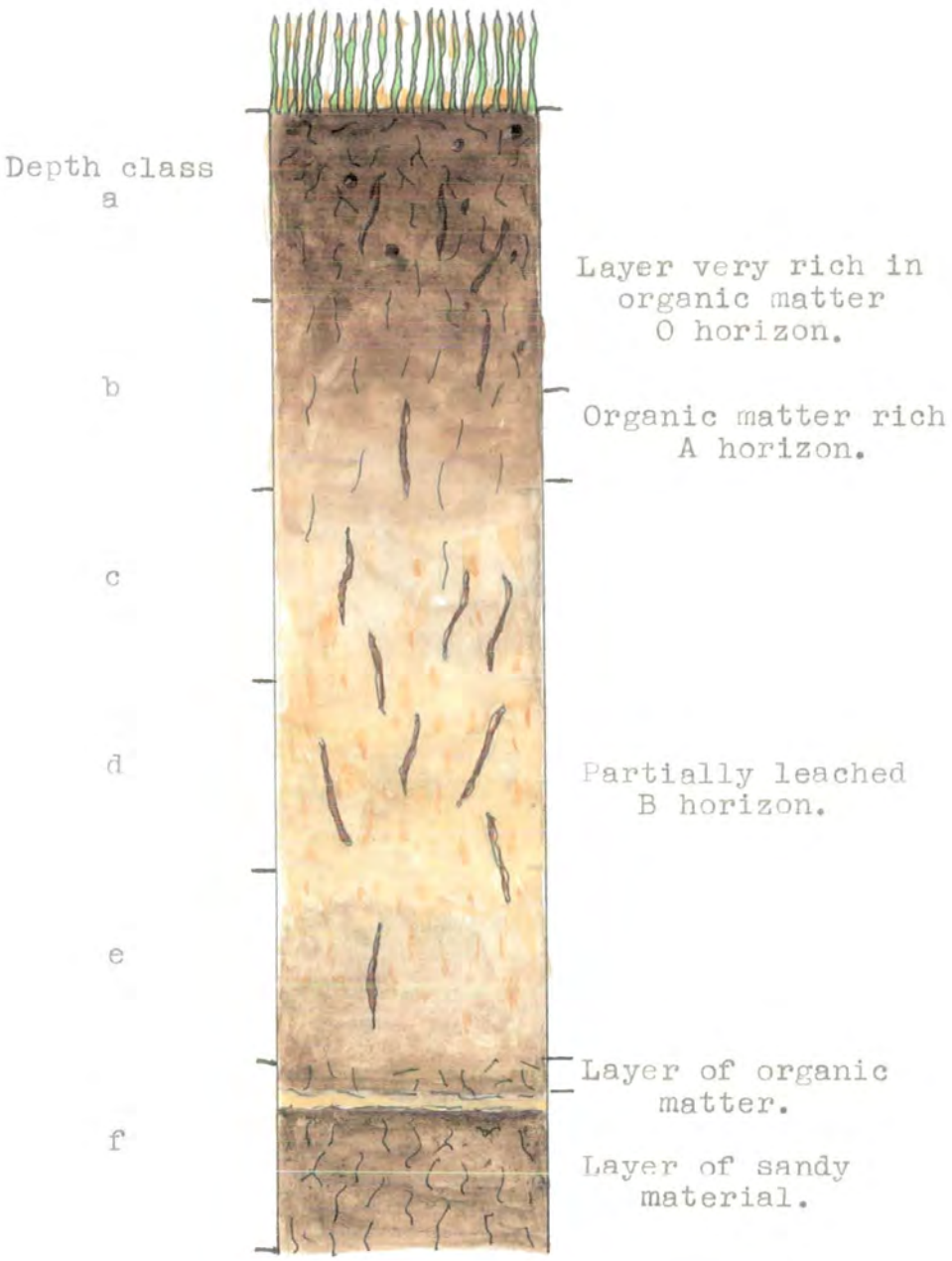


Figure 5e.

SOIL PROFILE OF SITE E.

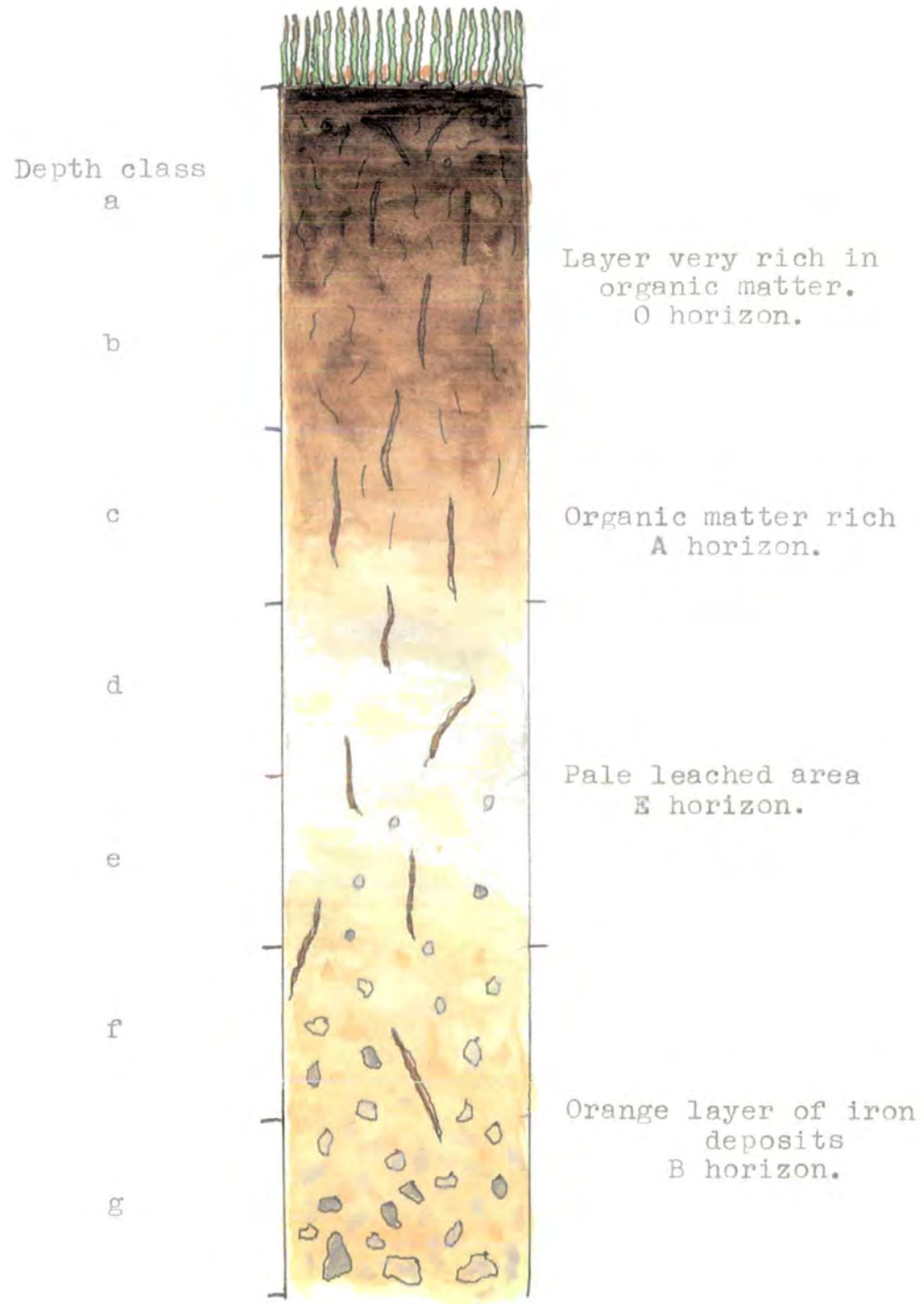
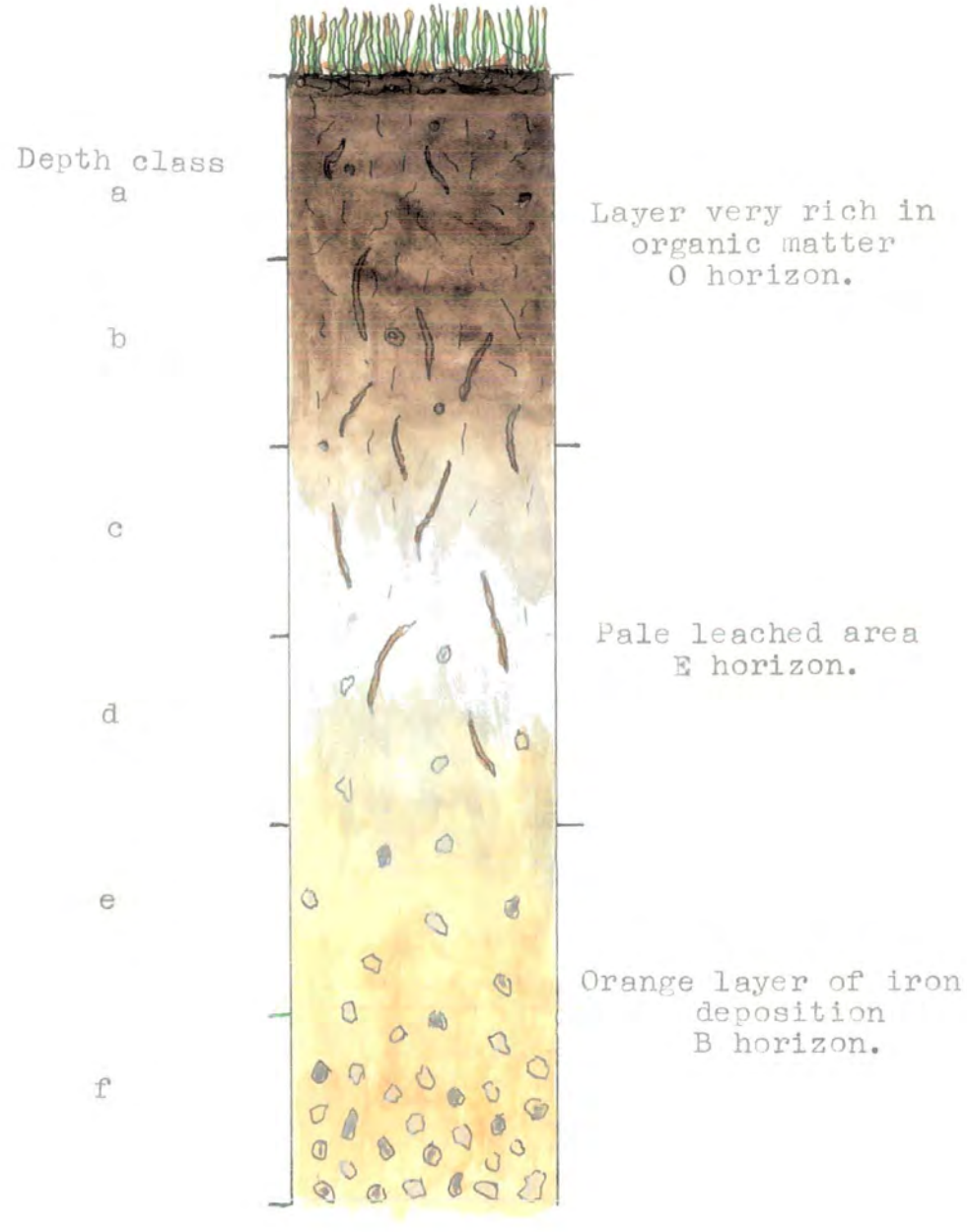


Figure 5f.

SOIL PROFILE OF SITE F.



THE CHEMICAL ANALYSES OF THE SOIL.

The results of the soil chemical analyses are shown in Tables 2 & 3 (Appendix 2) and are presented in text figures. These results are, (except pH) expressed as per unit area for reasons given in the method appendix.

The mineral status of a soil is determined by five factors; 1) The content of the parent material, 2) leaching due to through flow after rain, 3) supply by rainfall, 4) supply by the addition of fertilizers, and 5) biotic cycling. This interplay is in part reflected by the base status of the soil and its pH.

