Soil fertility as a parameter in land evaluation of moorland, Waldridge Fell, County Durham

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SOIL FERTILITY AS A PARAMETER IN LAND EVALUATION OF MOORLAND, WALDRIDGE FELL, COUNTY DURHAM

by

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ABSTRACT

The aim of these investigations is to assess the importance of soil fertility as a parameter in land evaluation of moorland. Waldridge Fell of County Durham is chosen as a specific reference, and the thesis comprises three parts:- I. General background to the problem, II. The environment of Waldridge Fell and III. Investigations and implications.

Part I indicates the contemporary land use in Britain and its relation to the potential of moorland. The present land capability classification of County Durham and Waldridge Fell is reviewed and the approaches to the assessment of biological production in land evaluation are discussed. There follows a resumé of moorland soils, and the influence of grazing and afforestation on them.

Part II outlines the environemental background of Waldridge Fell, including a detailed description of the study site. The vegetation pattern and the correlated edaphic and biotic variables of the area are analysed in detail.

Part III consists of experimental work and its implications. Environmental monitoring, from Nov. 1970 - June 1972 was undertaken to investigate the seasonal fluctuations of soil fertility and biological yields of Calluna as affected by the weather conditions. A further assessment of different soils from the research area was undertaken in the laboratory. This leads to conclusions relating to the factors regulating productivity of Calluna in the field. The last chapter integrates soil fertility and the biological productivity assessment in land evaluation. Further analyses were carried out to test the interrelationships between the nutrient contents both in the soils and Calluna tissues, the effects of climate and the productivity of Calluna. The possibility of using soil chemical nutrients as parameters in predicting yield is also discussed.

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AIMS OF THE PRESENT STUDY

The principle of Conservation has received widespread acceptance in recent years. Man has become more aware of the importance of his natural resources (including wildlife - plants and animals) and the inevitable reaction to his own power of destruction. This has led to the development of special measures to conserve the natural environment. The functions of the Nature Conservancy for instance, are to provide scientific advice on the conservation and control of the natural flora and fauna, to establish, maintain and manage nature resources (including the maintenance of physical features of scientific interest), and to organise and develop the research and scientific services related thereto. Nature Reserves have been established since 1949 in many parts of the highlands (Darling and Morton 1972). Field laboratories have been set up, such as Moor House, for the purpose of investigating problems involved with moorlands. The contribution of conservation is two fold as suggested by Poore (1970). 1. It provides a general philosphy within which flexible policies for the use of the moorlands may be developed, avoiding over specialization or the pushing of any use to its environmental limits. 2. When the social aims of a policy have been determined it can help to plan so that these may be most effectively implemented in such a way that the potential of the area may be retained or even increased.

Thus, theoretically, there should be no conflict between forestry, grazing activities or other usage, providing that the relationships between their supporters are cordial and co-operative. In drawing up land use plans, the bringing together of a team of people to look at an area from several points of view is desirable and the study should be evaluated professionally for all possible purposes. The production and economy of the moorlands can be increased by an integrated programme of pasture improvements and afforestation. Areas best adapted to hill sheep farming which are indicated by their existing productivity, should be improved for more production, whereas areas of low productivity might be afforested. Locally, for example, within a farming area, it is ideal to improve the productivity of the best soil, while the poorer and more exposed areas could be given over to shelter belts or other uses. Shelter, provided by trees, can make a considerable contribution both to agricultural expansion and other environmental conditions - Verney (1970), for instance, commented that shelter planting might well be an economic proposition for an owner-occupier who would himself derive benefit from it. Generally speaking, the poorest and highest moorland which cannot be economically utilized or improved for production purposes, would seem to hold potential for recreational development. Many problems in moorlands will arise from the changing pattern of land use in response to changes in economics, government policies and the increasing demand for recreation.

With this background, the aim of these investigations is to assess the importance of soil fertility as a parameter in land evaluation of moorland. Waldridge Fell of County Durham is chosen as a specific reference, and the thesis comprises three parts: I, General background to the problem, II. The environment of Waldridge Fell and III. Investigations and implications.

Part I indicates the contemporary land use in the United Kingdom and its relation to the potential of moorland. The possibilities of development of moorland in view of increased biological productivity, agriculture and forestry, are discussed in detail and reclamation techniques outlined. Usages other than agriculture and forestry are also noted. The present land capability classification of County Durham and Waldridge Fell is reviewed and the factors contributing to the down-grading of land related to Waldridge Fell are discussed. Three approaches to the assessment of biological production in land evaluation are discussed as well as the source, availability and function of plant nutrients to plant growth. There follows a resumé of moorland soils, the causes of podzolization and types of podzolic soils, and the influence of grazing and afforestation on them.

Part II outlines the environmental background of Waldridge Fell, including a detailed description of the study site. The vegetation pattern and the correlated edaphic and biotic variables of the area are analysed in detail. The former includes soil texture, organic carbon content, pH, total cation exchange capacity and the contents of the three major nutrients, i.e. total nitrogen, available phosphate and exchangeable potassium. The latter , the biotic aspect, includes burning, grazing and trampling.

Part III consists of experimental work and its implications. Environmental monitoring, from November 1970 - June 1972 was undertaken to investigate the three-dimensional relationship of climate, soil and vegetation. Seasonal fluctuations of soil fertility and biological yields of *Calluna* as affected by the weather conditions were investigated. The uptake of the three major nutrients (total nitrogen, available phosphate and exchangeable potassium) by *Calluna* and the contents of the nutrients in the soils were analysed monthly. The relationships between two of the most important weather data (temperature and rainfall) and the nutrients status are quantified. A further assessment of different soils from the research area was undertaken in the laboratory. A fast growing species - *Lathyrus* spp. (pea) was used for this investigation.

This leads to conclusions relating to the factors regulating productivity of *Calluna* in the field. The last Chapter integrates soil fertility and the biological productivity assessment in land evaluation. With the data available from these investigations, further analyses were carried out to test the interrelationships between the nutrient contents both in the soils and *Calluna* tissues, the effects of climatic conditions, and the productivity of *Calluna*. The possibility of using soil chemical nutrients as parameters in predicting yield is also discussed. The main conclusions of the whole thesis is given at the end of this chapter.

C H A P T E R T W O

UPLAND LAND USE

2.1 HISTORICAL RESUMÉ

The agricultural area of Britain expanded since Saxon times to reach a maximum at the end of the nineteenth century when about 81% of the total area of England and Wales was used for agricultural production (Best 1968). A persistent decline in agricultural areas occurred during this century mainly as a result of the striking growth of competing uses for land.

The initial decline in farmed area was largely due to the onset of less prosperous conditions in agriculture and these lasted from the end of the nineteenth century until 1939. The expansion of forestry activity also had an impact on land use especially in the 1930's although later it was secondary to that of urban growth (Table 2.1).

	Percentage of total area					
	1900	1925	1939	1950	1960	1965
Agriculture	83.6	82.9	81.3	80.6	79.3	78.6
Forest and Woodland	5.1	5.1	6.2	6.4	6.8	7.5
Urban land	5.4	6.2	8.6	9.7	10.8	11.5
Land unaccounted for	5.9	5.8	3.9	3.3	3.1	2.4

Table 2.1 Changes in the major uses of land in England and Wales between 1900 and 1965 (Source: Best 1965).

Competition between agriculture and urban growth became severe after World War II with the rapid urban development, while agriculture became less important in the general economic growth. In the table, urban areas include all built-up land - housing, industry, communications and urban open spaces.

Best and Coppock (1962) calculated that the net loss of farmland to all other uses in England and Wales over the period 1900 and 1950 was about 7%, with about 80% of this loss being given over to urban areas. The extension of urban land in the future will be the result of a number of interacting factors:- population increase, economic growth and social progress. (The latter includes urban space standard and recreational requirement).

The urban growth affects agriculture in three directions: absolute area loss, land quality, and urban intrusion effects (Edwards and Wibberley 1971). What is vital is the quality of the soils taken and the location of the land being developed. In general, the implication is that it is the best agriculturel land that is being used up.

Edward and Wibberley (1971) further assessed the loss of agricultural area in terms of production potential based on the system of agricultural land classification devised by Stamp (1962) and found out that in terms of area alone agricultural land will sustain a loss of 1.0 per cent. per decade, while in terms of production potential this loss will account to almost 2.2 per cent. per decade.

It is thus important that all agricultural land should be used to its maximum productivity in order to make up for this loss. Moorlands make up some 29% of the area of Britain, much of which are only extensively used and probably not producing to their maximum capability. The following sections reveal the potential of moorlands especially the possibilities of agricultural and forestry developments in such marginal areas.

2.2 MOORLAND POTENTIAL

Out of Britain's total land area of 22.4 million hectares (56 million acres), approximately 11.6 million ha. (29 million acres) are under crops and grasses; 6.8 million ha. (17 million acres) are under moorland; 1.6 million ha. (4 million acres) are under woodland; and the remaining 2.4 million ha. (6 million acres) cover urban and residential uses (Arvill 1969).

The Land Utilisation Survey (Stamp 1962) put heathland, moorland, commons and rough hill grazing (or rough grazing) into one category. Also included in this category are all the open lands, not wooded, afforested, cultivated, or improved by ploughing or by enclosure and management. The areas of these lands have been slowly and steadily increasing in Britain over the last seventy years (Fig. 1).

The decline in the area of farm land was mainly due to the less prosperous conditions for agriculture, greater productivity on the better lands and the urban growth. The former resulted from the development of the vast grainlands of the Argentine, Australia and Canada and the consequent increase in world trade in agricultural commodities. Much of the land was put down to grass or was allowed to 'tumble to grass' and permanent pastures took the place of ploughland. At the same time, the demand of grazing area was increased because of the development of dairying and the requirement of grazing animals for food and wool. The poor quality land became agriculturally submarginal and, especially where adjacent to moorland, much land was abandoned. There was thus a progressive increase in rough grazing and the altitudinal limit of agriculture was lowered (Stamp 1962).

Moorland areas, although they have not in the past been put to their fullest productive use, undoubtedly have some potential. Stamp (1962), for instance claimed that the moorlands have a distinct part to play in the life of the nation, and he listed the principal uses as follows:-

a. grazing for animals, especially hill sheep and ponies.

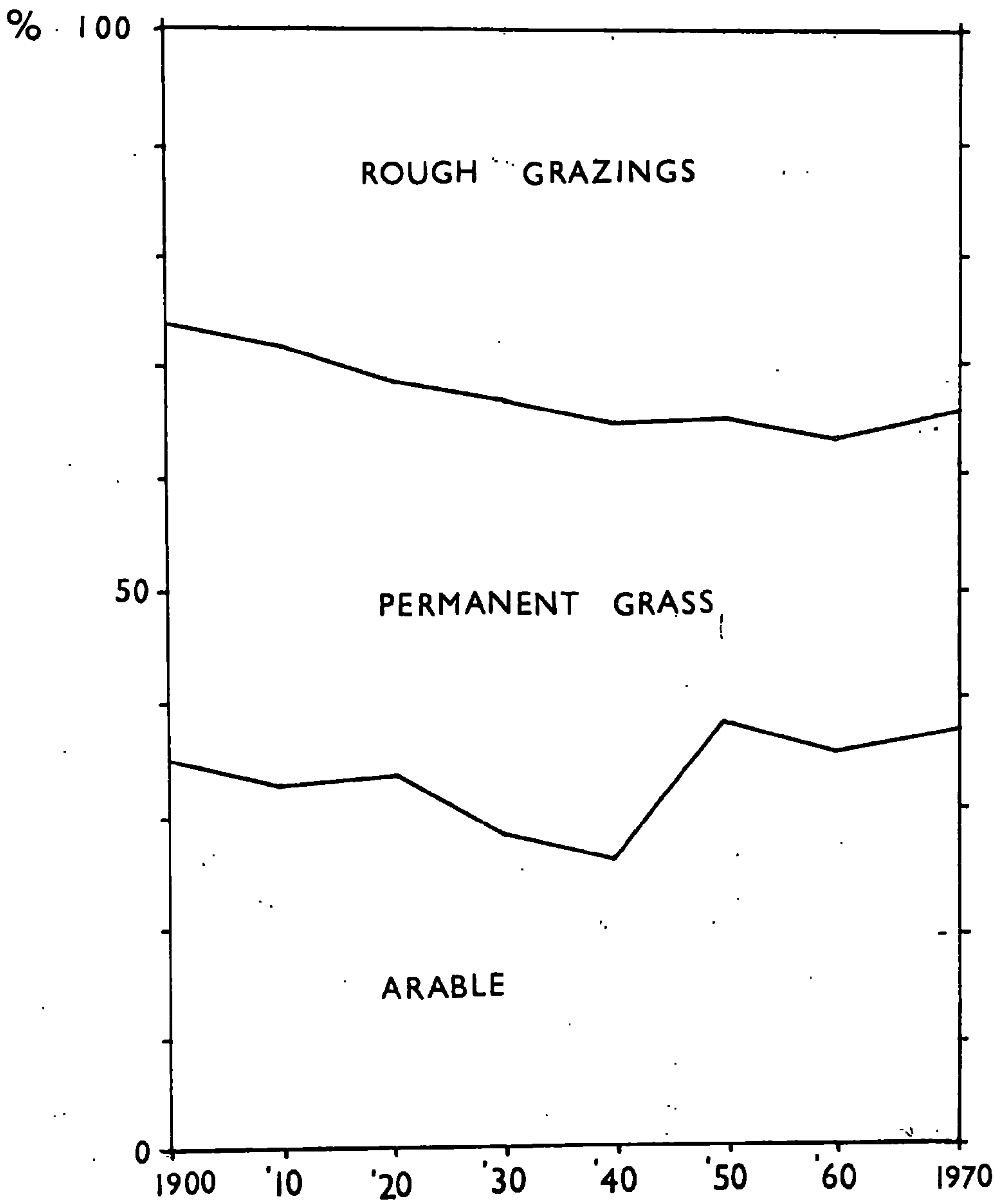


Fig. 1 Britain use of total agriculturally productive area 1900-1970, based on Agricultural Department, Annual Abstracts of Statistics, 1970.

b. gathering grounds for water supply and water for hydro-electric power works.

c. sporting areas, especially as deer forests and grouse moors, sometimes with fishing associated.

d. potential areas for afforestation.

e. recreational areas for public enjoyment.

f. Nature reserves for the conservation of the natural flora and fauna.

g. supply of peat.

h. practice areas for the armed forces.

In the context of the national economy, the possible increase of the biological productivity of moorland must be an important consideration for, these areas are not being utilised to a maximum. Experience from other similar lands has shown that afforestation and pastoral forms of agriculture are usually the best forms of land utilization under the extreme climatic conditions.

2.3 AGRICULTURE

A large part of the moorland of Wales, Scotland and the Pennines due to the combination of high altitudes, harsh climate, poor drainage and thin soils comprises poor agricultural land. These physical limitations affect the choice of farming systems by restricting them to extensive types like sheep and cattle rearing involving relatively low labour inputs. The Hill Farming Act (1946) and the Livestock Rearing Act (1951) encouraged the development of these extensive forms of agriculture so that the hill areas might play a greater part in the country (Mackenzie 1951).

There are a number of problems in developing moorland agriculture. Firstly, the physical limitations have a major effect on husbandry while the economic difficulties (low output per hectare and per farm) also, in part reflect the environment. Other problems relate to the scattered, small population and social structure (selective rural migration, with the remaining elderly people being reluctant to change). The interrelated problems that occur in such areas are presented in a simple diagrammatic way (Fig. 2, from Wibberley 1959). The land has been settled in the form of isolated farms and hamlets with few villages or small towns.

Although moorland comprises one quarter of the total land surface in Britain, such areas only provide 4% of the total agricultural output of the nation. However, Wibberley (1959) claimed that the development of the upland and rough grazing area would add quite substantially to an agricultural potential. It has been estimated that a little over 2.0 million hectares (5.0 million acres) could be significantly improved (by at least 50%) if the right husbandry techniques were employed. The main object in reclamation of this land is to clear away the natural or existing vegetation and replace it by better species. The procedures of reclaiming shallow peat and deep wet peat areas are different:-

2.3.1 Areas of shallow peat

(1) Ploughing, mulching and burning

When iron humus pans exist, deep ploughing (approximately 76 cm.) is necessary to break up the subsoil in order to promote the penetration of rootlets. This is followed by heather mulching or burning off the surface vegetation. The latter not only increases the efficiency of machinery used to produce a good tilth but also decreases the acidity of the surface and promotes the conversion of organic phosphate and nitrogen compounds to inorganic forms available for plant growth (Robertson 1957).

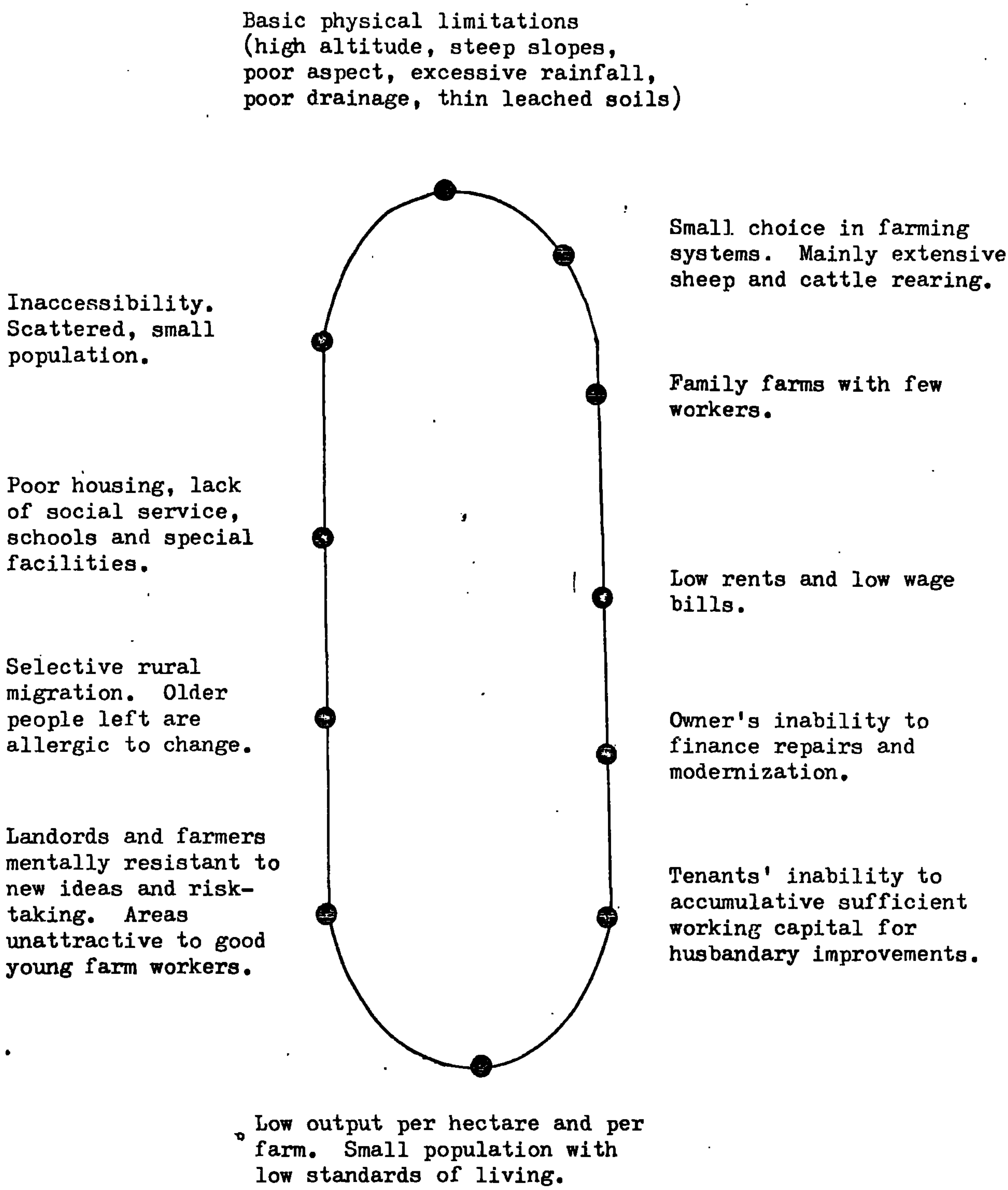


Fig. 2 The cycle of events in marginal farming (adopted from Wibberley 1959).

(2) Lime and fertilizers

Dressings of ground limestone or paper-works waste lime at rates of up to 50 tons/ha are essential to correct the severe acidity. Lime in the form of ground limestone is considered most suitable for modern methods of reclamation due to the uniform distribution which can be obtained and the ease with which it can be mixed with the surface horizons during cultivation.

Uncultivated moorland soils contain very small supplies of plant nutrients so that successful conversion to more productive land depends largely on the application of well-balanced fertilizers. Liberal dressings of phosphatic fertilizers are essential at the outset, basic slag, superphosphate or ground mineral phosphate being primarily used. 145-180 Kg/ha of P_2O_5 before sowing and repeated within the first 2-3 years should give satisfactory results and build up reserves. Heavy initial dressings of potassium fertilizers of 0.13 - 0.25 tons/ha 60% muriate potash should be applied before sowing pioneer crops (Mixtures of grass species). A dressing of 0.18 - 0.25 tons/ha of nitro-chalk or the equivalent as sulphate of ammonia is required at sowing time to aid establishment although small quantities of assimilable nitrogen may become available after drainage, liming and cultivation.

(3) Cropping

A high percentage of Yorkshire fog (*Holcus lanatus*) together with a variety of other species such as perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), are used as pioneer crops. The nitrogen content will be increased by the nitrogen-fixing bacteria and leguminous plants such as white clover, fixing nitrogen from the air when the lime status has improved. Good grass crops for hay and grass-meal may be grown; it has been noted that even potatoes and oats can grow allowing suitable rotations to be established in the low-lying peat lands in the western half of England, Wales and in Ireland. (Russell 1940).

The porous nature of the soil allows rapid drying of the surface tilth by evaporation and the tilth contains virtually no crumb structure. Consequently a strong wind from any quarter blowing across bare moorland can produce spectacular erosion. Strip cropping with rye (*Lolium*) and cocksfoot (*Dactylis*) for seed can reduce erosion although coniferous belts are more effective in protecting such areas especially vulnerable to wind erosion.

Stapledon (1936) suggested an alternative method which can solve the problem of soil regeneration other than reforestation:- lime and phosphate fertilizers are used, followed by controlled grazing. Additional ploughing and cultivation of suitable grass mixtures can be more effective on gentle slopes. This results in the spread of the more productive grasses (e.g. leguminous plants such as *Trifolium*) instead of the poor ones.

Moorlands have the capacity to provide abundant summer pasture, but little grazing in winter. The problem is to increase the winter carrying capacity of the moorlands either by increasing the winter production, or by providing a supplementary supply. A management system called 'complementary grazing' has been devised for increasing the winter carrying capacity of moorlands (Gregor 1946, adopted by Hart 1955). Selected areas of moorland are given a rich dressing of nitrate fertilizer and protein-rich grasses are planted to compensate nitrogen deficiency in the hill grazings. Sheep which graze on the enriched pastures for a short time each day will enrich other poor areas with their manure as they seek their requirements of bulk feed. However, this is not practical on an extensive scale as too much labour is involved.

It has been reported (Chillingworth 1971) that the less difficult fringes of the North Yorkshire Moors (particular the south-eastern parts where the land is free-draining and the soils relatively stone-free) have been reclaimed during the past ten years. For example, the 8ha (20 acres) of moorland at Givendale Head was reclaimed by using the following procedure:- The vegetation was burnt off during dry spells in the winter, then dressed with limestone and basic slag. After vigorous seed bed cultivations, a seed mixture (containing *Dactylis*, *Lolium* and *Phleum*) was sown and compound fertilizer added. Copper was injected into the soil regularly and magnesium was checked especially at a critical time of the year for 'stagger' - magnesium deficiency.

The existing vegetation can also be improved without completely changing the ecosystem. *Calluna* has considerable grazing value and should not be disturbed except for the regular or rotational burning. Areas dominated by *Molinia* require drainage and fertilization though ploughing and re-seeding with *Agrostis* or other better grasses often follows. *Nardus* and *Agrostis*-*Festuca* grassland require liming although drainage is not normally necessary. They may be improved by ploughing and re-seeding with *Lolium* and *Trifolium*. Areas dominated by *Pteridium* are good for improvement as it accumulates phosphate.

2.3.2. Areas of deep wet peat

In the past, when peatland was considered for agriculture, the main attention was given to the removal of the peat and cultivation of underlying mineral soil. Present reclamation is now mainly concerned with the conversion of peat lands into farmland by the addition of mineral fertilizer on the surface, followed by the sowing of grass and seed mixtures (Russell 1940, Ratcliffe 1964). The general procedure is to drain the peats, then plough deeply and add sand or lime. After leaving to the action of the weather for a period of 2-3 years, the procedure is repeated and it is finally harrowed down when a good seed bed can be obtained.

Chapters 8 and 9 suggest that peat can be relatively productive with the major limiting factor being waterlogging. Waterlogging of the soil has two disadvantages. It cuts off the air supply to the plant roots and therefore prevents the growth of crops. It also leads to reduction of nitrate and other oxidized substances forming compounds harmful to plant growth, e.g. ferric compounds are reduced to ferrous compounds, sulphates to sulphides, etc. The hydrophysical properties of drained peat bogs, chiefly compaction and mineralization, change considerably following the initial extraction of ground water. Sufficient aeration will be available for root growth and the rate of mineralization will be accelerated by microorganisms after drainage.

Therefore, any development of peatland for agricultural purposes must be preceded by the establishment of an efficient drainage system to remove excess water from the upper horizon of the bog and allow modern machinery to operate on the surface. There are several methods on drainage:-

(1)
Deep open main ditches combine with regular series of closed laterals -

It is now generally accepted that this is the best method of securing the effective drainage of deep wet peat. As a result plants are able to root more deeply and are less susceptible to sudden periods of drought, deep drainage (e.g. on raised moss basin peat at Carnwath, Scotland, open main collecting ditches 2m. deep and 270m. apart with subsidiaries at 20m. centres and 1m. deep provided an efficient drainage system) also ensures a more efficient utilization of fertilizers which in an area drained by shallow ditches would soon be leached beyond the rooting zone. In addition, open drains are not only cheaper to establish but have the advantage that they can be kept clean and deepened as shrinkage takes place.

(2) Box drains and tile drains - These methods are expensive and their construction may seriously affect the economics of peat bog cultivation although box drains allow better utilization of the ground for agricultural purposes and are preferred to tile drains. Tile drains have to be laid on wooden soles to prevent or reduce sagging.

(3) Mole drains - Mole drains should be approximately lm. deep in order to reduce the likelihood of drainage without any reduction in efficiency. It has been shown in Russia that mole drains in peat are not only effective in reducing the moisture content of the surface horizons but also increase aeration and soil temperature thereby improving crop yields (Robertson 1957). The establishment of mole drains in close parallel rows in conjunction with more widely spaced tile drains lowers the overall cost of drainage without any reduction in efficiency.

A fairly wide variety of crops has been successfully cultivated on deep peat which, if properly prepared and managed, can become highly productive. Excellent yields of oats, rye, peas and beans can be obtained although grass is generally the most important crop grown on peatland.

The fertility build-up in moorlands is a long-term feature as bacterial life is lacking at the outset due to the acidity. For example, the pH on Waldridge Fell ranges between 3.3 - 4.1 which reduces the establishment of many micro-organisms. The nutritional value of the herbage will rise as the soil conditions improve.

Some rough grazing is being improved each year to become permanent pasture although the area in which this improvement takes place remains very marginal and can easily revert to its former status. It can never be equivalent to fertile lowland, permanent pasture or be suitable for arable crops. Nevertheless, there seems to be scope for improving the use of farm land in the hills and upland and bringing in some of the land now in rough grazing into the cultivated area of farms.

2.4 FORESTRY

Britain has one of the lowest percentages of forest and woodland cover relative to total area among west European countries (less than 8 per cent.), yet much of the land at present afforested is the result of plantings undertaken only in the last twenty years.

The timber shortage of World War I emphasized the seriousness of Britain's deficiencies in forestry products and led to the establishment of the Forestry Commission in 1919 as the national forestry authority charged with promoting the interests of forestry, the development of afforestation and the production and supply of timber in Britain. A large portion of woodlands were again felled during World War II. Post War Policy (Forestry Commission 1946) included a target of 2 million hectares (5 million acres) of productive forest in Britain within fifty years. Between 1947 and 1967 almost 0.4 million hectares (1 million acres) were added to the area of state forest (Edward and Wibberley 1971). Much of the land that the Forestry Commission acquires is upland rough grazing and moorland. The main reasons for this are that competition with agriculture is minimized while the Forestry Commission cannot afford to purchase good lowland. Table 2.2 shows the type of land the Commission acquired in 1963, and afforestation appears to offer a profitable long-term utilization of upland areas.

	Proportion covered (%)	Agricultural value
Upland heaths, moors and bogs	70	Poor
Lowland heaths	13	Poor
Chalk downlands	4	Poor
Heavy clay	6	Average
Sites with high growth potential	7	Good
	100	

Table 2.2 Forestry Commission planting by the type of site used, 1963 (source: Verney 1970).

2.4.1 Choice of tree species for moorland afforestation

The problems of afforestation in moorlands can be understood better in terms of the ecology and utilization of the suitable tree species. The major coniferous tree species planted by the Forestry Commission are as follows:-

(1) *Pinus sylvestris* (Scots pine)

It is estimated that *Pinus sylvestris* has been used on more than half the area of upland moorland planted by the Forestry Commission (Zehetmayr 1960). The main reason is its ability to compete with heather and to grow under conditions of infertile acid soils and on exposed sites. Until recently, no other species could tolerate such conditions and provide an economic crop. There have been constant efforts to find other species which could replace Scots Pine on certain moorland areas due to its comparatively slow growth rate and low production although the quality of the wood is high. It is also used as a nurse tree when inter-planted with spruce on the moorland.

(2). *Picea sitchensis* (Sitka spruce)

This species survives on acid, peaty soils, and can stand strong winds; therefore it is well adapted to the upper wetter moorlands where the rainfall is higher and the temperature lower. Although the species has been widely planted because its timber has a variety of uses, biological productivity is relatively low. This is particularly true when Sitka spruce is planted in areas where there is danger of attack from late spring frosts or summer droughts.

(3) *Pinus contorta* (Lodgepole pine)

Pinus contorta is one of the best pioneer species for areas of poor soil (such as areas dominated by *Cirpus caespitosus)* and can tolerate severe exposure beyond the limits of Scots pine. It can also serve as a better nurse species than Scots pine on the poorest peat soil. Therefore, it is being used on an increasing scale although the value of its timber is comparatively low.

(4) *Larix lepotolepis* (Japanese Larch)

This species plays an important part in the moorland afforestation, being planted on the lower slopes with moderately deep and fertile soil (particularly those areas dominated by *Pteridium)*. This variety resists larch canker and insect pests and has replaced *Larix decidua* (European larch) in popularity. The advantages of this species are its rapid growth and good timber quality.

(5) *Picea abies* (Norway spruce)

Picea abies is resistant to frost and is commonly planted in frost hollows of Sitka spruce plantations. This species cannot be planted in pure blocks, however, because its shallow root system, which permits it to grow in thin soils, makes it susceptible to drought and particularly to wind damage.

Zehetmayr (1960) drew the conclusion, after comparing the results of the production of these species, that the role of Scots pine should not be underrated, Japanese larch and lodgepole pines are attractive because of their early production, while Norway spruce is only planted on a local scale. The other species planted by the Forestry Commission have relatively limited significance on the moorlands. They are *Larix decidua* (European larch), *L. eurolepis* (Hybrid larch), *Pseudotsuga taxifolia* (Douglas fir) etc.

Pure plantations of conifers will further acidify an already over-acid soil as the trees absorb little mineral material, so that few bases are returned by the falling leaves and their decay produces an acid 'mor' or 'raw' humus thus favouring podzolization. Therefore, some intermixtures of the soil-improving hardwoods, despite their lack of value, would seem desirable. A great number of species of hardwood trees have been tested by planting on a limited scale, e.g. *Fagus* (Beech), *Quercus* (Oak), *Betula* (Birch). Beech and Oak are restricted to relatively deep fertile soils, and are not suited to upland conditions. However birch is adapted to moorland conditions though is neglected, due to its lack of commercial value.

2.4.2 Reclamation techniques

Mechanical cultivation has replaced hand methods for efficiency and economy. The main purpose of cultivation is to disturb the surface peat or humus, to promote the aeration of the soil and to break up the iron pan which occurs, for instance, in the typical peaty podzol. The method actually employed is of a single cultivation with a heavy plough for each line of trees. This is followed by planting; furrow-planting is adapted for the drier area while planting on the side of the plough ridge is normal on wetter sites. Dressing of phosphate is necessary for the poorest moorlands, whereas on the more fertile soil, phosphate dressings may not be necessary.

Mixed plantings may serve one of two objects, either to increase early returns by the use of fast-growing species (such as Japanese larch or Lodgepole pine), or to increase the volume of the final crop (by the use of spruce). Often, the establishment of a plantation is affected by an inability of the tree species to compete with the moorland vegetation. Mulching with cut *Calluna* has proved to be the most effective method for the relief of *Calluna's* competition toward tree growth. This has been proved successfully with *Picea sitchensis* (Sitka spruce), *P. abies* (Norway spruce) and *Chamaecyparis lawsoniana* (Lawson cypress) in Yorkshire on podzolized heather moor (Weatherell 1953). The increased vigour of the mulched trees was accompanied by increases in the concentration of nitrogen, phosphorus and manganese in the needles. The response must be attributed primarily to the improved moisture conditions under the mulch providing better conditions for the trees and also enhancing the availability of nutrients.

Peatlands are being afforested on a large scale where natural coniferous forests are scarce. When utilizing peatlands for forestry, fertilizer application and effective drainage are necessary. Only four species have been planted to any great extent on peat, they are *Pinus sylvestris* (Scots pine), *Larix leptolepis* (Japanese larch), *Picea abies* (Norway spruce) and *Picea sitchensis* (Sitka spruce).

Pinus sylvestris is suited for all the drier peat areas, especially the *Calluna* covered knolls which form such a prominent feature of so many peatlands. It is also used in mixture with *Pinus contorta* (Contorta pine) in sites marginal for planting and also in mixture with *Picea* (Spruce) or other species as a nurse, on sites marginal for these species. *Larix leptolepis* grows well on the thinner peats overlying moraine or mineral soil which occur in many areas of the north-west Highlands. *Picea abies* grows well on *Molinia* peat but has proved quite useless on all the poorer *Scirpus* types. *Picea sitchensis* has been extensively planted on the richer peats. Although it showed more early promise on the poorer peats than *Picea abies*, subsequent growth was slow. Other less popular species are *Pinus mugo* (Mountain pine), and *Larix eurolepis* (Hybrid larch).

Some form of turf planting has been shown to be effective on peats, especially flush peats. A single turf is usually sufficient to induce good early growth on *Molinia* peats while more extensive turfing is desirable on the poorer areas to provide a better planting site for trees. The most successful method has been shown to be that where the roots are spread below the turf so as to lie on the decaying vegetation. Drainage is essential and it was reported that more intensive drainage gives better growth (Zehetmayr 1954). Zehetmayr also noted that manuring with phosphate was an established practice on the poorer peats. Phosphate is essential to the survival of all species, other than pines, on the *Scirpus* peats while even with pine, growth rates might be more than doubled with phosphatic additions. On the *Molinia* and better peats, phosphate is not so necessary, while on intermediate types it is advisable to apply it to all species other than pines, to ensure survival and good early growth.

Production of timber is thus an alternative use to grazing in the upland of Britain; each species has areas to which it is particularly suited. However, with the post war programmes of agricultural development on marginal hill land and the progressive extension of forests, both forms of land use have come increasingly into competition.

Though physical limitations upon timber growth vary regionally it is generally agreed, with present forestry practice, that 533 metres (1750 feet) represents the upper altitudinal limit to commercial timber production, unless soil, and site conditions are unusually favourable (Pearsall 1970). Shortness of the growing season and the high wind speeds, as in north-west Scotland, are the greatest natural hinderances at the upper altitudinal limit for species selection. Drainage, planting techniques and fertilizing have overcome some of the difficulties of moorland or peaty soils.

Conflicts with sheep and cattle graziers for the use of potential agricultural moorland have been difficult to solve. The interests of graziers have increased due to post-War improvements in productivity. Government policies of improvements and subsidies under the Hill Farming Act (1946) and the Livestock Rearing Act (1951) have already had marked effects on the landscape of many upland areas.

Productivity can be converted to economic terms although it is basically a physical measurement of the utilization of resources. Productivity in technical or economic terms is a precise measurement which is sensitive to the number of stages in the production process which are considered, the range of inputs and outputs used, aggregation and index number problems and price change (Organization for Economic Co-operation and Development 1961). If a given set of inputs produces a greater output than previously, or a given output is produced with less resources than before, an improvement in productivity is said to have occurred. Productivity gains are the result of technological change if there are gains in the productivity with increase in output and without a corresponding increase in all inputs. Comparison of yields and values may be invidious, as agriculturalists point out, for prices of meat and timber fluctuate and improvements in technology and management of trees or sheep may invalidate comparison.