The soil pH values are remarkably similar, and this may in part be due to the high rainfall (50-55 inches per annum) Piggot (1956) leaching away the acids in the soil, Pearsall (1950), and to the reduction of the acid forming oxidation processes caused by the water logging of the soil, reducing the acidity of site D & F. The pH values given for all of the sites parallel the analyses for total alkalinity Fig. 8 and calcium Fig. 11. It would appear that when the /m^2 value for calcium drops below 50 gms. the total alkalinity drops below 300 gms. then the soil pH falls below 6.0. The upper horizons of site F where these low levels are very noticeable are heavily leached by ground water, while the depletion throughout the profile of site D may

similarly be due to leaching in this seepage fed area. The high pH of the surface horizons of the meadow soil (Site B) may be due to the limeing of this area, although this has not taken place for about five years. The natural pH of this site may be similar in value to the results obtained at site A which is not limed.

The plant nutrients in the soil at site F are, in comparison, present in only small quantities and their distribution in the soil profile shows three basic trends; Carbonate Fig. 8, and the cations to which it is usually compounded, calcium, Fig. 11 and magnesium Fig. 12, are at very low levels in the organic matter rich surface strata and become abundant only in the lower, clay rich, region. Sodium Fig. 9. potassium, Fig. 10, and phosphorus, Fig. 13, show two peaks of abundance, one in the organic matter rich upper horizons and another in the deep clay. Between these peaks there is a sharp trough related to the drainage zone of the organic matter rich;clay interface. Nitrate, Fig. 14, shows a consistently low level throughout the depth of the soil.

At site D these three trends loose definition, and although the picture for calcium and carbonate remains the same, magnesium mirrors potassium in that its level falls in the lower regions of the profile and does not rise again. Phosphorus again has two peaks, and sodium which does not drop sharply at site F remains

in equal abundance throughout all depths of the soil, this too is the situation for nitrate which, as at site F, remains at its consistant low level.

At site B there are two easily explicable trends: For the nutrients which are added as fertilizers there are large surface concentrations which drop reguarly through the depth of the soil profile. This is not so noticeable in the case of potassium but it will be seen later that this element is taken up by the vegetation in large quantities. The only two elements analysed for that are not applied as fertilizers are sodium and magnesium and the trend shown above is reversed, the content of these elements increases down the profile.

At site A it is more difficult to explain the distribution of the soil chemicals, there are however two tempting hypothises.

1) That since the levels of magnesium, calcium and carbonate are low in the surface depth classes at site F where there is a flow of leaching water, these substances are not as strongly bound to organic material as sodium, potassium, phospate and nitrate, therefore, when spring flooding occurs they are leached preferentially from the soil by the water which would predictable flow faster through the upper layers of the soil.
2) That calcium, magnesium, and carbonate are retained

by the litter, while other nutrients are recycled into the underground parts, Rieley (1967), and thus tend to be washed away in the litter material by the flood water.

The drop in the levels of calcium, magnesium and carbonate in depth classes g & h of this site, and to a lesser extent sodium in depth class h, reflect a slight rise in the water content of the soil at this depth, which may be due to the drainage waters of the meadow passing through the soil at this depth and leaching these nutrients from the soil. For nitrate, phosphorus and potassium, there is a rise in their abundence in depth class h of this site, and since these nutrients are regularly added to the meadow as fertilizer it is likely that this rise in level is due to solutions of these which have been washed from the soil in the fertilized area enriching the soil at this depth.

Although complete profiles of the soil have been analysed, at all sites the rooting zone of the vegetation extends down only as far as the beginning of depth class e, and so it is the content of nutrients in the top four depth classes which is immediatly available to the vegetation.

Figure 8.

TOTAL ALKALINITY OF SITES A,B,D & F.

(Expressed as Carbonate).

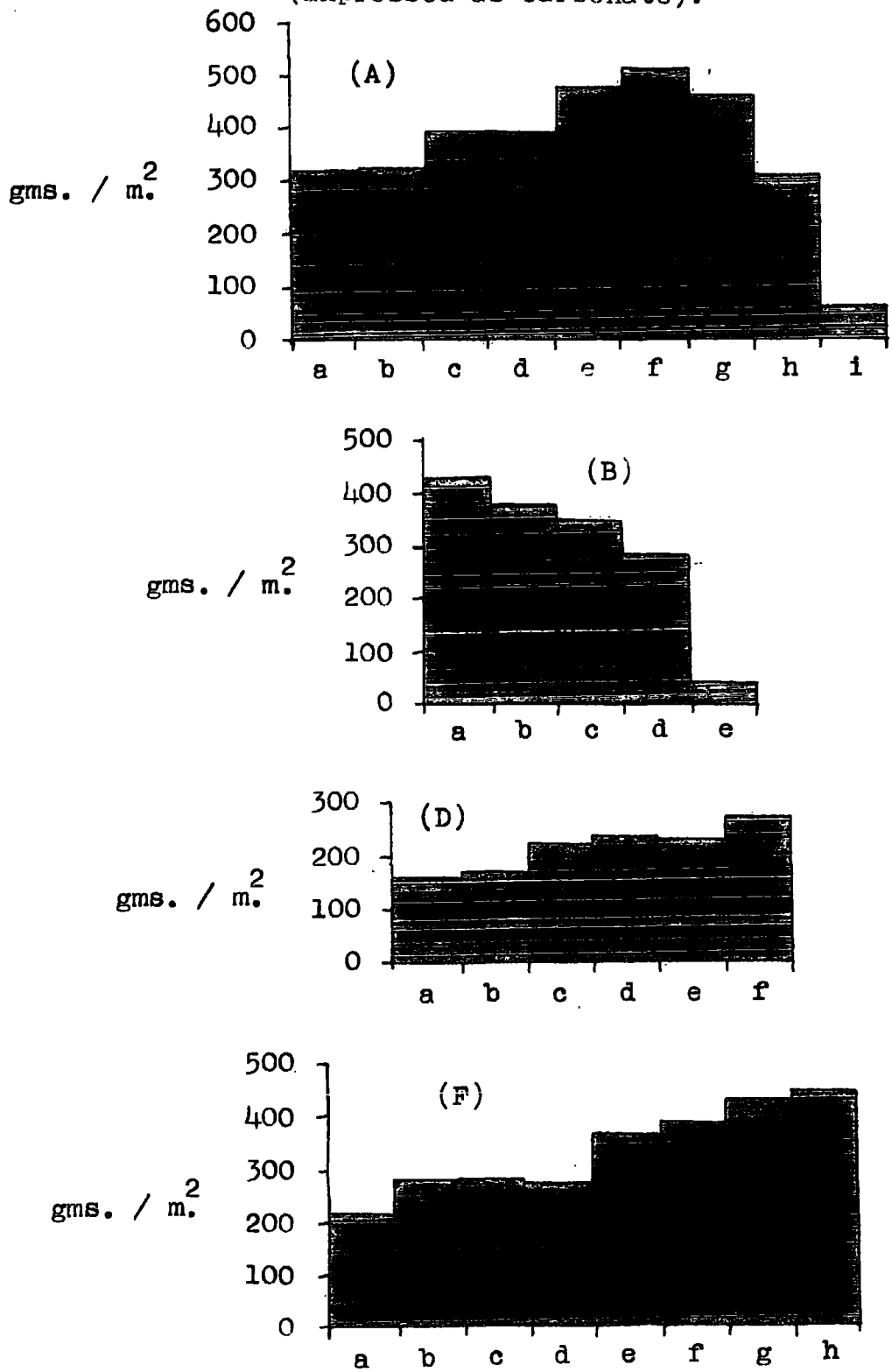


Figure 9.

POTASSIUM LEVELS OF THE SOIL AT SITES A,B,D & F.

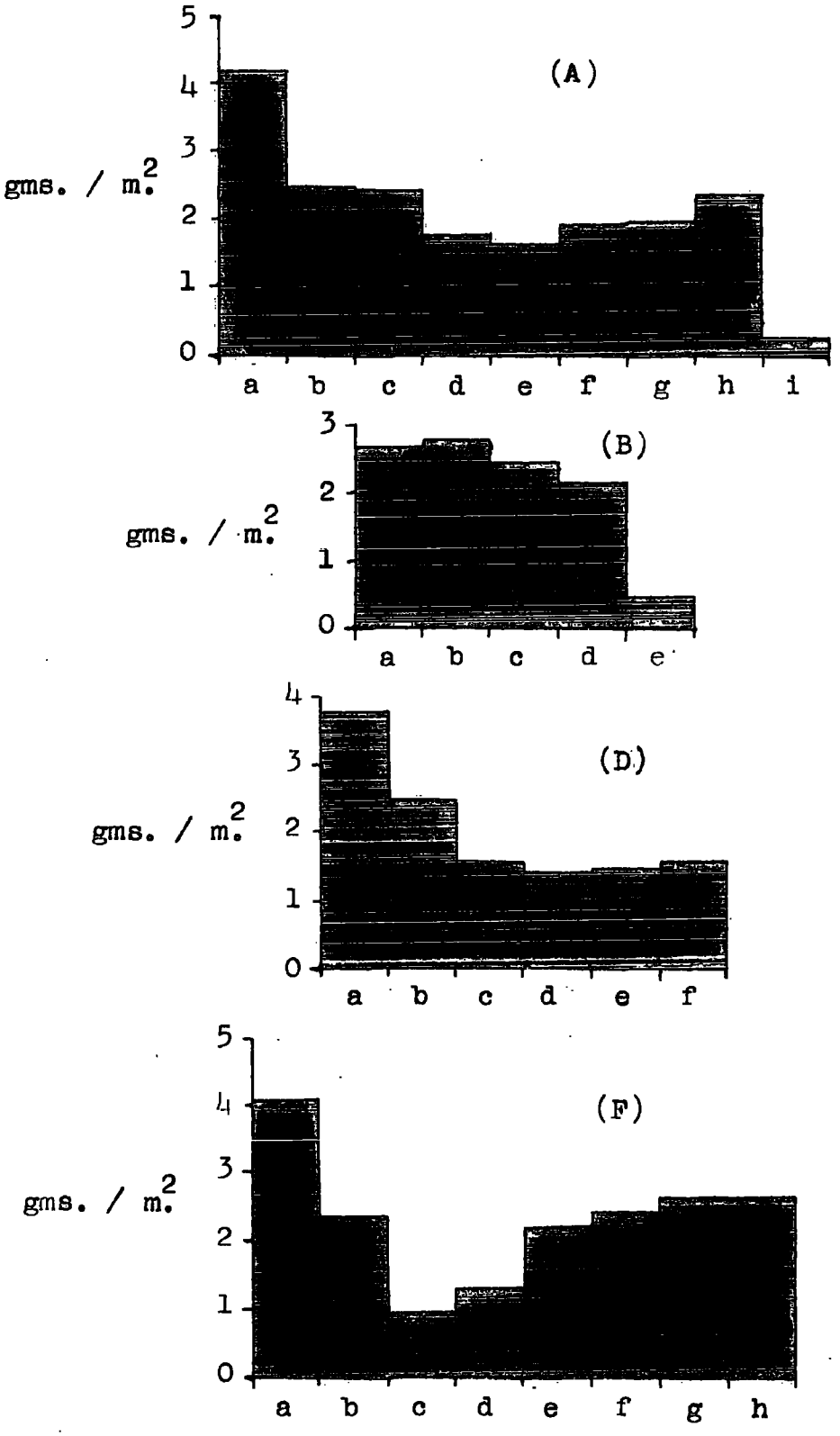


Figure 10.

SODIUM LEVELS OF THE SOIL AT SITES A,B,D & F.