2.5 OTHER USAGE OF MOORLAND

2.5.1 Moorland as recreational area

Studies made by Burton and Wibberley (1965) have emphasized the role of the countryside in providing for outdoor recreation both in relation to existing levels of use and future demands. All the factors determining recreational pursuits - population, leisure time, money, mobility, inclination - have grown rapidly since 1945 and are still rising. The land accessible for recreation is estimated at about 1.2 million hectares (3 million acres) (Arvill 1970) and more moorland areas would probably go to recreational use.

The National Parks movement is directed toward the preservation of selected woodland and moorland areas for this purpose under the National Parks and Access to the Countryside Act 1949 (e.g. The Peak District, The Lake District, Snowdonia, Dartmoor, the Pembrokeshire Coast, the North Yorkshire Moors, the Yorkshire Dales and Exmoor).

The Forestry Commission in 1935 (Forestry Commission 1949) established the Argyll National Forest Park and has subsequently created more which have the four-fold purposes of:-

1. protecting wild life, buildings, and places of interest.
2. providing access and facilities for public open-air enjoyment.
3. preserving the characteristic beauty of the landscape, and
4. maintaining established farm use.

Certain lands are devoted to both agriculture and recreation where footpaths and bridgeways cross farmland and are used properly. Agricultural activity can go on unaffected. Bird-watching and fishing combined with farming have been found to have a harmonious coexistence. However, heavy tourism can result in the deterioration of vegetation and even soil erosion.

2.5.2. Moorland as water catchment areas

The high rainfall and the deep valleys provide suitable areas for water-supply projects in the moorland regions and since the middle of the last century increasing areas have been taken for this purpose. Reservoirs were constructed or lake levels raised by damming to store impounded water. This form of utilization is often associated with the development of hydro-electric power, for example, the hydro-electric schemes in different parts of the Scottish Highlands. This development can help to improve the conditions of life in these mountain areas and may also lead to industrial developments.

Catchment areas pose a land use problem both with regard to land actually flooded and to the restrictions placed on the use of the area. Agriculture, casual human access and grazing (the effect of human sewage, farmyard manure, etc.) have been prohibited in some water catchment areas to avoid the danger of contamination. Some water authorities oppose the afforestation of their catchment areas by suggesting that trees transpire more than other types of vegetation, and so planting them will result in a loss of water. However, there is retention of more water in the soil under trees while the other benefits derived from tree cover, especially those of a more stable ecology and an economic return from the tree make a good combination.

Much more research is required into the effects of the multi-purpose use of catchment areas on the supply of water and the implications of such uses for the quality of the water.

2.5.3. Moorland for military training

The land required as training areas for the armed forces reached a maximum during wartime but has declined subsequently. However, most of the sizeable areas suitable for this purpose are found on moorland, as agricultural and urban developments have priority over the military services in the lowland areas. However, this kind of land use is always conflicting with the recreational requirement in the moorland regions especially those close to large urban centres. In spite of this, the Interdepartmental Committee on Services Land Requirements in 1946 (Town and Country Planning Committee 1951) attempted to harmonize Services and Civilian needs. A public inquiry is commonly held before large blocks of land are diverted to military use.

2.5.4. Moorland for mineral resources

In addition to the possibility of crop production, moorland areas often contained mineral resources. This is particularly the case in northern England and even the study area, Waldridge Fell, has not been unaffected by past mineral extraction.

(1) Coal - Coal mining still constitutes the major industry of northern England while most of the mining is concentrated on coastal pits, past mining was extensive in central and west Durham. The Waldridge Colliery situated on the north-east of Waldridge Fell, is still working and has influenced the landscape in the form of pit heaps.

(2) Limestone - Limestone is among the most important minerals within northern England. It is used in cement and lime production and in powdered form for agricultural purposes. In the past the moorland areas of Weardale had extensive quarries, but now the main production is from

the Magnesian limestone around Coxhoe in the east of County Durham.

(3) Roadstone - Sources of rock which can be crushed for roadstone include igneous rocks, the harder limestones, and gravels derived by glacial outwash from ice that has passed over hard rocks. Roadstones are worked around High Force.

(4) Sand and gravel - Sand and gravel are mainly used in concrete for building purposes. There is a high proportion of sand and gravel among the glacial deposits of the Wear Valley, for example, near Stanhope. On Waldridge Fell, there are three old gravel pits found on the north of the plateau, used in the past for local purposes.

(5) Lead and Zinc - Lead and zinc ores are mined on both sides of the Pennines, e.g. around Rookhope. In recent years production of the ores of lead and zinc has declined to almost nothing, except as a by-product of the mining of the spar minerals.

(6) Iron - Much of the iron in former days was obtained from the clay ironstones in the Coal Measures, e.g. Stanhope, there is also a disused smithydene quarry on the south-west of the plateau of Waldridge Fell.

CHAPTER THREE

LAND EVALUATION AND SOIL FERTILITY

3.1 INTRODUCTION

" Land evaluation is the assessment of the suitability of land for man's use in agriculture, forestry, engineering, hydrology, regional planning, recreation, etc." Stewart (1968).

The object of a land capability classification is to provide the physical information concerning the land resources in a systematic, factual form. Information on land quality and soil attributes is given and the degree of flexibility in respect of cropping and soil fertility (which is estimated by expected yields at particular levels) and its management would also be indicated.

3.2 THE LAND CAPABILITY CLASSIFICATION OF COUNTY DURHAM AND WALDRIDGE FELL

A classification of the soils of County Durham in terms of their agricultural potential was made by the North East Development Council in 1950. Three major categories (I. Good quality land, II. Medium quality land and III. Poor quality land) with sub-categories were recognised. The classification was based on the primary factors of site (including topographic, hydrologic and climatic criteria) and soils. 15 per cent of the land in the County was classified as being of good quality; 55 per cent medium quality and the rest, poor quality land which was confined to the West of the County and limited areas in the east. However, this was purely a local inventory.

In the current national survey of land capability for agricultural purposes, the Agricultural Land Services Division of the Ministry of Agriculture (1966) classified the land in County Durham in four grades, II to V, with increasing limitations towards agricultural use. There is no Class I land in the county since areas regarded as being first class regionally may not be up to the national standard (Stevens and Atkinson 1971). This is mainly due to the climatic conditions limiting the agricultural use of land.

A summary of the classification grades of agricultural land devised by Agricultural Land Service (1966) is as follows:-

Grade I

The soils of Grade I land are deep, well drained loams, sandy loams, silt loams or peat, lying on level sites and are easily cultivated, with very minor or no physical limitations to agricultural use. They retain good reserves of available water and are either well supplied with plant nutrients or highly responsive to fertilizers. No climatic factor restricts their agricultural use to any major extent. Yields are consistently high on these soils and cropping highly flexible.

Grade II

Land with some minor limitations which exclude it from Grade I. Such limitations are mainly due to soil (for example, its texture, depth or drainage) though minor climatic or site restrictions (such as exposure or slope) may also cause land to be included in this grade. Yields are comparatively low on these soils and cropping less flexible than that in Grade I.

Grade III

Land of average quality, with limitations due to the soil (such as structure, texture, drainage, depth, stoniness or water-holding capacity), relief or climate (such as altitude, slope or rainfall, for example, much of the land over 122 m. (400 ft.) which has more than 1016 mm (40in.) in annual rainfall), or some combination of these factors which may restrict the choice of crops, timing of cultivations, or level of yield. Grass and cereals are the principal crops as the range of cropping is comparatively restricted on land in this grade. However, the land is capable of giving reasonable yields when judiciously managed and fertilized.

Grade IV

Land with severe limitations due to adverse soil (such as unsuitable texture and structure, wetness, shallow depth, stoniness or low water-holding capacity), relief or climate (such as steep slope, short growing season, high rainfall or exposure, for example, much of the land over 183 m. (600 ft.) which has over 1270 mm. (50 in.) annual rainfall) or land with a high proportion of steep slopes (between 1 in 5 and 1 in 3) or a combination of these. A high proportion of land in this grade will be under grass with lower output enterprises than that in Grade III.

Grade V

Land of little agricultural value with very severe limitations due to adverse soil, relief or climate or a combination of these. (The main limitations include very steep slopes, excessive rainfall and exposure, poor to very poor drainage, shallow depth of soil, excessive stoniness, low water-holding capacity and severe plant nutrient deficiencies or toxicities). Land over 305m. (1,000 ft.) which has more than 1524 mm. (60 in.) annual rainfall or land with a high proportion of very steep slopes (greater than 1 in 3) will generally be graded under this category. The land is generally under grass or rough grazing, except for occasional pioneer forage crops.

Stevens and Atkinson (1971) noted that the majority of soils of the agricultural land in County Durham were either imperfectly drained Brown Earths or Surface Water Gleys, with limitations caused by poor air/moisture relationships, thus ensuring a relatively low capability rating.

According to Chapters 6, 7 and 8, the most important factors affecting land quality in terms of agricultural productivity in Waldridge Fell are climatic conditions, topography, and soil characteristics which include leaching, moisture content, acidity and nutrient status. Adverse factors like leaching and acidity are the main problems on Wanister Hill and Nettlesworth Hill, while the relatively poor drainage conditions and the extremely poor air/moisture relationship affect the Plateau and Wanister Bog. These are the main factors that cause a down-grading in the assessment of the soils in terms of agricultural potential - the Agricultural Land Service has, in fact, categorised Waldridge Fell as being in Grade V.

3.3 APPROACHES IN ASSESSING BIOLOGICAL PRODUCTION IN LAND EVALUATION

There are three approaches to the assessment of biological production in land evaluation:- (1) Analogue methods, (2) Site factor method and (3) Systems analysis and simulation methods. The importance and possible application of these methods are discussed as follows:-

3.3.1 Analogue methods

This method is based on land as a resource, either studies of the total complex (e.g. land system - land unit) or of the separate major components (e.g. land form, soil, vegetation, climate). Land is classified on the basis of a number of observed and measurable characteristics. Land units are parts of the land surface having similar genesis and described similarly in terms of topography, soils, vegetation and climate, and land systems are the assembly of these land units into geographical and genetically related areas (Christian 1958). Each of the major attributes, climate, vegetation, soil and topography has an important influence on productivity.

(1) Climate

Climate is a major determinant of the productivity of a particular species of crop at a particular site though individual climatic parameters may not only affect the yield but also the range of the crop. For instance, a comprehensive review of attempts to delineate climatic zones by Jackson (1962) in a study of Slash pine growth in the Southern United States, Australia and New Zealand showed that many climatic indices are concerned with range rather than productivity of native species and that soil factors are important both within a climatic zone and across different climatic zones. He also indicated that growth (measured as height increment) was highly correlated with several soil factors, including depth to least permeable horizon, silt and clay content of the least permeable horizon, and among climatic factors, it highly correlated with mean annual precipitation and average diurnal temperature range.

Holdridge (1964, 1966, 1971) devised a three dimensional model which divided the world into over 100 life zones (under headings of tundra, forest, desert, etc.) arranged according to latitudinal belts, and humidity provinces. The method of this life zone classification is precisely defined in climatic terms, though there are many areas of the world for which climatic records are not available. Life zone maps have been prepared for 12 central and South American republics.

In Canada, there has been an attempt to use climate as an index of crop growth and to delimit potential agricultural regions. Temperature and rainfall are the two main indices used to give climatic regions.

There also has been an attempt in the recent land use capability classification of Britain (Agricultural Land Service 1966) to classify climates for agricultural purposes. It has been noted that climate has a direct bearing on the incidence of arable and grassland enterprises (including rough grazings) and so directly affects the grading, as flexibility of cropping is a primary requirement of high quality land. Within any grade or series of grades there are further marginal effects due to meso-climatic variations. A summary of this classification and its association with climatic factors was given in Chapter 2.2.

In Australia, Condon (1968) estimated grazing capacity of arid land by selecting a standard land class of known grazing capacity, and setting up scales for the various factors which influence grazing capacity. Numerical rating scales have been developed for soils, topography, tree density, palatable trees and shrubs, pasture conditions (as influenced by erosion or growth of weeds), and annual rainfall. It was discovered that average annual rainfall is the most important factor in determining grazing capacity.

However, there are several difficulties in using climatic parameters in land evaluation:- (1) Standard climatic data is not always available especially in remote areas. Also data have to be collected for a considerable length of time before it can be meaningful. (2) Readings may only be taken twice a day and it is difficult to estimate the significance of hourly variations in the weather. (The development of remote automatic recording stations may in the future help to solve some of the problems of data availability). (3) It is difficult to analyse and classify the data as it includes so many variable factors (e.g. daily, monthly, and seasonal variations of temperature, humidity, rainfall and windspeed, etc.) Difficulties also arise when long term climatic changes are to be considered.

It is concluded that although most land classification schemes recognize the importance of climate, the majority tend to be more closely related to vegetation, soils and topography.

(2) Vegetation

Vegetation has long been used in many land evaluation surveys. In land capability assessment in Africa, Langdale-Brown (1960) considered that the nature of the vegetation was of greater importance to native agriculture of the territory than other characteristics and was used by many tribes as an indicator of the soils potential. This work has been applied by Allan in 1965 in the planning of certain major resettlement schemes in North Zambia.

In Russia it is suggested (Ignatyev 1968) that land evaluation for agriculture and forestry should be based on basic land properties that separate vegetation types, both natural and cultural. The survey is carried out by grouping of categories of land systems that show similar response to particular types of land use. Crop yields are assessed both by direct measurement and by recorded data from collective and state farms. The prediction of yields appears to be by analogue, although reference is made to a number of indices (e.g. moisture and nutrient availability). Quantitative input-output data at various levels of management are made, and the monetary value of the land is assessed.

This approach is based on vegetation for the identification of land systems in the surveys. Where changes in the land surface are sharp, the vegetation communities usually change just as markedly. Nevertheless, where the change is gradual, vegetationally constant communities are difficult to discern on a reconnaissance survey. Therefore, vegetation can be used as attribute of the land units to be defined on the reconnaissance survey scale but is too variable to be used in the main criterion in the identification of the land system.

(3) Soil

In general, crop yield tends to reflect the fertility of the land under the existing socio-economic conditions (including the present farming systems) although the potential productivity of an area can theoretically be increased to high levels by appropriate fertilizers and management, e.g. 'green farming' is an extreme case, using a fine quartzose sand or silt as a foundation for the roots and adding an optimum fertilizer. It has been possible to obtain ten times the normal yield (Stamp 1962). However, this can only be done locally and on a small scale.

At the present time the basic descriptive information for assessing land resources is found on the soil maps. In studying the productive capacity of the soils of an area, as well as the knowledge of the characteristics and distribution of the soils, their management requirements are also needed. Agricultural productivity is greatly influenced by the existing socio-economic conditions and may not always appear to relate to the physical environment. To a certain extent, this can be overcome by selecting farms where socio-economic factors are uniform, e.g. similar size of farms and level of management in a relatively small area, and then basing agricultural land classification only on physical criteria. The main purpose of the soil survey is to delineate areas of soils and predict the management and expected productivity. These relie on the homogeneity of the soil mapping unit which serves as a basis for the predictions. Several soil survey organizations attempt to specify the 'purity' of mapping units, that is the average pecentage of the area of each unit which is occupied by its eponymous profile class. For example, soil surveyors in the U.K. attempt a purity of 85% (Findlay 1965), the U.S.D.A. attempts 80-90% (U.S.D.A. Soil Survey 1951) and surveyors in the Netherlands about 70% or more (Buringh et. al. 1962). Therefore, the function of a soil survey is to classify, locate on a base map, and describe the nature of soils as they occur in the field. The soils may be classified into series and types on the basis of their profile characteristics.

Soil surveys which are based on a supposedly general-purpose classifications have been strongly criticised and may be strictly limited in value, as they do not often make assessment of soil properties that are significant for different purposes. Gibbons (1961) suggested two approaches in order to make surveys more valuable:-
(1) To devise an improved approximation to a general - purpose classification by selecting better key criteria, and to ameliorate its deficiencies by incorporating it into a ecosystem survey. (2) To adopt a specialist classification for each different purpose of survey.

Lee and Ryan (1966) working in Ireland considered soil series units imperfect as agricultural productivity map units, and produced a subdivision of series units, based on soil type (distinguished by texture of the cultivated horizon) and soil phase (using properties such as stoniness, salinity, slope, degree of erodibility, etc.).

Webster and Beckett (1968), in their study of "Quality and utility of soil map" in the Oxford District, also claimed that soil maps vary greatly in quality and need some general standards. Stating the variations and interclass correlation increases the usefulness of soil maps.

However, there is some correlation between productivity and soil units. Rennie and Clayton (1967) studied the comparative productivity of soil profile types in Saskatchewan. Over a 6-year period, interactions between soil and climatic factors caused wide fluctuations in yields on calcareous, orthic and eluviated chernozermic profile and on a humid eluviated gleysol (all formed on similar glacial parent material and subjected to the same management practices in the past). Whether or not phosphatic fertilizer was added, mean yields suggested that production increased in the order: calcareous soil, eluviated soil, orthic soil, gleysol.

A direct correlation between soil, natural vegetation types and productivity, in terms of sheep output has been demonstrated by Hughes (1958, 1960). Hughes' approach was based on the fact that main vegetation communitie are linked to specific soil types and he further indicated that the vegetation could be associated with definite levels of productivity measured by the counting, at weekly intervals, over several years the numbers of sheep grazing on marked plots of soils in the Snowdonia area. The soils which ranged from brown earths to brown podzolic soils, peaty podzols and peaty gleys were affected by a wide rainfall range. The carrying capacity of the best soils was 2.8 ewe-units per acre whereas the poorest was 1 ewe-unit per acre. The differences between productivity of soils under similar rainfall was accompanied by a general fall in sheep numbers from lower rainfall to higher rainfall area. Hughes, Milner and Dale (1964) further measured the productivity in terms of energy in the plant communities. The results revealed that there was a greater output in animal material per acre from brown earth sites than from peaty podzol sites under the same rainfall, a net gain being recorded over a 6-week period in 1961 of 39.24 kg/ha (35 lb/acre) compared with 15.69 kg/ha (14 lb/acre), for the two sites respectively. In the present investigation, as will be shown, vegetation patterns in Waldridge Fell were found to correlate to the soil types, drainage status and other edaphic factors, such as pH and nutrient status.

(4) Topography

Topography is normally used as one of the factors in land evaluation for agriculture. For instance, in the U.S.S.R., the classification of land is carried out by the landscape approach, mainly as integrated land systems, although in some areas as separate soil, vegetation, and physiographic surveys (Ignatyev 1968). Condon (1968) also has taken topography as one of the factors in his method of estimating grazing capacity of arid lands in Australia (for other factors, refer to this section (1) Climate).

3.3.2 Site factor methods

This method is based on the relation between the key parameters to biological productivity within a given environment. The yield at a given site wibin a region studied can be described by a multiple regression equation (Nix 1968):-

$$Yg = a + b_1 x_1 + b_2 x_2 \ldots\ldots b_n x_n$$

(Yg = predicted yield of specified genotype, b_1, b_2 ....., b_n are the partial regression coefficients, and x_1, x_2, ..., x_n are the observed values of independent site parameters)

In order to obtain the maximum information on potential crop performance, studies need to be supplemented by sufficient meteorological data, together with the comprehensive data on soil morphology, physical, chemical, and mineralogical properties.

As the various factors affecting plant growth do not act independently, no general relationship will exist between any one soil characteristic and crop performance. However, some experiments have proved relationships which afford a reasonable basis for yield prediction under a limited range of conditions. For instance, it has been discovered that the depth of soil solum was the main factor responsible for the yield of sugar beet in County Wexford, Ireland (Lee and Ryan 1966).

In California, U.S.A., Storie (1933) devised the 'Storie index', an inductive method which is based on the soil profiles. The main characteristics of the soil profile are expressed in three factors, i.e. (1) surface texture, (2) general character (excluding texture) of the soil profile and particularly to stratification and degree of weathering, and (3) soil modifying conditions, such as drainage, acidity and alkalinity, erosion, etc. Each is quoted as an estimated percentage of the optimum conditions of that factor for plant growth, and the factors are then multiplied to give the rating as a percentage of the possible 'score'. Although quantitative, such schemes have not been able to avoid a high degree of subjectivity in the allocation of the points, or in deciding what constitutes normal management, optimum conditions, etc.

Visser (1950) developed multi-factor analysis of crop performance and suggested that crop performance can be predicted by integrating the quantitative effects on yield of various factors (including any physical, chemical and management factors). A low correlation (correlation coefficient +0.3) is obtained when only 4 factors are taken into account but a good correlation (correlation coefficient +0.88) is found when 15 factors are considered.

Clarke (1951) also provided a 'profile-index' based on the physical factors of texture, depth and drainage of soils in the Cotswolds. A scale of values was assigned to different texture classes and a cumulative total vàlue x depth of each horizon. This value was reduced by a multiplying factor from $\frac{1}{3}$ to 1 according to the depth at which a true gley horizon occurred in the profile. He obtained the values of wheat yield from a formula:-

Yield = constant x profile-index; which showed good correlation with actual yield.

Bulter (1964) suggested that standardized treatments could be given to a range of selected sites and the yield/site factor interaction for a given treatment patticularized. A special classification for the stated form of land use may be generated when key site factors have been isolated.

3.3.3. Systems analysis and simulation methods

Systems analysis seeks to resolve a complex system into a number of simple component processes and then synthesises them into a mathematical model (or symbolic representation) of the whole system. By applying such a model to land evaluation for biological production, crop yields can be predicted under a defined systems of management at any location if the spatial and temporal variation of the key parameters are estimated.

Biological yield is the result of dynamic interactions between genotype and physical environment and it may be regarded as the integrated result of energy, water, nutrient, gas, and associated biotic variables during the course of growth and development of crops. According to Nix (1968), the model can be stated simply as follows:-

$$Yg(T) = \int_0^T yg\ (Re, Rw, Rn, Rg, Rb)\ dt,$$

In this equation, Yg = biological yield of genotype g at time T, yg = rate of change of Yg which, in turn, is a function of Re, Rw, Rn, Rg, Rb (energy, water, nutrient, gas and biotic regimes) all in turn functions of time t.

Research on simulation models for biological production in land evaluation is still in its infancy, and its development is complex due to yield dependence on genotype-environment interactions.

Generally speaking, analogue methods for assessing biological productivity based on soil classifications are still popular. These methods may be improved by using key parameters in constructing general classification. Site factor methods may only have good predictive value for the region in which they were developed.

3.4 FACTORS AFFECTING FERTILITY

A soil type has a definite level of productivity which can be enhanced or destroyed through the physical and chemical modifications brought about by cultivation techniques. Soil fertility refers both to the physical properties and to the chemical nutrient status of soil. The physical properties include soil structure and soil texture, which affect the water-holding capacity and drainage of the soil, the ease of penetration of roots, the degree of aeration on which root growth is largely dependent and the erodibility of the soil. The chemical properties include quantity, availability and ratios between different elements to meet the requirements of the growing plant during the different stages of growth. However, if the physical condition is poor, the soil will not be fertile even though the necessary plant nutrients are readily available.

In other words, soil fertility, whether defined in terms of physics or of chemistry, is usually regarded as the soil's ability to supply the plant food normally taken from the soil. In both approaches, soil fertility is regarded as both an actual and a potential property. However, biological influences (including man) and their relation to certain hydrothermic conditions are also important. This becomes more obvious when crop yield which is the numerical index of the producing system, i.e. soil and plant is taken as the measure of soil fertility. It must be realized that the plant's response to alterations in a single factor depends on the joint action of all factors under certain conditions (e.g. climate and cultivation techniques). The effects of climate, soil and of the activity of the organisms vary widely and they also interact profoundly with the inherent chemical and the physical characteristics of the soil, thus forming a multi-dimensional situation.

3.5 SOIL NUTRIENTS, THEIR FUNCTION, SOURCE, AND AVAILABILITY

Soil nutrients are classified on the basis of the relative amounts normally required by plants, (1) Major nutrients - include nitrogen, phosphorus and potassium; (2) Minor nutrients - include calcium, magnesium, sulphur, sodium and chloride; (3) Trace elements - include iron, copper, manganese, zinc, boron, molybdenum and Cobalt. This arbitrary classification has limited usefulness and does not necessarily imply relative importance in terms of requirements for metabolic activity by the plants.

Chemical analyses indicate that the total amount of nutrients in most soils is high compared with the requirements of plants. However, much of this total amount may be tightly bound in forms relatively unavailable to crops.

The organic fraction of soils mainly serves as a source of nitrogen, phosphorous and sulphur, and small amounts of other essential elements, made available to plants through biological processes. The inorganic fraction, derived from rocks and the products of their breakdown, mainly supplies the essential elements other than N, P and S. Phosphorus and sulphur can also be obtained from breakdown of minerals.

The composition and capacity of soil to supply plant nutrients is largely dependent on its texture. The minerals that make up the silt and clay fractions(though silt, like sand is dominantly composed of Quartz) contain the essential elements, but these are relatively unavailable to plants until considerable mineral decomposition take place. This decomposition goes on very slowly in the soil.

The clay fraction of soils is made up of secondary minerals and amorphorus materials which differ markedly from the components of sand. Clays are products of weathering and are composed of clay minerals, including kaolinite, montmorillonite and illite, as well as the hydrous oxides, notably those of iron and aluminium.

The cation-exchange properties of soils are associated with the clay fraction and also the organic matter fraction. The clay particle is represented as consisting of (1) an insoluble core of micelle which is negatively charged, and (2) a loosely held swarm of cations including H^+, Mg^{++}, K^+, Ca^{++} and Na^+. The degree of saturation of the collodial micelles with basic ions is an important measure of soil fertility.

3.5.1 Function to plants

The three elements or plant nutrients used in large quantities and which are likely to be deficient in many soils are nitrogen, phosphorus, and potassium. Typical effects of an abundance or deficiency of these elements are of great importance to plant growth and are summarised:-

(1) Nitrogen is the major constituent of protoplasm which is intimately involved in the activity of every living cell. An abundance of nitrogen results in rapid growth of vegetative tissues and a dark green colour. If plenty of nitrogen is available early in the season only, maturity of the plant may be hastened. However, if nitrogen is available in abundance throughout the growing season, later maturity results. Also, tissues may be soft and succulent, making the plant more susceptible to disease and mechanical injury.

(2) Phosphorus is essential for normal development. It is a nuclear component of cells and is essential in cell division, for transformation of carbohydrates, for assimilation of fats, and for increasing the efficiency of chloroplastic mechanisms. Adequate phosphorus is necessary for quality in forage legumes, normal development of plump seeds, and as an aid in decreasing lodging.

(3) Potassium is essential for the metabolic processes of cells. It is essential in the synthesis of carbohydrates and their translocation through the plant, and for chlorophyll development. It aids in synthesis of proteins, fats, and oils and also aids in forming rigid stalks and plump seeds.

3.5.2 Source and availability

(1) Nitrogen:- The nitrogen of the soil is combined as part of the organic matter. While almost all (98%) the nitrogen in the soil is in the organic form, about 30-50% of it is in the form of protein. About 5-10% is in the form of amino-sugars while the remainder is as yet unidentified (Russell 1971). Proteins and amino-compounds would be decomposed rapidly by the soil organisms. However, the clay minerals and the altered lignin appear to hold such proteins and

amino-compounds so firmly that the soil organisms cannot readily dislodge the nitrogen group to oxidise it. Therefore, the decomposition is slowed down to such good effect that on balance only about 1% of the total soil nitrogen becomes available in any one growing season, thus assuming a continuous supply even though it may be only on a low level.

The main forms of <u>inorganic nitrogen</u> in soil are nitrate, ammonium (both exchangeable and non-exchangeable) and, under certain conditions, small amounts of nitrite. Exchangeable ammonium, being readily adsorbed, is not easily leached, but under most normal conditions, its rapid conversion to nitrate or organic forms ensures that the amounts present are generally small.

Except under conditions of abnormally low pH, nitrate is not adsorbed by soils and remains completely water-soluble. This fact, allied with high plant uptake, ensures that in most soils the amounts of available inorganic nitrogen are small (usually less than 2% of the total soil nitrogen), and are subject to rapid changes both in amount and distribution through the soil profile. Thus, in the absence of fertilizers, plants are largely dependent on the steady mineralization of organic nitrogen for their nitrogen requirement.

Mineralization is the decomposition of organic matter and the release of inorganic compounds. In practice, it refers to production of ammonium and nitrate as other inorganic forms are usually transitional, although nitrite should be considered also. Mineralization is largely a microbiological process, the organic nitrogen being first changed to ammonium form,[25] this being referred to ammonification, and then via nitrite to nitrate nitrogen, the process of nitrification.

Organic nitrogen ⟶ Ammonium salts ⟶ Nitrite salts ⟶ Nitrate salts
(proteins, amino-acids, etc).

$\underbrace{\hspace{6cm}}_{\text{Decomposition + Ammonification}} NH_4^+ \underbrace{\hspace{5cm} NO_2^- \hspace{5cm}}_{\text{Nitrification}} NO_3^-$

Since these biochemical changes are largely due to the activity of the micro-organisms, they are retarded by soil conditions such as cold temperatures, waterlogged conditions or extreme acidity, the nitrifying organisms being especially sensitive to these conditions.

(2) Phosphorus:- Both organic and inorganic forms of phosphorus occur in soils and both are important to plants as sources of this element.

There is a relative lack of knowledge about organic phosphorus compounds because of their complexity. However, three main groups found in plants are also present in soils:- (a) Phytin and phytin derivatives; (b) nucleic acids, and (c) phospholipids.

Practically all the inorganic phosphorous in soils is present as orthophosphate. The amounts are relatively small, generally 0.01 to 0.30%, and because of this it has so far proved possible to identify positively only a few phosphate minerals (Williams 1967). Most inorganic phosphorus compounds in soils fall into one of two groups:- (a) these containing calcium and (b) those containing compounds of iron and aluminium. These compounds have varying levels of availability to plants depending on their chemical and physical nature, and all have low solubility so that the concentration of phosphate in the soil solution is usually extremely low.

When soluble phosphate is added to soil it is rapidly converted to insoluble forms by process of precipitation and adsorption (phosphate fixation). Phosphate is thus essentially immobile in the soil.

The capacity of soils to retain phosphate varies widely and is influenced by many factors, the most important of which include clay content and clay-mineral type, soil pH, the amounts of free calcium carbonate and the amount and nature of the free oxides of iron and aluminium.

When the soil phosphorus is held in organic matter, it can be simplified by decay. However, the mineral phosphorus presents a much more difficult problem as it is rather insoluble. A simple example is given below to illustrate the mechanism, by which tricalcium phosphate, representing the various insoluble soil phosphates, reacts with carbon dioxide and water.

$$Ca_3(PO_4)_2 + 4H_2O + CO_2 \longrightarrow Ca(H_2PO_4)_2 + 2Ca(HCO_3)_2$$

insoluble phosphate	water-soluble phosphate	soluble calcium bicarbonate

Therefore, a soil may be able to supply a crop with appreciable quantities of phosphorus, depending on the facility with which relatively insoluble phosphates become soluble and thus available.

(3) Potassium:- A large percentage of the potassium in the soil, possibly 90-98%, still exists in mineral form (orthoclase, microcline, muscovite, etc.). An appreciable quantity of this element, 1-10% exists in a 'fixed' or difficult exchangeable form in the soil colloids. A third source of potassium, possibly not more than 1-2% in most soils, may exist in an easily exchangeable position in the colloids and in the soil solution. A small constituent also occurs in organic matter, particularly if an appreciable quantity of fresh plant residues is present.

It is generally assumed that easily exchangeable ions are readily available for plant use. In fact the quantity of replaceable K is generally taken as a measure of the available supply of this element. Potassium in the soil solution and that in organic matter, because it is water-soluble, can be absorbed readily by plant roots unless some factor, such as the concentration of other ions, interferes. On the other hand fixed potassium ions are considered to pass into an available state at a relatively slow rate.

The potassium must also be overcome by the solvent action of water charged with carbon dioxide as it is held largely in mineral combination. The mechanism is often difficult as much of the potassium must first be released from a molecule or semi-molecular combination. The following equation illustrates the process:-

$$2KAlSi_3O_8 + CO_2 + 2H_2O \longrightarrow H_4Al_2Si_2O_9 + K_2CO_3 + 4SiO_2$$

Microcline feldspar — Hydrated silicate — Soluble carbonate

A potash feldspar represents the complex silicate compounds in which potassium is often found. Most of the potassium liberated is adsorbed by negatively charged colloidal surfaces and is available to plants. However, some of it remains in the soil solution to be used by the plant, or is lost in drainage.

3.5.3 Meaning of 'available' plant nutrients

It is essential to realize that all plants nutrients must be present in adequate quantities and in a form in which they can be utilized by the plant. The presence of a sufficient quantity of an element in the soil does not exclude the possibility that the plants may be deficient in this element. In fact, the plant can only make use of a very small proportion of the total quantity of any nutrient in the soil.

The term 'available' refers to plant nutrients in the soil in a chemical condition in which they may be absorbed by plant roots or may be readily transfered into such a condition. Nutrients absorbed on the collodial fraction in an easily replaceable state and organic nitrogen which is readily nitrified would be classified as available.

However, another interpretation includes the physical location of the nutrients in the soil - the portion of all the nutrients not contacted might be considered unavailable. For example, the root system of a plant may not be able to explore all the soil surfaces or an unfavourable structural condition might prevent root penetration in contact with all the chemically available nutrients in the soil. Nutrients in such areas even though water-soluble could be considered unavailable. However, the term 'available' used in the present text is confined to the former definition.

CHAPTER FOUR

MOORLAND SOILS

4.1 PODZOLIZATION AND TYPES OF MOORLAND SOIL

In a study of the development of British Heathlands and their soils, Dimbleby (1962) concluded that though a few soils in his studies had been podzols since the Atlantic period, the majority were secondary, having developed as a result of Man's assault on the landscape, particularly in the Bronze age. He further examined the causes of the onset of podzolization in what had previously been a brown forest soil and discovered that there was no absolute correlation with climate and no close correlation with vegetation except in so far as change followed the destruction of the original woody vegetation. Parent material alone was a critical factor only in a few cases but he considered that topsoil material which had been subjected to prehistoric human influence was much more readily podzolized than subsoil.

In contrast, Stevens and Atkinson (1970) consider that climate is an important regional factor in determining broad differences in soil properties, the effects of parent material and topography being important on the local scale. However, in the majority of soils in lowland Durham, man's influence in pedogenesis has been strong. As the result of ploughing, most soil profiles show a grey brown surface horizon (approximately 20 cm. in thickness). Artificial drainage, addition of fertilizers and coalmining activities have all had an effect on pedogenesis in the particular area around Waldridge Fell. It is only on the hill land of the Pennines and its flanks that podzolic soils are at all widely developed.

A podzol is characterised by having a band of light-coloured soil fairly sharply separated from a dark layer of soil above and below it. The word 'podzol' in Russian means 'ash-coloured soil' which indicates the band of light-coloured soil (Russell, 1961). A typical podzol profile has several clearly defined horizons:-

1. The upper humus layer is of mor, brown to black in colour (Ao horizon).
2. The top layer of mineral soil, also dark in colour (A horizon).
3. The light-coloured bleached layer (Ae horizon).
4. The next layer is dark coloured and usually lightens gradually with depth (B horizon).
5. The spodic (Bf) horizon is visibly enriched with rusty colour from ferric oxide.
6. The parent material (C horizon).

The chemical characteristics of the podzol profile are as follows:-

1. The pH is usually lowest in the Ao horizon and becomes less acid with depth.
2. The Ao and A horizons have a high base exchange capacity, but are very base unsaturated. The percentage of base saturation usually increases with depth.
3. The Ae horizon has been subjected to intense weathering. All easily weatherable minerals have disappeared and only those very resistant to weathering are left, predominantly quartz.
4. The B horizons are illuvial horizons in contrast to the A horizons which are eluvial. The B horizons may be enriched with organic matter, clay, iron and aluminium hydroxides (the spodic (Bf) horizon is enriched with oxidised iron) and the contrast between the chemical status of these two horizons is greatest in the contact area at their junction. Once the difference is established between

the A and B horizons, it becomes progressively greater as podzolization advances.

Podzolization involves the downward translocation of iron and aluminium compounds from silicate clays, and their concentration in the Bf horizon. The organic solution (mainly fulvic acid) from the base-deficient litter of needle-leaf conifers and heath vegetations is most effective in keeping iron and aluminium in solution and is able to remove iron and aluminium oxides from the A horizon by leaching, thus leaving a high silica content in the A horizon.

Stobbe (1952) agreed with the ideas of Duchaufour (1948) that the climax soil on a wide range of parent materials on the Atlantic Zone of France was a brown forest soil. The brown forest soils on the poorer materials may degrade rapidly and the rate of podzolization be enhanced by man's activities. Stobbe suggested the following dynamic sequence for American soils:-

Brown forest -----> grey-brown podzolic -------> brown podzolic ---> podzol

A number of podzol variants related to County Durham are apparent:-

<u>(1). Brown podzolics</u>

Brown podzolics have their highest organic carbon in the surface horizon and this decreases with depth, unlike some other podzols which have a second maximum in the B horizon from translocated humus. pH values do not reach the extremes that occur in the typical podzols and the percentage of base saturation range is more moderate not having the low values in the Ae horizon.

<u>(2). Gleyed podzols</u>

<u>a. Peaty gleyed podzol (or iron pan soil)</u>

Under particularly acid conditions and with the build-up of peat, podzols often develop a pan of concentrated ferric oxide in the B horizon. The pan may also contain significant quantities of organic matter. The iron pan is frequently impervious and causes subsequent gleying in the Ae horizon above. The soil is further characterized by a surface horizon of peat, up to 30 cms. in thickness.

b. Surface-water gleyed podzol

In some cases, the humus-iron horizon of the peaty gleyed podzol becomes so dense and compacted that it promotes surface water gleying in the A horizons, even though a pan has not necessarily formed.

c. Ground-water gleyed podzol

The gleying is associated with the ground-water table instead of following the formation of an impervious horizon. The profile of this podzol has two parts, a thoroughly leached A horizon and gleying in the lower part of the profile which is caused by the ground-water table. The ground-water gleyed podzols are often developed around peat bogs where the soil water has moved through iron-rich mineral and organic matter, ferrous iron compounds are mobilized and later oxidized on the surface of the water table.

(3). Peat soil

The waterlogged conditions that promote the development of gleyed podzols can lead to the accumulation of surface peat bog. Peat bogs, therefore, are frequently associated with level landscapes or ones receiving drainage. On high moist moorland areas where the drainage is poor and parent rocks supply few bases, a peat bog forms, which slowly breaks down to a highly acid raw humus. Beneath the peat layer is often a sticky mass of bluish-grey clay, a gleyed horizon which is stained with ferrous iron salts rather than ferric compounds.

4.2 FERTILITY OF PODZOL SOILS

Within County Durham, the most important factor affecting fertility of podzol soils is soil drainage status apart from elevation and its associated climatic effect. The excessively drained brown podzolics which lack moisture retention have a severe problem of losing nutrients by leaching while very poorly drained gleyed podzols and peat soil affect crop growth by an adverse air/moisture relationship.

There is also a barrier both to water movement and to root penetration when an iron-pan or humus-iron horizon exists , the subsoil becomes sealed off from root action, and even tree roots cannot penetrate it. A low pH and high per cent of saturation of clays and humus with hydrogen are also characteristic of podzols. They require much lime and large applications of fertilizers in order to make them productive.

4.3 INFLUENCE OF GRAZING AND AFFORESTATION ON SOIL FERTILITY

Miller (1963) in New Zealand carried out a comparison of nutrient uptake of beech trees and grass species on a brown forest soil. He found that the annual uptake of calcium, magnesium and sodium tended to be greater for the trees than for grass species. Uptake of nitrogen, phosphorus and potassium, however, by forest and by grassland was approximately the same (Table 4.1).

Both grazing and afforestation cause specific changes to the soil fertility of hill soils, through the loss of nutrients:-

4.3.1 Grazing

It is expected that in a grazing area, a proportion of the

Soil Nutrients kg/ha	Pasture	Trees	
		Total uptake	Immobilized each year
Ca	4	84	10
Mg	6	12	1
K	45	35	4
Na	3	6.2	0.2
P	3	3.2	0.7
N	45	41	3

Table 4.1 Annual uptake of nutrients by unfertilized pasture and by forest on the same soil in New Zealand (hard beech brown forest soil, source: Miller 1963).

soil nutrients that are removed from the field in the crop can be returned to the soil as manure. Other nutrients such as nitrogen, phosphorus, potassium and calcium are removed from the grazing area in considerable amounts in the bones, milk and wool of animals. Furthermore, manure is also subject to serious depletion.

The major portion of the ash contents of animals consists of nitrogen, calcium and phosphate (The latter two are mostly contained in the bones). For example, a 454 kg steer contains the equivalent of about 7.05 kg of phosphoric acid (P_2O_5), 8.16 kg of calcium oxide and 10.58 kg of nitrogen. The amounts of potassium and magnesium oxides in animal bodies are relatively small (Table 4.2).

Material	Calf	Steer	Lamb	Sheep	Pig
N	11.19	10.58	8.97	9.02	8.06
CaO	7.51	8.16	5.84	5.39	2.92
P_2O_5	7.00	7.05	5.14	4.74	2.97
K_2O	0.95	0.86	0.77	0.68	0.63
M_gO	0.36	0.27	0.26	0.26	0.13

Table 4.2 Contents of nitrogen and mineral oxides in animals, calculated on the basis of 453.59 kg live weight of animal (source: Lawes 1858, adopted by Bear 1951).

The composition of milk varies considerably, depending on field, kind of animal and period of lactation. In general, the nitrogen content of milk is relatively high, and phosphoric acid is present in greater amount than any other mineral constituent (Table 4.3)

Material	Highest	Lowest	Averages
N	52.03	19.10	27.67
P_2O_5	12.19	7.36	10.43
CaO	10.99	4.08	6.90
K_2O	8.92	1.90	6.50
Cl	13.05	3.90	6.50
SO_3	8.65	2.63	4.79
Na_2O	8.77	1.49	3.85
MgO	1.49	0.90	1.08
Total ash	41.02	30.99	35.18

Table 4.3 Contents of nitrogen and mineral oxides in 4535.9 kg milk of Holstein cows (Source: Forbes 1922, adopted by Bear 1951).

Chemical composition of wool also varies considerably, depending largely on the amount of suint adhering to it. The quantity of this material is especially high on the wool of Merino sheep, of which it may constitute as much as 50 per cent. Table 4.4 shows that losses of nutrients caused by the removal of wool are primarily those of nitrogen and potassium.

Material (kgs.)	Unwashed	Washed
N	24.49	41.73
K_2O	25.50	0.0
CaO	0.81	0.14
P_2O_5	0.31	0.53
MgO	0.18	0.31

Table 4.4 Contents of nitrogen and mineral oxides in 453.59 kg of wool. Source: Lawes 1858, adopted by Bear 1951).

Thus there will not be 100 per cent. recovery of the nutrients taken up in the feed that may be returned to the soil in the form of urine, faeces, perspiratory products, and wastes of skin, hoofs and hair as the animals are used for production of milk, meat and wool. A balance sheet for a Holstein cow is given in Table 4.5 (If the cow had been pregnant, recovery of phosphorus would have been less).

Material	Food. kg	Milk, Kg	Urine, kg	Faeces, kg	Recovery %
N	77.63	20.10	29.78	28.17	74
K_2O	44.45	6.70	34.77	2.90	85
CaO	37.54	6.65	0.59	30.34	82
P_2O_5	23.63	8.67	0.22	14.21	62
SO_3	19.2	2.75	7.26	8.92	84
MgO	15.77	0.99	1.63	8.61	94
Cl	9.22	4.99	2.08	2.17	46
Na_2O	7.95	2.13	4.17	1.63	73

Table 4.5 Balance sheet for production of 4535.9 kg milk "Percentage of the nitrogen and minerals of the feed that were contained in the combined liquid and solid excrements." Source: Forbes 1922, adopted by Bear 1951).

Furthermore, up to 50 per cent. of the excreted nitrogen, 96 per cent. of the potassium and 1 per cent. of the phosphorus were contained in the urine and hence subject to loss by leaching (Table 4.6).

	% of Nutrient in Feed Found in the Manure			
Condition of Cow	Excrement	N	P	K
Gestation, 49-68 days Lactation, 139-158 days	Urine	37.4	0.2	71.3
	Faeces	35.2	65.7	10.9
	Total	72.6	65.9	82.2
No breed Gestation, 55-74 days	Urine	44.9	0.2	75.4
	Faeces	43.6	86.0	8.8
	Total	88.5	86.2	84.2
Gestation, 246-265 days	Urine	53.3	0.6	96.9
	Faeces	29.9	79.7	5.1
	Total	83.2	80.3	102.0

Table 4.6 Percentages of the nutrients in feed, consumed by dairy cows, that are recovered in the manure (Source: Forbes 1922, adopted by Millar 1955).

Therefore, losses of nitrogen and mineral elements from a grazing area by removal in animals and their products are important. Those from manure may result from loss of urine by seepage, loss of soluble materials by leaching, and loss of ammonia by fermentation.

4.3.2 Forestry

Pearsall (1970) concluded that in the long run grazing may be more exhausting to the soil than afforestation would be. Any grazing animal (e.g. sheep) consumes large amounts of nitrogen, phosphorus and calcium which are derived from the soil via the grasses and other fodder species and unless the pastures are managed properly there is a constant drain being made on the soil fertility. Trees, on the other hand, are mainly composed of woody tissue - cellulose and its derivatives and carbonaceous compounds. These include a minimum of mineral elements and consequently, even with exploitation, the nutrient losses are not nearly so great as with pastoral activities. Much of the nutrient uptake is transmitted to the leaves and growing shoots and these are left behind on the site, the minerals returning to the soil on decomposition. Thus while the average annual removal of nutrients in the forest crop is small compared with that under most agricultural systems, the long term loss from woodlands by harvesting may be considerable. Trees often make the best use of poor soils in terms of dry matter they produce, but this is because they are perennials and hence can match rate of growth to the nutrient supply. This results from the efficient re-cycling of nutrients and the ability of canopy and litter layer to trap nutrients available both in the rain and in the air. Wide experience of afforestation on heathlands show that it can help to prevent leaching and soil erosion, while the correct choice of species can help to improve the quality of the soil (Zehetmayr, 1960).

Ovington (1962) claimed that the overall average annual loss of tree harvesting is small although considerable amounts of chemicals are removed (Table 4.7). The average annual loss would not exceed 0.2 kg/ha of Na, 7 of K, 15 of Ca, 2 of Mg, 14 of P and 14 of N if the standing trees were felled and all boles harvested. The amounts of removal are less since the nutrient-rich upper parts of trees trunks and bark are frequently left behind and some tree boles are not harvested. Therefore, the total weight of elements removed in the forest crop is relatively small compared with that of grazing animals.

kg/h	Na		K		Ca		Mg		P		N	
	Ps	Bv	Ps	Bv	Ps	Bv	Ps	Bv	Ps	Bv	Ps	Bv
Living plants Tree layer												
Fruit	<1		1		<1		<1		<1		1	
Leaves	1		52		36		8		10		115	
Branches	1	1	28	45	34	192	10	17	5	22	60	178
Trunks	1	1	34	17	56	120	8	7	5	8	59	62
Understorey plants	<1	1	2	14	1	15	<1	2	<1	3	2	24
Roots	6	-	35	-	48	-	16	-	11	-	189	-
Dead plant material On Trees (branches)	<1	-	4	-	15	-	2	-	3	-	44	-
Litter on ground	3	1	24	8	139	72	17	4	22	6	163	47
Mineral soil (exchangeable)	-	88	-	125	-	7105	-	156	-	230	-	1300
Removal in harvested trunks	<1	0	4	0	6	0	3	0	2	0	7	0
Total removal in tree trunks if clear felled	1	1	38	17	62	120	11	7	7	8	66	62

Table 4.7: Nutrients (kg/ha) in plant and soil materials and the amount of nutrients removed by harvesting (source: Ovington 1962). (Ps = *Pinus sylvestris*, Bv = *Betula verrucosa*)

There is strong evidence showing that heath vegetation and *Pinus sylvestris* have similar amounts of nutrient uptake. Robertson and Davies (1965) calculated the amount of nutrients in a 5 year-old stand of heather in northern England in which the vegetative matter weighed 12,868 kg/ha. Although the soil contains more nutrients than the natural vegetation, the amounts of available nitrogen, phosphorus and calcium limit the growth of crops at the sites (Table 4.8).

	kg/ha	N	P	K	Mg	Ca
Amount of nutrients	plant	89	6	45	12	32
in heather and soil	litter	54	2	4	2	6
	soil	5,675	362	209	62	108
	Total	5,875	370	258	76	146
Uptake of the heather per year		18	1	9	2	6

Table 4.8 Amounts of nutrients in heather and soil, and the uptake of the heather per year in northern England (Source: Robertson and Davies 1965).

Ovington (1959) found that a plantation of *Pinus sylvestris* on open heath in the East Anglican Breckland accumulated in 55 years, the amounts of nutrients as shown in Table 4.9. Rate of uptake per year by these trees is similar to that by heather.

	N	P	K	Mg	Ca
Nutrients in plant	1,062	86	303	142	643
Nutrients uptake per year	21	2	6	3	14

Table 4.9 Nutrients in *Pinus sylvestris* and their uptake per year in the East Anglian Breckland (Source: Ovington 1959).

CHAPTER FIVE

CALLUNA VULGARIS AS AN INDICATOR SPECIES

5.1 INTRODUCTION

Since vegetation is the product of the interactions between the environment and the genetic tolerance limits of its component species, theoretically it can be the best indicator in natural environments (Billings 1952). To this end it has long been put to practical use by foresters, range managers, soil conservationists and farmers.

Early investigations relied on differences in composition by the plant species and between the various ground vegetation communities as indicators of fertility. More recently, attention has been directed towards differences in vigor shown by a single prominent member of the main communities. This together with tissue testing and soil testing affords much information concerning the nutrient status of plants and the soil supporting them.

5.2 REVIEW OF LITERATURE

As early as 1918, Boyd claimed that the most useful and convenient guide for the classification and evaluation of a new area was to be obtained by careful observations and discriminations of the nature and quality of the natural herbage. There are several plants (*Calluna vulgaris, Eriophorum vaginatum, E. angustifolium,* etc). which can be used for indicating the quality of soil entirely or partially inimical to tree growth.

Gimingham (1949) summarized the indicator values of various heathland species. (*Calluna vulgaris, Eriophorum vaginatum, Molinia caerulea,* etc.) Certain habitat-types, such as flushes, slacks, impeded drainage and more fertile soils, may be indicated by characteristic assembleges of species as they differ in their tolerance of varying habitat conditions. Those having a limited tolerance have high "indicator value". If the tolerance ranges of two species overlap, their relative proportions in areas in which both occur form a valuable source of information. The performance and growth morphology (such as size and shape of leaves etc.) of certain species may also provide valuable information regarding habitat conditions, in particular the degree of exposure and depth of soil.

In line with Gimingham's views, Anderson (1950) proposed six fertility classes based on plant communities to be used when deciding which species of tree should be planted and claimed that the classification will be found to include most of the important waste land plant communities likely to be met with in the British Isles (Table 5.1).

Fertility class	1. Dry	2. Moist	3. Wet
A, B	No moorland vegetation in fertility classes A and B		
C	*Festuca ovina* & *Deschampsia flexuosa*	*Juncus articulatus*	*Molinia caerulea*
D	*Erica cinerea*	*Nardus stricta*	*Eriophorum vaginatum*
E	*Calluna vulgaris*	*Vaccinium*	*Myrica gale*
F	Scattered *Calluna*	*Erica tetralix*	*Sphagnum acutifolium*

Table 5.1 Anderson's (1950) classification of waste land communities.

Yang (1950) analysed the leaf tissue of *Calluna vulgaris* growing in different heathland communities corresponding to different levels in site fertility. He found little difference in the nitrogen, potassium and phosphorus composition of individual plants within the same community, but significant differences between different communities, e.g. *Calluna* growing in the presence of *Ulex minor* contained higher levels of nitrogen than *Calluna* growing alone. The finding put a new light on the possibility of using the tissue analysis of *Calluna* as a reliable index of the availability of nutrients on different sites where it occurs.

By developing this approach, Leyton (1954) used it as a guide to the growth and mineral nutrition of trees planted on heathlands. He showed that there was a significant relationship between nitrogen content of *Calluna* and the rate of growth of spruce and pine on the same site. Thus he claimed the nitrogen contents of *Calluna vulgaris* can be used as an index of suitability of heathland for tree growth.

Arron (1965) found that the luxuriance of growth of the *Calluna* was apparently reflected in the nitrogen content of its foliage at all seasons except during Spring, when the position is complicated by the development of new foliage. Foliage concentration of P and K were not so clearly related to growth. It is suggested that, if nitrogen starvation is the commonest cause of poor growth of tree crops after the afforestation of heathlands, then an assessment of the luxuriance of the *Calluna* communities growing on the site to be afforested could be used to indicate the availability of nitrogen; if necessary, this could be supplemented by foliage analysis.

In studies of the nutrient contents of soils from three adjacent and closely related plant communities in Bramshill Forest, north-east Hampshire, Loach (1966) found that *Molinia caerulea*, *Calluna vulgaris* and *Erica tetralix* were the major species present on all three sites, but their relative proportion varied considerably. Tree growth rates (natural hardwoods and planted conifers) varied with the natural status of each site, and were greatest on the Molinietum.

5.3 ECOLOGY OF *CALLUNA VULGARIS*

Calluna vulgaris L. (Hull) is a low, much-branched shrub, hemi-spherical (except in dense stands), evergreen with minute leaves. In Britain it seldom exceeds 1.25 m. in height (maximum 1.8 m) and is generally less than 0.8 m. The stems are branched from the base, either erect or divergent, with the lowermost prostrate and often rooting adventituously.

Covering one quarter of the 7 million ha. of rough grazings in Britain (Thomas 1955), the ecological amplitude of *Calluna* is fairly wide, including lowland and upland heath, moors and bogs, woodlands and fixed sand dune. It occurs on sand, gravel, leached soils from a variety of parent materials, and on mainly organic substrata such as mor humus, moss hummocks, drained or drying peat, and even on saturated peat. It is characteristically a plant of podzolic soils, to the development of which it contributes by the deposition of litter which gives rise to an acid, chocolate-brown to black layer of raw humus (Gimingham 1960).

5.4 GRAZING VALUE OF *CALLUNA VULGARIS*

Calluna is a fodder crop of very considerable economic importance. Thomas, et.al. gave the first comprehensive examination of heather ash constituents in 1945, and showed that, with the exceptions of phosphorus and potassium, it is a remarkably mineral-efficient food. The edible portion, leaf and stem, contains as much calcium and magnesium as the general run of pasture grass at the grazing stage, and actually contains more of the trace elements iron, manganese, copper and cobalt. This fact linked to the knowledge that 'pine', a disease caused by cobalt deficiency, is very uncommon on hill land with a reasonable proportion of well managed heather suggests that heather may prevent certain deficiency diseases (Thomas 1955).

Miller (1971) analysed the vitro-digestibility (the ability of grazing animals to digest the hard, outer-layer of the plants) and chemical composition of heather, grass, birch and juniper (Table 5.2) and further compared the utilization of these plants. He discovered that heather had a nutrient content which, although lower, was less variable than in any of the other materials analysed. Despite this, the general availability and winter-greeness of heather meant that it was potentially an important constituent of the diet of grazing animals in winter. It is less susceptible to die back and more available during snow than the grasses.

Calluna constitutes an essential part of the diet of hill sheep throughout the year, and is of particular importance in winter. In winter, the larger portions, including woody shoots up to 5 cm. long, are taken whereas in summer, preference is shown for the tips of growing shoots. On many hill farms the 'Blackface' sheep subsist largely on *Calluna*, excepting during the few weeks that are spent on the in-bye land at lambing time (Thomas 1937).

		% digestibility	% N	% P	% Ca
Grass	Oct.	49	1.8	0.16	0.47
	Jan.	35	1.3	0.12	0.30
	Apr.	32	1.1	0.09	0.28
	May.	44	1.9	0.15	0.33
Heather	Oct.	24	1.1	0.10	0.36
	Jan.	27	1.1	0.08	0.39
	Apr.	31	1.1	0.07	0.41
	May.	29	1.0	0.08	0.51
Juniper	Oct.	38	1.5	0.18	1.09
	Jan.	43	1.4	0.17	1.16
	Apr.	43	1.6	0.17	0.84
	May.	41	2.1	0.25	0.99
Birch	Oct.	25	1.3	0.17	0.36
	Jan.	29	1.4	0.17	0.32
	Apr.	27	1.6	0.20	0.34
	May.	34	2.7	0.37	0.33

Table 5.2 In vitro-digestibility (% of organic matter) and chemical composition (% of dry matter) of grass, and of shoots of heather, juniper and birch, October 1968 - May 1969 (source: Miller, 1971).

It is the staple diet of the red grouse, *Lagopus scoticus* (Lath.), which eats it at all seasons and entirely depends on it in winter. From September to May, 80% of the food of the red grouse, consists of *Calluna*, rising to almost 100% in March and April. Flowers and seeds are taken in the late summer and autumn (Wilson and Leslie 1911). It is also an important consitutent of the winter diet of cattle (Thomas 1937, Miller 1971) while upland breeds such as Galloway and Welsh Black utilize it is a food throughout the year. Deer also graze on *Calluna* (Thomas 1937, Miller 1971).

5.5 THE INFLUENCE OF *CALLUNA* MULCHING ON THE GROWTH AND MINERAL NUTRITION OF FOREST TREES

Experiments on podzolized heather moor at Allerston Forest, North Riding of Yorkshire. (Weatherell 1953) showed that a heather mulch applied around checked Sitka spruce (*Picea sitchensis* Carr.), Norway spruce (*P. abies* Karst,), and Lawson cypress (*Chamaecyparis lawsoniana* Parl.) produced improved colour and vigour of the trees.

A comparison between Sitka spruce trees growing in heather and under a heather mulch in Yorkshire (Leyton 1954) revealed that mulching affected a considerable improvement in the height growth of the trees and in the mean dry weight of the leaves. These responses were accompanied by increases in the N, P, Mn and Mg concentrations in the leaves of the Sitka spruce. Leyton suggested that it was possible that much of the benefit of mulching was derived from the improved moisture conditions brought about by this treatment and that these probably account for the increased availability of N, P, Mn and Mg to the trees.

5.6 THE CHOICE OF *CALLUNA VULGARIS* AS AN INDICATOR SPECIES

Out of the four most dominant species on Waldridge Fell, *Calluna vulgaris* has a high grazing value as all the three animal types (sheep, cattle and horses) graze on it. Being an evergreen species, it fulfills the requirement for monthly analysis (obtaining leaf samples for tissue analysis) for the longer term monitoring. The other three main species (*Vaccinium myrtillus*, *Nardus stricta* and *Pteridium aquilinum*) are not chosen because of one or more disadvantages:- Sheep only graze on *Vaccinium myrtillus* when other more palatable plants are not available (Ritchie 1956). Its leaves are not sufficient for the purpose of monthly analysis although it is also an evergreen species. *Nardus stricta* is widespread and has high grazing value but dies back in winter. *Pteridium aquilinum* is not available in winter and it is also avoided by sheep when the other species are available (Gimingham 1964). Table 5.3 shows the difference between the four species.

		Calluna vulgaris	*Vaccinium myrtillus*	*Nardus stricta*	*Pteridium aquilinum*
Grazing value	sheep	+	+	+	+
	cattle	+	+	+	+
	horse	+	+	+	+
High Dominancy		+	+	+	+
Ever Green		+	+	-	-
Leaves sufficient for analysis in winter		+	-		

Table 5.3 Comparison of the suitability for the present investigation of the four most dominant species on Waldridge Fell.

Calluna vulgaris is thus chosen as an indicator of soil fertility in the current work because of the following advantages:-

1. As an evergreen species, it fulfills the requirement of monthly analysis of nutrient uptake.
2. It is the most dominant species in moorland, and thus occupies wide expanses of land suitable for afforestation and grazing activities.
3. *Calluna* has high grazing value especially in winter.
4. *Calluna* mulching benefits the growth of trees where afforestation is practised.

C H A P T E R   S I X

THE ENVIRONMENT OF WALDRIDGE FELL

6.1 LOCATION OF THE AREA

Waldridge Fell (Fig. 3) is an educational nature reserve owned by Durham County Educational Committee. It is located in the northern part of the County of Durham, 4 km, south-west of Chester-le-Street, 6.4 km. north of Durham City, with Waldridge Village and Waldridge Colliery situated at its north-west limits.

The study area is roughly rectangular in shape and is drained by two tributaries of the River Wear - the Cong Burn, which bounds the north west side of the Fell, enters the river to the north of Chester-le-Street and the South Burn, forming the south east boundary, to the south of the town. They are both small streams, and are characterised by the yellow colouration of their water due to the pollution of nearby pit heaps (oxidation of ferrous sulphate in the water) The valley sides of these streams, away from the Fell, are mostly covered with plantations, excepting the portion of the South Burn to the south of the Chester Moor Road.

The area ranges in elevation from 46m. to 124m. Transects AB from south-east to north-west and CD, from south-west to north-east respectively are shown in Fig. 4.

The term 'Fell' denotes a wide, elevated stretch of waste, pasture or moorland, and is in common use in the north of England and parts of Scotland. In northern England any open hill side or mountain is designated 'Fell', e.g. Bow Fell, Beamish Fell, etc.

The word 'moor' originates from German which applies to the peat soil and to the vegetation which it bears while the corresponding English word as it is used to-day is rather wider in its meaning. One speaks of moors and moorland not only when one means heath or bog land with a deep covering of peat, but also when

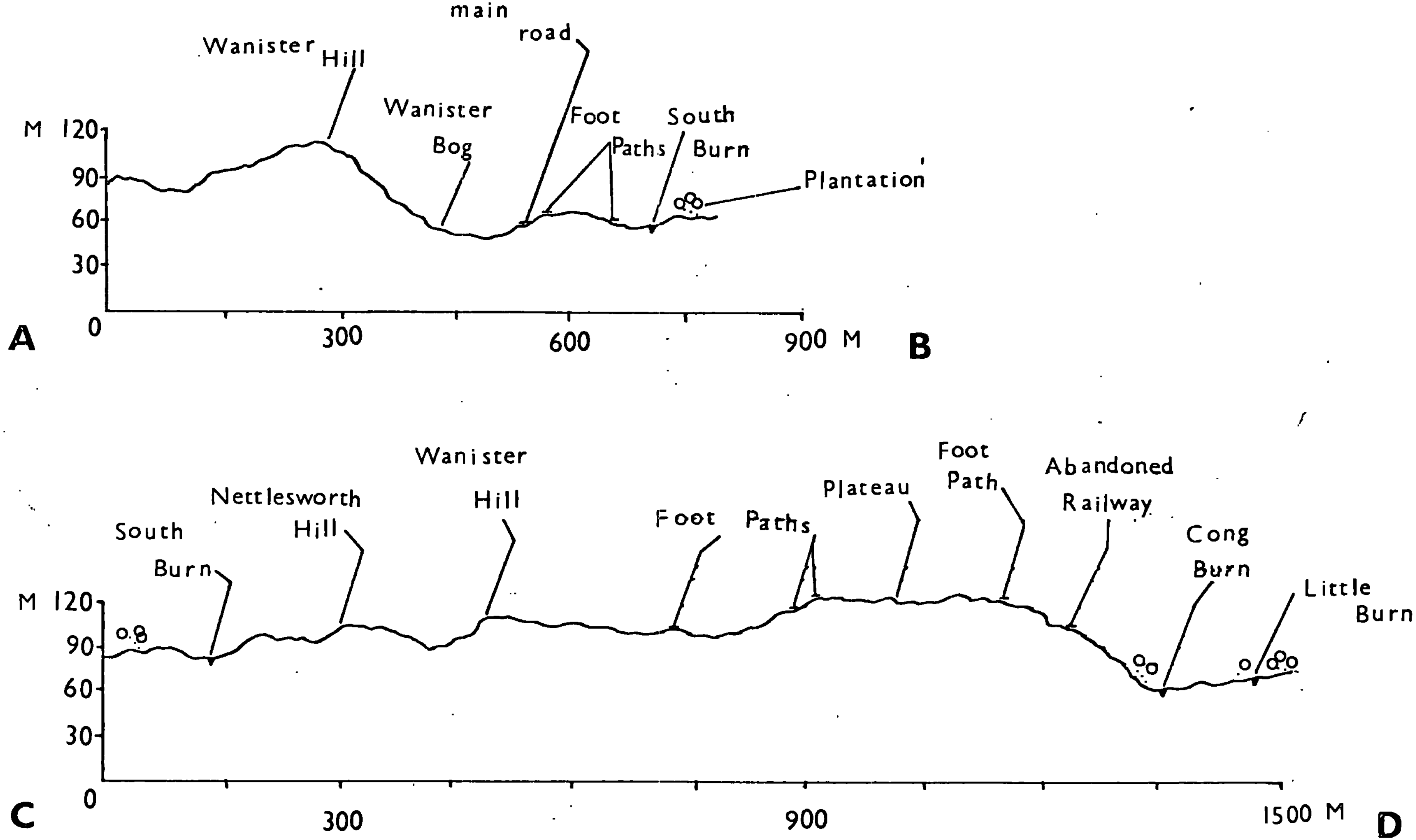


Fig. 4 Two transects, AB from SW to NE and CD from SE to NW (vertical exaggeration x 1.5)

there is only a shallow layer of surface peat much mixed with mineral substances derived from the underlying rocks. A very large proportion of the heathland and moorland vegetation has developed on peat and the line between moors and heaths is necessarily rather an arbitary one, and exactly where one draws it is largely a matter of convenience.

Table 6.1 shows the vegetation types growing on peat (Tansley 1953)

	Moisture	Common English Names
A. Growing on alkaline, neutral or somewhat acid peat:		
1. Sedge fen (*Carex*)	wet	Fen
2. Grass fen with mixed fen	drier	
B. Growing on very acid peat:		
3. *Sphagnum* bog	very wet,	
4. *Rhynchospora* bog	spongy	Moss or bog
5. Cotton-grass moss (*Eriophorum*)	wet	
6. Deer-grass moss (*Scirpus*)		
7. *Molina* moor	damp	
8. *Nardus* moor		Moor
9. Bilberry moor (*Vaccinium*)	dry = Grouse	
10. Heather moor (*Calluna*)	moor	
11. Lowland moor	dry	Heath

Table 6.1 Vegetation types growing on peat (Source: Tansley 1953).

6.2 CLIMATE

The climatic data used are taken from the Durham University Observatory records. The Durham University Observatory (102 m.) is on a slight eminence approximately 0.8 km. to the south-west of

Durham Cathedral, and 6.4 km. south of Waldridge Fell (The plateau 124 m. Wanister Hill 110 m., Wanister Bog 60 m.). It is the nearest meteorological station with comprehensive records.

6.2. 1 Temperature

Temperature is one of the most critical factors of the environment and exerts a profound influence on plant physiological activities by controlling the rate of chemical reactions. Each physiological function in a plant has temperature limits above and below which it ceases and an optimum temperature at which reactions proceed at a maximum rate. As the temperature deviates from this optimum, the rate of reaction decreases, stopping completely beyond a critical limit. Little or no plant growth is made during the heat of a hot summer day. Rather, growth is largely restricted to the cooler morning and evening hours when conditions are more favourable.

Plant species differ in their tolerance to temperature extremes. Each has its definite requirements for growth and reproduction. If the temperature in any given geographical area is unsuitable for even a single phase of plant development, the species may perish; or if it lives, it may not reproduce or be able to compete successfully with better-adapted biota.

The influence of temperature on microenvironment is every bit as pronounced as its importance on the general environment. Its influence is reflected in the different kinds of vegetation growing within a small area. Temperature, and consequently vegetation types, differ considerably with varying exposure and topography. Plants on the sunny side of a slope or even a large rock often differ markedly from that on the cooler, shady sides owing to the different microenvironment. This can be demonstrated on Waldridge Fell. The south-facing slopes are generally warmer in the winter than the north-facing slopes, which receive less solar radiation. Thus more species with a higher density can be found on the south-facing slopes, including *Calluna vulgaris*, *Pteridium aquilinum*, *Vaccinium myrtillus*, *Erica cinera*, *E. tetralix* and *Nardus stricta* while pure stands, of lower density, of *Calluna* and *Pteridium* co-dominate the north-facing slopes. Snow melts first on the warmer slopes and plant growth begins earlier in the spring. In winter cold air flows down the slopes, collecting in the depression where the valley bog has formed.

Two thresholds will be considered from the agricultural view point. 6°C (42.8°F) is generally accepted as the threshold temperature for onset of growth in most plants. 0°C (32°F) is critical for life and death in some plant species or during certain periods in their life cycle. Thus taking the threshold of mean monthly temperature of 6.1°C and above, the normal growing seasons lasts from about the beginning of April to mid-November in lowland Durham. At 500 M. this period is reduced to some five and half months, and the mean monthly soil temperatures for Durham (102 m.) and Moor House (556 m.) give some indications of this effect (Table 6.2).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Durham	2.5	2.8	4.5	7.1	10.6	14.2	15.2	15.3	13.8	11.0	7.0	3.9	9.0
Moor House	1.3	1.3	1.8	3.6	6.6	10.3	11.4	11.5	10.0	7.8	4.5	2.4	6.0

Table 6.2 Mean monthly soil temperatures at 30 cm. depth 1963-68 (source: Smith 1970).

Organic material has a very low coefficient of conductivity. When present at the surface as peat, the heat exchange with the atmosphere is limited to a shallow zone. This is further emphasised when the surface is wet as it is frequently near the surface. Thus peat areas retard crop growth in spring but it will be compensated by accelerated growth in high summer when the organic material is drier, together with its dark colour which becomes a powerful absorber of heat.

Taylor (1958) in his studies in the sand and peat districts of south-west Lancashire found that the contrasts in soil climate in cultivated sands and peats is clearly marked during cloudless weather and even discernable during cloudy weather . The onset of the growing season on peat can be as much as four weeks later than that which is on sand although two sites may only be half a mile apart. The peat-land harvest is usually one to two weeks later than that on sand as the gap is narrowed to two and sometimes even to one week by acceleration of growth on peatland in mid-summer (June and July).

The final air frost of the winter may be expected at Durham about 10th May with the frost-free period lasting until 5th October. (Manley 1941). Ground frost will be much more frequent, and is only reliably absent during July, with the highest incidence taking place in January and February.

Owing to the cumulative effect of the northerly latitude and the coolness of the adjacent North Sea, relatively low mean annual temperatures are found in this area. According to Fig. 5, a steady upward trend in mean temperatures from 8.2°C to 8.9°C was shown clearly from the 1880's through to about 1950. Although the mean temperatures have decreased since 1950, the values still remain

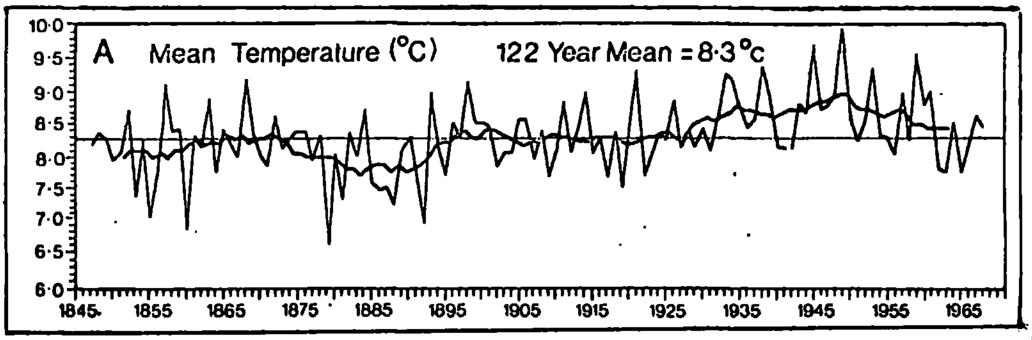


Fig. 5 Annual temperatures (C°), 1847-1968
Long-period annual data, with 10-year moving averages from Durham University Observatory (adopted from Smith 1970)

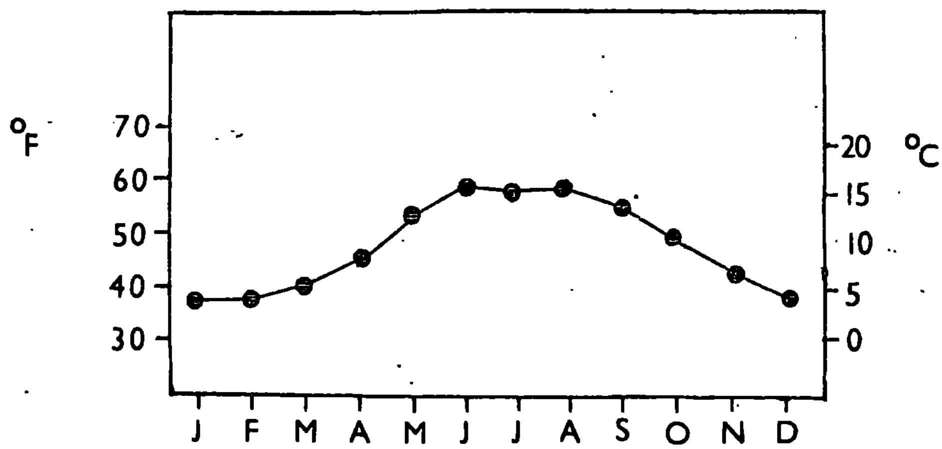


Fig. 6 Mean monthly temperature from Durham University Observatory

rather above the long-period average. The annual mean has varied from - 6.7^{o}C in 1879 to 9.9^{o}C in 1949 (Fig. 5) whilst the daily extremes have ranged from 31.7^{o}C on 16th July 1876 to -18.3^{o}C on 8th February 1895. Fig. 6 shows that the maximum average average monthly temperature occurs in July (15^{o}C) and the minimum in January (4.7^{o}C). In any one year the maximum temperature may occur anytime from May to September, with an absolute minimum possible right through the winter from October to April.