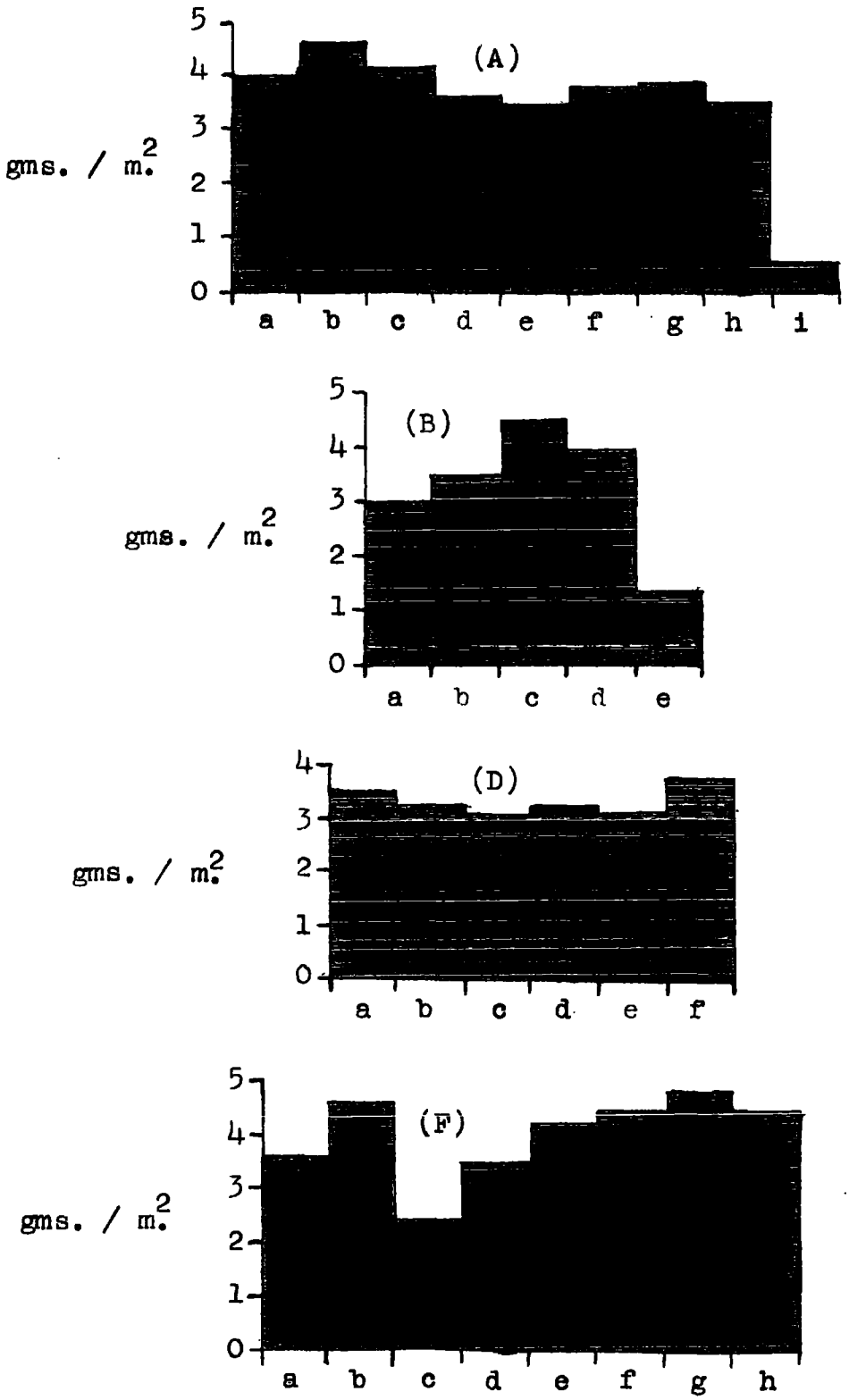


Figure 11.

CALCIUM LEVELS OF THE SOIL AT SITES A,B,D & F.

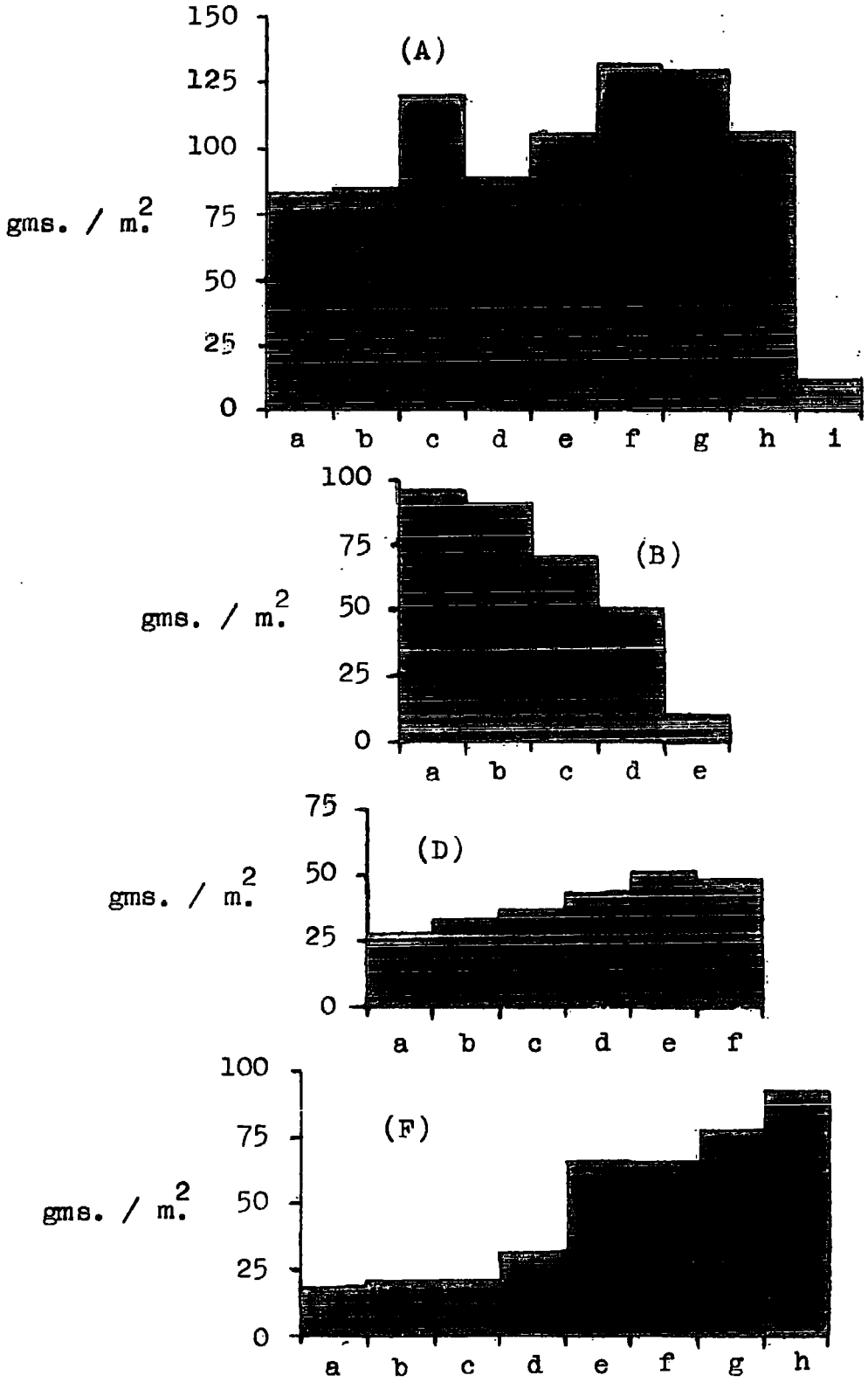


Figure 12.

MAGNESIUM LEVELS OF THE SOIL AT SITES A,B,D & F.

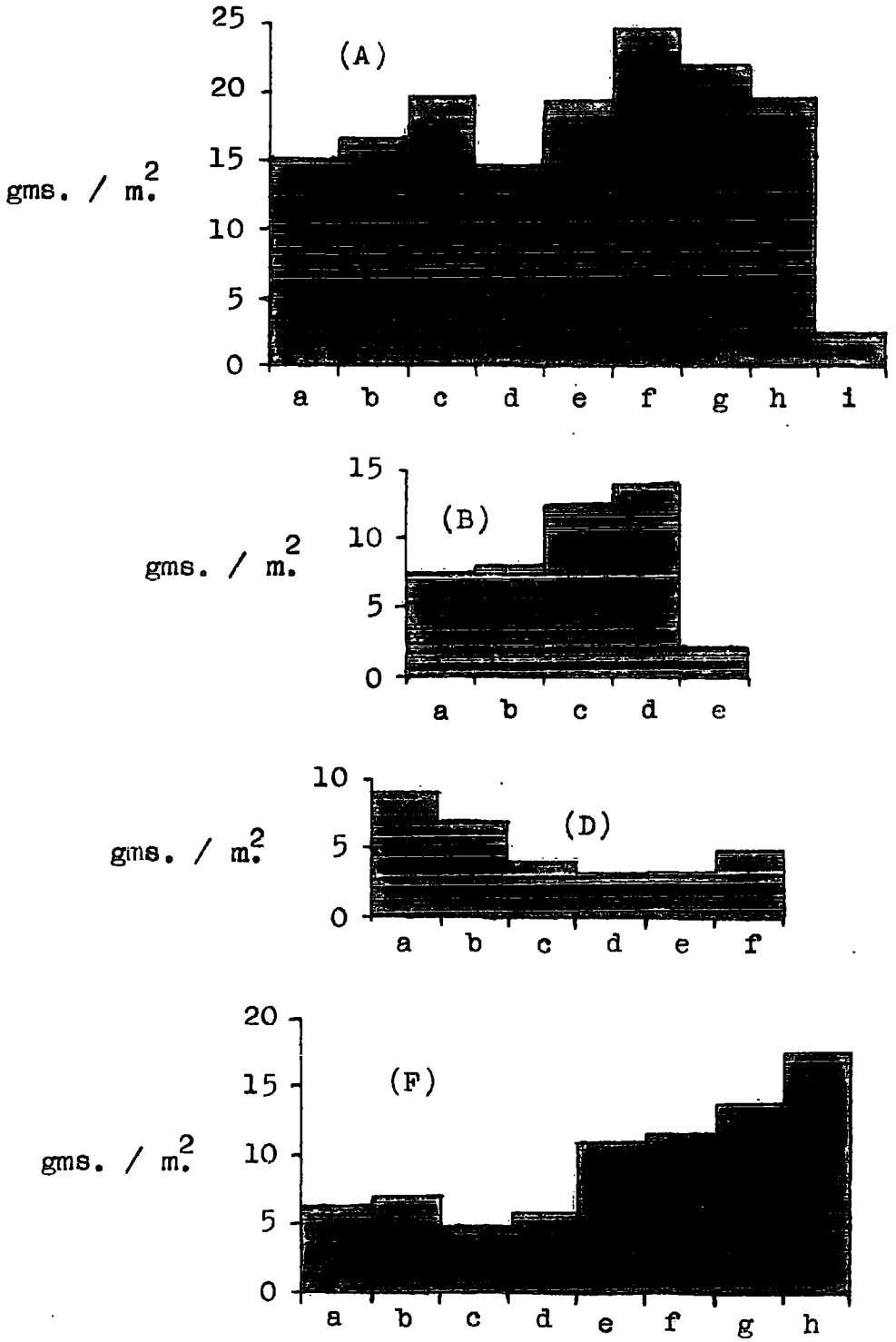


Figure 13.

PHOSPHORUS LEVELS OF THE SOIL AT SITES A,B,D & F.