6.2.2 Precipitation

Precipitation, whether in the form of rain, snow, or atmospheric humidity, is closely interrelated with temperature in its influence on plant development.

Water is required for all life processes and often limits plant development. Water is required to maintain cell turgidity, to provide a substrate and medium for chemical reactions and for the transport of mineral ions in the plant. Also, when transpired from the leaves, water is of some value in cooling and maintaining a plant temperature suitable for metabolic reactions.

Atmospheric precipitation is the main source of water for non-cultivated, terrestrial plants as in a moorland environment. The total amount of precipitation, its form and availability, and its annual distribution determine the type and distribution of plants found in different localities.

Not all the precipitation becomes available to plants as soil moisture. Much of the rain falling on the leaves and branches evaporates without ever reaching the soil. Once on the ground, much of the water is lost by evaporation from the soil. More is lost through run off, leaching, drainage and transpiration. The effectiveness of the rainfall on plants depends on all these conditions.

Plants respond to the effective moisture available and possess distinct and characteristic structural modificiations which characterize the flora of each environment. Adaptions found in the bog area, with excess water, on Waldridge Fell, are plants like *Juncus*, *Eriophorum*, *Equisetum*, *Hydrocotyle* and *Sphagnum* etc., all generally having shallow roots.

A rain shadow effect is apparent in County Durham because of the Pennine uplands, with the mean annual precipitation declining steadily towards the east coast (Fig. 7).

The fluctuation of the yearly totals since 1886 at the University Observatory is shown in Fig. 8. There may be big variations between the yearly totals with the extremes being 886 mm (1930) and 440 mm (1959).

The mean monthly rainfalls show February to be the driest month with a steady increase in the following three months (March, April and May). Rainfalls rise again in July and reach a maximum in August (Fig. 9). From September to January the monthly rainfall tends to fluctuate in amount.

The duration of rainfall is commonly expressed by the number of wet days or of rain days. The former is defined as days with 1 mm (0.04 in) of rain or more, and the latter as days with more than 0.2 mm (0.01 in.) of rain. The average number of rain days is about 175, at Durham Observatory (102 m.) but may be somewhat higher on Waldridge Fell (The Plateau 124 m., Wanister Hill 110 m.) owing to its slightly higher elevation.

Since most of the rainfall is basically cyclonic in origin,

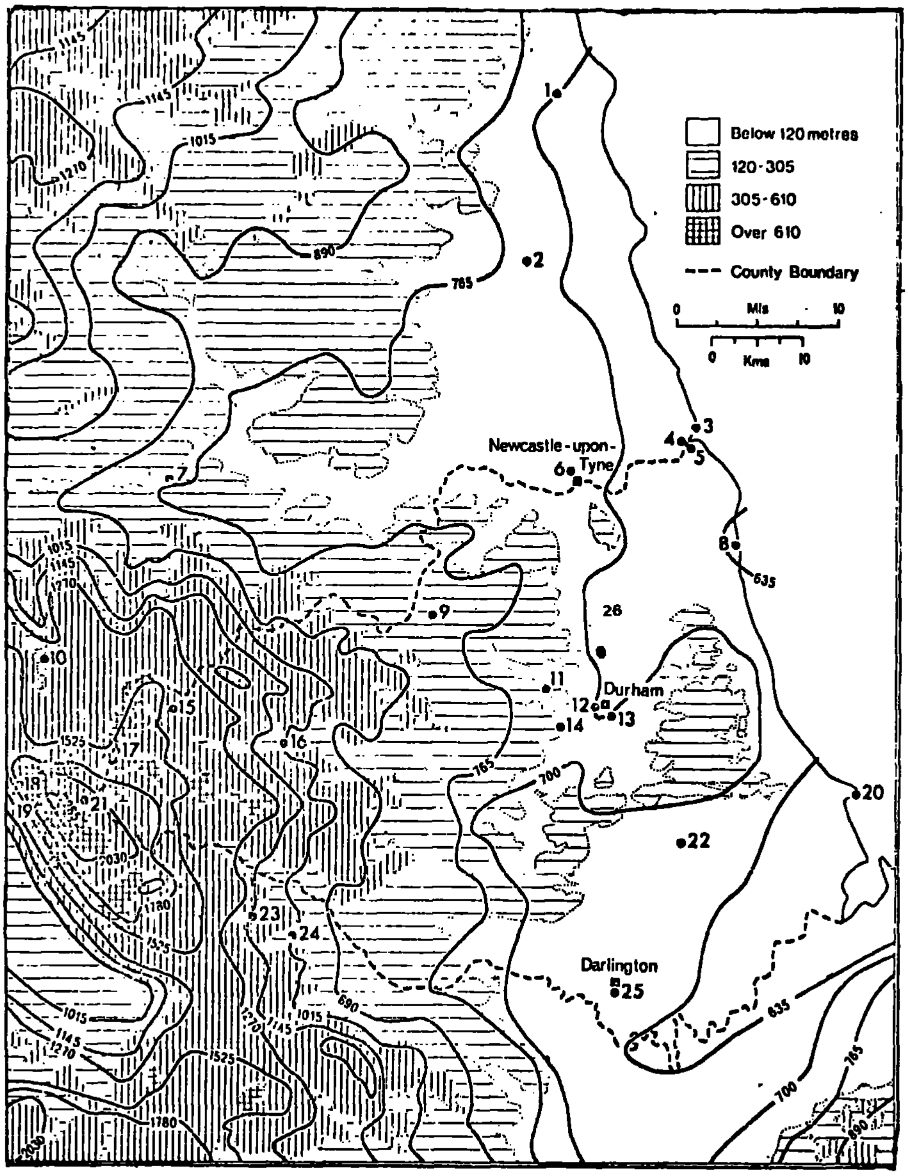


Fig. 7 Mean annual precipitation (1916-50, adopted from Smith 1970, isophyets rounded to nearest 5 mm.)

Place names:- 1. Acklington 2. Cockle Park (Morpeth) 3. Tynemouth 4. North Shields 5. South Shields 6. Newcastle 7. Haydon Bridge 8. Sunderland 9. Consett 10. Alston 11. Ushaw 12 Durham Observatory 13 Houghall 14. Brandon 15. Lanehead 16. Eastgate 17. Burnhope 18. Cross Fell 19. Great Dun Fell 20. Hartlepool 21. Moor House 22. Sedgefield 23. Selset Reservoir 24. Hury Reservoir 25. Darlington 26. Waldridge Fell

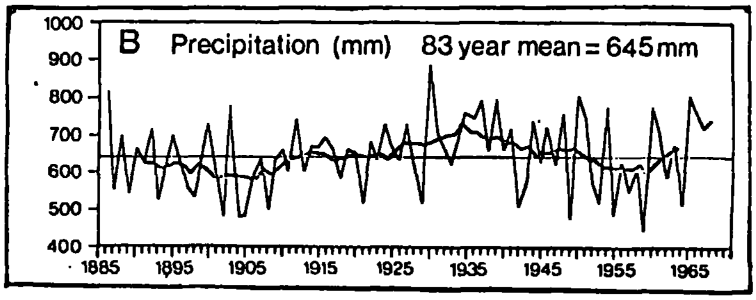


Fig. 8 Annual precipitation (mm), 1886-1968
Long-period annual data, with 10-year moving averages from Durham University Observatory, adopted from Smith 1970)

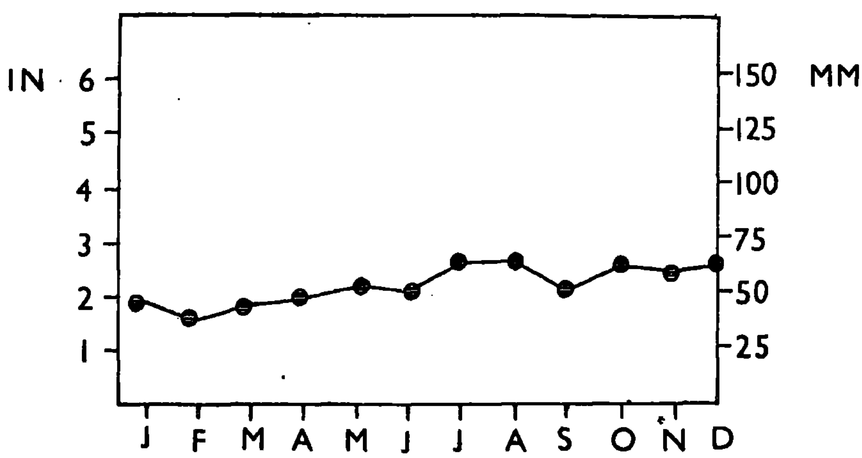


Fig. 9 Mean monthly rainfall from Durham University Observatory

there is usually a fairly direct relationship between monthly rainfall value and the number of rain days. This is less true when high individual monthly totals are considered as these often reflect heavy falls on particular days, and the large daily falls are not confined to the high rainfall areas.

17 individual storms with rainfall of 25 mm. and lasting for not more than 2 hours occurred between 1865 and 1960, and ten of these took place during July or August with none in the months October to May. Table 6.3 shows that heavy daily falls tend to occur between May and October 1916 - 50.

Amounts	J	F	M	A	M	J	J	A	S	O	N	D	Year
63 mm.	0	0	0	0	1	0	0	0	0	0	0	0	1
51 mm.	0	1	0	0	6	0	0	0	6	0	0	0	13
38 mm.	0	6	0	0	11	6	5	5	16	1	1	0	50
25 mm.	6	12	0	2	18	20	32	25	32	15	11	1	173
13 mm.	75	55	52	42	86	81	162	187	168	99	96	66	1178

Table 6.3 Frequencies of daily rainfall amounts equalled or exceeded 1916-50 (total number of occurrences) at Durham University Observatory altitude 102 m. Mean annual total 668.3 mm. (Source: Smith 1970).

Snowfall is a special case of 'rainfall' as it does not obey the laws of gravity the same way as rainfall. It not only remains on the ground until it melts, but it drifts, both at the time of falling and afterwards. These have two main effects:- it shelters dormant vegetation where it lies and it melts into water when it thaws.

The southerly and easterly winds from the North Sea carry instability showers from the polar air. This effect together with topographic effect of the eastern dip-slope of the Pennines can produce heavy snowfall in the upper parts of Weardale and Teesdale. The average number of days of snowfall at Moor House is 50 compared with only 20 at Durham. At Durham Observatory, snowfall is mainly restricted to the period from the beginning of November to early May, with most between December and March, while it occurs every month at Moor House, except July.

The number of mornings with snow lying can reflect the severity of the winter climate rather than the incidence of snowfall. This measurement also has a rather different distribution over North-east England, for whilst in the lowlands and along the coast the number of days with snowfall usually exceeds the period with snow lying, the reverse applies on the Pennine hills, due to the lower mean temperatures and the greater initial accumulations of snow which occur there. Thus, the duration of snow-cover (days) normally increases inland from the coast according to depths - At Durham the figure is 17 (102 m.), compared to 21 at Ushaw (181 m.), 40 at Alston (303 m.) and 55 at Moor House (556 m.).

6.2.3 Wind

Dry air and wind add greatly to the rate of water loss from both plant and soil. Despite the occasional cooling effect of wind, the net effect is one of desiccation. Evaporation and transpiration may increase to the point where appreciable amounts of water are lost to the atmosphere.

Wind can be physically devastating, and it is the principal agent limiting tree growth in hill areas. Trees and other woody vegetation sometimes adapt themselves to constant high winds by assuming a low-bushy, or prostrate growth. However, occasional gales do not have the same effect. Growth is not inhibited until the gale occurs, and only then does it cause severe damage or death by uprooting.

Whitehead (1957) in his studies of wind as a factor in plant growth suggested that three categories of plants might be recognized:-

1. Wing evaders or those that adopt a very low growth habit, e.g. rosette growth, the aerial parts of the plant being so near the surface as to be out of any significant wind.
2. Wind tolerant.
3. Wing susceptible.

In general, the vegetation on Waldridge Fell belongs to Group 2.

The University Observatory records indicate that some 60% of all winds blow from the south-west direction, although there have been slight directional changes within recent years. Between 1905-1935 southerly winds were marginally more frequent than either westerlies or south-westerlies, whilst the hourly observations from 1937 - 1962 reveal a clear dominance of south-westerlies which comprise almost one-quarter of all values. Apart from south-westerlies, it appears that north and north-east winds have recently become more frequent throughout the year, with an overall decrease of direct easterlies and westerlies (Fig. 10).

Some wind directions, such as south-east, have a constant frequency throughout the year, whilst others such as north-westerlies, are much more variable.

There is an interruption of the general westerly flow during spring and early summer by north and north-east winds. It is these

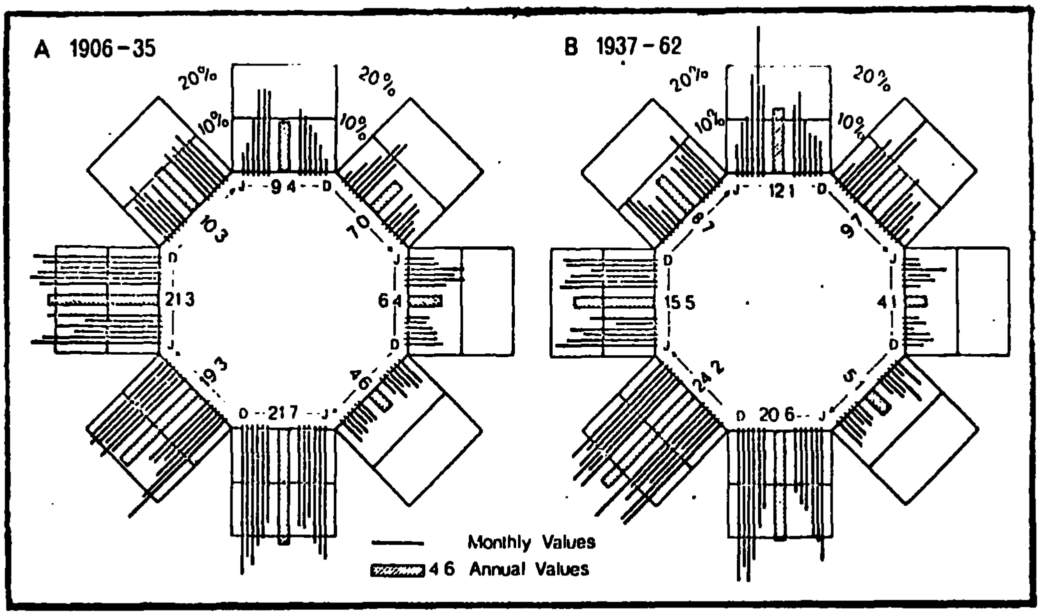


Fig. 10 Mean annual and monthly wind roses from Durham University Observatory (adopted from Smith 1970)

The diagram shows percentage frequency of cardinal wind directions for each month and the whole year. Monthly values to be read clockwise from January to December. Scale given by octagonal segments at 10% and 20% frequencies.

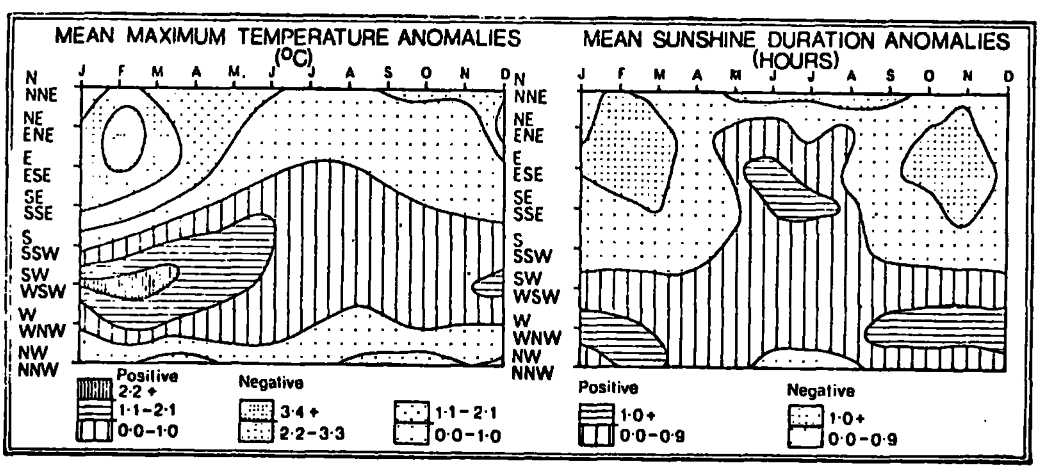


Fig. 11 Mean monthly anomalies of maximum temperature and sunshine duration in relation to wind direction at Durham University Observatory, 1937-62 (adopted from Smith 1970)

winds which bring Durham under the influence of the extension of the European high pressure system, and are responsible for prolonging winter.

The seasonal anomalies of maximum temperature and sunshine duration is related to wind direction (Catchpole 1966). Throughout the year, southerly and westerly winds produce higher maximum temperatures than the average, while greater negative anomalies occur with easterly and northerly flows. It is also interesting to note that, air mass properties have a considerable influence on maximum temperatures in late winter and early spring, when large contrasts exist between maritime and continental influences. Sunshine duration shows a slightly different situation with westerlies and easterlies giving positive and negative anomalies respectively for the greater part of the year from September to April, but with a reversed pattern through a short summer period as the positive westerly anomalies become weaker (Fig. 11).

Gales are much less frequent over north-east England than on the west coast and are usually restricted to about 5 days per year with the greatest incidence being northerly gales in Spring.

6.2.4. Sunshine

Sunshine also plays a vital role in determining the plants' characteristics, distribution, and survival. Light energy, radiation with wavelengths between 400 and 760μm is required directly to sustain the growth of all green plants. Light intensity quality, and duration all influence plant development. Too much or too little light is fatal. Low light intensities can be equally harmful to intolerant species unable to obtain the energy needed for survival.

There is a minimum survival light intensity for each species, below which more carbohydrates are burned in respiration than produced in photosynthesis. Inadequate light limits the available energy and prevents normal development of unadapted species. Should poor light conditions persist, various visible disease expressions of leaf yellowing, drying, and killing will appear.

On Waldridge Fell the influence of light intensity is reflected in the stratification of species in the Callunetum:-

1. The uppermost stratum is a *Calluna* canopy, 20 to 40 cm. above ground.
2. Second stratum, usually at about 10-20 cm., consists of sub-ordinate dwarf-shrubs (e.g. *Vaccinum myrtillus*), and grasses or sedges (e.g. *Deschampsia flexuosa* or *Carex goodenowii*).
3. Third stratum occurs about 5-10 cm. Robust mosses and low-growing herbs (e.g. *Potentilla erecta* and *Galium saxatile)* dominate.
4. The ground stratum comprises mat-forming or short, erect mosses (e.g. *Sphagnum* spp.)

Gimingham (1964) found that light intensity at ground level may only be 60% of that above the vegetation, and where the *Calluna* canopy is dense it may fall below 20%. The situation can be seen in a luxuriant even-aged stand of *Calluna*, resulting from well-controlled burning management, which becomes so dense as to exclude one or more of the other strata.

Marked variation in the duration of sunlight occurs with latitude and from one season of the year to another. Differences in the relative duration of daylight and darkness, that is the photo-period, exert a basic effect on flowering, fruit growth, stem elongation, and virtually every other plant process. Photo-period plays an important part in controlling reproduction and hence the distribution of all species having critical daylength requirements.

North-east England has one of the lowest sunshine totals in Britain, this being almost entirely due to the north sea 'harr' which occurs mainly during the late spring and early summer. Air from the continent usually comes over the North Sea and during its passage the air is in close contact with the sea surface. In summer the North Sea is cool and this is liable to produce air temperatures on the North-east coast as low as 9-12^{o}C (48-54^{o}F) in June and 13-16^{o}C in August (55-61^{o}F) in air which was causing a heat wave (25-30^{o}C) in Germany. (These situations commonly bring sea fog in the Channel or North Sea respectively, known as 'sea-fret' in Cornwall and 'harr' on the east coasts of Scotland and England.

Fig. 12 shows the annual sunshine duration and, based on 83 years records, the mean duration is 1317 hours. Extreme annual total have ranged from 1606 hours in 1901 to 982 in 1912. The low value which occurred in 1912 is believed to have been affected by the volcanic eruption of Mount Katmai in Alaska (Manley 1942). Fig 13 shows mean daily sunshine in June at Durham Observatory, of 5.6 hours which drops gradually and steadily till it reaches the minimum value in December of 1.4 hours. It then increases again to the June maximum.

As to the average daily duration of sunshine in a year, there is an obvious westward and altitudinal decline:- 3.6 hours at Durham Observatory (102 m.) compared with 3.3 hours at Moor House (556 m.) and 2.5 hours on the summit of Great Dun Fell (610 m.). This reflects the increased cloud cover on the Pennine summits.

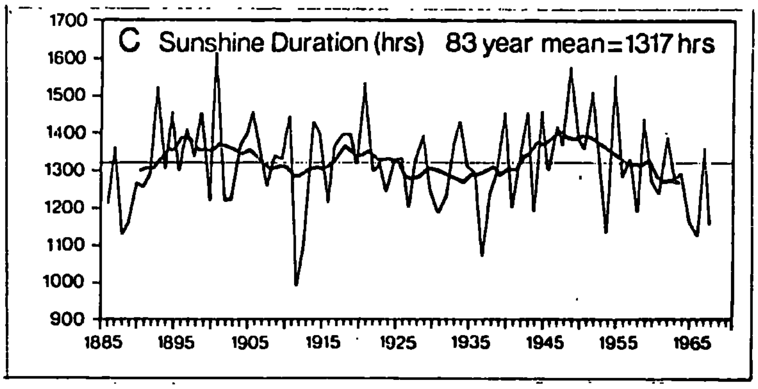


Fig. 12 Annual sunshine duration (hours), 1886-1968 Long-period annual data, with 10-year moving averages from Durham University Observatory (adopted from Smith 1970)

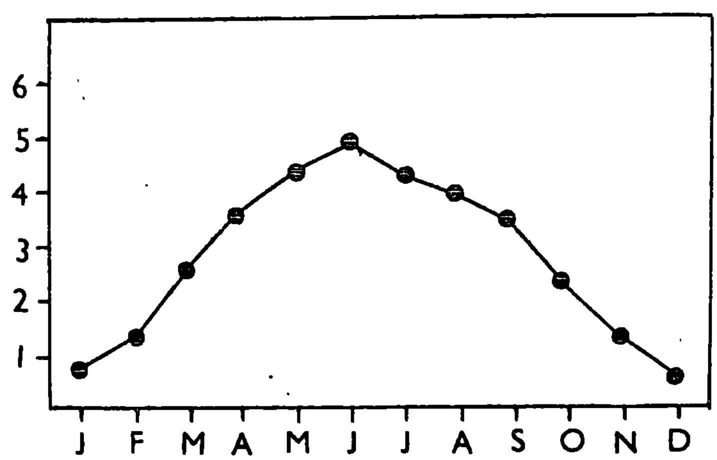


Fig. 13 Mean monthly sunshine (hours/day) from Durham University Observatory

6.3 Geology and topography

Three main lithological divisions can be distinguished in County Durham:-

1. In the north and west the yellow, grey, and black sandstones, silt-stones, shales and coals of Carboniferous age.
2. In the east the yellow dolomite Magnesium Limestone.
3. In the south, the bright red sandstone and the red and green Keuper Marls.

Waldridge Fell is situated on the Coal Measures age outcrop (Fig. 14) in the centre of the Durham Coalfield. The groups which occur under the study area are as follows:- (Maling 1955, Taylor et.al. 1971)

(1) Carboniferous Limestone

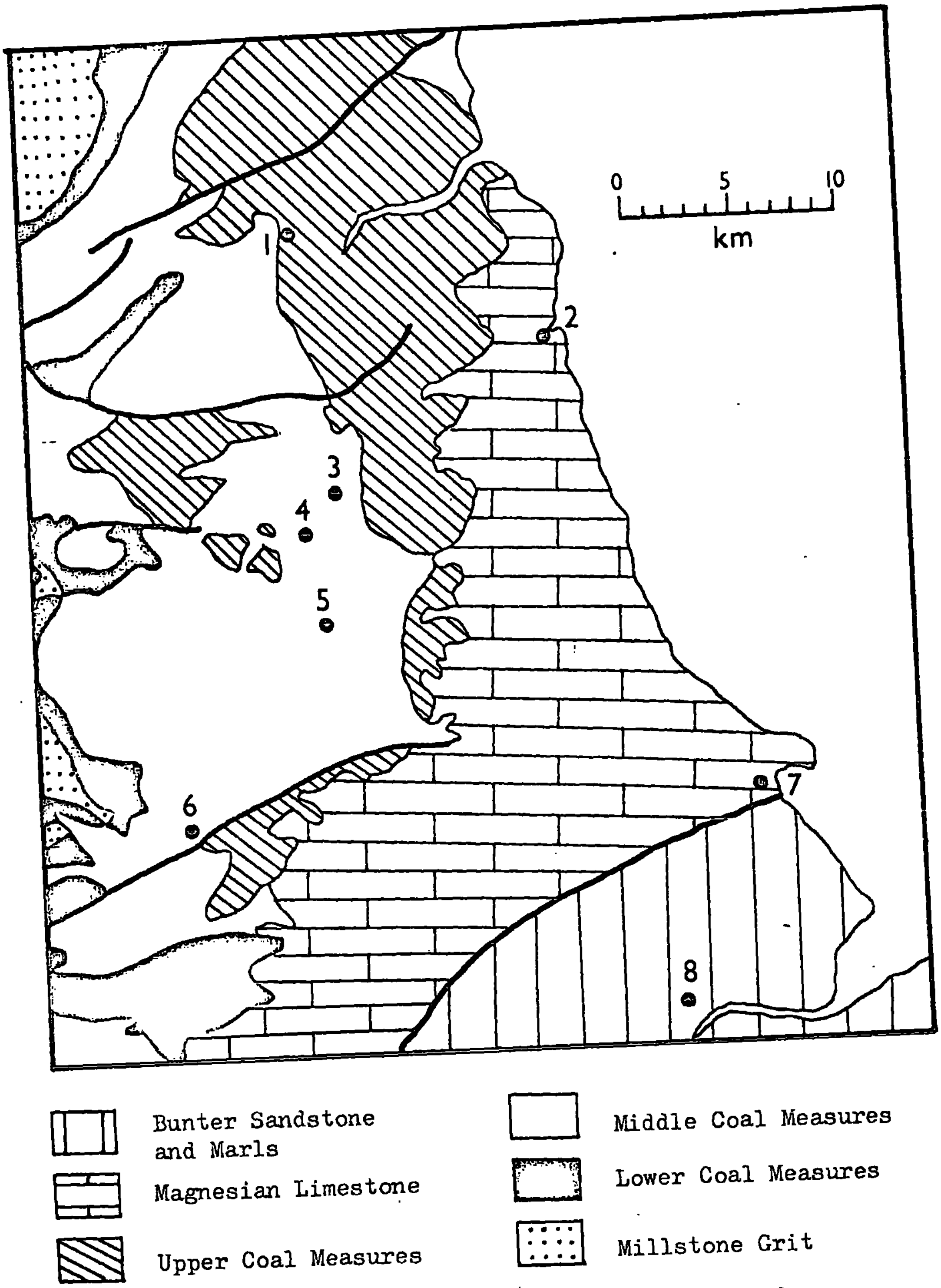
The Caledonian orogeny and its accompanying erosion created the area of Waldridge Fell and its vicinity a new basement surface on which sedimentation recommenced in late Devonian or early Carboniferous times. The Carboniferous Limestones are thin and tend to be argillaceous, coals are generally thin and seatearths numerous.

(2) Millstone Grit

The upper division of the Millstone Grit consists of coarse grits with interbedded sandstones, shales and ganisters, together with marine bands and thin coal seams. The base of the lower division is part of a well developed sedimentary cycle of the Great Limestone but above this there is a tendency for the limestone member to decrease and shales and sandstone to increase in thickness.

(3) Coal Measures (Lower and Middle Coal Measures)

The Lower Coal Measures include massive sandstone which tend to be coarse and some are siliceous enough to be termed ganister. The



Place names:- 1 Newcastle, 2 Sunderland, 3 Chester-le-Street, 4 Waldridge Fell, 5 Durham City, 6 Bishop Auckland, 7 West Hartlepool, 8 Billingham

Fig. 14 Geology of Northeast England.

Middle Coal Measures include sandstones which predominate near the base, thick coal seams characterize much of the middle of the sequence but shale and siltstone predominate near the top.

Throughout North-east England it is believed (Smailes 1961, Taylor, et al. 1971) that the main relief features were carved largely as the result of the Tertiary erosion and that almost all the valleys and upland areas existed in their present form prior to the Quaternary glaciation. The effects of glaciation have been found to be important in modifying the landscape of Waldridge Fell and its vicinity, forming nearly all the minor relief features.

The middle Wear Valley occupies part of a pre-glacial valley and it is believed that it stood considerably higher above sea level than now (as much as 61 m.) before the onset of glaciation (Smailes 1961). This was due to the coastline being considerably east of its present position. The glaciation powerfully affected the landscape of North England by glacial erosion (the removal of weathered rock debris) and the grinding, polishing, striation and plucking of bare rock surfaces, as well as by considerable deposition. Numerous borings by the National Coal Board have shown that the rock floor of the middle Wear Valley lies more than 61 m. below the drift surface. This means that the present crest of the Magnesian Limestone escarpment would have risen in places to more than 213 m. above the pre-glacial valley-floor (Maling 1955).

The glaciation appears to have interrupted an incomplete cycle of subaerial erosion and the ice-sheets generally smoothed and softened the contours of the pre-glacial surface by blanketing them for a long period and covering them with drift. Waldridge Fell and the adjacent area is covered by thick deposits of heavy glacial drift cover, and owns its diversified topography to rounded mounds of fluvio-glacial sand and gravel believed to represent material swept into a late Pleistocene lake through an extensive series of overflow channels swinging round from the north-eastern foothills of the Pennines to Waldridge Fell (Dunham and Hopkins 1958). Fig. 15 (based on work by Maling 1955) shows the drift deposits of the area. The boulder clay occupies most of the Plateau area, Wanister Hill and Nettlesworth Hill. The bog proper of Wanister Bog is underlain by alluvium while the fluvio-glacial sands cover the remainder of the area.

6.4 SOIL

In a study of the soils of County Durham, Stevens and Atkinson (1970) describe four soil landscapes:-

1. The Pennine Moors and Dales of West Durham, characterised by podzolic soils and hill peat.
2. The Wear Lowlands and North-west Durham, in which gley and imperfectly drained acid brown soils dominate.
3. The East Durham Plateau, with its calcareous soils.
4. The lowlands of south and south-west Durham.

Waldridge Fell is located in the second soil landscape area and the parent material of the soils consists of thick drift deposits of glacial origin. The boulder clay derived from Carboniferous rocks yields soils that may be described as heavy loams but they are sometimes sticky clays, which are poorly drained and restricted in their utilization. In contrast, the fluvio-glacial sands have the advantage of good natural drainage and areas covered by this material are mainly located on the north and the south of Waldridge Fell. They provide reasonable arable soils and tend to be used for agriculture and the forestry plantations.

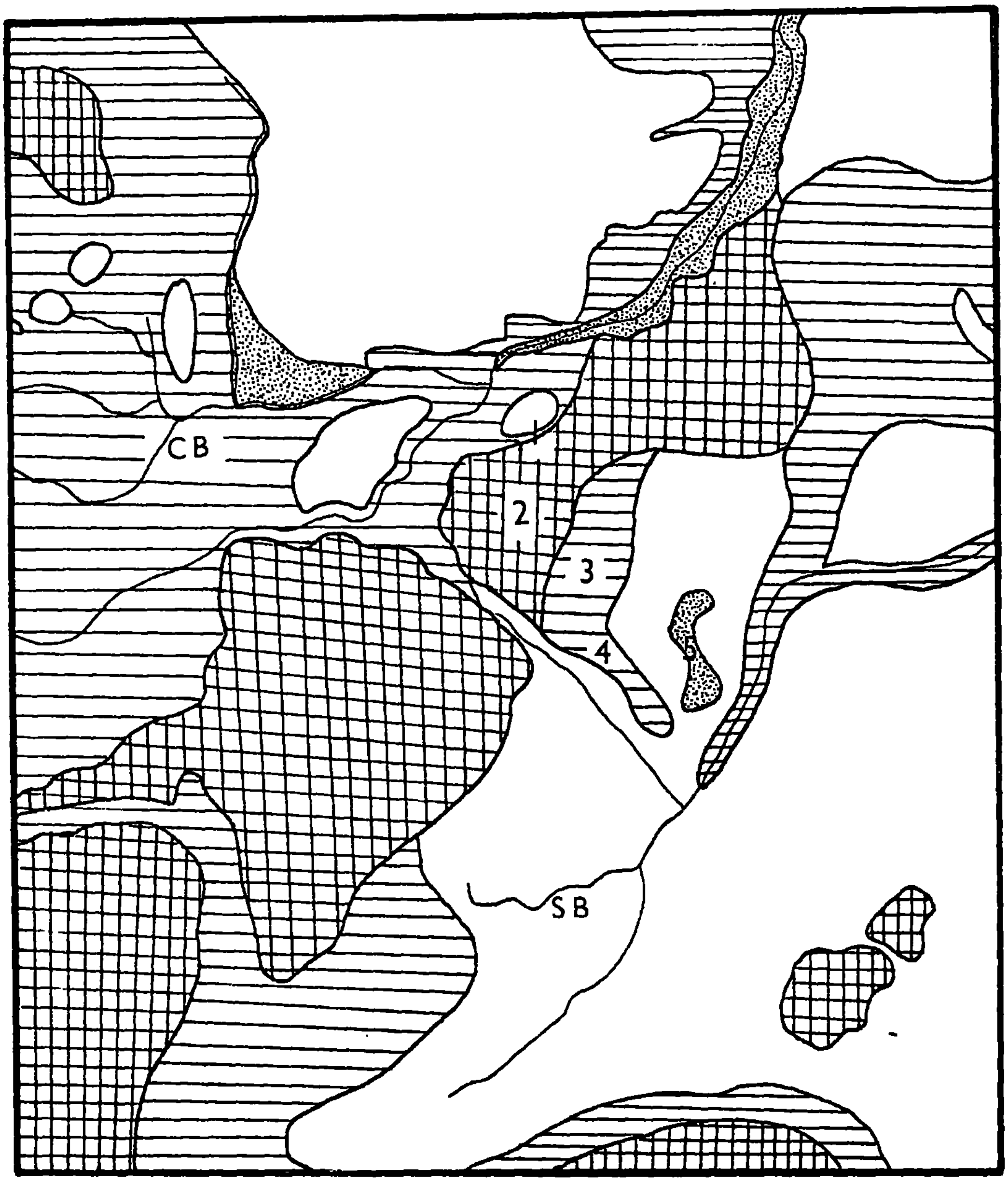
The term "catena" is used to describe any regularly repeating pattern of soils due, directly or indirectly, to topography, or to changes in parent material (Money 1972). A well-defined hydrologic sequence of profiles along slopes commonly occur in central and eastern part of County Durham (Stevens and Atkinson 1970). On Waldridge Fell this sequence is a brown podzolic soil which is freely drained on the upper slopes and imperfectly drained on the middle slopes, a poorly drained surface water gley on the lower slopes and peat or peaty gleys in the depressions (Fig. 16).

The soils on Wanister Hill are podzolic in nature and have been classified as Brown Podzolics. These soils are characterised by:-

1. an organic horizon (raw humus layer - 3.5 cm) beneath the litter layer.
2. the absence of a marked eluvial layer, though partially bleached Ae horizons occur.
3. the surface horizon has the highest organic carbon and this decreases with depth, unlike typical podzols which often have a second maximum in the B horizon arising from translocated humus.
4. pH values do not show the extremes as in the typical podzols but acidity decreases gradually with depth.

A typical profile diagram, description and analytical data are given in Fig. 17, Table 6.4.

Soils on the lower slope of the Wanister Hill differ from those at higher elevations as water tends to move laterally through the profile as well as downwards. The lower slopes receive runoff water from upper slopes and consequently the lower slopes have deeper sola with more organic matter than found on upper slopes. This results



[Alluvium symbol]	Alluvium
[Fluvio Glacial Sand symbol]	Fluvio Glacial Sand
[Boulder Clay symbol]	Boulder Clay
[Thin Drift symbol]	Thin Drift (mapped by Geological Survey as drift free. Revised by Maling to show <3 m. of clay cover)

CB Cong Burn, SB South Burn

1 The Plateau, 2 The north-west part of Wanister Hill,

3 The south-east part of Wanister Hill,

4 Nettlesworth Hill, 5 Wanister Bog

Fig. 15 Drift deposits of Waldridge Fell and the adjacent areas (adopted from Maling 1955).