(Log. Scale)

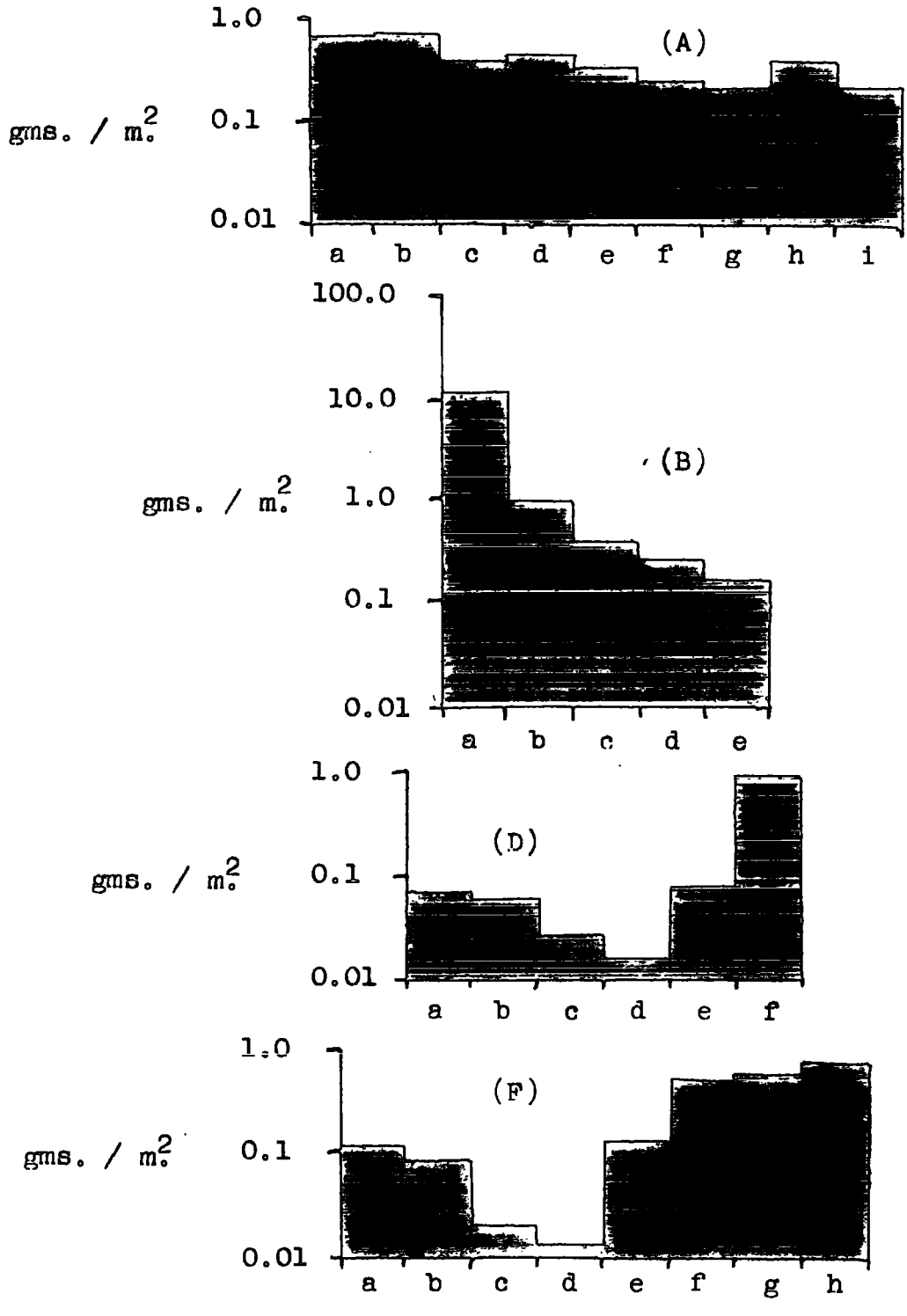
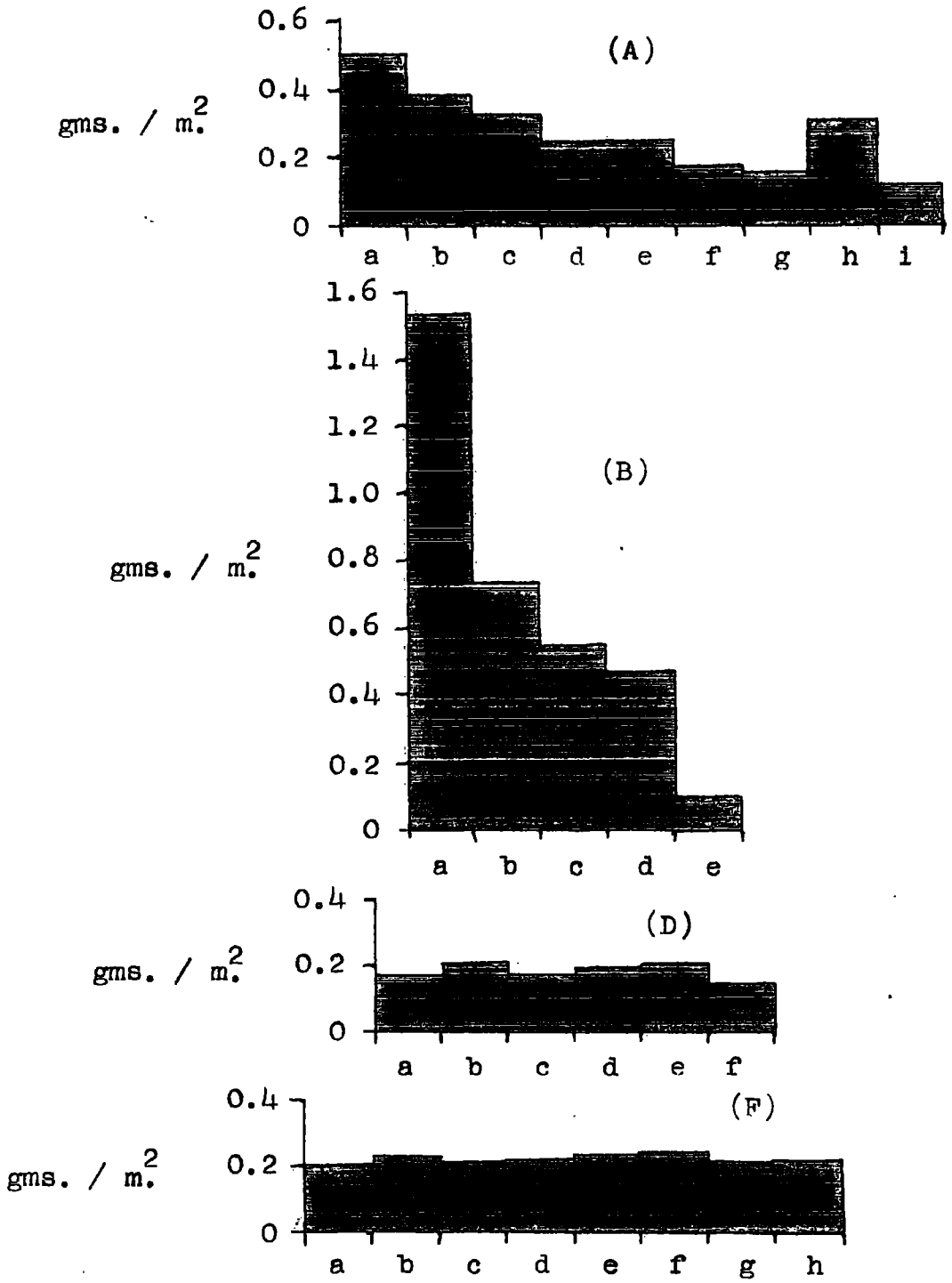


Figure 14.

NITRATE NITROGEN LEVELS IN THE SOIL.



FLOW OF NUTRIENTS IN RAIN AND GROUND WATER.

The results obtained from the analyses of rain water were found to be higher than those obtained by Gorham (1961), and Gore (1968) and, since it is likely that concentration of the samples may have occured by evaporation, or that contamination by bird droppings may have taken place, Gore (1968), the results obtained by Gorham (1961) for samples from Moor House National Nature Reserve have been adopted. These are given in Table 4, and have an added advantage in that the sampling period was more extensive.

The quantities of the nutrients entering the soil in one square metre per year were calculated, assuming that the annual rainfall of 50 inches Piggot (1956) was constant at at each of the sites, and are given below.

Nitrate Nitrogen	0.127 gms. / m^2
Sodium	2.413 gms. / m^2
Calcium	0.381 gms. / m^2
Magnesium	0.254 gms. / m^2
Potassium	0.254 gms. / m^2
Phosphorus	0.003 gms. / m^2

The quantities of nutrients leaving the soil in runoff waters are difficult to determine, as measurements of the annual water flow in the ditch were beyond

the scope of this study, while an accurate determination of water flow into the river is impossible. Therefore the results of the analyses of these water samples are given only as parts per million in Table 4.

From them it can be seen that in the ditch water, only the concentrations of calcium and magnesium are much increased, probably reflecting the leaching of these elements from the soils of the hillside.

Although the chemical concentrations of the river water must be related to the soil chemicals of the upstream catchment area, it can be seen that the levels of calcium, magnesium and sodium are less than the levels in the ditch water, while there is enrichment with nitrate nitrogen, potassium and phosphorus. Therefore, since it has been pointed out above that drainage water in the lower depth classes of site A tends to increase the quantities of these nutrients found in the soil, it is suggested that these enhanced levels are due to the leaching of fertilizer applied to meadows upstream, and that considerable quantities of the nutrients applied as fertilizer may be lost by leaching.

NUTRIENTS ADDED AS FERTILIZER.

The addition of fertilizer takes place only to the central portion of the meadow, away from the river bank and site A (due to the dangers of taking spreading machinary this close to the bank), and extends to the drainage ditch marking the break of slope to the South West. Therefore only site B receives direct application of fertilizer, although a little may be carried in the wind to sites A and D.

This fertilization is an annual proceedure taking place at the beginning of the growing season (early May) after the sheep have been taken from the meadow. The soil samples taken from this site for chemical analyses were removed before this fertilization took place, as was the May vegetation sample.

The fertilizer applied is I.C.I. 12.12.18 fertilizer containing; 12% Nitrogen

11% Soluable Phosphoric acid

1% Insoluable Phosphoric acid

18% Potash.

The application rate was 2.5 cwt. per acre (approx. 27 grams / square metre) and therefore:

3.24 gms. of Nitrogen

1.43 gms. of Phosphorus

(1.31 gms. Soluble

0.12 gms. Insoluble)

2.67 gms. of Potassium.

are added annually to one square metre of the soil at Site B.

Lime is added to the same region of the meadow as the fertilizer, and the last application of an unknown amount, occured about five years ago.

THE ABOVE GROUND STANDING CROP AND NET PRODUCTION.

The results of the croppings of the above ground vegetation and litter material, at the beginning (1st May 1969), and towards the end of the growth period (9th July 1969) are shown as grams dry weight per square metre in Table 5.

From the results it can be seen that the levels of net productivity for each site range from between 147 grams dry weight per square metre at site A, to 190 grams dryweight per square metre at site B, and although the method used to collect this data was crude, and the measurements did not extend over the entire growing season, it would appear that the net productivity at each of the sites is similar.

The differences between the sites are more clearly shown by the difference in the weights of the standing crop both live and dead. The lowest weight is at site A corresponding with the low organic matter content of the soil which may be due to the removal of litter material by the spring floods, see above. The standing crop at the other sites increases along the transect with site F having more than three times as much as site A.

When the summer production of the sites is expressed as a percentage of the over-winter standing crop it can be seen that at site A this percentage (57%) is the highest. Site B has the highest net production of any

site,but its maintained winter storage crop is higher than that of site A and therefore the percentage increase is reduced to 52%. Sites D and F both have very high over-winter storage crops and the percentage increases due to summer production are 32% and 22% respectivly.

NUTRIENT CYCLING.

With the aid of the data which has been presented so far it is possible to construct stylised diagrams for cycling of nutrients at each of the four sites.