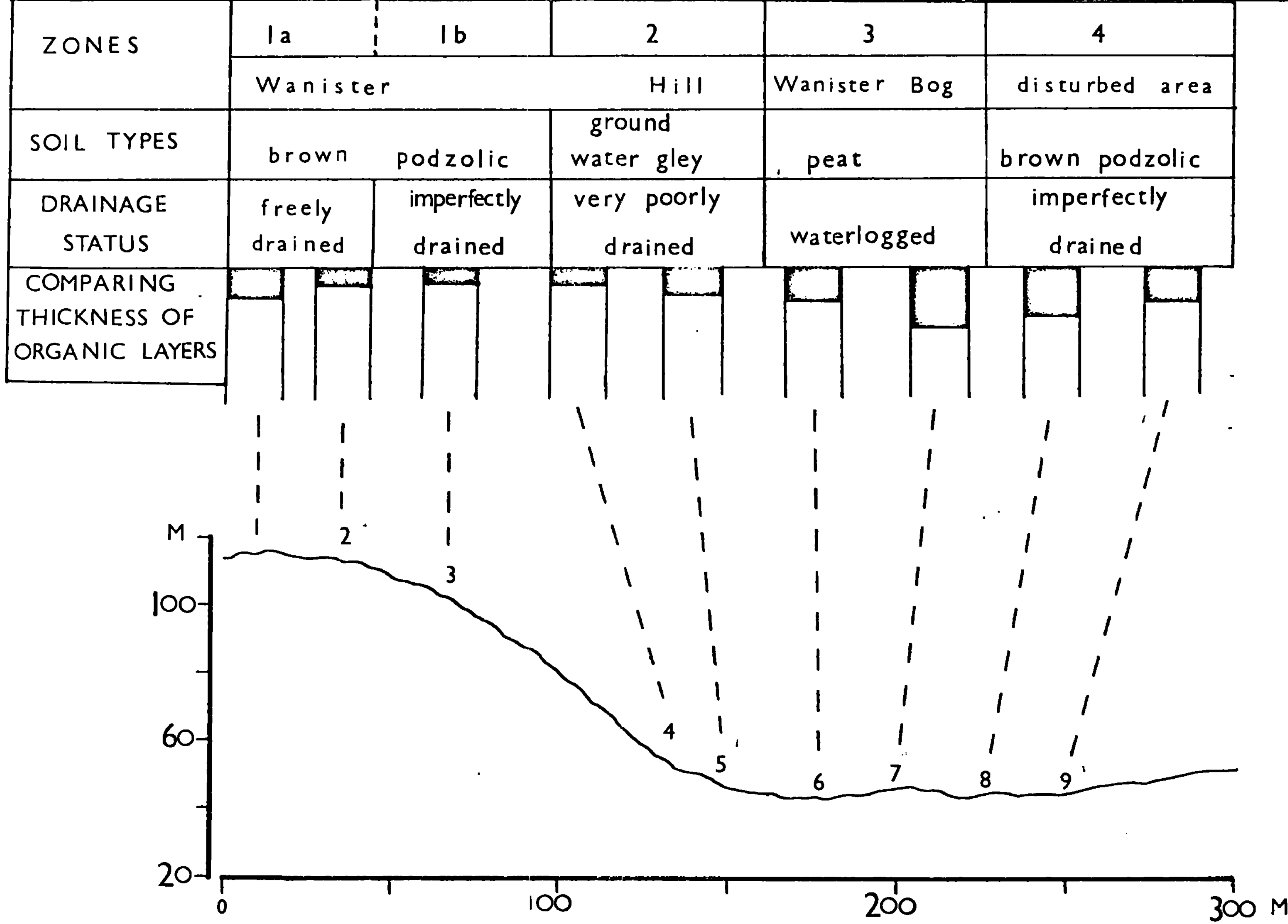
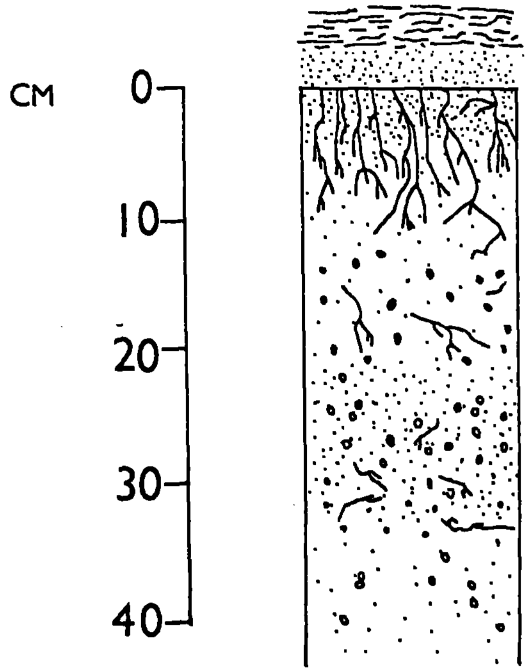


Fig. 16. Cate´nary sequence of soils on Waldridge Fell along the transect AB.

SOIL PROFILE 1



Horizon	Mechanical analysis (International Limit)			Air-dry moisture %	Loss on ignition %	organic carbon %
	%sand	%silt	%clay			
A	ND	ND	ND	1.45	8.72	10.31
B	65	17	18	1.25	6.32	5.31
C	66	16	18	0.90	5.20	2.97

Horizon	T.C.E.C. m.e./100 g	pH	Total N %	Available P (ppm)/g	Exchangeable K (ppm) / 5g
A	10.85	3.4	·490	7.0	22.5
B	4.88	3.6	·224	5.0	9.0
C	1.10	3.7	·126	4.8	8.5

Fig. 17 Soil profile diagram and analytical data (1)

SAMPLING DEPTH		
A	0 - 20	cm
B	20 - 30	
C	30+	

Soil profile description (1) : soil pit No. 2 along the transect

Type of profile: brown podzolic soil

Location: top of Wanister Hill, 90 m. above sea-level

Slope: moderate

Drainage of profile: freely drained

Vegetation: *Calluna vulgaris*, *Pteridium aquilinum*, *Vaccinum myrtillus*, *Deschampsia flexuosa*, *Ulex europaeus*, *Nardus stricta*.

(cm.)	
5.5- 2.0	Heather litter of leaves, shoots and flowers.
2.0- 0	Decomposing litter, very dark brown, merging boundary.
0 - 3.5	2.5YR 2/0 (black); humose fine sandy loam; weak small sub-angular blocks; very friable; high organic matter content; very abundant roots; stones absent; no mottles; sharp boundary.
3.5-20.0	5YR 3/4 (dark reddish brown); sandy clay loam; weak small sub-angular blocks; friable; moderate organic matter content; no mottles but occasional dark patches of humus accumulation; quite sharp boundary.
20.0-35.0	7.5YR 4/6 (dark brown); sandy clay; weak small sub-angular blocks; very friable; moderate organic matter content; occasional small roots; small rounded stones abundant; no mottles but some pieces of coal; merging boundary.
35.0+	7.5YR 5/6 (dark brown); sandy clay; medium sub-angular blocks; very friable; moderate organic matter content; roots absent; small rounded stones abundant; rusty mottles.

Table 6.4 Soil profile description (1)

in the development of the 'ground water gley' which has poor drainage in the sub-soil. There is a seasonal alternation of oxidization and reducing conditions, giving the rusty streaking and mottling of a 'gley' horizon. An example of such a soil is given in Fig. 18, Table 6.5.

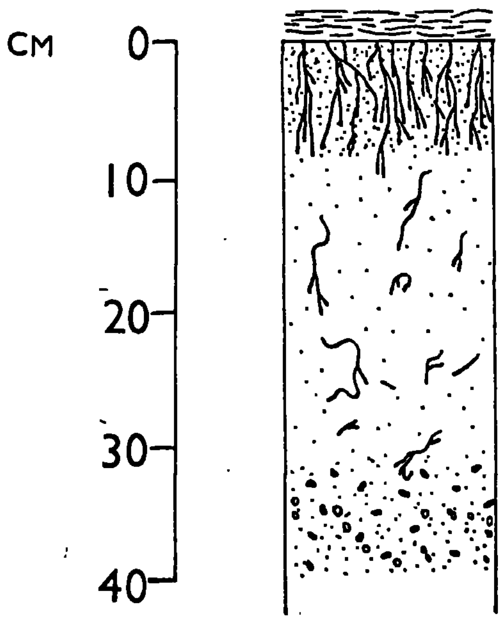
In the depressional areas where the maximum amount of runoff is received, waterlogging is severe and an accumulation of organic matter occurs causing the formation of peat bogs. Under the waterlogged conditions, there is an absence of oxygen, hindering the decomposing activities of bacteria. Therefore, plant decay is retarded and these partly decomposed plant materials form a peaty raw humus. Under such chemical reducing conditions, ammonia, methane, and various sulphides are formed, rather than nitrates, carbon dioxide, and sulphates which are produced in the presence of abundant oxygen. Beneath the peaty layer is the sticky mass of bluish grey clay of the gley horizon. An example of such a profile is given in Fig. 19, Table 6.6.

The soil between Wanister Bog and the main road is also a brown podzolic soil. However, the soils are imperfectly drained and show the phenomenon of compaction due to the effects of trampling. Consequently they slightly differ from the profiles described earlier. An example is given in Fig. 20, Table 6.7.

6.5 VEGETATION

The most suitable general term to describe the vegetation of Waldridge Fell is 'lowland heath'. The term is used by Tansley (1948), when referring to heath, moor,and bog vegetation, and implies that the heath is at low altitude, a distinct from upland heaths developed at 300-600 m., where the species composition differs slightly.

SOIL PROFILE 2



Horizon	Mechanical analysis (International Limit)			Air-dry moisture %	Loss on ignition %	Organic carbon %
	%sand	%silt	%clay			
A	ND	ND	ND	3.50	11.33	15.75
Bg	61	19	20	2.81	8.21	9.25
Cg	59	19	22	1.23	6.52	5.72

Horizon	T.C.E.C. m.e./100 g	pH	Total N %	Available P (ppm)/g	Exchangeable K (ppm)/5g
A	21.07	3.68	.946	10.3	36.3
Bg	20.59	3.86	.587	9.4	16.4
Cg	14.32	3.90	.245	7.5	9.0

Fig. 18 Soil profile diagram and analytical data (2)

S	D
A	0 – 7 cm
B_g	7 – 30
C_g	30+

Soil profile description (2) : soil pit No. 5 along the transect

Type of profile: ground-water gley

Location: lower slope of Wanister Hill, 68 m. above sea-level

Slope : 15-20°

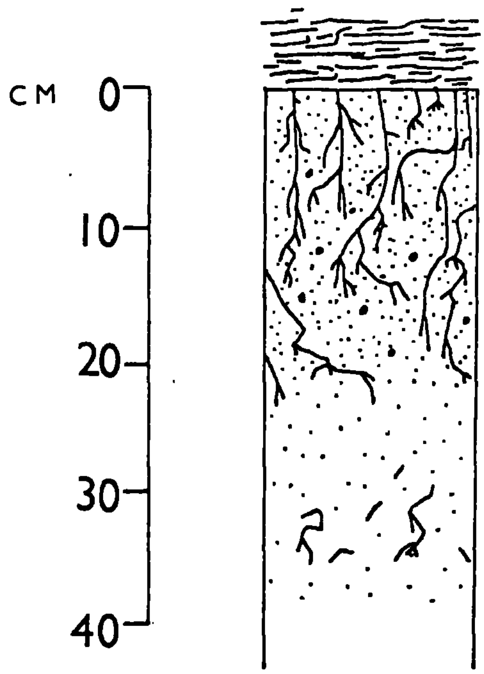
Drainage of profile: poorly drained

Vegetation: *Calluna vulgaris*, *Nardus stricta*, *Erica tetralix*, *Deschampsia caespitosa*, *Molina caerulea*.

(cm.)	
2.5- 0	Grass roots forming a litter layer of decomposing compacted mat; merging boundary.
0 - 7.0	5YR 2/1 (dark brown); humus; weak small sub-angular blocks; friable; high organic matter content; roots abundant; stones absent; no mottles; merging boundary.
7.0- 30.0	10YR 2/1 (black); humose clay; weak medium sub-angular blocks; friable; high organic matter content; roots frequent; stones absent; no mottles; clear smooth boundary.
30.0+	5YR 5/1 (grey); medium clay; moderate sub-angular blocks; friable; high organic matter content; roots absent; sandstone abundant; orcheous mottles with small fragments of coal.

Table 6.5 Soil profile description (2)

SOIL PROFILE 3



Horizon	Mechanical analysis (International Limit)			Air-dry moisture	Loss on ignition	Organic carbon
	%sand	%silt	%clay	%	%	%
A	ND	ND	ND	4.61	10.51	14.04
Bg	59	31	11	4.42	8.70	10.27
Cg	57	20	23	ND	ND	ND

Horizon	T.C.E.C. m.e./100 g	pH	Total N %	Available P (ppm)/g	Exchangeable K (ppm)/5g
A	25.76	3.9	1·008	8.0	27.0
Bg	22.34	3.9	1·078	5.5	9.4
Cg	ND	ND	ND	ND	ND

Fig. 19 Soil profile diagram and analytical data (3)

S D	
A	0 – 10 cm
B_g	10 – 20
C_g	20+

Soil profile description (3) : soil pit No. 7 along the transect

Type of profile: waterlogged peat soil

Location: center of Wanister Bog, 60 m. above sea-level

Slope: flat

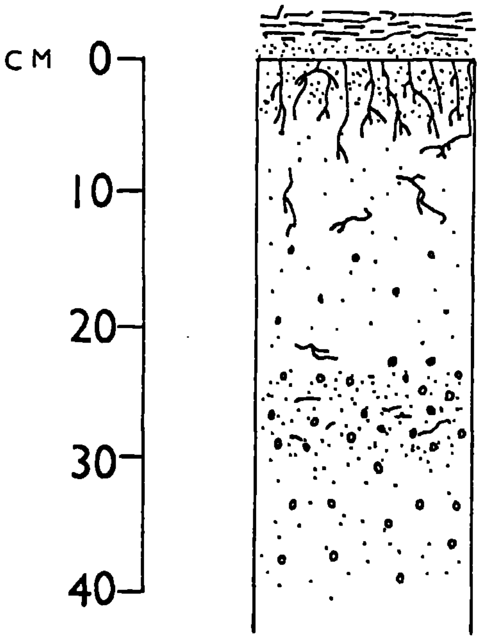
Drainage of profile: very poorly drained

Vegetation: *Deschampsia caespitosa*, *Molinia caerulea*, *Hydrocotyle vulgaris*, *Sphagnum* spp., *Juncus articulatus*, *Caltha palustris*, *Holcus lanatus*, *Eriophorum angustifolium*.

(cm.)	
5.0 - 0	5YR 2/1 (black); very humose decomposing plant material.
0 - 20.0	10YR 2/1 (dark); medium clay; medium sub-angular blocks; friable; moderate organic matter; abundant roots; stones absent; no mottles.
20.0+	10YR 3/1 (dark grey); upper part medium clay, lower part sandy clay; medium sub-angular blocks; friable; moderate organic matter content; occassional roots; stones absent; no mottles.

Table 6.6 Soil profile description (3)

SOIL PROFILE 4



Horizon	Mechanical analysis (International Limit)			Air-dry moisture %	Loss on ignition %	Organic carbon %
	%sand	%silt	%clay			
A	ND	ND	ND	2.06	8.64	10.74
B	56	36	8	1.43	8.52	9.89
C	61	20	19	1.47	8.21	9.25

Horizon	T.C.E.C. m.e./100 g	pH	Total N %	Available P (ppm)/g	Exchangeable K (ppm) /5g
A	15.37	3.62	·375	7.2	18.1
B	4.15	3.73	·217	6.5	15.5
C	1.07	3.75	·169	9.1	12.3

Fig. 20 Soil profile diagram and analytical data (4)

	S D	
A	**0 – 20**	cm
B	**20 – 30**	
C	**30+**	

Soil profile description (4) : soil pit No. 9 along the transect.

Type of profile: brown podzolic soil

Location: 25 m. north-east of Wanister Bog, near the main road.

Slope: flat

Drainage of profile: imperfectly drained

Vegetation: *Calluna vulgaris*, *Pteridium aquilinum*, *Deschampsia flexuosa*, *Ulex europaeus*, *Vaccinum myrtillus*, *Epilobium palustre*.

(cm.)	
4.0- 1.5	Litter layer, mainly *Calluna*, *Vaccinum* and *Pteridium*.
1.5- 0	Decomposing litter layer; dark brown; merging boundary.
0 - 2.5	2.5Y 2/0 (black); humus; small sub-angular block; friable; high organic matter content; roots abundant; stones absent; no mottles; sharp boundary.
2.5-20.0	5YR 3/4 (dark reddish brown); sandy clay loam; small sub-angular block; very friable; moderate organic matter content; occasional small roots; frequent small smoth stones; no mottles; quite sharp boundary.
20.0-30.0	5YR 4/6 (yellowish red); sandy clay loam; weak medium sub-angular block; very friable; moderate organic matter content; less roots; small rounded sand stones; no mottles; merging boundary.
30.0+	7.5 YR 5/6 (dark brown); sandy clay loam; weak medium sub-angular blocks; friable; moderate organic matter content; small and large stones abundant; frequent rusty mottles.

Table 6.7 Soil profile description (4)

Tansley (1949) indicated that heath or moor formation is primarily a West European feature, replacing bog on better drained soils and forest on lighter and poorer soils. Further it can only be considered as a climatic climax on exposed coasts and exposed mountain slopes where this is combined with good drainage and acid soils. Eyre (1968) also supported Tansley's opinion that heath should be regarded as a stage in succession to forest as, where forest was removed and the ground never improved, plants of the siliceous heath now dominate. Such land was probably left as unfenced common land and grazed to some extent. As long as the vegetation was prevented from reverting to forest by continued grazing and burning, then the heath would remain.

In his studies of the vegetation of four Durham fells formed on Coal Measure deposits, Jeffrey (1916 and 1917) found that *Pteridium aquilinum* was dominant on Waldridge Fell especially where the subsoil was dry sand. At present, apart from *Calluna vulgaris* which has increased in importance at the expense of *Pteridium aquilinum*, the vegetation would appear to be largely unchanged. The expansion of *Calluna* is probably due to the management - regular burning and the effect of mild grazing which enhances the generation and colonization of *Calluna* (see chapter 7.3 Biotic variables).

The present vegetation can be regarded as the product of a succession of change since the retreat of the ice. If the changes were at first entirely natural, they have now been a combination of natural and man-induced modifications of the earlier plant cover. Human activity has been the principal cause of modification to the vegetation cover since the Atlantic climatic phase. There can be little doubt that the existing grasslands and much of the moorland vegetation have succeeded woodland and that the rest of the upland vegetation is ultimately derived from blanket bog (Pearsall 1970, Arvill 1969).

Nardus stricta (mat grass) is characteristic of the leached, acid soils that are also fairly well-drained and covered by a thin, dry peat on the plateau of Waldridge Fell. *Molinia caerulea* (purple moor-grass) is more typical of wet patches in this area and is a feature in the retrogression of mosses, where tussocky clumps have replaced the blanket cover. *Juncus* is also frequently associated with *Molinia* in such areas. *Agrostis vulgaris* (common bent) and *Festuca ovina* (sheep's fescue) are frequently found on the drier tracts of the plateau.

Calluna vulgaris (heather) and *Vaccinium myrtillus* (bilberry) are closely associated species on the top and the upper slopes of Wanister Hill and Nettlesworth Hill. *Pteridium aquilinum* (bracken) and *Ulex europaeus* (common gorse) frequently invade *Calluna* areas. *Calluna* is characteristic of dried 'mor' peats and of gley soils. Where the peat-layer is deep and waterlogged (lower slope of Wanister Hill and Nettlesworth Hill), *Calluna* is absent and *Eriophorum angustifolium* (cotton-grass) takes its place. *Molinia caerulea* (purple moor-grass) is characteristic of the wet tracts enriched by mineral salts, where water carrying the salts leached from the higher slopes of Wanister Hills runs down slope to the Wanister Bog.

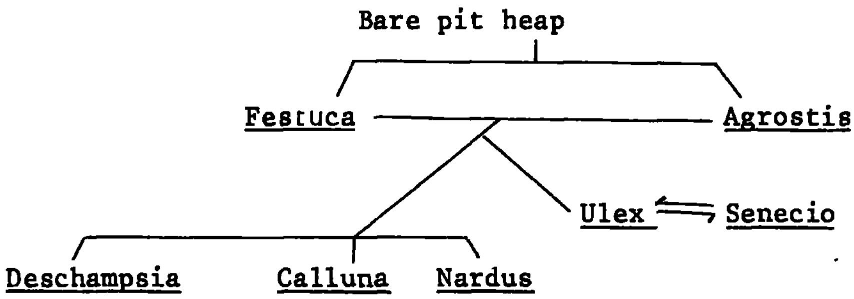
The Wanister Bog is dominated by *Sphagnum* moss, a blanket of moss through which shoots of other plants protrude. It is also evident that the underlying deep peat has been derived chiefly from *Sphagnum*. In general, the water table is slightly above the surface. When there is sufficient movement of water into and through the valley bog to maintain some supply of mineral salts and oxygen circulation, species of *Juncus* (rushes) and *Carex* (sedges) dominate locally. Where the surface is drier at the edge of the bog area, *Erica tetralix* (cross-leaved heath) and *Calluna vulgaris*, became important.

The sides of the streams (Cong Burn and South Burn), away from the Fell, are covered with plantations, excepting the portion of the South Burn to the south of the Chester Road. *Betula alba* (birch) is dominant on the south bank of South Burn with *Alnus rotundifolia* (alder) on the north bank. The north bank of the Cong Burn is almost precipitous slope all the way. From the point where the stream enters the Fell to the old railway bridge it is covered with a natural woodland co-dominated by *Quercus sessiliflora* (sessile oak) and *Coryllus avellana* (hazel). Sparse *Alnus rotundifolia* lines both banks of the stream lower down, before it leaves the Fell.

The plant communities of Waldridge Fell can be grouped into those of woodland, heathland, grassland and blanket bog. The dominant species are as follows:-

Woodland:	*Alnus rotundifolia, Betula alba, Crataegus monogyna* *Corylus avellana, Pinus sylvestris, Quercus sessiliflora*
Heath:	*Calluna vulgaris, Deschampsia flexuosa, Holcus mollis,* *Ulex europaeus, Vaccinium myrtillus, Pteridium aquilinum*
Grassland:	*Festuca rubra, Agrostis vulgaris, Nardus stricta*
Bog:	*Hydrocotyle vulgaris, Sphagnum* spp., *Juncus articulatus* *J. effusus, J. glaucus, Epilobium hirsutum, Alopecurus* *geniculatus, Carex nigra, Molinia caerulea.*

A large pit heap, mainly composed of material derived from the underclay found beneath the coal, is located at the south of Waldridge Colliery. The vegetation on the heap is slightly different from other parts of the fell, being characterised by *Galium saxatile, Festuca rubra, Agrostis vulgaris, Trifolium repens, Holcus mollis* and *Deschampsia flexuosa*. A very good example of vegetational successions can be seen by the growth of plants of those heaps. Several former pit heaps which were described by Jeffrey (1917) now have dense growth of *Calluna* with very few associated plants. The following process of vegetational successions on pit heaps is modified from Jeffrey:-



CHAPTER SEVEN

VEGETATION PATTERN RELATED TO THE EDAPHIC AND BIOTIC VARIABLES ON WALDRIDGE FELL

7.1 Introduction

Relatively distinct species assemblages occurring on particular sites are real functional and formal components of the landscape. Plant communities may be sharply or diffusely differentiated from each other according to the intensity of environmental change from one site to another. Also, different communities may be similar or dissimilar depending upon the convergence or divergence of floristic and environmental gradients from site to site (Daubenmire 1959, Ashby 1961).

Plant distribution is primarily controlled by the interaction of climatic and edaphic factors. The climatic factors related to plant growth on Waldridge Fell have been further investigated by long term monitoring as described in the next chapter. Edaphic factors are those soil properties which affect plant growth and distribution and are most likely to show sharply defined patterns within small areas. In general, major plant community groups are often closely correlated with the developed soil type and independent of individual parameters such as texture or chemical characteristics of the soil, though these are, of course, related to soil type. However, the smaller or minor communities are often directly affected by such factors. Edaphic factors become controlling according to their duration, summation or extremes, and any individual parameter either of physical or chemical origin may in itself become limiting to one or more species. Therefore, the influences that seem to be dominant or the individual factors affecting a phase of growth either in combination or summation, must be assessed both for single species and for groups or associations.

The physical environment of soil and climate must satisfy at least its minimum requirements in a given area for a particular type of plant to grow and reproduce. But whether or not a particular species will be able to occupy a potentially favourable physical habitat will depend on the effect of other plants and animals which are capable of living under similar conditions. Normally, the more favourable the physical environment the greater the variety of plants and animals for their occupation.

Therefore, the environment of any plant is partly physical and partly biological. The biological or biotic factors, which influence plant growth and distribution, are those which result from the action of living organisms.

The aim of this research is to quantify the edaphic and biotic variables related to the occurrence and performance of the vegetation in a selected area in Waldridge Fell in order to understand the moorland ecosystem.

7.2 ANALYSIS OF VEGETATION

7.2.1 Method

After a preliminary survey in the research area, changes of the vegetation and environment at selected location were described and examined to discover relationships between environmental variations and changes in the vegetation.

A belt transect which consisted of 48 quadrats (6 $m.^2$ each) was laid down orthogonally from the top of the Wanister Hill across Wanister Bog to the main road. At each quadrat, plants were collected and identified using the nomenclature of Clapham, Tutin and Warburg (1952) (Table 7.1) The modification of Gradient Analysis (Whittaker, 1967) and van der Marrel's Group Analysis (van der Marrel, 1968) were employed in analysis (for Gradient Analysis and Group Analysis refer to Appendix A.1 and A.2).

Plant species/Quadrats	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
Calluna vulgaris	20	20	30	30	20	45	30	25	40	70	65	60	70	40	65	80	70	80	65	50	50	40	40	15	10	10	10	20	15	+							+	65	40	30	30	40	55	20	+	10	+	10
Pteridium aquilinum	50	10	+	+	40	30	30	+	+	+	10	10	+	+	15	15	10	15	30	20	20	50	40															30	30	65	70	40	+	30	70		70	10
Deschampsia flexuosa	30	70	60	50	40	25	40	25	20	10	5	10	10	+	5				+	+	+		+	+	+															+	+	+	20	+	20	40	30	+
Ulex europaeus			10	10	+	+		10	10	+			+	+	+																							+	20	5	10	+	+	50		+		
Nardus stricta		+	+	10		+	+		+			+	+	+			+		+	10	5	+	+	20	15	25	25															+	+	+	+	+	+	
Vaccinium myrtillus			+	+		+	+	40	30	20	20	20	20	60	15	5	20	5	5	5	+	5	15																			20	25	+	+	20	+	80
Erica tetralix																								10	5	+	15	+	+	+	+	+		+		+	+											
Deschampsia caespitosa																			+	5	5		+	20	30	25	25		+	+	+	30	20	15	5	20	25	5										
Molinia caerulea																			+	+	15	5	+	35	40	20		50	40	50	20	15	15	25	20	10	30											
Ranunculus repens																											+						+					+						+	+		+	+
Epilobium palustris																										+	+	10				+	+	+	+	+							+		10	30	10	+
Rubus idaeus																									+	5	10										+								+	+	+	+
Potentilla erecta																+			+	+		+	5	+	+	5																						
Galium saxatile																				5	5				+	10	10																					
Hypnum cupressiforme																			+	5	+	+	+	+	+		5			+																		
Caltha palustris																												+	+						+													
Hydrocotyle vulgaris																											+	10	25	40	40	30	30	35	25	+	+											
Holcus lanatus																												+	+	+	10	5			+	+	+											
Sphagnum spp.																													+	10	20	20	20	15	25	20	20		10									
Juncus articulatus																												10	20	+				+	25	45	20	+										
Juncus effusus																														+	+		5	+		5	+								+		+	+
Juncus squarrosus																													+	+	+	+	5	+	+													
Eriophorum angustifolium																														+	10	5	5	5	+	+	5											
Galium palustris																												+	+					5	+	+												
Mentha aquatica																																				+	+											
Equisetum fluviatile																													+	+	+	+	+	+	+	+	+											
Carex nigra																												+	+		+	+			+													
Dactylorchis maculata																																		+														
Pohlia nutans																+																																
Dichorum spp.												+																																				
Senecio visosus																																											+					
Poa annua	+																																								+				+		+	+
Empetrum nigrum																			+																													
Glyceria fluitans																														+																		
Sparganium ramosum																												+																				
Eleocharis palustris																																				+												
Alopercurus pratensis																																		+														
Agrostis stolonifera																																										+						

Table 7.1 Association table of the plant species along the transect.

7.2.2 Results

Histograms (Fig. 21) of cover percentage of the common species in each quadrat along the transect were plotted, then superimposed. These histograms indicate that although no two species have identical distributions, 'community types' (Whittaker, 1967) or zones having dominant species can be recognized. The exact position and the nature of the boundaries within different zones were located by employing van der Marrel's Group Analysis. The heterogeneity between contiguous quadrats was obtained using the differential occurrence of the species. This gave the differential profile (Fig. 22) with acute peaks which implied that there were spatially abrupt changes while the remainder of the graph profile showed a rather variable and disturbed form indicating gradual change.

Three marked discontinuities can be detected - between quadrats 18 and 19, 27 and 28, 37 and 38, with lower fluctuations in between. There are thus four communitiesdistinguished:- 1. the dry heath (Wanister Hill); 2. the wet heath (the low slope of Wanister Hill); 3. the peat bog (the Wanister Bog) and 4. the disturbed area (mainly due to trampling). In the descriptions following, the Wanister Hill is described as 'Zone 1', the lower slope of Wanister Hill 'Zone 2', Wanister Bog 'Zone 3' and the disturbed area 'Zone 4'.

7.2.3 The vegetation:

Calluna vulgaris is the only species that appears in all four zones although its performance and occurrence is least in the 'Zone 3'.

'Zone 1' is also dominated by *Pteridium aquilinium, Deschampsia flexuosa, Ulex europaeus* and *Vaccinium myrtillus* as well as *Calluna*

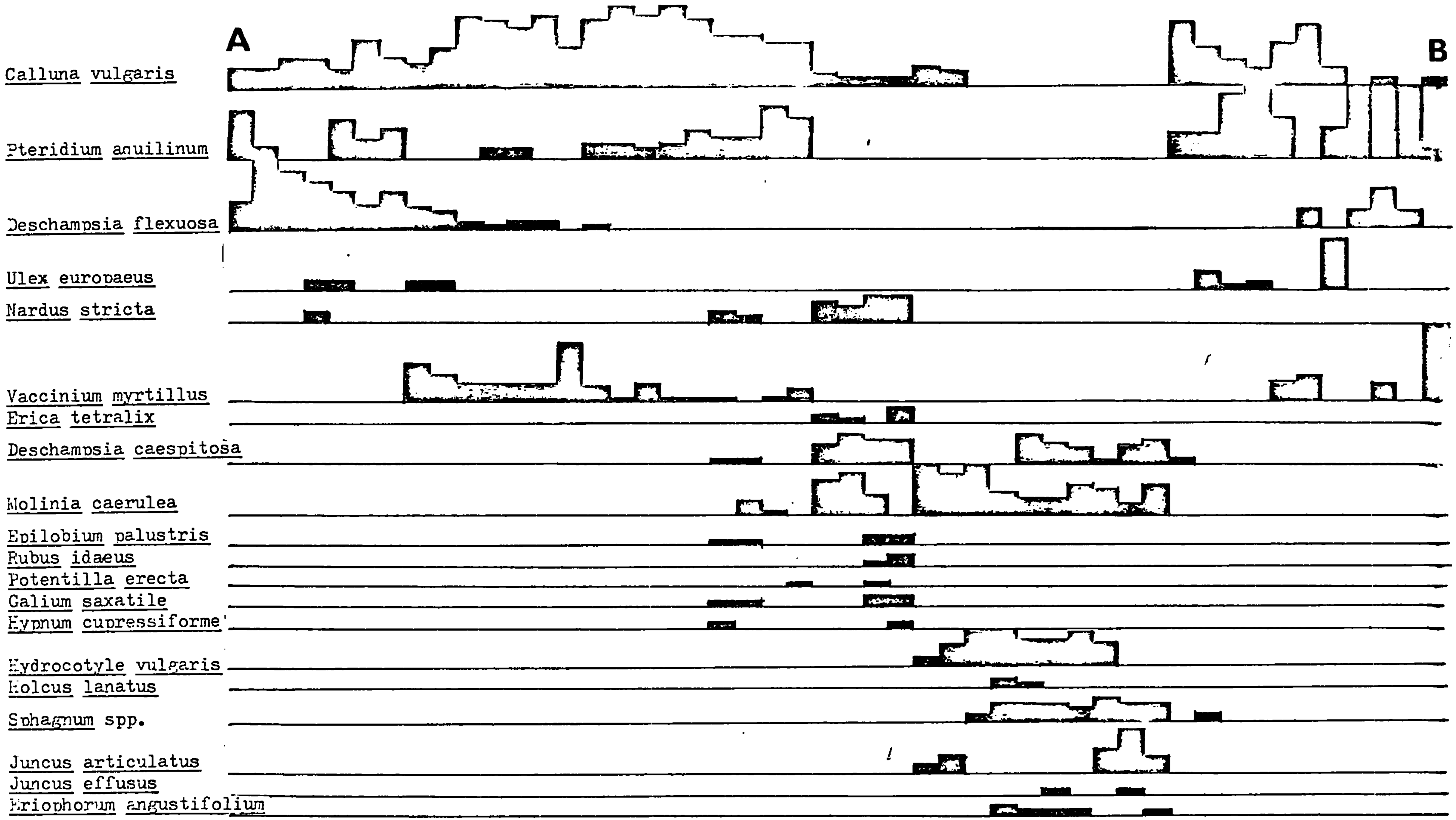


Fig. 21 Histograms showing cover percentage of the common plant species in each quadrat along the transect AB.

— : 10 % COVER

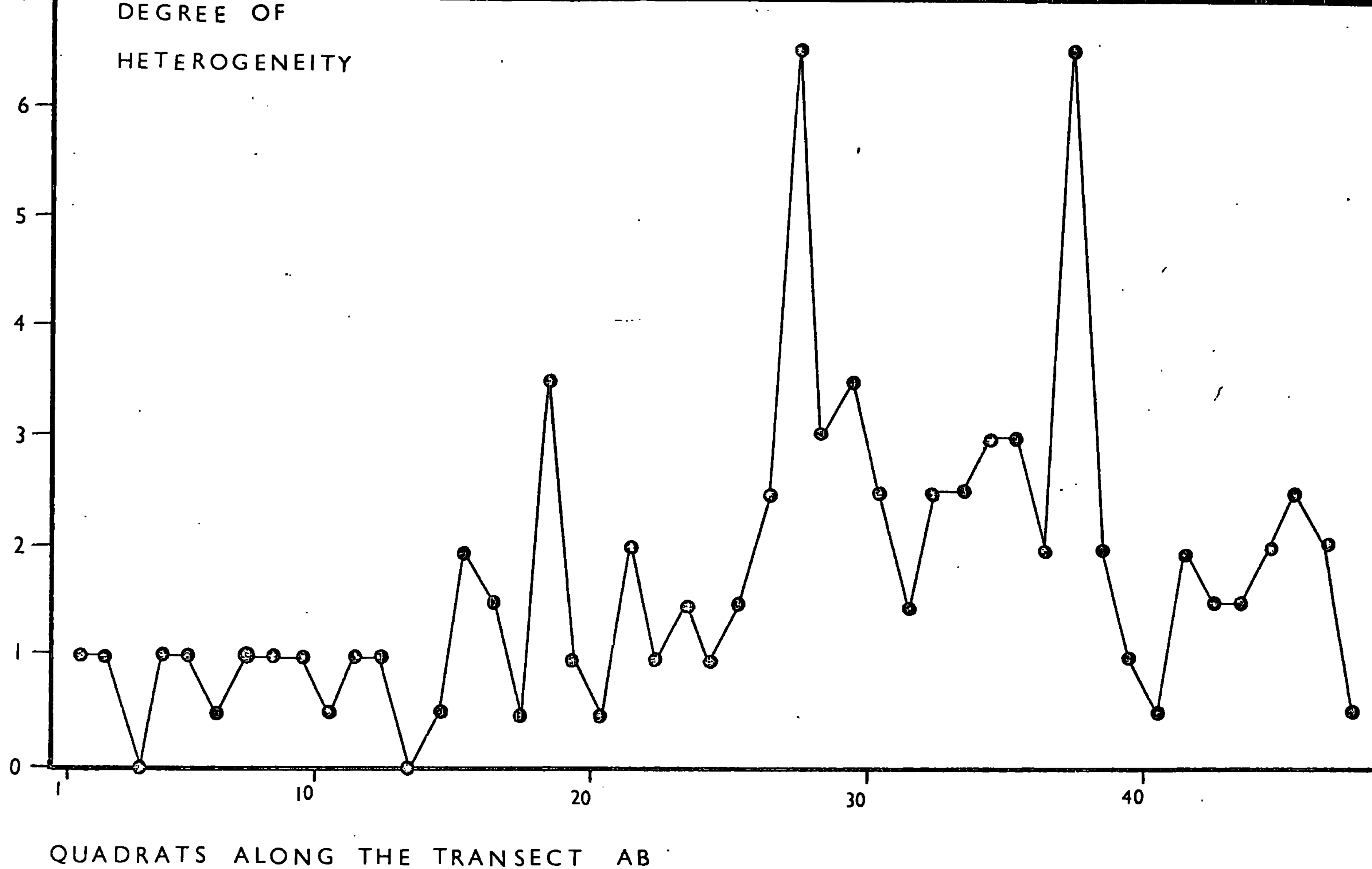


Fig. 22 Different profile showing the heterogeneity between contiguous quadrats along the belt transect

vulgaris.