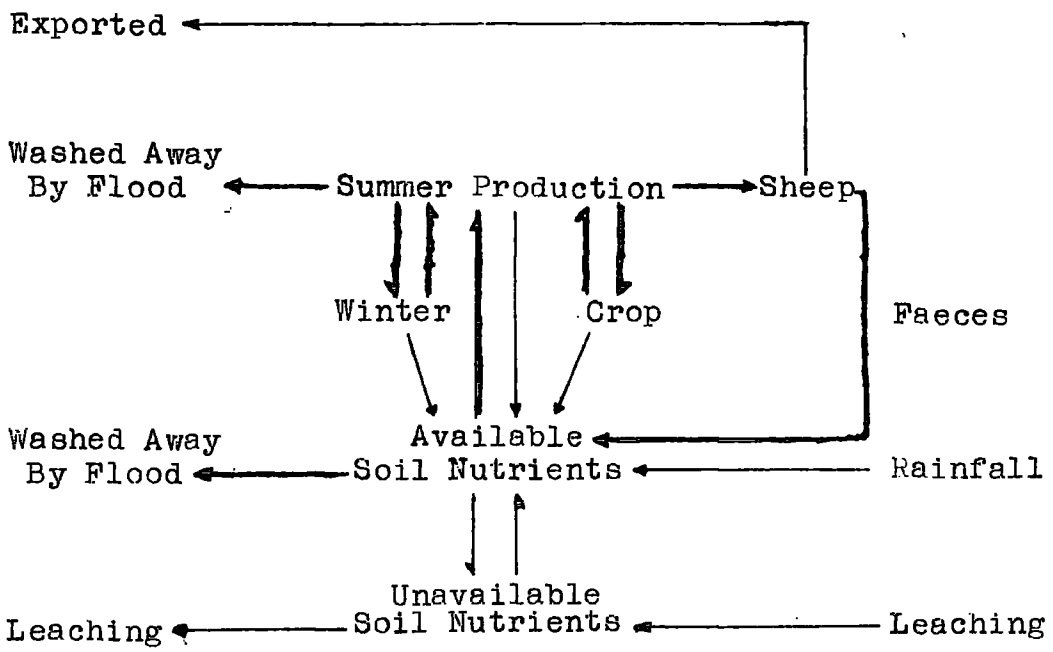
The 'cycle' diagrams Fig. 16 show four main pathways inflow of nutrients; their uptake into the vegetation, and passage on decay, of this vegetation, back to the soil; their cycling through a herbivore (sheep); and their exit from the system. These four pathways are similar for all of the sites, the only difference being the relative importance of one or more of the pathways, or parts of these pathways. The most important parts of the cycle at each site have been emphasized by thick lines in the diagrams, although the importance of each part of the cycle may vary with time. This is illustrated at sites D and F where, although leaching of the surface strata may not as a rule have a great effect upon the cycle, it would tend to wash from the soil any nutrients released by the decay of vegetation in the autumn.

The river edge, site A. This part of the meadow is not fertilized, and because of the low levels of nutrients entering the cycle, the spring flooding, which will wash away the surface litter and its contained nutrients, the efficiency of cycling through the sheep-faeces-soil, and summer crop-winter vegetation-available (by virture of being either four depth classes comprizing the rooting

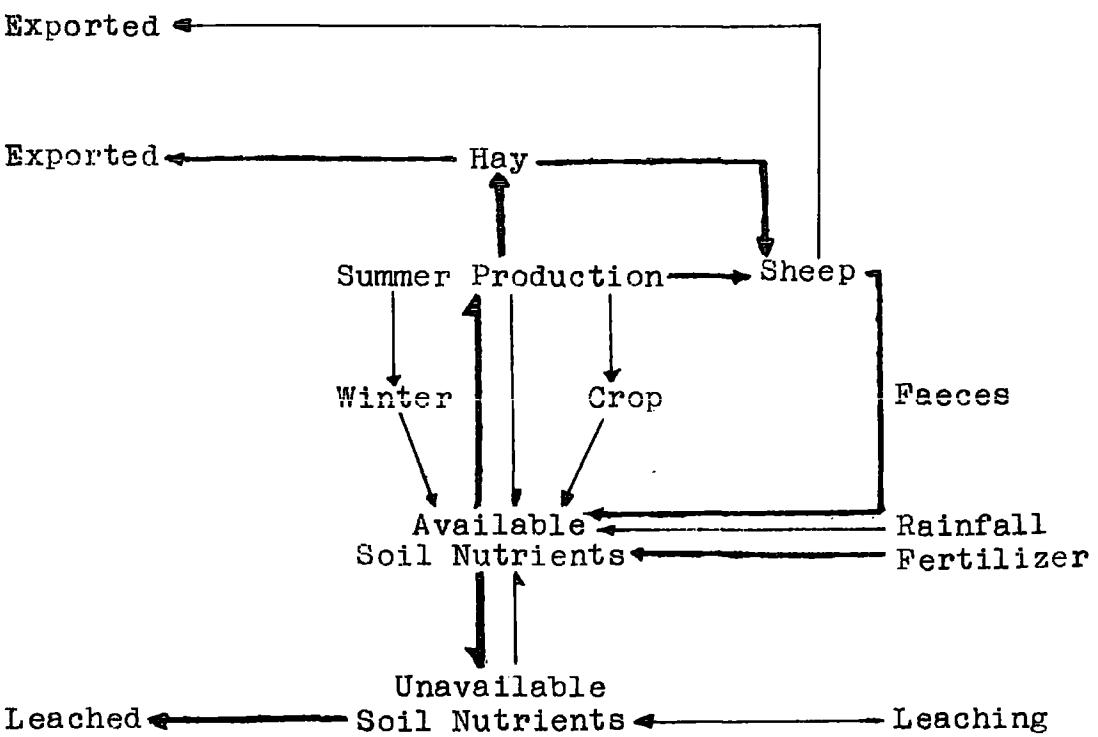
FIGURE 16.

NUTRIENT CYCLES OF EACH OF THE SITES.

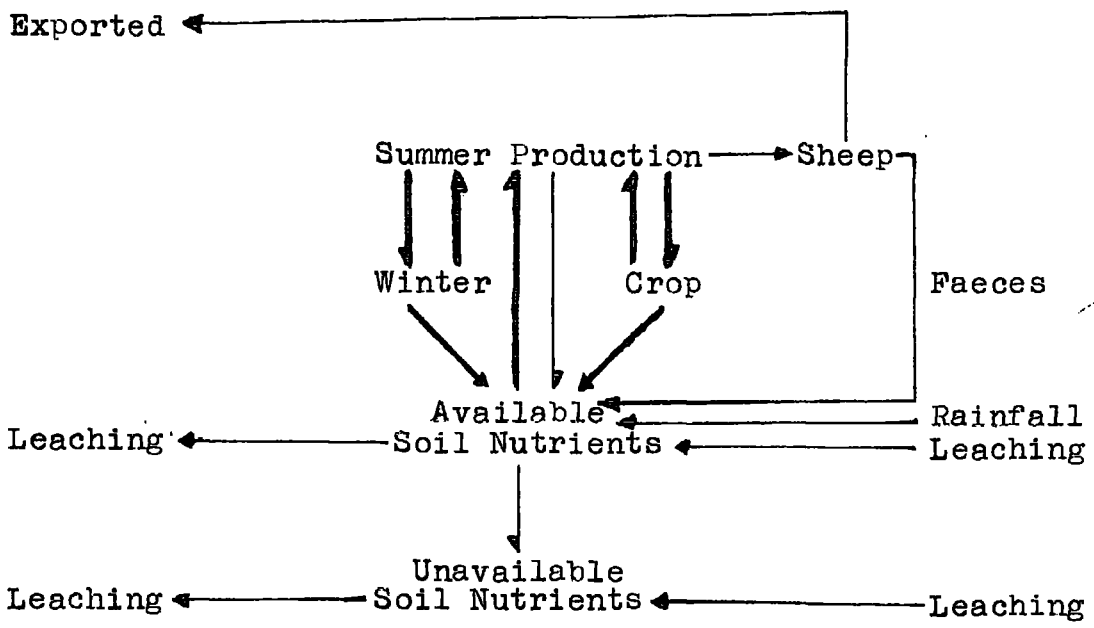
SITE A



SITE B



SITES D and F.


Exported
Summer Production
Sheep
Winter
Crop
Faeces
Available
Soil Nutrients
Rainfall
Leaching
Leaching
Unavailable
Soil Nutrients
Leaching
Leaching

zone) soil nutrients, is critical. The sheep cycling is probably quite efficient. For, when the sheep are returned to the meadow in the autumn the vegetation in this area, which is not cut for hay, would be highly palatable to them especially as they have been feeding on the poor vegetation of the Fells. Assuming the sheep tend to defaecate in areas where they are grazing, this vegetation would be consumed and the mineral matter returned to the soil very soon after the return of the sheep, and the faeces would have all autumn and winter to decompose into the soil before the spring floods.

The fact that nutrients and the surface litter will be lost in the spring floods has undoubtedly effected the vegetation of this area, and adaptions to these conditions would be expected in the flora.

Site B is, due to its management, a highly artificial system with an annual input of the most important nutrients in the form of fertilizer. It is the most productive of the site, the vegetation is grazed by sheep, and cut for hay. Although some of the nutrients will be exported in these forms, some of them will be returned to the soil in faeces, as the hay is used as over-winter fodder for the sheep which are kept on the meadow. The free draining nature of the soil, and its shallow depth would indicate that leaching is the major form of loss from the system and the low levels of potassium found in the soil at this site, before fertilization, indicate a large loss by this

by this pathway. Because of this rapid leaching of nutrients the timing of the fertilizer application would appear critical.

Sites D and F, can be considered together for these areas are not fertilized, nor are they cut for hay, they are subject to low grazing pressures, and hence cycling and export are comparitivly low. The low level of many of the nutrients in the upper strata have been explained by vertical and lateral leaching. It would appear therefore, that efficient recycling of the nutrients in the standing crop is required.

THE PLANT TISSUE ANALYSES.

When the results of the analyses for sodium, calcium, magnesium, potassium and phosphorus (unfortunatly no time was available for a nitrogen determination) are expressed as grams per square metre, Table 6, the quantities of nutrients in the plant tissue at the beginning, and at the end of the growing season can be seen, and the difference (flux) between the two calculated.

This flux can then be expressed as a percentage of the nutrients present in the plant tissue of one square metre at the end of the growing season Table 7. This gives an indication of the proportions of nutrients taken up from the soil by the summer production at each of the sites.

Thus, where this percentage is low it can be assumed that most of the nutrients for summer production come from nutrients stored in the over-winter crop, and it can be seen that there is twice as much phosphorus taken up from the soil by the summer production at site B, as there is from sites A,D & F. When these percentages are compared with the results of the soil analyses, Table 3, it can be seen that they echo the levels of nutrients in the soils of each site.

For calcium, magnesium and potassium the figures show a similar trend, with the levels taken up from the soil echoing the quantities of these elements found in

the rooting zone. For sodium the position is less clear but the supply of this element in rainfall is high (2.4 gms. / m^2) and its role in metabolism is as yet doubtfull, and so its uptake may not be of great significance.

Thus, it appears that when an element is in short supply in the soil the vegetation tends to be independant of the soil for the supply of this element, as is clearly seen in the case of calcium.

At site F all of the nutrients in the soil are at very low levels, and from Table 7 it can be seen that in no case does the amount of a nutrient taken up by the vegetation from the soil exceed 50% of that required, and that in several case this portion is considerably less. At site D phosphorus is the element which is in the lowest quantities in the soil and the vegetation obtains only 30% of its requirements from this source. For calcium and magnesium the low soil quantities are again reflected in the uptake by the vegetation although, sodium is taken up in disproportionate amounts. Site B takes 80% of its phosphorus from the soil and only in the case of magnesium, which is not applied as fertilizer, and is in only low quantities in the rainfall, does the vegetation rely on its own resources more than the soil as a source of supply. Site A in most cases takes from the soil about half of its nutrient requirements, while phosphorus which again is at low concentrations in the soil has a reduced uptake from

this source.

These data refer only to the above ground vegetation and since many plants have their perenating organs below soil level it is probable that much of the nutrient uptake, which has been classed as 'from the soil', will in fact be from these under ground parts which were not analysed. This may be of special importance at site A where the spring flooding will make the storage of nutrients above ground precarious.

THE PHYTOMETRIC LABORATORY STUDY.

In the growth experiments (Appendix 1, Section D) three crop plants were grown in soils from each of the sites, and a culture medium of known composition. The results given in Table 8 show that, under conditions of similar microclimate and a more even soil aeration, the crops in soil from site B have significantly better performance when compared to those grown in any of the other soils.

These plants however, do not fare as well as those grown in the culture medium, and it is possible that a nitrate deficiency occurs in this soil. This was indicated by a lack of colour formation when the diphenylamine solution, Lunt et al. (1950), used in the soil analysis, was placed on freshly cut portions of stems of barley which had been grown in this soil.

The growth of the crops in the soils from the other sites was significantly less. At site A this retardation is, in the case of barley and carrots, enough to reduce growth to one half and one quarter of that of site B, while the tomatoes were retarded to one tenth of their growth in soils from site B. It is indicated that the retardation is due to lack of phosphorus, and a test for phosphorus in the tomato plants grown in this soil gave a negative result. Nitrate does not appear to be the limiting nutrient at this site as both the carrots and

tomatoes grown in this soil had a dark green leaf colour indicative of an adequate nitrate supply.

The soils of site D and F gave, for all crops, severely and significantly, lower growth than was found at any of the other sites, and it can be seen from the results of the soil phosphorus and nitrate analyses that both of these soils are exceedingly low in both of these nutrients. Each of the crops grown in soil from site D have developed less well than those in soil from site F but these differences cannot be proved statistically significant.

The results of these experiments show that the productivity of the crop plants vary greatly, and that these differences are statistically significant, according to the soil in which they were grown. These differences can be explained mainly on the basis of the varying content of phosphorus and/or nitrate in the soil.

However, these differences in the productivity of the plants in the laboratory experiment contrast markedly with the situation in the natural plant communities, for, as can be seen in Table 5, the net production of the four sites A,B,D & F is very similar. It is therefore indicated that the plant species of the nutrient poor sites are adapted to these low concentrations, and evidence has been presented which suggests that one of the major adaptions is the development of efficient nutrient cycling and recycling systems.

THE ON-SITE VEGETATION.

When the floristic composition of the vegetation of each of the sites is expressed on a presence or absence basis, Table 9, it is clear that the vegetation of the three sites where nutrients would tend to be removed without replacement (A,D & F.) differs markedly from the fertilized site B. Sites A and D & F which have different over-winter standing crops, soil parent material, and nutrient export pathways, are also clearly separated. The differences in vegetation between site D and F are also distinct, and here the different types of soil material, the differences in slope, times of grazing pressure, and differences in soil chemistry are clear enough to account for the difference in the vegetation.

These fundemental differences between the sites are reflected in the species composition of each site, for out of the 85 species found in the experimental area only four are common to all sites.

Site A, on the river bank, supports a flora rich in species and this area can be regarded as unstable, with the floods washing away vegetation and litter material preventing the soil from stabilizing. Thus, the plant community is kept open allowing colonisation by adventive species. The net productivity is the lowest of any site, and is noteable that this site containes five of the 'Teesdale Rarities' whose presence may, in part, be attributed to this instablity.

Site B, in the centre of the meadow contains a restricted range of the species found at site A, and the increased stablity of this site is also reflected in its high productivity, which may have caused the loss of many of the river bank species due to their lack of competitive vigour in a productive community. It is noteable that the 'Teesdale Rarities' do not occur at this site, and Bellamy et al. (1969) suggest that these species are restricted to areas with productivities of less than 150 gms. dry weight / square metre / annum.

Site D contains few species unique to itself, it has several of the species found in the dry areas of the adjacent meadow, and others more typical of the nutrient poor, and waterlogged hillside.

Site F has a noteably resticted Angiosperm flora, and is rich in species of the rushes and sedges which are also found at site D. In this area there is a large increase in the importance of Bryophytes in the vegetation.

CONCLUSIONS.

From the data presented above four ecologicaly different areas of Cronkley Farm have been determined: site A, situated on the river bank, is subject to flooding which keeps the soil, and hence the floristically rich plant community its supports, unstable. There are indications of a soil phosphorus deficiency, although the flora appears to overcome this by a system of recycling within the plant tissue, and hence a moderatly high productivity is maintained.

Site B is the meadow of the farm, and like site A the soil here is alluvial. The plant communities here are poor in species, and have a high productivity which is maintained by regular fertilization, and cut for winter fodder.

Site D is situated at the area where the hillside begins to break from the level ground of the meadow. The area forms a catchment for the ground waters of the hillside and is continually waterlogged. The soil is clay overlying alluvial material similar to that found beneath the meadow soil. Above this clay there is a layer rich in organic matter, while in the vicinity there are peat deposits. The soil here is poor in nutrients although the overwintering standing crop is high, indicating that recycling of nutrients may account for the productivity which is at a similar level as the other sites.

Site F is situated in the out-by-land and is typical of the area which forms the bulk of the farm. The soil consists of boulder clay above which is a layer of material rich in organic matter, through which most of the downslope flow of drainage water takes place. This upper layer is poor in nutrients, while there are considerable quantities deep in the boulder clay out of reach of the plants. The vegetation of this area has the highest over-winter standing crop, and its production, despite the low nutrient levels, is on a par with that of the other sites. It is from this site that evidence of mineral recycling within the standing crop is strongest, cf. Goodman and Perkins (1959).

The limits imposed upon the farmer by site A are few, the natural vegetation is productive and palatable to sheep, and since it is so close to the river it is unsuitable for mechanised farming.

Site B is the area which is exploited to the maximum to produce over-winter fodder, the soil is 'good', and the levels of nutrients in it have only to be maintained by the regular addition of fertilizer to keep the productivity of the vegetation constant. However, the problem of vertical leaching is great and the timing of the fertilizer application must coincide with the beginning of the growing season, to prevent the nutrients in the fertilizer being too rapidly washed from the soil.

Site D is an area which is of very little economic value, it is waterlogged throughout the year, and the terrain is uneven and marshy to an extent which would prevent the use of farm machinary. The vegetation is unpalatable to sheep, and shows little evidence of grazing damage. Its productivity is high but is maintained only by the recycling of nutrients within the plant tissue, as was shown by the poor growth of the crop plants grown in this soil.

Site F is again waterlogged throughout the year, and while the productivity of the natural vegetation is high it is suitable only as rough pasture. Since the levels of nutrients in the soil are low, recycling within the vegetation is considered the major factor maintaining productivity.

Because of this, most of the soil nutrients are within the vegetation and resistant to leaching, thus, if an attempt was made to destroy this vegetation and improve the pasture by reseeding, these nutrients would be rapidly lost from the soil and poor productivity, similar to that in the laboratory experiment would be found.

The only methods which could forseeably be used to improve this pasture would have to be spread over a considerable period of time, to allow the required plant community to develop slowly. A suitable plan of management would be as follows. Drainage ditches should be dug

across the slope to reduce the effect of nutrient leaching by the down-slope drainage, after several years fertilizer should be applied at the beginning of the growing season and continued annually.

This should slowly allow the development of the more economically useful vegetation, without causing a complete loss of nutrients which would occur if destruction of the existing plant communities were to take place.

Since this study has been more extensive than intensive, there has been a need to generalize and hypothesise on what is often circumstantial evidence, and, as many of the suggestions put forward have far reaching implications in ecologial theory, much more work is required on several of the points which have been raised.

This work might be undertaken as outlined below: A more thorough study of the plant communities where recycling of nutrients within the vegetation is suggested. This would have to extend over at least one year. Regular cropping, weighing and analysis of; soil, surface vegetation (which should be separated into dead, previous seasons live growth, and current production), and below ground plant tissue, should be attempted.

The effects of the addition of fertilizers to the natural plant communities (especially those of the

nutrient poor areas) should be determined, again with the use of croppings and plant tissue analysis.

Further phytometric studies of the soils should be undertaken with the use of nutrient additives. At first crop plants might be used, and then perhaps members of natural plant communities.

Since it has been suggested that substrate instability due to removal of surface litter by floods is responsible for the presence of some of the 'Teesdale Rarities' at site A it is possible that similar substrate instability, caused by wind, rain, frost or ground water erosion, may account for the low productivity, Bellamy et al. (1969), of other plant communities where the 'Teesdale Rarities' are found. And the hypothesis that natural erosion has caused stablization of early seral stages should be investigated at other sites containing species of 'Teesdale Rarity'.

Pigott in his classic paper on Upper Teesdale suggested that the vegetation of the meadows must have been directly derived from the forest communities which existed in the area in Boreal times. Palynological evidence now being gathered,Turner (in press),shows that the lower slopes and river areas were dominated by herb rich Oak/Alder forest with Birch and Juniper on the drier outcrops. These forest communities must therefore, have been self sufficient in as far as their nutrients.

The freely draining alluvial soils of the riverside have probably supported rich meadow communities since the advent of man to the catchment. While the poorly draining soils of the hillsides have, since the destruction of the forest vegetation and its store of nutrients, developed a herb community which is again dependant on efficient nutrient recycling. Thus, the forest clearance and its disturbance of the ecosystem may mark the first step in the degradation to the blanket mire ecosystems which are now the dominant feature of the Pennines.

SUMMARY.

1) The soil types of Cronkley Farm, Upper Teesdale, are described.
2) These soils, their vegetation, and water samples from the rain, drainage, and river water were analysed to determine their chemical content.
3) The quantities of plant nutrients applied as fertilizer were determined.
4) Nutrient cycles for the four sites were constructed.
5) The productivity of the natural vegetation of the four sites was determined.
6) The productivity of three crop plants when grown in soil from each of the sites was determined in a laboratory experiment.
7) The plant species found at each of the sites were recorded.
8) It is suggested that nutrient recycling within the standing crop enables a high productivity to be maintained in nutrient poor areas.
9) Suggestions as to the limits of the farming potential of the area are put forward.
10) An hypothesis for the existance of some of the 'Teesdale Rarities' in the river bank community is put forward.

ACKNOWLEDGEMENT

Although I should like to thank by name everyone who has helped and encouraged me while this work was in progress; space is against me, so I will just say that they have not been forgotten, and thank you.

However, special thanks are due to my supervisor Dr. Dave Bellamy for his helpfull advice throughout this work, my wife Rita, not only for her tolerance and encouragement, but for typing the drafts of this dissertation, Miss Sandra Nye for providing transport to and from the study area, the Nature Conservancy for permission to work in the Upper Teesdale National Nature Reserve, and finally to the Natural Environment Research Council whose Advanced Course Studentship I was receiving during the time when this work was carried out.

Brian R. Sinclair.

30th. August 1969.

APPENDIX 1

METHODS.

Section A) SOIL ANALYSIS.

Before commencing the description of the methods used in the soil chemical analyses some consideration will be given to the form in which these results are presented.

In the literature results of soil chemical analyses are presented in very many different forms, the result unit being: ugrams, mgrams, grams, kilograms, mequivilents, equivilents, part, pounds, per cent. While the sample unit being: grams, 100 grams, square metres, hectares, acres, millions of: soil, fresh soil, dry soil, air dried soil, oven dried soil, from each: horizon, depth or root zone. The exact combination of these units apparently being left to the whim of the experimenter.

In this work I have chosen to express the results of the chemical analyses as grams per square metre of each depth class. The weight of soil in a square metre of each of these depth classes was measured by weighing soil cores of known volume and converting the results to the weight of soil in a square metre at that depth. This enables the construction of nutrient budgets since the results describe the chemical content of a volume of soil (100 cms. x 100 cms. x 8cms.), and not only a weight (100 grams dry weight).

The expression of results in the latter form is unfortunate, as equal volumes of the soil from different sites may have vastly different water contents, but almost the same fresh weight. So that the weight of a

waterlogged soil, with a 70 per cent water content (eg. sites D,E and F), which would have to be dried to produce a unit of dry weight would be twice that needed to produce the same dry weight as a soil containing only 35 per cent water (eg. site A).

Because of this results expressed as per grams of a given dry weight of soil cannot (unless data on the water content of the soil and the weight of fresh soil in a given volume are presented) be converted accuratly to data in the form shown in nutrient cycles, and in many instances the opportunity of comparing my results to those of other workers has been lost.

SOIL WATER CONTENT.

This was determined from field moist soil taken from the area on 28th November 1968. Samples from each site and depth class were weighed, and then dried to constant weight in an oven at 110°C. The percentage of water in the sample was calculated. This data is presented in Fig. 3 and Table 1.

SOIL ORGANIC MATTER CONTENT.

The soil organic matter content was determined by the low temperature ignition method of Jackson (1958) (after Mitchell 1932). The dried soil from the water content determination was heated for seven hours in a muffle furnace at 400°C. The material left at the end of this time was weighed and the percentage of organic matter was calculated. This data is presented in Fig. 4 and Table 1.

SOIL pH VALUE.

For the determination of the soil pH 10 gms. of fresh soil from each depth class of sites A,B,D & F, were placed in 50 ml. beakers and to it added 25 mls. of distilled water, giving a soil: water ratio of 1: 2.5 (Soil Reaction Committee 1930). These soil suspensions were left for 30 minutes with regular stirring. The pH

value was then determined by the use of an Electronic Instruments Ltd., Model 23A Direct Reading pH metre. The soil suspension being stirred immediately before the immersion of the electrode. The results are presented in Table 2.

SOIL WATER FLOW.