'Zone 2' is demarcated where the above taxa are gradually die out and *Erica tetralix*, *Deschampsia cespitosa* and *Molinia caerulea* become dominant along with *Calluna vulgaris*. Besides these, there is a group of distinct species which appear in the zone. They are *Potentilla erecta*, *Galium saxatile* and *Hypnum cupressiforme*.

Deschampsia cespitosa and *Molinia caerulea* still have a high performance in 'Zone 3' but *Erica tetralix* becomes extinct. The zone also presents a group of newly established flora: *Hydrocotyle vulgaris*, *Eriophorum angustifolium*, *Sphagnum* spp. and *Juncus articulatus* are the most important members. These together with *Caltha palustris*, *Holcus lanatus*, *Juncus effusus*, *J. squarrosus*, *Galium palustris*, *Mentha aquatica*, *Equisetum fluviatile* and *Carex nigra* make up the highest number of species among all zones.

A fourth zone is found adjacent to the main road where *Calluna vulgaris*, *Pteridium aquilinium*, *Deschampsia flexuosa*, *Ulex europaeus* and *Vaccinium myrtillus* become restablished. *Epilobium palustris* also exhibits an importance in terms of cover percentage.

7.3 BIOTIC VARIABLES

7.3.1 Competition

The establishment of a particular species in an accessible and physically favourable site will depend on its ability to compete for space, light, water, and soil nutrients with other potential occupants. Competition between plants of the same or different species arises because the resources of a habitat are insufficient to meet the demands of all the plants available and capable of growing there. The relative success of individual plants or species in competition will be dependent upon their ecological requirements, their life-forms, their vigour and density and of growth and the seasonal development.

Above ground, competition for light dominates the struggle for existence. In the struggle for light the competitive ability of plants is closely related to their life-forms and habit of growth. *Calluna vulgaris* is the tallest plant in the area (Zones 1, 2 and 4) and therefore the most aggressive as has been seen in 6.2. The influence of competition of light and its final outcome may be determined by competition for soil nutrients and water and plants vary in their optimum requirements for both. Their ability to obtain these in competition with others will depend profoundly on the vertical and horizontal extension of their root system, and the rate of their development. These rooting characteristics are dependent partly on the species of plant and partly on soil conditions which modify root systems.

In zone 3, well adapted species to the water-logged conditions such as *Hydrocotyle vulgaris*, *Sphagnum spp*, *Juncus articulatus*, *J. effusus*, *J. squarrosus*, *Carex nigra*, *Equisetum fluviatile*, *Mentha aquatica* and *Caltha palustris*, dominate the whole zone. Many plants which occur in other zones are excluded by the competition of these well adapted and vigorous species. Even *Calluna vulgaris* is distinct in the bog proper and its failure in competition with these better adapted species is reflected in a smaller size and sparse cover even near the bog area (Zone 2).

However, there are many plants whose relationships and interactions are symbiotic. They live together to their mutual advantage. The presence of nodulated plants on certain comparatively nitrogen deficient soils is undoubtedly aided by this symbiotic relationship. Another well known example is mycorrhiza, species of fungi which penetrate and exist within the living cells of the roots of higher plants. This condition has been most closely studied in relation to the pines and heath plants usually associated with acid soils. It has been demonstrated that mycorrhiza must be present for the successful growth of the particular species. Attempts to introduce pines into such poor soils have failed mainly due to the absence of the necessary fungal symbions. Several members of the heath family (Ericaceae) - including *Calluna vulgaris* are dependent on the presence of mycorrhiza that require a relatively high degree of soil acidity (Russell 1961). The more alkaline condition together with the effect of waterlogging in Zone 3 suggests a less favourable condition for such mycorrhiza and hence affects the vigour of *Calluna vulgaris* in their struggle for existence in that particular area.

Biotic factors also include those related to the activity of animals that live among, and are dependent upon, the plants growing in a particular area. The dominant and the most powerful and destructive animal in the environment is man. Man has, by clearance and cultivation (including the grazing activities of his animals) given preference and protection to some plants at the expense of others. Some accounts of the effects of burning, grazing by animals and trampling upon the vegetation are given accordingly:-

7.3.2 Burning

Jeffery (1917) claimed that fires are frequent but rarely extensive on Waldridge Fell. The 'muirburn' (regular firing) is employed not only to prevent tree generation but also to promote new, young growth of *Calluna* which provides an important proportion of the diet of animals which graze on the moorland. *Calluna* is most frequently burnt when it is old and 'leggy', and at this stage regeneration by seedlings or vegetative spread is difficult (Whittaker and Gimingham 1962). Regeneration gives rise to dense form of plants grown from seed. The controlled rotational burning of sections of moorland is usually carried out as far as possible in the early spring but also to a considerable extent in autumn. It may occur accidently at any season of the year.

Fire is one of the most important ecological factors on the Fell. With extremely frequent fires, the moorland vegetation may be modified by the elimination of all herbaceous species without buried perennial organis. Thus dominance of *Calluna* is also reduced although it will regenerate readily after fire. There will be invasion by other species at the expense of *Calluna*, e.g., *Erica cinera*, *Pteridium aquilinum*, *Vaccinium myrtillus*, *Molinia caerulea*, and *Juncus squarrosus*, according to the moisture regime of the habitat as the requirements of moisture condition of plants are different. *Erica*, *Pteridium* and *Vaccinium* favour drier conditions while *Molinia* and *Juncus* favour wetter conditions.

A controlled (with intervals of eight to fifteen years) or less frequent burning may cause more permanent difference in the flora than the occasional severe fire (Whittaker 1961). It can maintain the dominance of *Calluna* at its maximum. It leads to the progressive elimination not only of species most sensitive to fire but also of those sensitive to competition with *Calluna*. Almost pure stands of *Calluna*, with few associates other than bryophytes and lichens, may be produced over large areas. Thus the dominance of *Calluna* on Waldridge Fell is due to controlled and less frequent burning, and plant species, in association with *Calluna* are poor. Burning can also devastate the soil to a depth of 8 cm. or more by destroying the organic horizon of the soil, and causing the destruction of the structure.

Soil degradation occurs as a result of moor-burning (Imeson 1972). An increase of erosion following the disturbance of vegetation cover is to be expected since this upsets the balance of the ecosystem. This is particularly true when firing is followed by drought or if the surface accumulation of litter or raw humus is burnt away (Gimingham 1960). Imeson (1972) measured the soil erosion beneath *Calluna* in various stages of growth on the north Yorkshire Moors and found that where *Calluna* was recolonizing burnt ground and forming an incomplete cover, the rate of soil erosion correlated negatively with the height and density of the vegetation. However, any loss of soil occurring where *Calluna* formed a complete canopy was very small compared to the rate of litter accumulation. Gully development on *Calluna* moorland was considered to occur in response to wetter conditions brought about by moor-burning.

The need for the burning of vegetation on Zones 1a and 3 is less than the others. The former is located on the top of the comparatively steep slope (the top and the upper slope of Wanister Hill) while the latter is located on the waterlogged peat bog where there is less pressure from grazing animals. The main purpose of burning is to promote the growth of new foliage in plants, mainly *Calluna vulgaris* which is palatable for the animals.

7.3.3 Grazing

The Fell used to provide grazing for cattle, goats and fowls (Jeffrey 1917) but it is no longer used for this purpose by the adjacent farmers. Apart from these, the ravage of vegetation by rabbits also seems to have died out. However, a few horses now graze frequently on the Fell and some vegetation exhibits the effects of grazing although these are not striking. The shortness of the grass species, *Agrostis* and *Festuca* and the bushes of *Calluna* indicates that they have been nibbled at the ends of their lower branches by animals.

Under mild grazing, the dominance of *Calluna* is enhanced, but many herbaceous species are also progressively eliminated. A further increase in grazing intensity can damage *Calluna*, and it may be eventually eliminated in favour of grasses.

On comparatively base-rich soils, intensive grazing may lead to the replacement of *Calluna* by *Agrostis* - *Festuca* grassland and where *Pteridium aquilinum* is present its spread may become a serious problem. On base-poor (acidic) soils, *Deschampsia flexuosa* tends to increase, while in wet conditions (usually on peatlands), *Nardus stricta* and *Molinia caerulea* may become dominant (Tansley 1949, Fenton 1935 and 1949).

Grazing pressure is lower in Zones 1a and 3 since the grazing animals find it difficult to reach the slope (Zone 1a) and avoid the waterlogged conditions (Zone 3), and consequently in these zones there is virtually no evidence of grazing damage.

7.3.4 Trampling

People in leisure pursuits affect the vegetation on Waldridge Fell. Due to the repeated pressure of numerous people walking, the earth tends to be pressed down and hardened along the tracks. The tracks usually act as intermittent water courses in rainy weather and thus tend to have a less xerophytic flora than the surrounding areas. *Calluna vulgaris*, *Ulex europaeus* and *Pteridium aquilinum* are usually absent on these footpaths being replaced by grasses.

Nardus stricta, *Poa pratensis*, and *Juncus effusus* become dominant as the soil becomes compacted and the track begins to form. The invaders are usually in dwarf form, mainly due to the compaction of the soil which makes it difficult for root penetration, while the aerial portions are damaged by walkers.

Vegetation deterioration and even soil erosion may be caused as a result of severe and continuous trampling. A zonation of path vegetation on Massingham Heath and Wooton Heath in Norfolk was studied by Bates (1935) and he suggested that resistant species frequently possessed flat leaves and a conduplicate stem. In the area he investigated, *Poa pratensis* formed the central zones (the most heavily trampled), with *Trifolium repens* and *Lolium perenne* occurring on the outer edges. He then further concluded that the physical bruising of vegetation and the puddling caused by trampling had a greater effect on the vegetation than the indirect effect of soil compaction.

The activity of trampling is least in Zones 1a and 3 by man as well as his grazing animals. Since Zone 4 is situated near the main road, this is the main zone in which vegetation is disturbed by frequent trampling.

7.4 EDAPHIC VARIABLES

7.4.1 Aim and objectives

Plant communities are often closely correlated with the soil series. Within a climatic region, natural vegetation can afford an index of the sum total of edaphic factors affecting land fertility and therefore an adequate vegetation survey has long been used to obviate detailed investigation of soil characteristics for land evaluation purposes.

The findings of the vegetation analysis (7.3) delineated the selected research area (along transect AB) into four zones which are closely correlated to the soil types and their performance (using Braun-Blanquet Scale) related to the soil types and their drainage status.

Zone	Vegetation	B.B. Scale	Soil type	Drainage Status
1a	*Calluna vulgaris* *Deschampsia flexuosa* *Pteridium aquilinum* *Ulex europaeus*	3.5 3.4 2.4 2.3	Brown	freely drained
1b	*Calluna vulgaris* *Pteridium aquilinum* *Vaccinium myrtillus* *Deschampsia flexuosa*	4.5 2.4 2.4 2.3	podzolic	imperfectly drained
2	*Calluna vulgaris* *Molinia caerulea* *Deschampsia caespitosa* *Nardus stricta*	3.4 2.3 2.3 2.3	Ground water gley	poorly drained
3	*Molinia caerulea* *Sphagnum* spp. *Hydrocotyle vulgaris* *Juncus articulatus*	3.4 2.3 2.3 2.3	waterlogged peat soil	very poorly drained
4	*Calluna vulgaris* *Pteridium aquilinum* *Deschampsia flexuosa* *Ulex europaeus* *Vaccinium myrtillus*	3.5 3.4 2.3 2.3 2.3	Brown podzolic	imperfectly drained

Table 7.2 Relation between the performance of the dominant vegetation, soil types and their drainage status within different zones.

(Braun-Blanquet Scale:- The figure on the left of the scale indicates cover-abundance, in which

1^{st} = 1 plant

\+ = sparse, very low cover

1 = common, small scale

2 = either 5-25% cover or low cover, but high numbers

3 = 25-50%, any number of individuals

4 = 50-75%, any number of individuals

5 = 75-100%, any number of individuals

(+)= occur just outside record area

The figure on the right of the scale indicates sociability of the vegetation, in which

1 = single stem or shoot

2 = small tufts or loose tufts

3 = smaller patches or cushions

4 = extensive patches or carpets

5 = plants in great crowds giving complete dominance).

The aim of this section is to analyse the physical and chemical characteristics of the different soil types along the catenary sequence to serve two purposes:- (1) to quantify the soil properties which separate the occurrence of vegetation types, and their performance. (2) to provide the basic data for a study of the seasonal fluctuations of the three major nutrients (nitrogen, phosphate and potassium) both in the tissues of *Calluna vulgaris* and in the soil.

7.4.2 Methods

Each of the four zones of the selected area along the transect can be regarded as homogenous as each has uniform topography, soil types, drainage status and vegetation. The whole area was subdivided into sections according to the vegetational zones and the correlated soil types. 80 4x4 m. sample plots were located by random selection and reduced to 25 with 10 in Zone 1 (subdivided into 1a and 1b) and 5 each in the other three zones. Soil samples from each soil horizon of each sample plot were analysed in the laboratory for the following:- pH, air-dry moisture, loss on ignition, total nitrogen content, available phosphate and exchangeable potassium. A representative sample from each horizon of each zone was used to determine the following:- Mechanical analysis, natural moisture, total cation exchange capacity and organic carbon (Appendix A.3 Analytical methods).

7.4.3 Results

The soil analytical data (1) and (2) are presented in Table 7.3 and 7.4. The soil profiles within each zone are found to belong to the same soil type and to have similar morphological characteristics. Statistical comparisons of data (1) were made by calculating the 95% confidence limits and coefficients of variation to the mean values on each set of data within each zone (Table 7.3). The data will be used for selecting more constant (soil properties) sites for the study of seasonal fluctuations of nutrients (Chapter 8) and for the investigation on using soil chemical properties as parameter in land evaluation in terms of agricultural production (Chapter 10).

7.4.4 Discussions

(1) Texture

Soil texture is one of the basic properties of soil and probably one of the most important from the agriculturalist's point of view. It does not only determine the relative ease with which roots can penetrate into the soil but also has a decisive influence on many of the soil properties, such as on the ability to supply nutrients, on the moisture-air and thermal regimes, as well as the structure. All of these are essential for the living inhabitants and in turn determine the type of vegetation that develops on the soil.

The results of the mechanical analyses are shown in Fig. 23

	H	% AIR-DRY MOISTURE	% LOSS ON IGNITION	% ORGANIC CARBON	pH	% TOTAL N	AVAIL. P(ppm)/g	EXCHANGE. K (ppm)/5g
1	A	1.45	8.72	10.31	3.40	.490	7.0	22.5
	B	1.25	6.32	5.31	3.60	.224	5.0	9.0
	C	0.90	5.20	2.97	3.70	.126	4.8	8.5
2	A	1.40	7.04	6.81	3.41	.460	7.5	24.5
	B	1.23	6.76	6.22	3.50	.306	4.7	10.5
	C	0.97	5.45	3.50	3.53	.168	4.0	11.4
3	A	1.53	7.05	6.83	3.28	.397	6.9	17.0
	B	1.41	7.30	7.35	3.45	.254	5.0	8.2
	C	1.05	6.01	4.66	3.77	.157	4.2	10.4
4	A	1.50	8.86	10.60	3.42	.369	6.0	24.4
	B	1.51	7.42	7.60	3.40	.232	3.4	12.6
	C	0.86	6.21	5.08	3.58	.110	6.2	10.7
5	A	1.62	8.90	10.68	3.38	.512	5.7	18.4
	B	1.30	7.15	7.04	3.40	.233	5.0	7.4
	C	1.15	6.18	5.02	3.70	.127	4.8	9.5
MEAN	A	1.50	8.11	9.04	3.38	.440	6.62	21.36
	B	1.34	6.99	6.70	3.47	.250	4.62	9.54
	C	0.98	5.81	4.25	3.66	.138	4.80	10.11
STAND. DEVIATION OF SAMPLE MEAN	A	±0.031	±0.43		±0.06	± .022	±0.33	±1.55
	B	±0.06	±0.18		±0.12	± .014	±0.30	±0.92
	C	±0.04	±0.19		±0.04	± .010	±0.38	±0.50
95 % LIMIT CONFIDENCE	A	±0.08	±1.19		±0.16	± .061	±0.91	±4.30
	B	±0.18	±0.50		±0.33	± .038	±0.83	±2.56
	C	±0.11	±0.52		±0.11	± .029	±1.05	±1.39
COEFFICIENT OF VARIATION %	A	2.0	5.3		1.7	5.0	4.9	7.2
	B	4.4	2.5		3.4	5.6	6.4	9.6
	C	4.0	3.2		1.0	7.7	7.9	4.9

Sampling depth

A	0 - 20 cm
B	20 - 30
C	30+

ZONE 1a

Table 7.3 Soil analytical data (1)
(The values of organic carbon are based on the values of loss on ignition and therefore subjected to the variation of loss on ignition).

	H	% AIR-DRY MOISTURE	% LOSS ON IGNITION	% ORGANIC CARBON	pH	% TOTAL N	AVAIL. P(ppm)/g	EXCHANGE. K(ppm)/5g
1	A	1.62	8.65	10.16	3.40	.481	8.0	21.4
	B	1.42	6.45	5.58	3.46	.317	6.4	11.0
	C	1.07	5.31	3.20	3.80	.135	6.2	10.5
2	A	1.45	7.69	8.16	3.50	.407	6.5	26.5
	B	1.40	6.42	5.52	3.52	.245	6.3	9.6
	C	1.12	5.70	4.02	3.84	.101	7.1	8.7
3	A	1.72	7.43	7.62	3.45	.157	8.7	19.7
	B	1.21	7.21	7.16	3.44	.276	7.3	9.7
	C	0.99	5.34	3.27	3.65	.168	5.0	7.2
4	A	1.51	8.12	9.25	3.50	.476	9.9	20.7
	B	1.35	7.31	7.37	3.48	.315	7.2	6.4
	C	0.95	6.35	5.37	3.46	.125	4.5	8.5
5	A	1.66	8.52	9.87	3.60	.386	8.5	21.1
	B	1.40	6.86	6.43	3.70	.301	6.7	11.3
	C	1.32	6.26	5.18	3.60	.159	4.3	10.0
MEAN	A	1.59	8.08	8.97	3.49	.453	8.32	21.88
	B	1.35	6.85	6.41	3.52	.291	6.78	9.60
	C	1.09	5.79	4.20	3.67	.138	5.42	8.98
STAND. DEVIATION OF SAMPLE MEAN	A	±0.04	±0.22		±0.10	± .013	±0.55	±1.19
	B	±0.03	±0.18		±0.04	± .014	±0.20	±0.87
	C	±0.05	±0.21		±0.06	± .011	±0.33	±0.58
95 % LIMIT CONFIDENCE	A	±0.11	±0.61		±0.27	± .036	±1.52	±3.31
	B	±0.08	±0.50		±0.11	± .038	±0.55	±2.49
	C	±0.13	±0.58		±0.16	± .032	±0.91	±1.61
COEFFICIENT OF VARIATION %	A	2.5	2.7		2.8	2.8	6.6	5.4
	B	2.2	2.6		1.1	4.8	2.9	9.0
	C	4.5	3.6		1.6	7.9	6.0	6.4

Sampling depth

A	0 - 20 cm
B	20 - 30
C	30+

ZONE 1b

	H	% AIR-DRY MOISTURE	% LOSS ON IGNITION	% ORGANIC CARBON	pH	% TOTAL N	AVAIL. P(ppm)/	EXCHANGE. K (ppm)/5g
1	A	3.50	11.33	15.75	3.68	.946	10.3	36.3
	Bg	2.81	8.21	9.25	3.86	.587	9.4	16.4
	Cg	1.23	6.52	5.72	3.90	.245	7.5	9.0
2	A	3.07	10.82	14.68	3.65	.901	12.5	29.0
	Bg	2.89	7.50	7.77	3.93	.694	11.0	16.5
	Cg	1.35	5.31	3.20	4.00	.375	6.2	8.8
3	A	3.26	10.75	14.54	3.65	1.012	14.5	32.1
	Bg	2.24	8.46	9.77	3.74	.573	8.5	12.5
	Cg	1.41	7.24	7.22	4.10	.315	9.0	11.0
4	A	2.88	11.57	16.25	3.72	1.101	14.5	37.5
	Bg	2.72	6.74	6.18	3.78	.609	10.0	11.7
	Cg	1.36	5.91	4.45	3.80	.401	10.5	6.5
5	A	2.76	12.40	17.97	3.60	.806	11.4	29.9
	Bg	2.50	8.52	9.87	3.72	.588	7.3	13.2
	Cg	1.28	5.40	3.39	3.70	.291	7.2	10.3
MEAN	A	3.09	11.37	15.83	3.62	.953	12.64	32.76
	Bg	2.63	7.88	8.56	3.80	.610	9.24	14.06
	Cg	1.32	6.07	4.79	3.90	.325	8.08	9.12
STAND. DEVIATION OF SAMPLE MEAN	A	±0.12	±0.29		±0.14	± .050	±0.83	±2.48
	Bg	±0.12	±0.33		±0.10	± .021	±0.63	±1.02
	Cg	±0.03	±0.35		±0.06	± .028	±0.75	±0.77
95 % LIMIT CONFIDENCE	A	±0.33	±0.84		±0.38	± .139	±2.30	±6.89
	Bg	±0.33	±0.91		±0.27	± .059	±1.75	±2.84
	Cg	±0.08	±0.97		±0.16	± .078	±2.08	±2.15
COEFFICIENT OF VARIATION %	A	3.8	2.5		3.8	5.2	6.5	7.5
	Bg	4.5	4.1		2.6	3.4	6.8	7.2
	Cg	2.2	5.7		1.5	8.6	9.2	10.9

Sampling depth

A	0 - 7 cm
Bg	7 - 30
Cg	30+

ZONE 2

	H	% AIR-DRY MOISTURE	% LOSS ON IGNITION	% ORGANIC CARBON	pH	% TOTAL N	AVAIL. P(ppm)/g	EXCHANGE. K(ppm)/5g
1	A	4.61	10.51	14.04	3.90	1.008	8.0	27.0
	Bg	4.42	8.70	10.27	3.90	1.078	5.5	9.4
	Cg	ND	ND	ND	ND	ND	ND	ND
2	A	4.88	12.00	17.14	3.81	1.076	18.7	45.0
	Bg	4.80	8.52	9.87	3.90	.596	15.2	27.0
	Cg	ND	ND	ND	ND	ND	ND	ND
3	A	3.93	14.86	23.10	3.92	1.019	9.5	19.8
	Bg	3.87	9.20	11.31	4.45	.689	12.3	16.4
	Cg	ND	ND	ND	ND	ND	ND	ND
4	A	4.21	14.66	22.68	4.47	.994	8.6	27.5
	Bg	4.00	10.90	14.85	4.45	.630	6.5	18.5
	Cg	ND	ND	ND	ND	ND	ND	ND
5	A	4.65	13.45	20.16	4.40	1.232	19.2	39.2
	Bg	4.12	9.64	12.22	4.50	.784	8.7	10.6
	Cg	ND	ND	ND	ND	ND	ND	ND
MEAN	A	4.45	13.09	19.41	4.04	1.066	12.80	31.70
	Bg	4.24	9.39	11.70	4.24	.755	9.64	16.38
	Cg	ND	ND	ND	ND	ND	ND	ND
STAND. DEVIATION OF SAMPLE MEAN	A	±0.16	±0.77		±0.11	± .270	±2.52	±4.56
	Bg	±0.16	±0.42		±0.16	± .080	±1.81	±3.16
	Cg	ND	ND		ND	ND	ND	ND
95 % LIMIT CONFIDENCE	A	±0.44	±2.14		±0.30	± .750	±7.03	±10.16
	Bg	±0.44	±1.16		±0.44	± .224	±5.03	±8.78
	Cg	ND	ND		ND	ND	ND	ND
COEFFICIENT OF VARIATION %	A	3.5	5.8		2.7	25.5	19.6	14.3
	Bg	3.7	4.4		3.7	10.5	18.7	19.2
	Cg	ND	ND		ND	ND	ND	ND

Sampling depth

A	0 - 10 cm
Bg	10 - 20
Cg	20+

(ND = no data)

ZONE 3

	H	% AIR-DRY MOISTURE	% LOSS ON IGNITION	% ORGANIC CARBON	pH	% TOTAL N	AVAIL. P(ppm)/g	EXCHANGE. K(ppm)/5g
1	A B C	2.06 1.43 1.47	8.64 8.52 8.21	10.14 9.89 9.25	3.62 3.73 3.75	.375 .217 .169	7.2 6.5 9.1	18.1 15.5 12.3
2	A B C	2.57 1.55 1.25	9.02 7.34 6.35	10.93 7.43 5.37	3.68 3.62 3.65	.681 .314 .148	17.4 14.4 6.0	35.2 16.0 7.9
3	A B C	2.40 1.51 0.96	9.35 7.01 7.42	11.62 6.75 7.60	3.90 3.55 4.10	.654 .254 .130	8.0 5.1 5.6	28.5 16.5 15.0
4	A B C	1.79 1.50 0.90	9.67 6.99 6.85	12.29 6.70 6.41	3.70 4.00 4.00	.912 .543 .136	7.5 6.5 4.3	27.5 8.7 8.5
5	A B C	1.70 1.84 1.20	10.01 7.65 6.01	13.00 8.08 4.66	3.50 3.60 3.75	.384 .219 .109	16.5 4.3 6.0	37.4 25.4 15.6
MEAN	A B C	2.10 1.56 1.15	9.33 7.50 6.01	15.44 7.77 4.66	3.68 3.70 3.84	.0601 .309 .138	11.32 7.36 6.20	29.74 16.42 11.46
STAND. DEVIATION OF SAMPLE MEAN	A B C	±0.17 ±0.06 ±0.10	±0.23 ±0.28 ±0.39		±0.16 ±0.07 ±0.08	± .097 ± .050 ± .011	±2.31 ±1.81 ±0.35	±3.60 ±2.36 ±1.40
95 % LIMIT CONFIDENCE	A B C	±0.47 ±0.18 ±0.28	±0.66 ±0.78 ±1.03		±0.18 ±0.19 ±0.22	± .271 ± .139 ± .030	±6.42 ±5.04 ±0.78	±10.08 ±6.56 ±2.87
COEFFICIENT OF VARIATION %	A B C	8.0 4.2 8.6	2.4 3.7 6.4		4.3 2.0 2.7	16.1 16.1 7.9	20.4 24.5 5.6	12.0 14.3 12.0

Sampling depth

A	0 - 20 cm
B	20 - 30
C	30+

ZONE 4

ZONES	HORIZONS	MECHANICAL ANALYSIS (INTERNATIONAL LIMITS)			% MOISTURE	TOTAL CATION EXCHANGE CAPACITY m.e./100 g.
		% sand	% silt	% clay		
1a	A	ND	ND	ND	36.2	10.85
	B	65	17	18	30.9	4.88
	C	66	16	18	29.5	1.10
1b	A	ND	ND	ND	39.8	10.67
	B	65	18	17	37.5	3.78
	C	66	18	16	28.6	1.06
2	A	ND	ND	ND	47.6	21.07
	Bg	61	19	20	38.4	20.59
	Cg	59	19	22	35.2	14.32
3	A	ND	ND	ND	66.6	25.76
	Bg	59	31	11	44.0	22.34
	Cg	57	20	23	ND	ND
4	A	ND	ND	ND	41.3	15.37
	B	56	36	8	30.5	4.15
	C	61	20	19	28.6	1.07

Table 7.4 Soil analytical data (2) showing results of mechanical analysis, % moisture and total cation exchange capacity. (ND = no data)

Sampling depth (cm)

1a A 0 - 20	1b A 0 - 20	2 A 0 - 7	3 A 0 - 10	4 A 0 - 20
B 20 - 30	B 20 - 30	Bg 7 - 30	Bg 10 - 20	B 20 - 30
C 30+	C 30+	Cg 30+	Cg 20+	C 30+

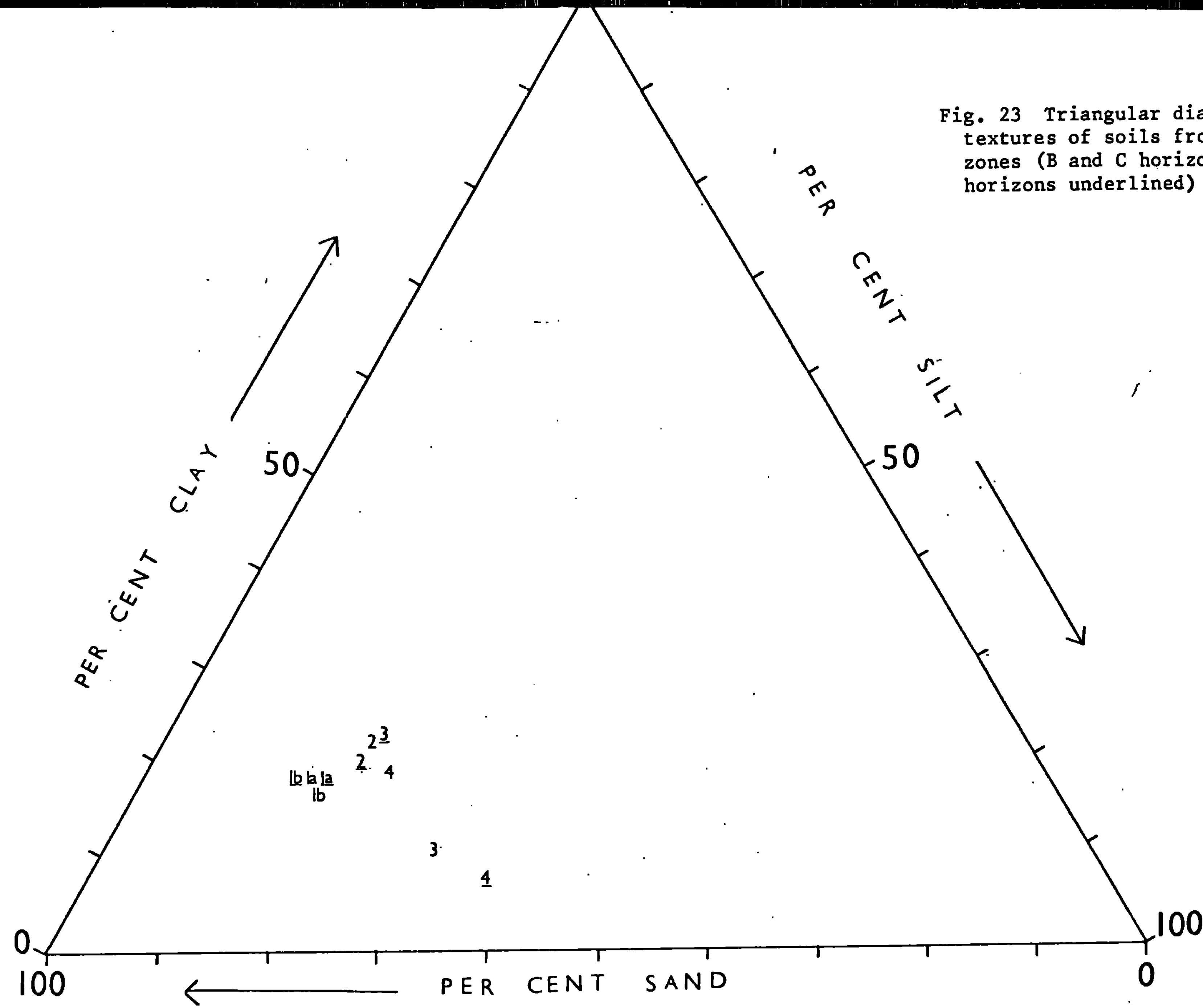


Fig. 23 Triangular diagram showing textures of soils from different zones (B and C horizons, B horizons underlined)

and little significance can be derived from the variability of the data. This is probably due to the soils being derived from the same parent material. In general, the texture of soil from Zones 1a and 1b are very similar while Zone 2 has slightly more clay. Zone 3 increases in fine fraction - notably silt which is washed down the slope, it also has a corresponding higher percentage of clay. Zone 4 has values between Zones 2 and 3.

(2) Moisture

Soil moisture is related to plant growth in many ways, directly and indirectly. Directly its effects pertain to the adequacy of the moisture supply. Indirectly, it influences plant growth by its effects on properties of soil.

The soil moisture has a close relationship with soil texture as heavier soils with a higher percentage of collodial clay fraction will hold more water than the lighter, coarser sandy soils. The finer-textured soil will also impede water movement, and will be slow to drain being more susceptible to waterlogging. On the other hand the coarser soils are characteristically well-drained but as a result are more highly leached. A rise of moisture is found from Zone 1 to 3 which is related to higher organic matter content and fine fraction on the lower slopes. The number of plant species increases following the rise of soil moisture content along the transect (Fig. 24) with 3-6 in Zone 1, 7-10 in Zone 2, 9-13 in Zone 3 and 4-10 in Zone 4 (correlation coefficient +0.58). The species located in Zone 3 commonly occur in waterlogged areas, *Hydrocotyle vulgaris*, *Mentha aquitica* and *Sphagnum* spp. are the typical ones.

(3) pH

The pH of a soil affects the solubility of plant nutrients and

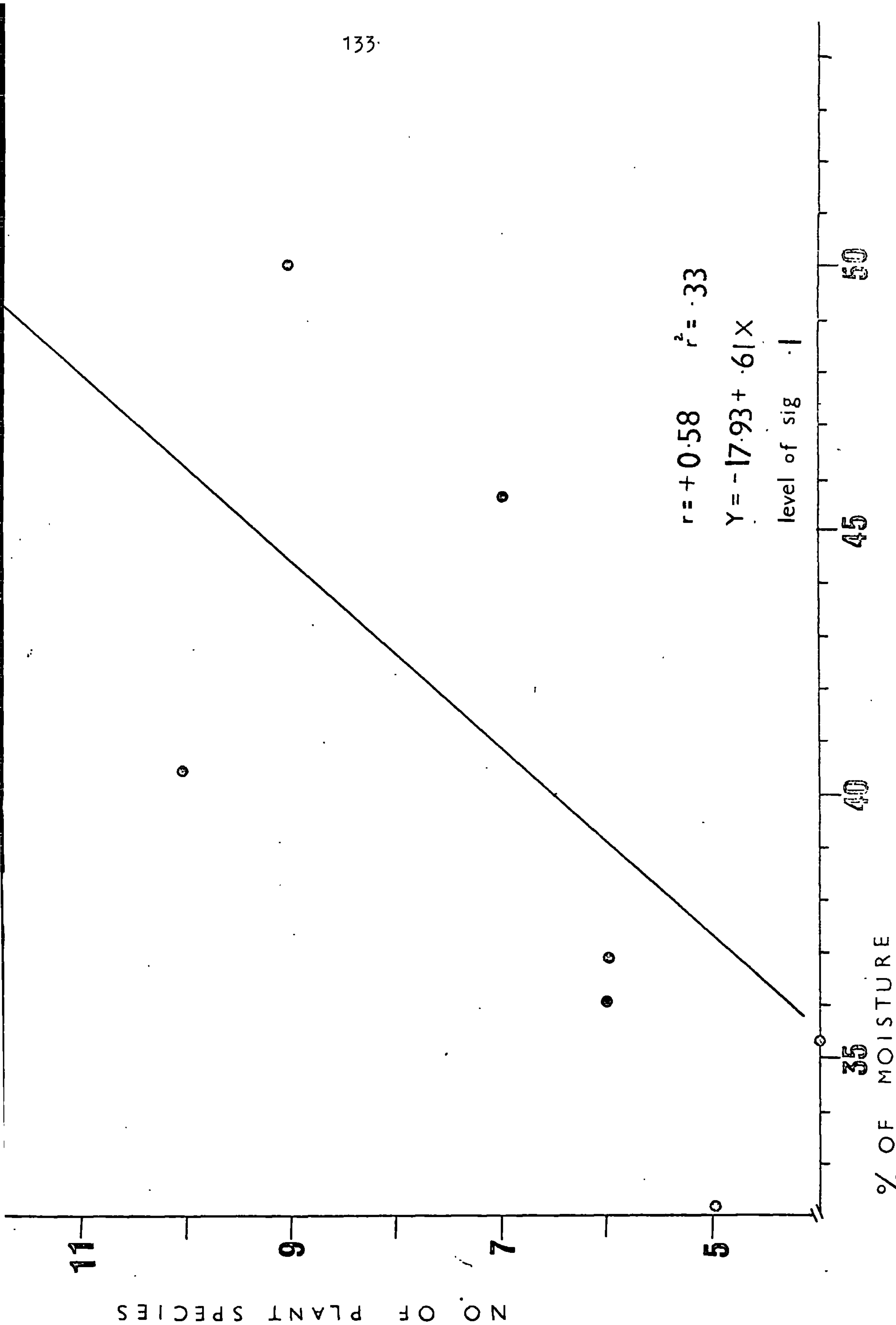


Fig. 24 Relationship between moisture and number of plant species.