To determine the direction and speed of movement of the run-off water in the soil 250 ml. of a concentrated solution of sodium chlorate weed killer (75 gms. made up to 250 mls. with distilled water) were applied via a two inch diameter hole to the soil at each of the four sites. After six days the area of dead and dying vegetation was mapped and the results are shown in Fig. 6.

OXYGEN STATUS.

The oxygen status of the soil was estimated by a field test which determine the 'state' of the iron salts in the soil. The method used for this determination was taken from Jackson (1958) after Hoffer (1945).

A 9 cms. diameter filter paper was folded across its diameter and two pinches of soil placed at opposite ends of the fold. (This soil was taken from the ground immediately before the test took place so that it was not too long in contact with the air). Two drops of

1 N.HCl were added to each of the soil samples, the paper folded over, and moisture squeezed through the filter paper. To the wet area on the left one drop of potassium thiocyanate solution was added while to the area on the right one drop of potassium ferricyanide solution was added. The appearance of a red colour at the KCNS treated area indicates the presence of ferric iron (good oxygen supply), while the appearance of a blue colour at the $K_3Fe(CN)_6$ treated area indicates ferrous iron (poor oxygen supply). When both red and blue colours appear the presence of both ferric and ferrous iron is indicated, and the oxygen deficiency is classed as not severe. The results of this investigation are presented in Fig. 7.

TOTAL ALKALINITY.

The main forms of potential alkalinity in the soil are the compounds calcium, and magnesium carbonate. In this method they are reacted with dilute hydrochroric acid which is then titrated against sodium hydroxide of known normality.

10 gms. of oven dried soil from each depth class of sites A,B,D & F, were added to 25 mls. of exactly N/10 HCl, left for one hour with periodic stirring. Then two 10 ml. aliquots of the solution were pipetted off and titrated against N/10 NaOH with a methyl-orange

indicator. The mean of the two titres was found and the results are shown in Fig. 8 and given in Table 3 expressed as gms. of carbonate per square metre.

SOIL POTASSIUM, SODIUM, CALCIUM AND MAGNESIUM.

The exchangable and soluble forms of these cations can be extracted from the soil using many different extractant concentrations of extractants, and soil to extractant ratios:-

N Ammonium nitrate (E.E.L. method for magnesium).
N Ammonium chloride (E.E.L. method for calcium).
N Ammonium acetate (Prianishnikov 1913).
2N Ammonium acetate (Jeffries and Willis 1964).
N Acetic acid (Jackson 1958).
2N Acetic acid (Macphee and Ball 1967).

The method of extraction in this work used IN Ammonium acetate, 100 mls. extracting 10 gms. of air dried soil. Soil samples from each depth class of sites A,B,D & F, were weighed, air dried for seven days and reweighed to determine the water content. 10 ml. portions of this soil was stood over night in 25 mls. of IN Ammonium acetate solution. They were then washed into Whatman extraction thimbles in leaching funnels and leached through with a further 75 mls. of the acetate solution. The extractant was run through three times and the solution obtained was analysed by the

following methods.

POTASSIUM AND SODIUM.

The concentrations of these cations in the soil extracts were determined using an E.E.L. Mark 2 Flame photometer, and the galvanometer reading was converted to parts per million from calibration curves constructed from readings obtained from samples of known sodium and potassium concentrations. The results of these determinations are shown in Figs. 9 & 10 and Table 3 expressed as gms. of potassium and sodium per square metre.

CALCIUM AND MAGNESIUM.

The concentrations of these cations in the soil extracts were determined using an E.E.L. Model 140 Atomic Absorption Spectrophotometer. The technique followed that of David (1960) although in place of the 3,000 p.p.m. strontium chloride solution that he used to surpress interference by aluminium, phospate, and sulphate, 13,000 p.p.m. lanthanum chloride was used as this has since been recommended in E.E.L. methods for both calcium and magnesium determinations.

A calibration curve for each cation was constructed from readings given by 1 ml. samples of known concentration after the addition of an equal volumn of 13,000 p.p.m. lanthanum chloride solution, giving a

final lanthanum concentration of 6,500 p.p.m. The soil extract samples were similarly treated with lanthanum chloride and the reading given converted to part p.p.m. by reference to the calibration curve. These results were finally converted to gms. of calcium and magnesium per square metre, and these results are presented in Figs. 11 & 12 and Table 3.

PHOSPHORUS.

The phosphorus content of the soil samples was determined by a form of Deniges (1921) adaption of the molybdophosphoric blue method of Osmond (1887), and modified by methods used in the Purdue (Ohirogge 1952) rapid test for soil phospate. This method involves, as does the Purdue test, the use of ammonium molybdate in a hydrochloric acid solution to extract the soluble and acid soluble phospate from the soil. The development of the molybdophosphoric blue colour by the use of chlorostannous acid reductant solution, and the measurement of the density of colour so formed.

1 gm. samples of air dried soils from each depth class of the sites A,B,D & F, were placed in glass specimen tubes, and 10 mls. of the acid molybdate reagent which was prepared by the dissolution of 8 gms. of ammonium molybdate in 200 mls. of distilled water, and the addition to this solution of 126 mls. of

concentrated Analar hydrochloric acid in 74 mls. of distilled water. The mixture was shaken and left for 1 hour, then the liquid portion was poured into centrifuge tubes and centrifuged for 2 minutes to clear the suspension. 2 mls. of the supernatent liquid were pipetted into colourimeter tubes and a further 10 mls. of molybdate solution added. To this 2 drops of the chlorostannous acid reductant prepared by the dissolution of 12.5 gms. of Analar $SnCl_2.2H_2O$ in 25 mls. of concentrated HCl. This solution was made up to 500 mls. with freshly distilled water. The mixture in the colourimeter tubes was stoppered, shaken, and the developed colour measured immediatly in a E.E.L. colourimeter fitted with a red filter.

A calibration curve was prepared by the addition of 2 mls. of solution containing known phosphorus concentrations and 2 mls. of distilled water as a reagent blank to 10 mls. of the molybdate reagent, adding the chlorostannous acid reductant, stoppering, shakeing, and measuring the density in the colourimeter. The colourimeter readings for the samples were, with the aid of this calibration curve, converted to parts per million phosphorus, and then to gm. of phosphorus per square metre, and are displayed in this form in Fig. 13 and Table 3.

SOIL NITRATE.

The soil nitrate concentration was determined by the Morgan system rapid nitrate test, Lunt et al. (1950). In this test 1 gm. of the air dried soil from each depth class of sites A,B,D & F, was extracted with 2 mls. of 10% sodium acetate in a 3% solution of acetic acid, for half an hour. One drop of this extract is placed on a spot plate and to it added four drops of 0.05 gms. of diphenylamine in 25 mls. of concentrated sulphuric acid, after two minutes the mixture is stirred and the resultant (blue) colour compared to that formed when the reagent is added to solutions of known nitrate concentrations. The nitrate concentrations for each site and depth class are given in Fig. 14 and Table 3. expressed as grams of nitrate nitrogen per square metre.

METHODS.

Section B) WATER ANALYSIS.

WATER ANALYSIS.

Samples of water were collected in acid washed glass bottles from the River Tees, the ditch between sites C and D, and the rain.

These samples were analysed for sodium, potassium, calcium, magnesium, phosphorus and nitrate by the methods given in the previous section for the analysis of the soil extracts.

The results of the analyses are given in Table 4.

METHODS.

Section C) ANALYSIS OF PLANT MATERIAL.

SAMPLING OF PLANT MATERIAL.

Samples of the vegetation from sites A,B,D & F, were taken at the beginning of the growing season (1st May 1969), and towards its end (9th July 1969). The sampling was done in three 10 cm. by 10 cm. quadrats at each site. All of the above ground standing crop and litter was harvested. This material was then dried in an oven at 110°C and the weight of dry plant material in 1 square metre calculated. These data are presented in Table. 5.

DIGESTION OF PLANT MATERIAL.

The dry plant material from each sample was ground, and 1 gm. samples digested using the wet oxidation method described by Jeffries and Willis (1964), but with a change in the proportions of the acids used, as Nye (Pers. Comm.) has indicated that a more thorough and rapid digestion is obtained. Volumns of acids used to digest 1 gm. of plant tissue.

Jeffries and Willis (1964)	Benham
20 mls. concentrated HNO_3.	20 mls.
5 mls. concentrated HCl.	20 mls.
5 mls. 60% $HClO_4$.	10 mls.

These acids were added to the plant material in

250 ml. conical flasks, and the mixture heated on a sand bath in a fume cupboard for six hours, with the addition of distilled water when required to prevent evaporation to dryness. At the end of the six hours the solution was cooled and diluted with distilled water to about 200 mls. It was then filtered, to remove undigested silica, into 250 ml. volumetric flasks, and made up to 250 mls. with distilled water.

ANALYSIS OF THE PLANT TISSUE DIGESTS.

The samples were then analysed for calcium, magnesium (atomic absorption spectrophotometer), sodium, potassium (flame photometer), and phosphorus (molybdophosphoric blue), using the techniques described in the section on soil analysis.

The results of these determinations were, by multiplication by the dry weight of plant material in one square metre at each sampling, converted to grams of nutrient per square metre and are given in Table 6.

METHODS.

Section D) PLANT CULTURE EXPERIMENTS.

CULTURE METHODS.

To determine, under controled conditions, the value of the soils from sites A,B,D & F, as a medium for plant growth, quantities of soil from the depth classes a and b of each site were brought back to the laboratory. There the soil was put into five inch, distilled water washed, plastic flower pots. A lower layer of depth class b, soil was covered by a three inch layer of depth class a, soil. Control pots were filled with distilled water washed vermiculite.

The pots were sown with seeds of carrot, variety Early Nantes, the tomato variety Ailsa Craig, and barley grown on the mixed section of the Haughley Experimental Farm. Four pots of soil from each site were sown with each crop, plus four control pots of each crop. The tomato seeds were sown six per pot, while the seeds of barley, and carrot in what was judged to be an even manner. The seeds were then covered with a layer of distilled water washed vermiculite, and labelled as to site or control.

The pots were then placed in a greenhouse, randomized as to site. The pots containing soil were watered regularly with distilled water and the control pots with a complete culture solution formulated from Rieley (1967) after that of Hewitt (1952). This culture solution contained:-

Calcium	100 p.p.m.
Potassium	78 p.p.m.
Sulphur	48 p.p.m.
Nitrogen	40 p.p.m.
Phosphorus	40 p.p.m.
Magnesium	38 p.p.m.
Sodium	30 p.p.m.
Iron	5.6 p.p.m.
Manganese	1.1 p.p.m.
Copper	0.13 p.p.m.
Molybdenum	0.02 p.p.m.

HARVESTING.

After four weeks the six tallest tillers of barley from each pot were harvested at soil level, oven dried, and weighed. After a further two weeks the four largest tomato plants from each pot, and all of the carrot plants from each pot were similarly cropped, dried, and weighed. The results of these experiments are given in Table 8.

APPENDIX 2

TABLE 1.

VARIATION IN WATER AND ORGANIC MATTER CONTENT WITH DEPTH IN SOIL SAMPLES FROM SIX SITES IN CRONKLEY PASTURE.

SITE A

Sample depth	Fresh wt. (gms.)	Dry wt. (gms.)	Water content (% fresh) (wt.)	Ash wt. (gms.)	Organic matter (% dry) (wt.)
0- 8cms.	28.0	18.2	35	16.5	9.3
8-16cms.	29.0	21.3	30	19.9	6.6
16-24cms.	28.5	21.2	26	20.1	6.1
24-32cms.	34.5	25.5	26	24.0	5.9
32-40cms.	20.9	15.6	25	14.8	5.1
40-48cms.	30.7	23.6	23	22.6	4.2
48-56cms.	28.4	21.0	26	19.9	5.2
56-64cms.	30.0	21.6	28	20.4	5.5

SITE B

Sample depth	Fresh wt. (gms.)	Dry wt. (gms.)	Water content (% fresh) (wt.)	Ash wt. (gms.)	Organic matter (% dry) (wt.)
0- 8cms.	16.4	8.2	50	7.0	17.0
8-16cms.	16.4	11.8	28	11.1	6.3
16-24cms.	17.0	13.1	23	12.5	5.0
24-32cms.	18.6	14.2	24	13.6	4.0

SITE C

Sample depth	Fresh wt. (gms.)	Dry wt. (gms.)	Water content (% fresh) (wt.)	Ash wt. (gms.)	Organic matter (% dry) (wt.)
0- 8cms.	36.1	18.0	50	15.5	14.0
8-16cms.	19.0	13.4	35	12.5	6.7
16-24cms.	21.9	15.8	32	14.8	6.3
24-32cms.	14.4	10.2	29	9.6	5.9
32-40cms.	23.0	16.7	27	15.7	6.0

SITE D

Sample depth	Fresh wt. (gms.)	Dry wt. (gms.)	Water content (% fresh) (wt.)	Ash wt. (gms.)	Organic matter (% dry) (wt.)
0- 8cms.	20.6	7.8	62	6.0	23.1
8-16cms.	17.0	7.7	55	6.3	18.2
16-24cms.	24.2	12.2	50	10.5	13.9
24-32cms.	23.3	13.4	42	12.4	7.5
32-40cms.	21.1	12.5	41	11.4	8.8
40-48cms.	28.5	17.9	37	16.8	6.1

SITE E

Sample depth	Fresh wt. (gms.)	Dry wt. (gms.)	Water content (% fresh) (wt.)	Ash wt. (gms.)	Organic matter (% dry) (wt.)
0- 8cms.	18.2	6.0	67	4.1	31
8-16cms.	19.5	9.3	52	7.8	16
16-24cms.	18.9	9.0	52	7.7	14
24-32cms.	19.0	10.1	47	8.9	12
32-40cms.	23.0	15.5	33	14.4	7
40-48cms.	24.9	18.5	26	17.7	4
48-56cms.	32.0	23.5	27	22.5	4

SITE F

Sample depth	Fresh wt. (gms.)	Dry wt. (gms.)	Water content (% fresh) (wt.)	Ash wt. (gms.)	Organic matter (% dry) (wt.)
0- 8cms.	13.5	3.9	71	2.5	36
8-16cms.	16.3	6.2	62	5.0	19
16-24cms.	15.4	6.4	58	5.2	19
24-32cms.	15.9	8.8	45	8.0	9
32-40cms.	15.2	11.2	26	10.9	3
40-48cms.	14.2	10.5	26	10.2	3

TABLE 2. RESULTS OF pH MEASUREMENTS.

Depth class	pH value Site A	pH value Site B	pH value Site D	pH value Site F
a	6.6	6.8	5.0	5.6
b	6.6	6.8	5.3	5.6
c	6.6	6.5	5.3	5.9
d	6.5	6.4	5.3	5.9
e	6.5	6.4	5.3	6.4
f	6.4		5.4	6.6
g	6.3			6.9
h	6.3			6.9
i	6.6			

TABLE 3 RESULTS OF SOIL ANALYSES

SITE A

Depth Class	Carbonate gms./m^2.	Potassium gms./m^2.	Sodium gms./m^2.	Calcium gms./m^2.	Magnesium gms./m^2.	Phosphorous gms./m^2.	Nitrate Nitrogen gms./m^2.
a	324.77	4.19	3.97	82.27	15.16	0.65	0.51
b	326.45	2.49	4.66	83.94	16.71	0.66	0.39
c	394.49	2.46	4.11	119.96	19.72	0.38	0.33
d	394.49	1.81	3.70	88.74	14.79	0.44	0.25
e	474.67	1.66	3.54	105.76	19.57	0.35	0.25
f	512.97	1.97	3.85	137.65	24.79	0.26	0.17
g	468.34	1.97	3.90	130.64	22.18	0.23	0.16
h	311.78	2.40	3.60	106.33	19.59	0.40	0.32
i	65.95	0.32	0.60	13.00	2.50	0.22	0.12

SITE B

Depth Class	Carbonate gms./m^2.	Potassium gms./m^2.	Sodium gms./m^2.	Calcium gms./m^2.	Magnesium gms./m^2.	Phosphorous gms./m^2.	Nitrate Nitrogen gms./m^2.
a	429.95	2.71	3.03	95.72	7.68	11.32	1.54
b	375.89	2.80	3.46	91.40	8.11	0.99	0.74
c	354.71	2.44	4.53	70.94	12.61	0.37	0.55
d	280.08	2.18	4.08	51.35	14.00	0.27	0.47
e	46.68	0.52	1.35	9.80	2.10	0.17	0.10

SITE D

Depth Class	Carbonate gms./m^2.	Potassium gms./m^2.	Sodium gms./m^2.	Calcium gms./m^2.	Magnesium gms./m^2.	Phosphorous gms./m^2.	Nitrate Nitrogen gms./m^2.
a	162.11	3.80	3.46	27.24	9.29	0.07	0.17
b	167.62	2.51	3.20	32.25	7.17	0.06	0.20
c	221.85	1.59	2.84	36.40	3.98	0.03	0.17
d	237.55	1.45	3.13	42.23	3.30	0.02	0.20
e	231.56	1.48	3.02	51.01	3.36	0.08	0.20
f	279.53	1.58	3.76	47.30	5.02	0.88	0.14

SITE F

Depth Class	Carbonate gms./m^2.	Potassium gms./m^2.	Sodium gms./m^2.	Calcium gms./m^2.	Magnesium gms./m^2.	Phosphorous gms./m^2.	Nitrate Nitrogen gms./m^2.
a	213.63	4.07	3.63	18.02	6.68	0.12	0.20
b	274.21	2.36	4.66	20.18	7.24	0.10	0.23
c	277.82	0.97	2.42	20.63	5.05	0.02	0.21
d	264.59	1.32	3.44	31.97	6.06	0.01	0.22
e	367.12	2.22	4.26	64.52	11.12	0.12	0.23
f	389.37	2.45	4.45	65.26	11.87	0.57	0.24
g	433.86	2.67	4.82	78.62	14.09	0.62	0.22
h	456.11	2.67	4.45	92.71	17.80	0.85	0.22

TABLE 4. RESULTS OF THE WATER ANALYSES.

	Rain Water	Ditch Water	River Water
Nitrate Nitrogen: p.p.m.	0.10	0.5	1.0
Sodium: p.p.m.	1.9	5.0	2.8
Calcium: p.p.m.	0.3	16.5	15.5
Magnesium: p.p.m.	0.2	5.25	2.5
Potassium: p.p.m.	0.2	0.15	0.3
Phosphorus: p.p.m.	0.002	Trace	0.125

TABLE 5.

DRY WEIGHT (grams) OF VEGETATION PER SQUARE METRE.

	Site A	Site B	Site D	Site F
May	260	350	480	790
July	407	540	633	965
Produced	147	190	153	175

TABLE 6.

RESULTS OF PLANT TISSUE ANALYSIS

(Grams / square metre).

		Site A	Site B	Site D	Site F
Sodium	May	0.18	0.26	0.24	0.69
	July	0.36	2.23	1.11	1.08
	Flux	0.18	1.97	0.87	0.39
Potassium	May	1.84	3.06	2.61	3.16
	July	4.68	6.51	5.70	6.03
	Flux	2.84	3.45	3.09	2.87
Magnesium	May	0.49	0.74	0.60	1.04
	July	1.07	1.62	1.14	1.51
	Flux	0.58	0.58	0.54	0.47
Calcium	May	1.62	2.10	1.56	3.35
	July	3.56	5.33	2.69	3.62
	Flux	1.94	3.23	1.13	0.27
Phosphorus	May	0.23	0.47	0.40	0.41
	July	0.38	1.70	0.57	0.64
	Flux	0.15	1.23	0.17	0.23

TABLE 7.

NUTRIENT FLUX AS A PERCENTAGE OF NUTRIENT IN SUMMER STANDING CROP.

	Site A	Site B	Site D	Site F
Phosphorus	42%	80%	30%	35%
Calcium	52%	61%	42%	7%
Magnesium	54%	30%	48%	31%
Potassium	61%	53%	55%	47%
Sodium	50%	88%	80%	36%

Dry Weight (mgrams) Of Six Barley Tillers.

	Site A Soil	Site B Soil	Site D Soil	Site F Soil	Control
Pot 1	190	460	200	180	640
Pot 2	200	530	190	190	830
Pot 3	300	680	210	200	770
Pot 4	210	500	190	230	780
Mean dry weight of 6 plants	225	545	197	200	755
Standard Deviation	±44	±81	±16	±19	±70

Dry Weight (mgrams) of Ten Carrot Plants.

	Site A Soil	Site B Soil	Site D Soil	Site F Soil	Control
Pot 1	59	266	30	45	244
Pot 2	55	195	26	32	154
Pot 3	61	218	31	31	286
Pot 4	56	175	32	35	220
Mean dry weight of 10 plants	58	213	30	36	226
Standard Deviation	±3	±37	±3	±4	±48

TABLE 8.

RESULTS OF THE GROWTH EXPERIMENTS.

Dry Weight (mgrams) Of Four Tomato Plants.

	Site A Soil	Site B Soil	Site D Soil	Site F Soil	Control
Pot 1	45	418	22	31	767
Pot 2	61	503	21	22	858
Pot 3	42	316	32	33	811
Pot 4	23	477	21	34	824
Mean dry weight of 4 plants	43	428	24	30	815
Standard Deviation	±13	±75	±4	±5	±33

Taraxacum palustre			X	
Trifolium repens	X	X	X	X
Trifolium pratense	X	X		
Trisetum flavescens		X		
Trollius europaeus	X			
Valeriana dioica			X	
Veronica chamaedrys	X	X		
Vicia cracca	X	X		
Vicia sepium	X			
Viola palustris			X	X
Viola tricolor			X	

Holcus lanatus	X	X	X	X
Hypochaeris radicata			X	
Juncus acutiflorus	X		X	
Juncus asticulatus			X	X
Juncus conglomeratus				X
Juncus squarrosus			X	X
Lathyrus pratensis	X	X		
Leontodon hispidus	X			
Lotus corniculatus	X			
Luzula multiflora	X	X	X	X
Molinia caerulia			X	X
Nardus stricta				X
Pedicularis palustris			X	
Plantago lanceolata	X	X	X	
Poa annua		X		
Polygala vulgaris	X			
Polygonum viviparum	X			
Potentilla erecta			X	X
Potentilla fruticosa	X			
Prunella vulgaris				X
Primula farinosa	X			
Ranunculus arvensis	X	X		
Ranunculus sardous			X	X
Rhinanthus minor	X	X	X	
Rumex acetosa	X	X	X	
Salix phylicifolia	X			
Sanguisorba officianalis	X	X	X	
Succisa pratensis			X	

TABLE 9.

THE VEGETATION OF THE SITES.

Nomenclature of Bryophytes after Watson (1955),
of Angiosperms after Clapham, Tutin and Warburg (1964).

	Site A	Site B	Site D	Site F
Bryophytes				
Acrocladium cuspidatum		X		X
Pleurozium schreberi				X
Polytrichum commune				X
Pseudoscleropodium purum				X
Rhytidiadelphus squarrosus				X
Sphagnum rubellum				X
Thuidium tamariscinum				X
Angiosperms				
Achillea millefolium	X	X		
Achillea ptarmica	X		X	X
Agrostis canina				X
Agrostis tenuis		X		
Ajuga reptans			X	
Alchemilla glabra	X			
Alopecurus pratensis		X		
Anthoxanthum odoratum	X	X	X	
Avena fatua		X		
Bellis perennis	X	X		
Briza media	X		X	

Caltha palustris	X			
Campanula rotundifolia	X			
Carex echinata			X	X
Carex nigra	X		X	X
Carex panicea			X	X
Cerastium vulgatum		X		
Centaurea nigra	X			
Cirsium heterophyllum	X			
Cirsium palustre			X	X
Conopodium majus	X		X	
Crepis paludosa	X			
Cynosurus cristatus	X	X		
Dactylis glomerata	X	X		
Dactylorchis purpurella	X			
Deschampsia flexuosa	X		X	X
Festuca ovina			X	X
Festuca rubra	X	X	X	X
Filipendula ulmaria	X			
Galium boreale	X			
Galium cruciata	X	X		
Galium saxatile				X
Galium uliginosum	X			
Galium verum	X			
Geranium sylvaticum	X			
Geum rivale	X			
Gymnadenia conopea	X			
Helictotrichon pratense	X	X		
Heracleum sphondylium	X	X		

APPENDIX 3.

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