* *

r = coefficient of correlation

r^2 = coefficient of determination. The coefficient of determination of the total variation in Y which can be explained by the linear relationship between X and Y. When multiplied by 100, the proportion is converted to %.

their relative availability for plant growth. Various interrelated factors tend to promote soil acidity. Acid parent-materials derived from rocks low in bases such as on Waldridge Fell support only those plants tolerant of nutrient-deficient condition, which produce on decomposition a poor humus and abundant organic acids. Carbonic acids are formed by the combination of rain water and the carbon dioxide which is produced during decay and respiration in the soil. Where these conditions are combined with high rainfall and coarse texture (as soils in Zones 1a and 1b), the process of leaching is severe as not only is the easily soluble calcium leached away but also other minerals. Under conditions of very high acidity, the collodial clay and humus fraction of the soil becomes unstable. In the absence of exchangeable calcium, the fine clay particles tend to deflocculate and can be leached downwards. The clay mineral itself also tends to undergo decomposition liberating compounds of iron, aluminium and manganese which being soluble are also leached. Most mineral nutrients become more soluble and liable to be washed out of the soil solum when pH falls below 4.5. Soluble aluminium can then appear in harmful quantities and the activities of bacteria and many soil animals can be affected (Russell 1971).

In general, when the pH is about neutral or only slightly acid (pH 6.5) nutrients are usually available to satisfy plant requirements and there is enough calcium to counteract acidity, maintain the stability of the clay/humus complex, and promote crumb structure. The number of plant species was positively correlated (correlation coefficient + 0.96) with the pH of the soil along the selected transect in Waldridge Fell (Fig. 25).

The general trend of lower pH is usually associated with an

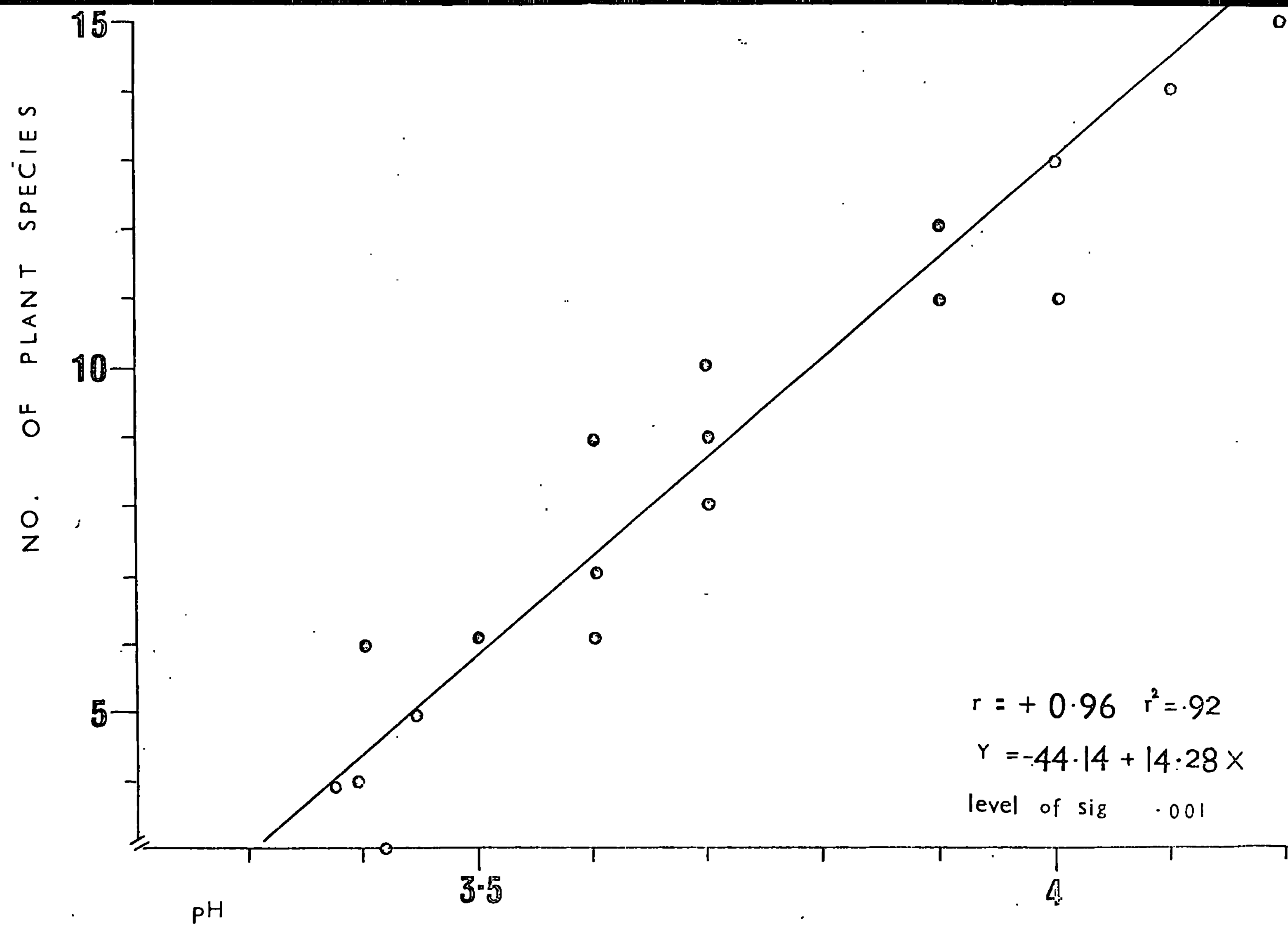


Fig. 25 Relationship between pH and number of plant species.

increase in soil organic matter (Pearsall 1970). The correlation coefficients (r) of different zones are as follows:- Zones 1a = -0.72, 1b = -0.65, 2 = -0.72, 3 = -0.57 and 4 = -0.41. Zones 1a, 1b and 2 have comparatively high values while Zones 3 and 4 are comparatively low. This is probably due to the uneven distributions of organic matter in Zones 3 and 4 which are subject to the effects of grazing and trampling. The graphs also show the more abundant decomposing plant material in the A horizon corresponded to the lower pH values and increased with depth as the organic matter declined (Fig. 26-30).

The average pH value for each zone was found to be as follows:- Zone 1a, 3.50; Zone 1b, 3.56; Zone 2, 3.68; Zone 3, 4.12 and Zone 4, 3.74. The distribution of different plant species was correlated to the optimum pH conditions. *Pteridium aquilinum* and *Deschampsia flexuosa* were more abundant with pH under 3.5 while *Calluna vulgaris* dominated the area with pH ranging from 3.5 to 4.0. *Hydrocotyle vulgaris*, *Molinia caerulea*, *Eriphorum angustifolium* and *Sphagnum* spp. were found in the bog area with higher values of pH (higher than 4.0). The latter flourish in acid water, and by absorbing the bases of nutrient salts onto acid substances in the cell wall, help to maintain a low pH (Tansley 1949). The increase of pH and moisture content along the transect is mainly due to the percolating water which tends to move laterally across the profile instead of merely downwards and percolating water will be enriched in bases from the higher ground, and the soils will correspondingly be less acid.

(4) Organic matter

Organic matter content can be estimated from a determination of the organic carbon content of soil, or vice versa if an assumption is made that the proportion of elemental C to organic matter is

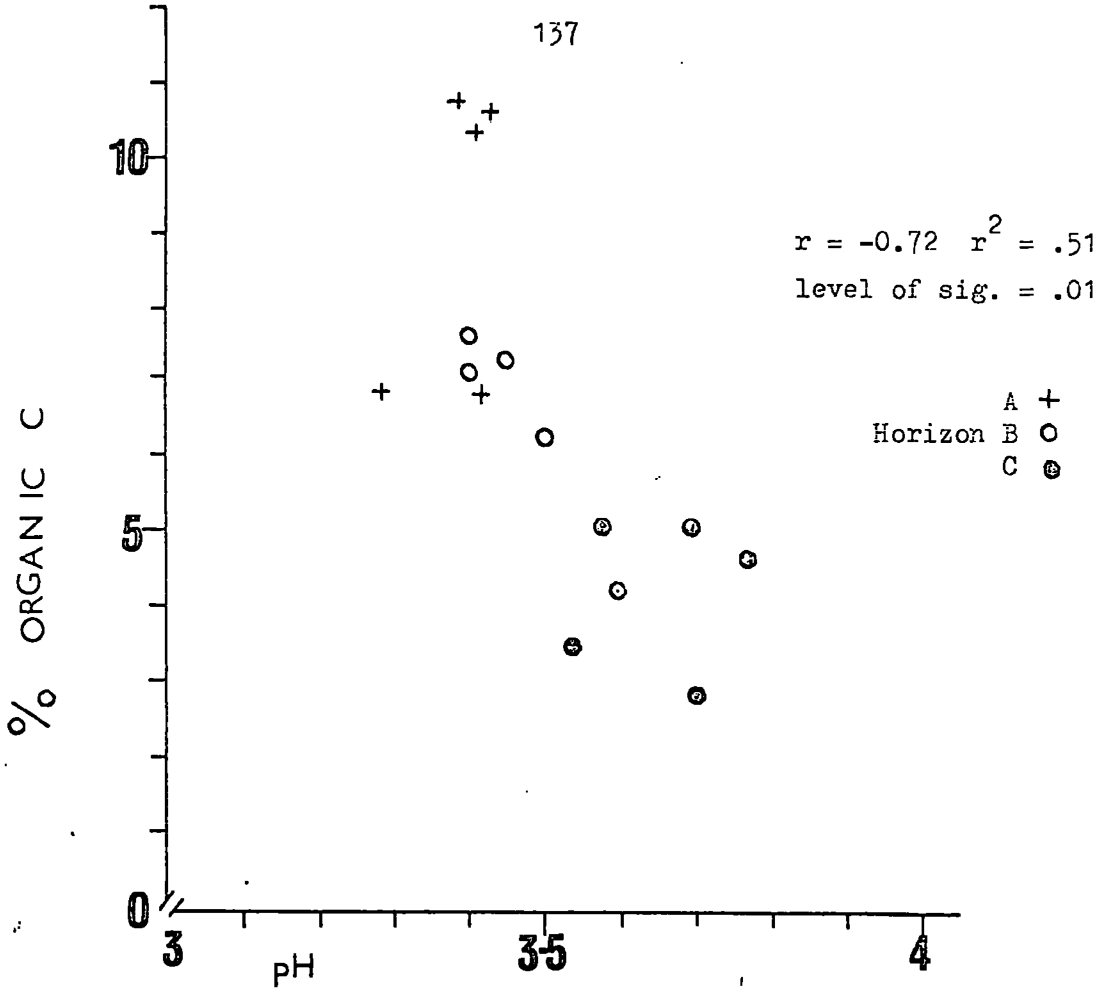


Fig. 26 : relationship between pH values and organic carbon contents - Zone 1a

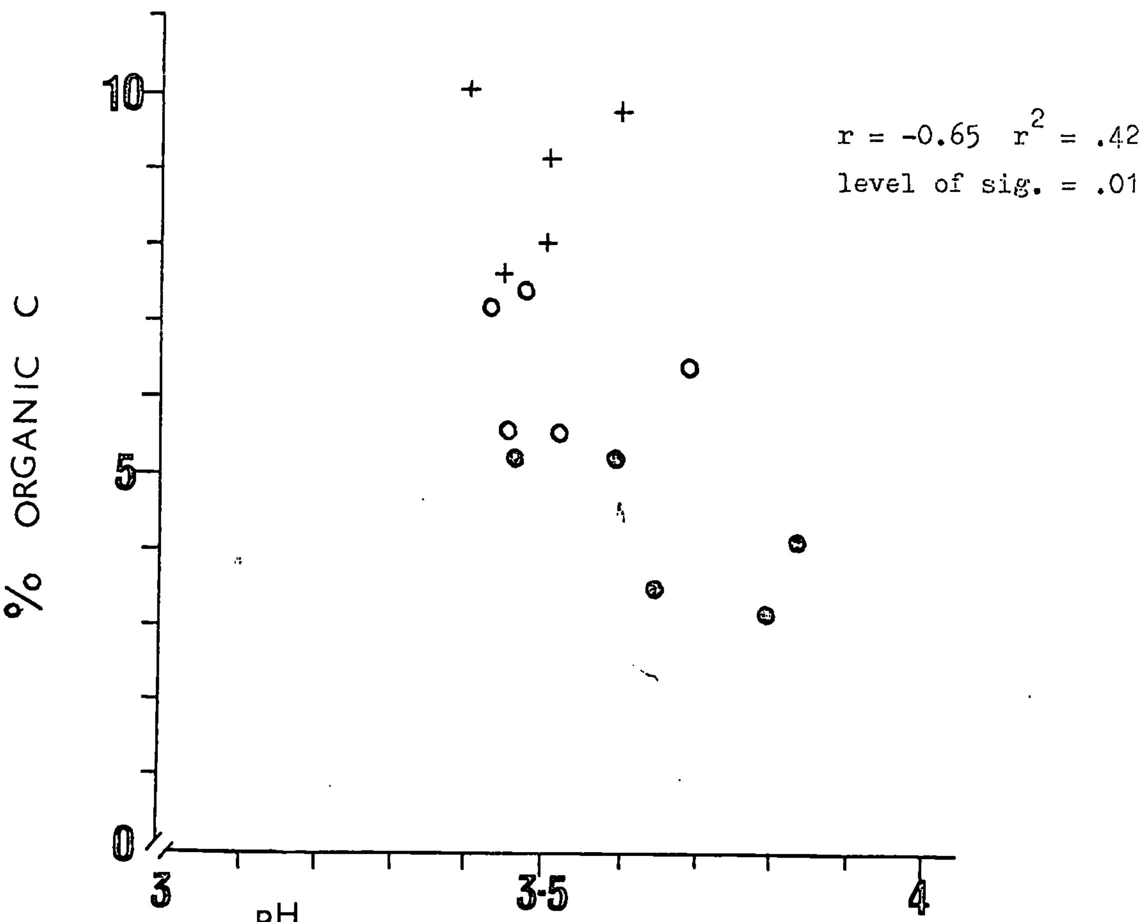


Fig. 27 relationship between pH values and organic carbon contents - Zone 1b

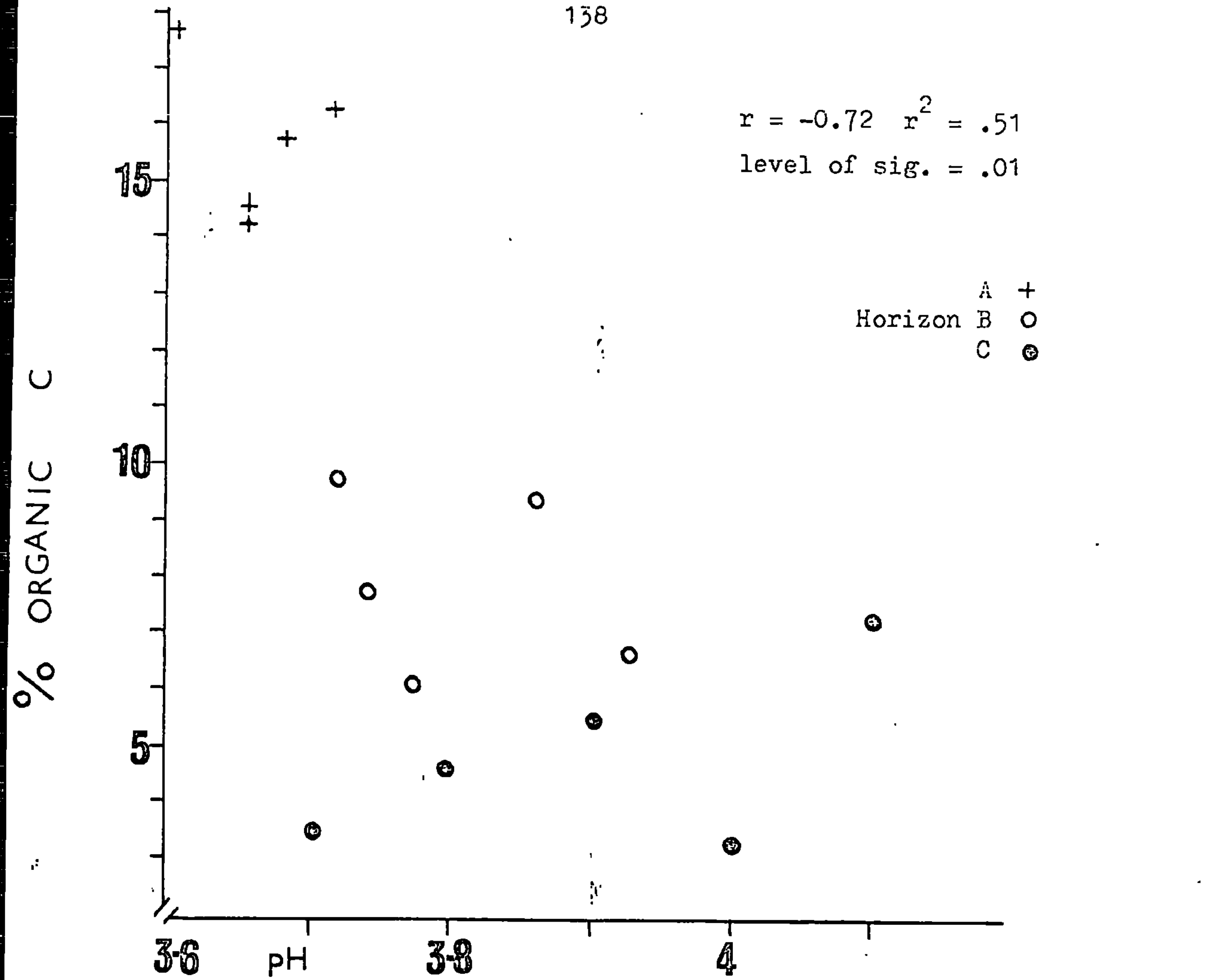


Fig. 28 relationship between pH values and organic carbon contents - Zone 2

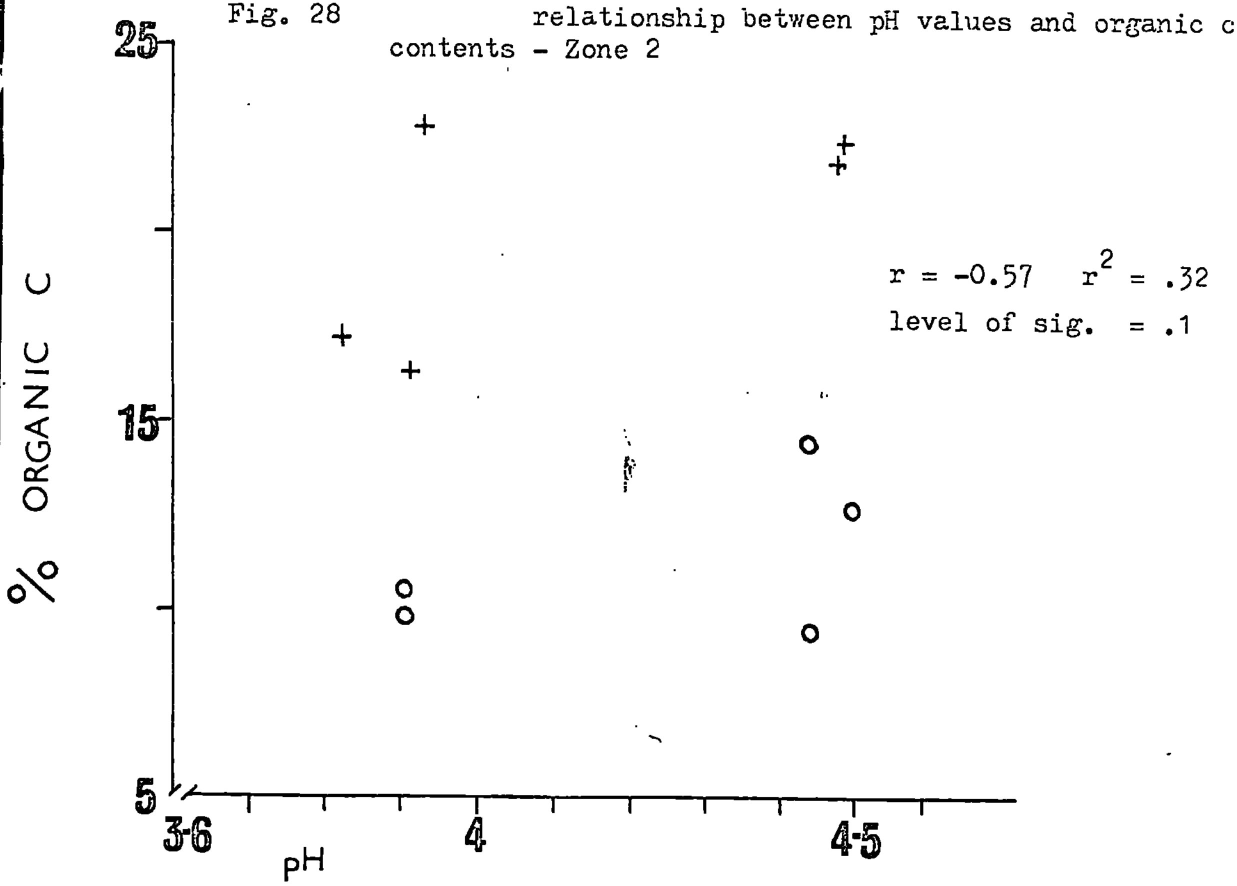


Fig. 29 relationship between pH values and organic carbon contents - Zone 3

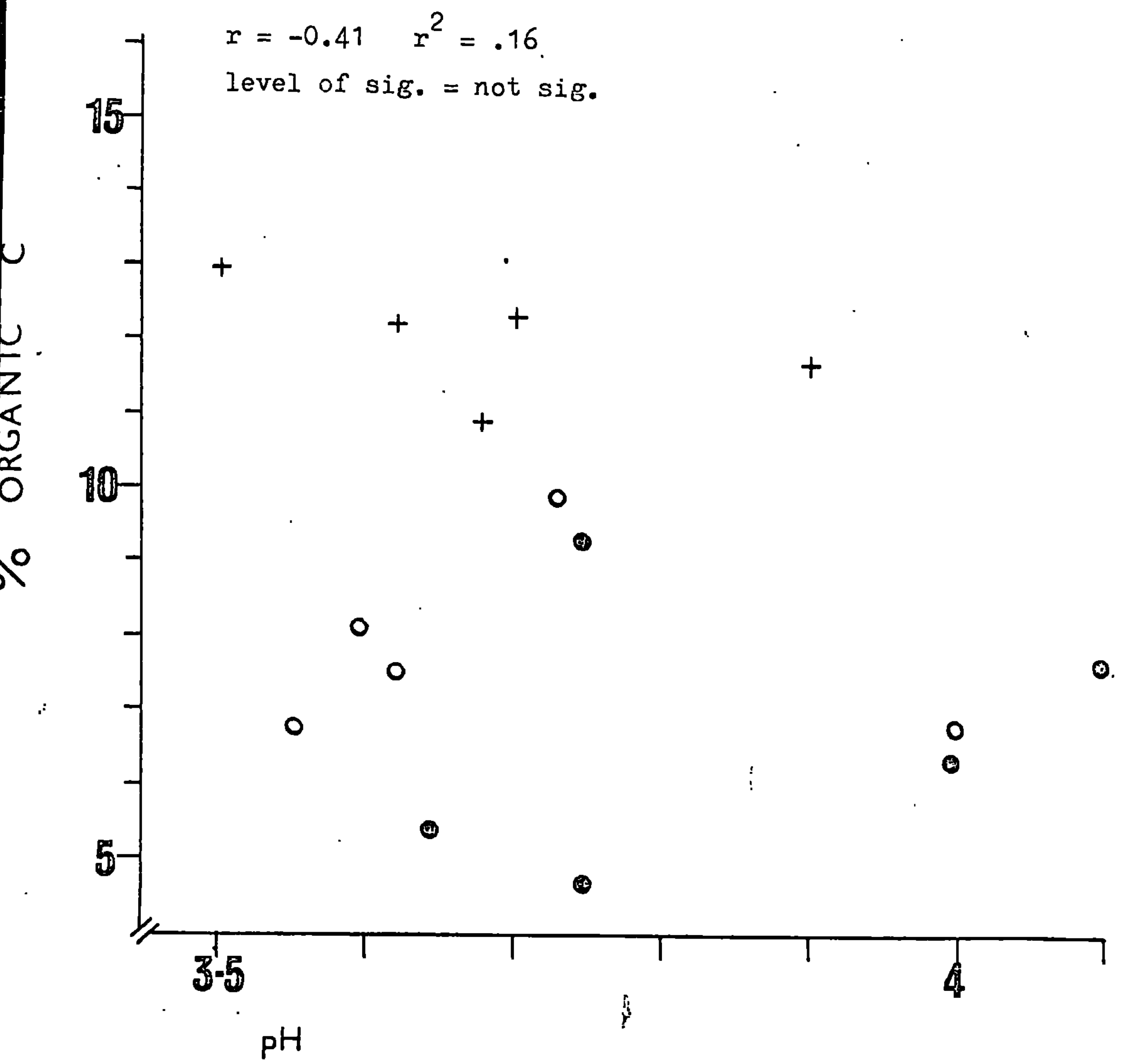


Fig. 30 relationship between pH values and organic carbon contents - Zone 4

Horizon A +
Horizon B o
Horizon C ⊙

constant (Ball 1964).

Organic matter is the major source of plant nutrients, and the bulk of the minerals necessary for plant growth is made available in the decomposition of organic matter. Many of the nutrients (e.g. phosphorus, potassium, sulphur and calcium), originally derived from weathered rock, are held and kept in circulation in organic compounds in the soil. Nitrogen is closely correlated to organic matter as about 98% of nitrogen is in organic form (refer to chapter 2). Therefore, the organic matter in soils is traditionally associated with soil fertility and a soil rich in organic matter is often productive.

Organic matter has collodial properties like the clay fraction, with a high capacity to link water and mineral particles and increase their stability. It holds water equivalent to an amount several times its weight (high water-holding capacity). The progressive and pronounced accumulation of organic matter is a characteristic of those soils where drainage is impeded (Zone 2, average value of A horizon 15.83%). When soils become fully saturated with water the result is a deficiency of oxygen. This retards decomposition as the partially decayed organic matter forms a progressively thicker layer of peat (Zone 3, average organic carbon value of A horizon 19.41% and a thickness of 30 cm.).

<u>(5) Total cation exchange capacity</u>

Cation exchange functions in two ways as nutrients are released for the use of plants. The nutrients freed by cation exchange enter into the soil solution and may ultimately contact the absorptive surfaces of root hairs (unless removed by leaching) or a direct exchange of cations between the soil and the roots occurs. The latter depends on whether colloidal surfaces of the soil and the roots are close enough.

In general, the exchange capacity increases as soils become heavier. This is because sandy loams are low in collodial clay and are very likely to be deficient in humus also. Heavier soils always carry more clay and generally more organic matter. Therefore, their cation exchange capacity is higher and the results come out in the following order: Zone 3, Zone 2, Zone 4, Zone 1a and Zone 1b (24.05, 18.66, 10.29, 5.61 and 5.17 m.e./100 g. accordingly)*

Zone 3 and Zone 2 both have comparatively high contents of organic matter and are more humified, the colloidal properties are more marked and therefore their cation exchange capacities are correspondly greater. The leaching process is dominant in the other zones with H-ions readily entering the adsorptive complex of soils, with the bases, especially Ca ions, being more or less easily forced out. The base saturation of soils in these zones is lower, especially Zone 1a and Zone 1b.

(6) Nitrogen, phosphate and potassium

Table 7.3 reveals the average contents of these three major nutrients. In general these soils commonly contain small reserves of nitrogen (range from ·28% in Zone 1a to ·91% in Zone 3)* and it is expected that only a limited amount of the total will be in a form available to plant nutrition. This is mainly due to the climatic conditions (such as low temperature and high rainfall) and the low pH status. The former promotes the losses of nitrate nitrogen through leaching while the latter affects the activities of microorganisms and therefore retards the decomposition of organic matter. The contents of available phosphate and potassium were moderate (available phosphate;* range from 5.35 ppm in Zone 1a to 11.22 ppm in Zone 3; available

* ....
average values of A, B and C horizons.

potassium, range from 13.47 ppm in Zone 1a to 24.04 ppm in Zone 3).

Table 7.3 also shows that the nutrient contents increase from Zone 1a downslope to the maximum of Zone 3. Zone 3, being at the base of the slope may receive more nutrients (available phosphate and exchangeable potassium) in run-off water. It may also be affected by the dominant species, *Molinia*, a deep-rooted plant which enriches the surface horizons by withdrawing nutrients from lower in the profile and depositing them at the surface.

The critical limiting factor of crop production in moorland may be the rate of nutrient supply in the soil. The actual supply of these nutrients during the growing season not only depends on the total reserves but also upon the available nutrients which are replenished by the uptake of plants and the leaching process. This phenomena is further investigated in the following chapters.

The results show that the peaks observed in the vegetational profiles (van der Marrel) correspond exactly to the changes in values of pH,moisture content and the contents of total nitrogen, available phosphate and potassium (Fig. 31). The analysis of the parameters reinforce the thesis that vegetation boundaries are not chance phenomena but correspond rather closely to specific detectable changes in the environmental milieu. (Bridgewater 1969, Wong 1969, Bridgewater 1970).

The reason that similar vegetation is found in Zones 1 and 4, with rather different environmental parameters, is that a similar net effect may be produced by the interaction of the various parameters. The environmental gradients described are better thought of as an expression of environmental complexes rather than a single factor directly affecting behaviour of a single species.

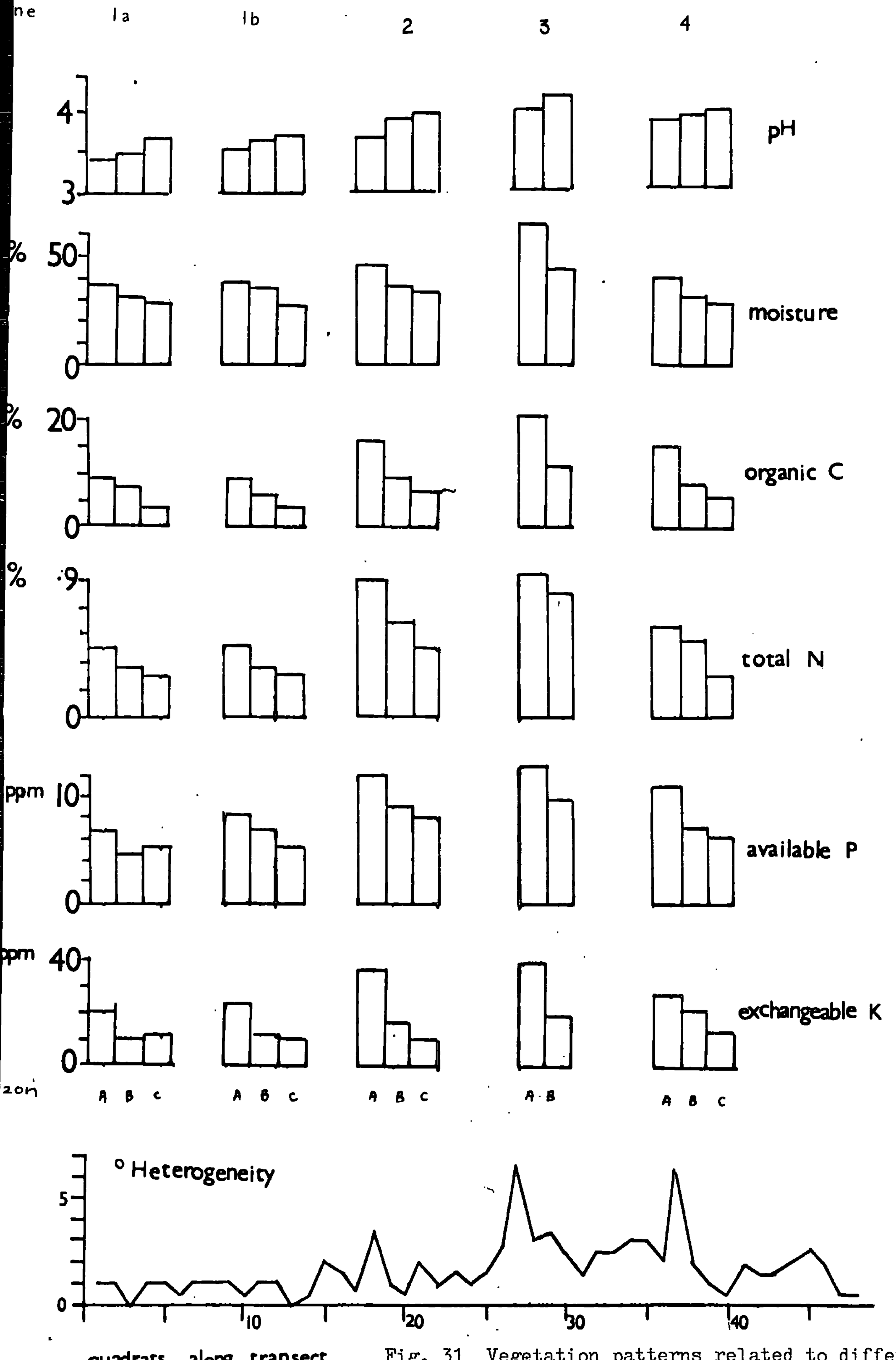


Fig. 31 Vegetation patterns related to different soil parameters along the transect.

7.5 CONCLUSION

The vegetation stands reflect the interaction of biotic and edaphic factors. A technique which plots vegetational differences among stands also plots the environmental complexes that control them. Although precise correlations between plant community types and single environmental factors would hardly be expected, some patterns of interaction involving certain edaphic factors have been recognized in the present data.

The complexity of environmental interrelationships in determing plant community composition is such that environmental gradients may be more meaningful in term of groups of factors. Within the restricted area sampled, the chief factors contributing to environmental variations were topography, pH, soil moisture regime and content of soil nutrients, Biotic influences also play an important, though local role.

C H A P T E R   E I G H T

SEASONAL FLUCTUATIONS IN SOIL FERTILITY

8.1 INTRODUCTION AND GENERAL REVIEW

This section is concerned with the seasonal pattern of crop yield (*Calluna vulgaris*), nutrient uptake in the crop and nutrient availability in the soil related to the meteorological conditions. It is hoped that the results may be used to quantify soil nutrient status in moorland ecosystems in view of afforestation and pasture development.

Bean (1942) and van der Paauw (1948 and 1950) both confirmed the idea of Beveridge (1922) who investigated periodicities of wheat yields in England, with periods varying between 2.735 and 68.0 years, which he identified with well known meteorological cycles. It may follow that the sequence of other crop yields has also depended on periodicities of meteorological causes. Van der Paauw (1962) further studied the effect of 'cyclic' rainfall periods on the fertility of the soil in Holland and found that the soil fertility status is related to the prevailing weather conditions. Changes in the amount of precipitation gave rise to considerable changes in the fertility of the soil. Periodic fluctuations of soil factors such as the contents of water-soluble phosphorus , of exchangeable potassium and the pH originate from gradual and cumulative effects of rainfall in alternating periods of markedly different precipitation. The contents of phosphorus and potassium rise in dry and fall in wet periods, the pH reacts in the opposite sense.

Voigtländer (1963 and 1968) studied the effect of weather and soil on yields in different localities in Germany and discovered in dry years of warm and cold summers that the locality with higher temperatures was more productive. Yields on garden sort (mixture of compost, soil and sand) were consistently higher than on any of the 'natural' soils (leached brown earth) at the two localities (at 400m. and 700m. altitude), indicating that the effect of unfavourable weather can be compensated by improved soil fertility.

Therefore, the explanation of violent seasonal fluctuations in crop yields often observed in regions with extreme climatic conditions, should be based on long-term experiments which take into account the fluctuating parameters, soil and climate.

Loach (1968) made the following comment:- 'The primary requirements for a fundamental understanding of the nutrition of crops are a knowledge of the amounts of nutrients held within the soil and vegetation, together with information relating to the extent, and the seasonal pattern of exchange between the two'.

8.2 Methods

8.2.1 The choice of sampling sites

For long term observations involving soil chemical properties at any site, it is essential to test the degree of variability. Statistical comparisons of the data (Table 8.1 based on the study of Chapter 7.4 Edaphic variables, Table 7.3) were made by calculating the standard deviation of sample means and the 95% confidence limits to the overall mean values on a zone basis. The latter is presented in Fig. 32. The figure reveals that the soil properties of Zones 1a, 1b and 2 are relatively more uniform than Zones 3 and 4.

In order to test the actual variability of the soil properties, calculations of coefficients of variation (CV = $\frac{\text{standard deviation}}{\text{sample mean}} \times 100$) for the soil physical and chemical characteristics in the four zones were carried out (Table 8.1). The variations for the physical properties are less than for the chemical properties, for example, for air-dry moisture content, CV averages (3 horizons) 3.5% for Zone 1a, 3.1% for Zone 1b, 3.5% for Zone 2, 3.6% for Zone 3

ZONES		% AIR-DRY MOISTURE 1a	1b	2	3	4	pH 1a	1b	2	3	4	AVAILABLE PHOSPHATE (ppm) 1a	1b	2	3	4
SAMPLE MEAN	A	1.50	1.59	3.09	4.45	2.10	3.38	3.49	3.62	4.04	3.66	6.62	8.32	12.64	12.80	11.32
	B	1.34	1.35	2.65	4.24	1.56	3.47	3.52	3.80	4.24	3.70	4.62	6.78	9.44	9.64	7.36
	C	0.98	1.09	1.32	ND	1.15	3.66	3.67	3.90	ND	3.84	4.80	5.42	8.08	ND	6.20
STANDARD DEVIATION	A	±0.03	±0.04	±0.12	±0.16	±0.17	±0.06	±0.10	±0.14	±0.11	±0.16	±0.35	±0.55	±0.83	±2.52	±2.31
	B	±0.06	±0.03	±0.12	±0.16	±0.06	±0.12	±0.04	±0.10	±0.16	±0.07	±0.30	±0.20	±1.63	±1.61	±1.81
	C	±0.04	±0.05	±0.05	ND	±0.10	±0.04	±0.06	±0.06	ND	±0.08	±0.38	±0.33	±0.75	ND	±0.35
95 % CONFIDENCE LIMITS	A	±0.08	±0.11	±0.33	±0.44	±0.47	±0.16	±0.27	±0.38	±0.30	±0.18	±0.91	±1.52	±2.30	±7.03	±6.42
	B	±0.16	±0.08	±0.33	±0.44	±0.18	±0.33	±0.11	±0.27	±0.44	±0.19	±0.83	±0.55	±1.75	±5.03	±5.04
	C	±0.11	±0.13	±0.08	ND	±0.28	±0.11	±0.16	±0.16	ND	±0.22	±1.05	±0.91	±2.08	ND	±0.78
COEFFICIENT OF VARIATION %	A	2.0	2.5	3.8	3.5	8.0	1.7	2.8	3.8	2.7	4.3	4.9	6.6	6.5	19.6	20.4
	B	4.4	2.2	4.5	3.7	4.2	3.4	1.1	2.6	3.7	2.0	6.4	2.9	6.6	16.7	24.5
	C	4.0	4.5	2.2	ND	6.6	1.0	1.6	1.5	ND	2.7	7.9	6.0	9.2	ND	5.6
ZONES		% LOSS ON IGNITION 1a	1b	2	3	4	% TOTAL NITROGEN 1a	1b	2	3	4	EXCHANGEABLE POTASSIUM (ppm) 1a	1b	2	3	4
SAMPLE MEAN	A	8.11	8.08	11.37	15.09	9.33	·440	·453	·953	1·066	·601	21.36	21.88	32.76	31.70	29.74
	B	6.99	6.85	7.88	9.59	7.50	·250	·291	·610	·755	·309	9.54	9.60	14.06	16.38	16.42
	C	5.81	5.79	6.07	ND	6.01	·138	·138	·325	ND	·138	10.11	8.98	9.12	ND	11.46
STANDARD DEVIATION	A	±0.43	±0.22	±0.29	±0.77	±0.23	± ·022	± ·013	± ·050	± ·270	± ·097	±1.55	±1.19	±2.48	±4.56	±5.60
	B	±0.18	±0.18	±0.35	±0.42	±0.28	± ·014	± ·014	± ·021	± ·080	± ·050	±0.92	±0.87	±1.02	±3.16	±2.56
	C	±0.19	±0.21	±0.35	ND	±0.39	± ·010	± ·011	± ·028	ND	± ·011	±0.50	±0.58	±0.77	ND	±1.40
95 % CONFIDENCE LIMITS	A	±1.19	±0.61	±0.84	±2.14	±0.66	± ·061	± ·036	± ·139	± ·750	± ·271	±4.30	±3.31	±6.89	±10.16	±10.08
	B	±0.50	±0.50	±0.91	±1.16	±0.78	± ·038	± ·038	± ·059	± ·224	± ·139	±2.56	±2.49	±2.84	±8.78	±6.56
	C	±0.52	±0.58	±0.97	ND	±1.08	± ·029	± ·032	± ·078	ND	± ·030	±1.39	±1.61	±2.15	ND	±2.87
COEFFICIENT OF VARIATION %	A	5.3	2.7	2.5	5.8	2.4	5.0	2.8	5.2	25.5	16.1	7.2	5.4	7.5	14.3	12.0
	B	2.5	2.6	4.1	4.4	3.7	5.6	4.8	3.4	10.5	16.1	9.6	9.0	7.2	19.29	14.3
	C	3.2	3.6	5.7	ND	6.4	7.7	7.9	8.6	ND	7.9	4.9	6.4	10.9	ND	12.0

Table 8·1 Comparisons of soil variability (ND = no data) (Sampling depth refer to p.130)

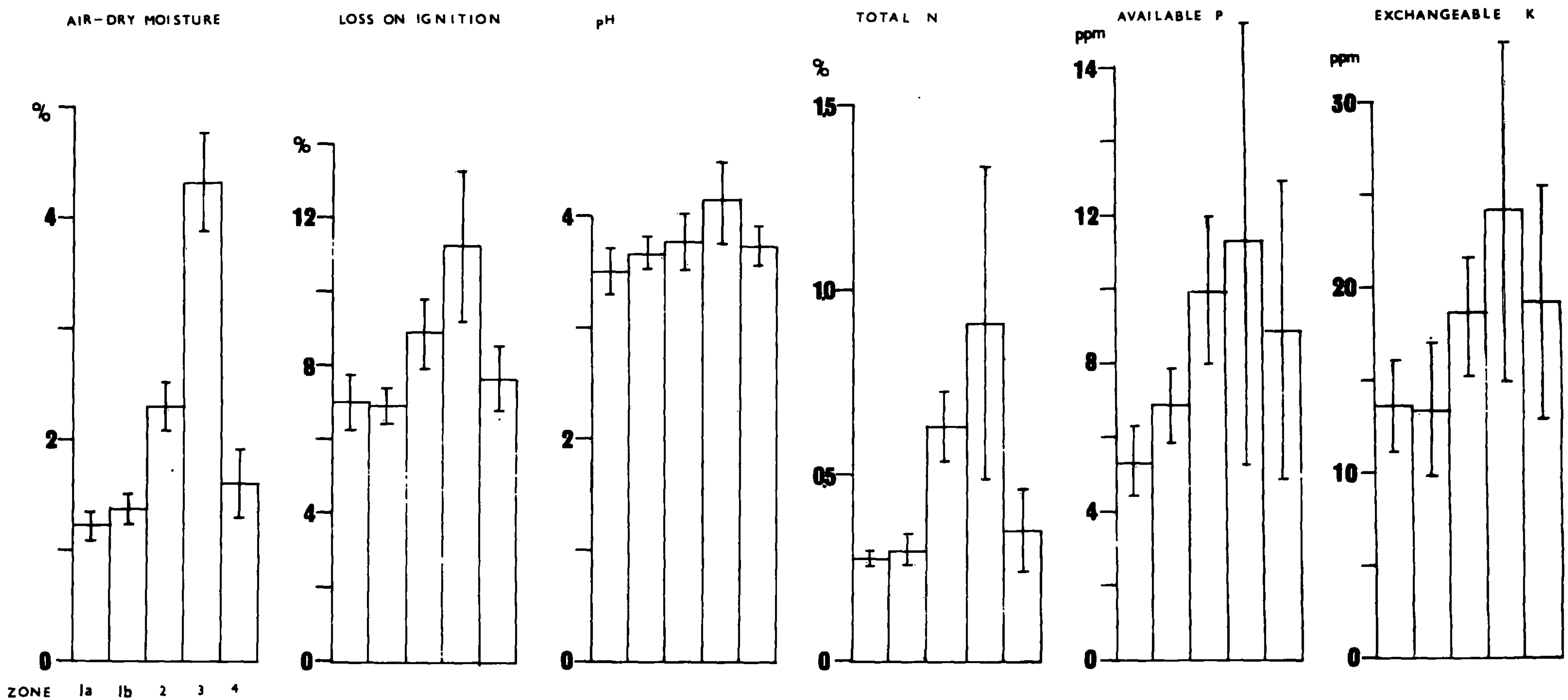


Fig. 32 Mean values $\pm$ 95% confidence limits for the soil properties.

and 6.9% for Zone 4; for loss on ignition, 3.7 for 1a, 3.0 for 1b, 4.1 for 2, 5.1 for 3 and 4.1 for 4. The data also indicates that the physical properties are more constant in Zones 1a, 1b and 2. This is also true for pH values, CV averages 2.0% for Zone 1a, 1.8 for Zone 1b, 2.6 for Zone 2, 3.2 for Zone 3 and 3.0 for Zone 4.

In general, high variations are obtained for the chemical nutrients although Zones 1a, 1b and 2 again tend to be more constant. The CV values of total nitrogen are the least variable among the three nutrients with 6.1% in Zone 1a, 5.2 in Zone 1b, 5.7 in Zone 2, 18.0 in Zone 3 and 13.1 in Zone 4, while available phosphate with 6.4 in 1a, 5.2 in 1b, 7.5 in 2, 19.15 in 3 and 16.9 in 4. The results of exchangeable potassium show the irregularities which probably reflect an uneven distribution of clay colloids in the soils. Peat colloids readily absorb potassium and *Sphagnum* spp., which are the major constituents of the peat, have a collodial absorption mechanism in addition to the plant and soil (Loach 1968). The uneven occurrence of *Sphagnum* spp. together with the waterlogged condition in Zone 3 probably increase the irregularities of potassium content in the zone. CV values are 7.2 in Zone 1a, 6.9 in Zone 1b, 8.5 in Zone 2, 16.8 in Zone 3 and 12.7 in Zone 4.

The more variable environments in Zones 3 and 4 are probably due to the effects of grazing and trampling and therefore not used for studying seasonal fluctuations in nutrient status.

8.2.2 Sampling and analytical methods

A time saving and yet accurate method was used in this study:- 5 subsamples of *Calluna* and soil from each sample plot in Zones 1a, 1b and 2 were taken randomly each month. The 5 plant samples and 5 soil samples from each zone were each carefully mixed, using the same amount of material from each subsample, into one sample representative of each zone.

Over even a small area, not only are there lateral variations in soil fertility, but it also varies vertically according to the soil horizonation. Ideally, the sampling depth ought to correspond to the depth of soil from which the plant is extracting its nutrients (Smith 1959). 2-10 cm. has been found to be the most abundant rooting zone of *Calluna* on Waldridge Fell and therefore soil samples were taken from this depth.

Both plant and soil samples were analysed for the following items:- % of total nitrogen, available phosphate (ppm) and exchangeable potassium (ppm) (APPENDIX A.3).

8.3 RESULTS

The results of monthly nutrient uptake (measured by the tissue analysis of *Calluna*) and retained in the soil (2-10 cm) are shown in the following figures:- Fig 33 total nitrogen, Fig. 34 available phosphate (ppm) and Fig. 35 exchangeable potassium (ppm).

The weather data (mean monthly temperature and mean monthly rainfall) were obtained from the Durham University Observatory and are presented in the same figures as the nutrient contents (Figs. 33, 34 and 35).

8.4 DISCUSSION

8.4.1 Nitrogen

(1) Soil content

The results of the soil contents show that the percentage of total nitrogen from each of the three sites remained relatively constant throughout the research period although there tended to be generally

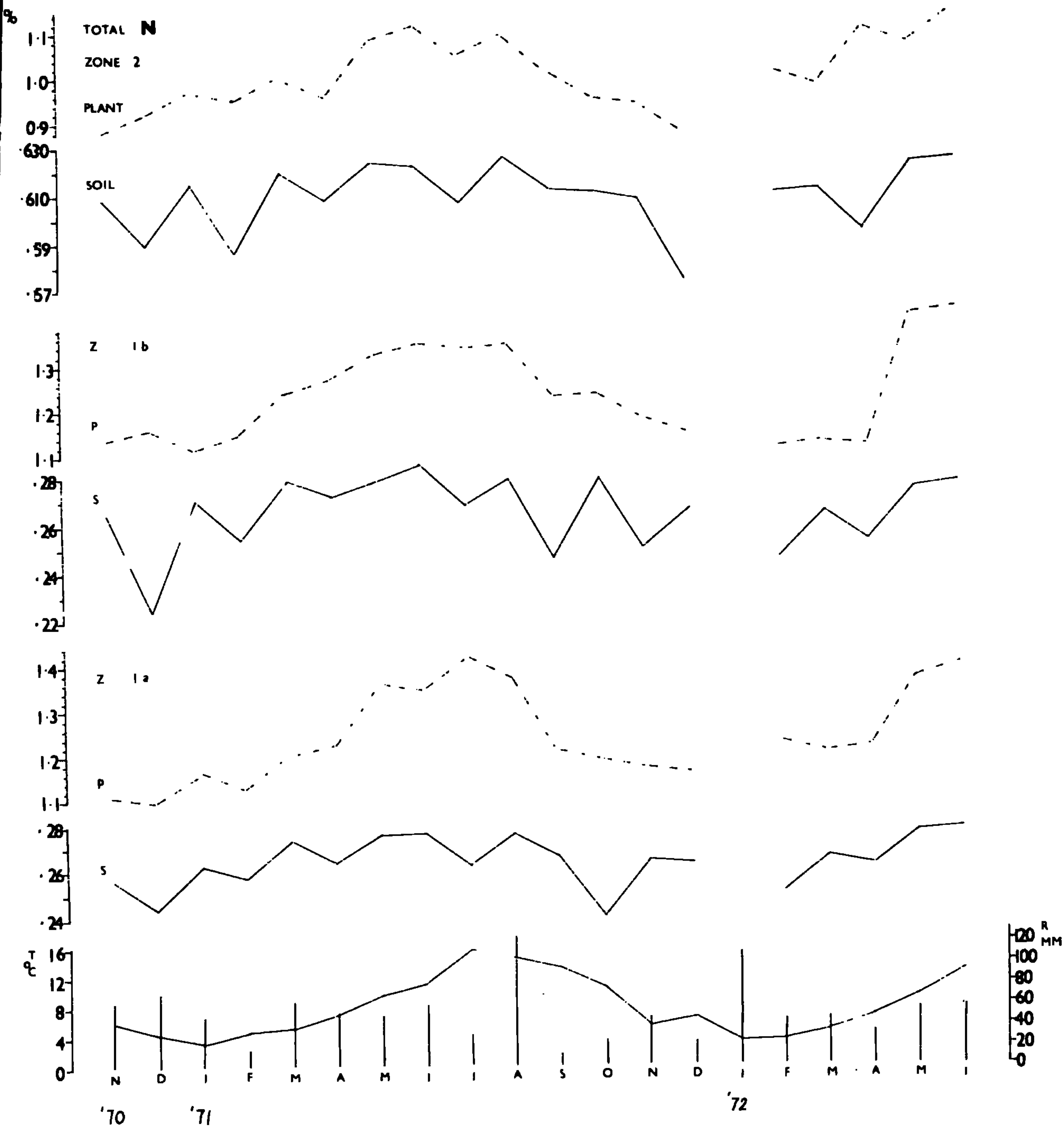


Fig. 33 Seasonal fluctuations of total nitrogen contents in soil and *Calluna* uptake.
(2-10 cm)

higher values with the warmer temperature and higher rainfall in the summers. The maximum values of Zone 1a occurred in June 1971 with ·28%; Zone 1b also in June 1971 with ·28% and Zone 2 in August 1971 with ·62% (Fig. 33).

The relatively steady levels of total nitrogen in the soil are mainly due to the larger amount of nitrogen combined in the organic matter as has been discussed in Chapter 3. The organic matter content remains relatively stable and resistant to microbial attack and only a proportion of the total nitrogen is mineralized in a year. This feature of constant levels of nitrogen in the soil has long been recognized and examples include:-

(1) The percentage of total nitrogen in air-dry soil, 0-23 cm. deep of the Broadbalk wheat and Hoosfield barley experiments (source: Warren 1956).

Broadbalk (wheat)		Hoosfield (barley)	
1865	0.105	1882	0.098
1944	0.106	1946	0.103

(2) The percentage of total nitrogen in top soil of the Agdell rotation experiment (source: Warren 1958).

	Fallow	Clover
1867	0.127	0.130
1953	0.119	0.152

(3) The percentage of total nitrogen in soil of an experiment at Woburn (source: Mann and Barnes, 1956).

1942	0.082
1951	0.089

The results here obtained agree broadly with the above works. Although the research period of the present experiment was less than two years, the constant level of total nitrogen in the soils is fairly marked.

However, the fluctuations and accumulation seem to be consistent with those that could be expected from the decomposition of soil organic matter in warm and humid conditions and losses through leaching with rain-water. The comparatively high values in the months with high rainfall can be explained by the additional nitrogen being supplied in the rainfall (Ovington 1962). Over much of the world rain supplies from 2.2 to 11.2 kg nitrogen/ha/year (2 to 10 lb/acre/ year) - for example, at Rothamsted, a total of 5.04 kg nitrogen /ha/year (4.5 lb/ha/year) was obtained with 3.36 kg as ammonium (3 lb) and 1.68 kg as nitrate (1.5 lb) (Cooke 1970).

The lower values occurring after the periods of heavy rainfall indicate the process of leaching after mineralization. Mineralization would be accelerated under favourable conditions, i.e. suitable moisture, warm weather, etc. The minimum values in Zone 1a occurred in October 1971 with ·24%; 1b in December 1970 with ·22% and 2 in December 1971 with ·57%. Nitrate, the product of mineralization, would be leached under heavy rainfall. The excess of winter rainfall over transpiration usually leads to much leaching that removes not only nitrate but other nutrients, too. According to the figures, a flush of nitrogen is mineralized in spring and early summer, with a smaller flush occurring in autumn. Simpson (1964) stated that wetting and drying cycles were important factors in the accumulation of nitrate and that most of the nitrate was mineralized, as a result of humus decomposition which followed the wetting (rainfall) of dry soil.

The soils of Zone 2 tend to have a higher percentage of organic content and therefore higher nitrogen content than Zones 1a and 1b. This higher nitrogen content in Zone 2 is also probably due to the heavier soil with nitrate being not so easily removed by drainage.

(2) Plant content

The results of tissue analysis reveal that the nitrogen content of the *Calluna* from Zone 2 was considerably lower than that of Zone 1a and 1b although there was a higher percentage of total nitrogen content in the soils of that area. It is considered that this is due to the lower rate of decomposition of the organic matter and therefore, a slow release of soluble nitrogen. Furthermore, this zone was seasonally waterlogged particularly after periods of heavy rainfall. This, together with greater compaction of the profile, created an anaerobic condition which was unfavourable for either decomposition or mineralization. That the flooding of the soil can have important effects on the availability of nitrogen to the plant has long been known. In many cases nitrogen is lost in the gaseous form, especially as elemental nitrogen. This has been shown by Jones (1951), De and Dijar (1954, 1955) and many others. Chemical transformations of the soluble nitrogen compounds in the soil may also influence availability to plant (De and Sarkar 1936). Nevertheless, factors other than nitrogen availability were also imposing limits on root growths in the waterlogged conditions.

Calluna is known to be particularly efficient in absorbing nitrogen (Weatherell 1935, Leyton 1954) probably owing to the activities of root mycorrhizas. Plants with well-developed mycorrhizas have been known to obtain adequate nitrogen supplies from even acutely nitrogen-deficient peats (McVean 1963). If this is true, the reason for the low values in Zone 2 would seem to be the result of competition from other plants growing in this area. The high cover percentage of *Molinia caerulea* might support such an assumption.

According to figure 33, higher nitrogen contents in *Calluna* tissues occur during the late spring and summer than in autumn and winter. (The maximum values in Zone 1a occurred in July 1971 with 1.42%, Zone 1b in June and August 1972 with 1.38% and Zone 2 in June 1972 with 1.12%). These higher values of nitrogen content might to some extent be explained by the increase in the products of photosynthesis causing an increase of nitrogen content under favourable growth conditions. The percentage of nitrogen in the plant tissues declined between November and April reflecting the slow growth of *Calluna* resulting from unfavourable growth factors. The minimum values in Zone 1a occurred in December 1970 with 1.10% Zone 1b in November 1970 with 1.14% and Zone 2 in both November and December 1971 with 0.88%. Heavy litter fall in winter also contributed to the low values. Frankland, Ovington and Macrae (1963) claimed that the percentage total nitrogen and percentage phosphorus in litter from both Roudsea and Grizedale sites, increased gradually to a maximum in October.

Nutrients can be leached from growing plants by rain although loss of nitrogen by this means is unlikely. Nevertheless, nitrogen is lost from growing plants in gaseous form. These possible losses are important as the nitrogen may escape from the system while other nutrients lost from plants are not volatile and usually return to the soil (Ovington 1962).

8.4.2 Available phosphate

(1) Correlation between available phosphate and temperature

The seasonal patterns of available phosphate both in soil and plant are shown in Fig. 34. A positive correlation is obtained by plotting the contents of available phosphate in *Calluna* against values of monthly temperature (Fig. 35). This is probably due to the warmer

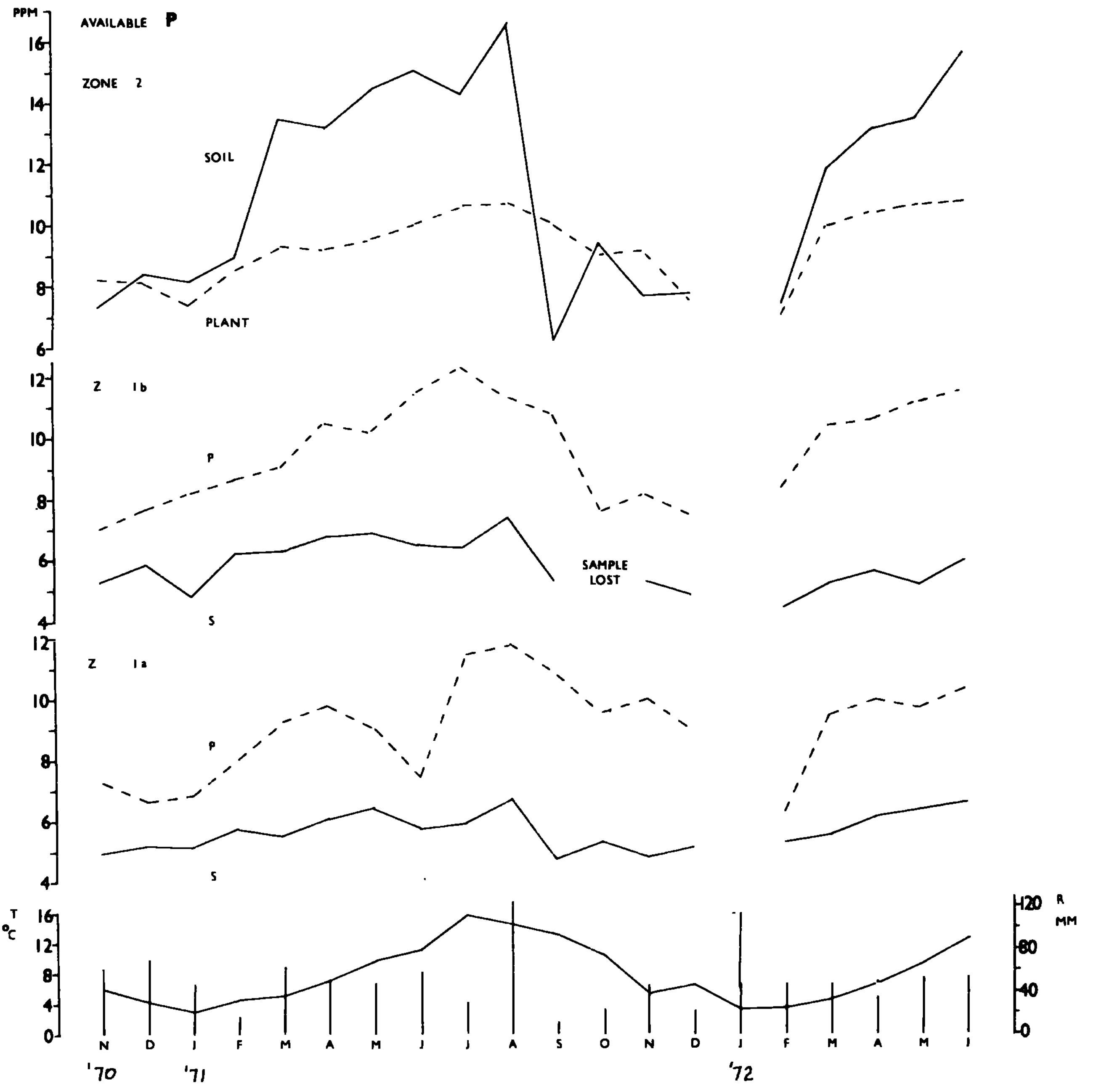
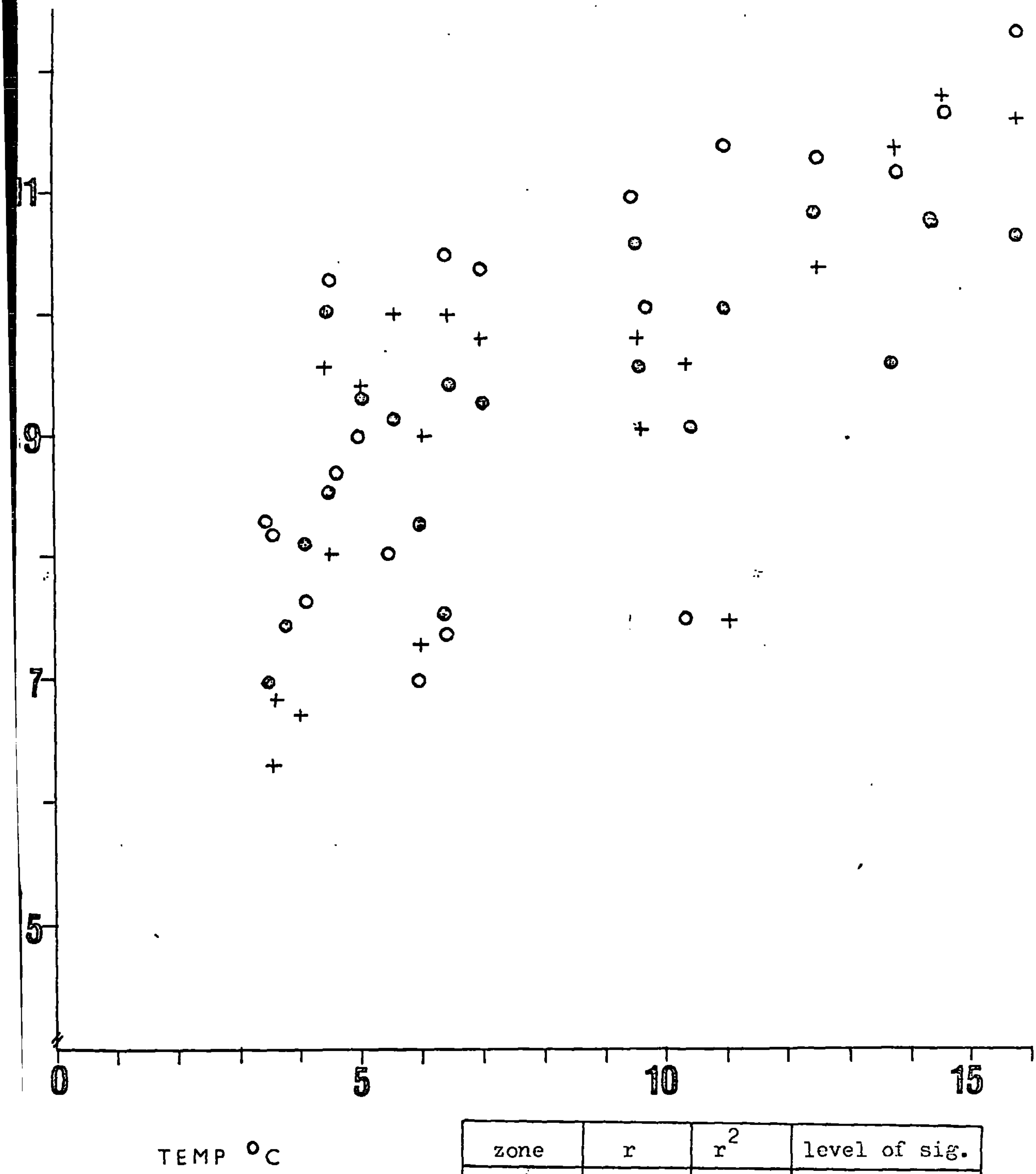


Fig. 34. Seasonal fluctuations of available phosphate contents in soil (2-10 cm) and *Calluna* uptake.



zone	r	r^2	level of sig.
+ 1a	+0.71	.50	.001
O 1b	+0.70	.49	.001
⊙ 2	+0.74	.54	.001

Fig. 35 Relationship between monthly temperature figure and phosphate content in Calluna tissue.

condition which favour the growth of *Calluna* thus causing it to absorb more phosphate. The correlation coefficient in Zone 1a is +0.71, Zone 1b is +0.70 and Zone 2 +0.74. Mineralization of organic soil phosphorus may have been responsible for the increase of available phosphate in soil under warmer conditions.

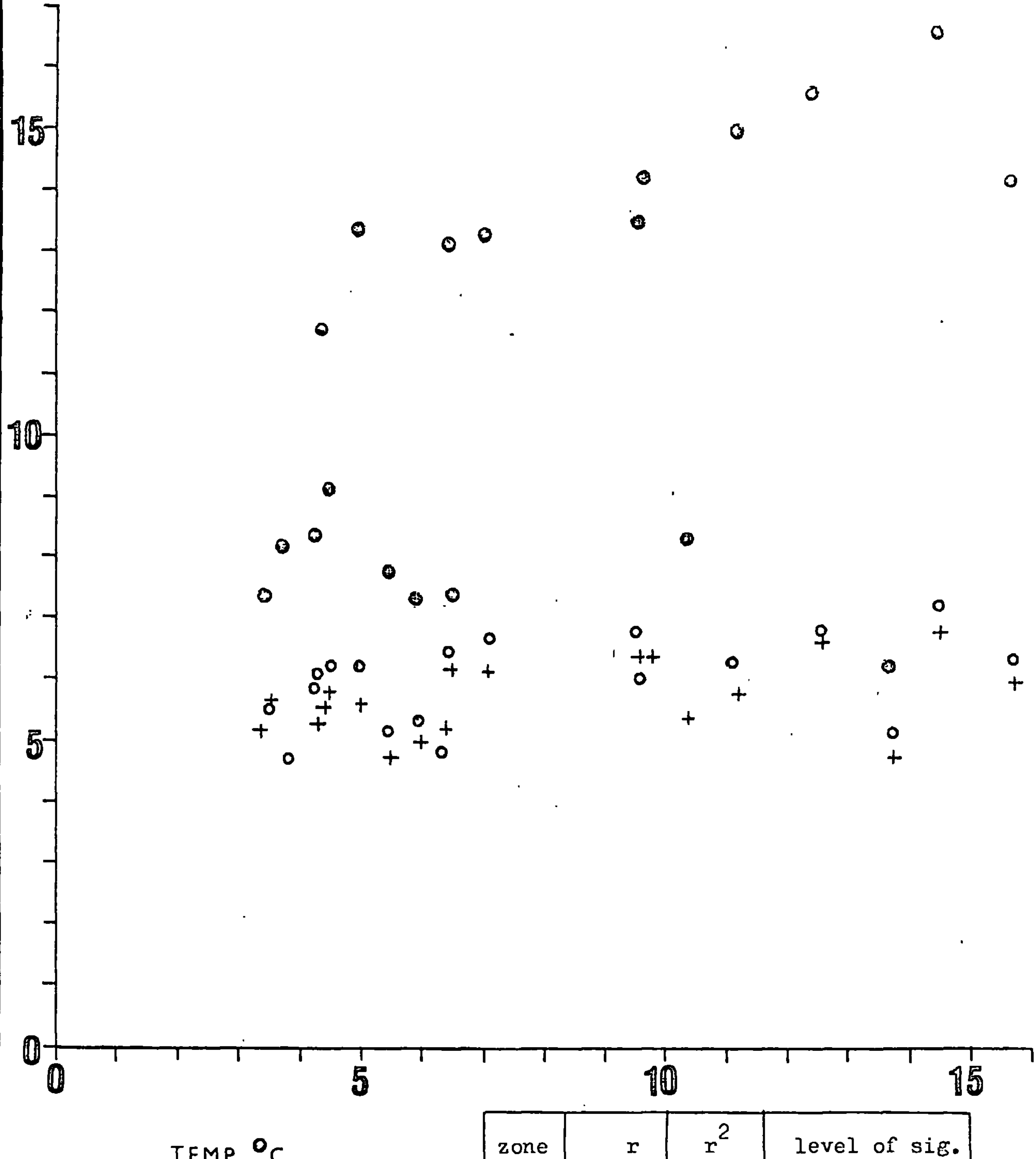
Simpson (1956) discovered that an increase of 5°C in soil temperature resulted in double the uptake of soil phosphorus (Table 8.2). The amount increased was comparable to a dressing of superphosphate (Smith 1959).

Sampling	Low temperature	High temperature
1	6.2	13.0
2	9.1	16.3
3	10.4	26.5

Table 8.2 Effect of a 5°C increase in soil temperature on uptake of soil phosphorus by oats (mg./50 plants) (Source: Simpson 1956).

It is expected that higher soil temperatures followed higher air temperatures although soil temperatures are not taken into account in the present study due to a lack of data from the study area. Fig 34 shows the seasonal fluctuation of available phosphate in soil and the correlation with the temperature record. The correlation coefficient (Fig. 36) in Zone 1a is +0.63, Zone 1b +0.61 and Zone 2 +0.50. These are comparatively low values and the lowest value in Zone 2 is probably due to the uneven waterlogged conditions resulting in uneven temperature in the zone. It may also be caused by the lower temperatures in the peat area as discussed in Chapter 6.2.

Another possible explanation of the soil temperature effects lies in the penetration and ramification of the root system, e.g. while plants can make some growth in soils as cool as 2°C, they do not grow actively until the soil has warmed up to 7°C (Russell 1961). On the other hand, if the temperature becomes too high, growth again



zone	r	r^2	level of sig.
+ 1a	+0.63	.39	.01
O 1b	+0.61	.27	.01
⊚ 2	+0.50	.25	.05

Fig. 36 Relationship between monthly temperature figure and available phosphate content in soil.

is checked, and this check is more severe as other soil conditions, such as pH and aeration, become limiting.

The mechanism of uptake was expected to be more efficient under warmer conditions where their roots were growing and functioning. According to Fig. 34, the higher values of phosphorus content in plants appeared between spring and early Autumn, the maximum values being, for Zone 1a 11.8 ppm (August 1971), Zone 1b 12.3 ppm (July 1971) and Zone 2 10.8 ppm (June 1972). With respect to the uptake of phosphorus during the growing season, it has already been noted that much of the phosphorus content of the crop was taken up very early in the season. This has been commonly observed (Russell 1961).

(2) Correlation between available phosphate and rainfall

The lower values of available phosphate present in the soil after periods of heavy rainfall on Waldridge Fell are probably due to the effect of leaching although it could be also due to a temporary lowering of pH causing phosphate to be fixed. The correlation between the monthly rainfall values and the soil phosphorus contents are not always in evidence. However, a positive correlation is found when only over 45 mm. monthly values are taken into account (Fig. 37). However, the correlation coefficient is comparatively low with +0.43 in Zone 1a, +0.40 in Zone 1b and +0.31 in Zone 2. Zone 2 has the lowest correlation because of the higher contents of silt and clay and lower sand than the other zones. Loss of phosphorus is significant in sands and peats that have little tendency to react with phosphorus (Millar 1955). Thus Zone 2 has shown less the effect of leaching, this together with the percolating water running down the slope of the Wanister Hill and accumulating in Zone 2, probably contributes to higher values of available phosphate in Zone 2 (the highest value in Zone 2

Zone	r	r^2	level of sig.
+ 1a	+0.43	.18	not sig.
o 1b	+0.40	.16	not sig.
⊙ 2	+0.31	.09	not sig.

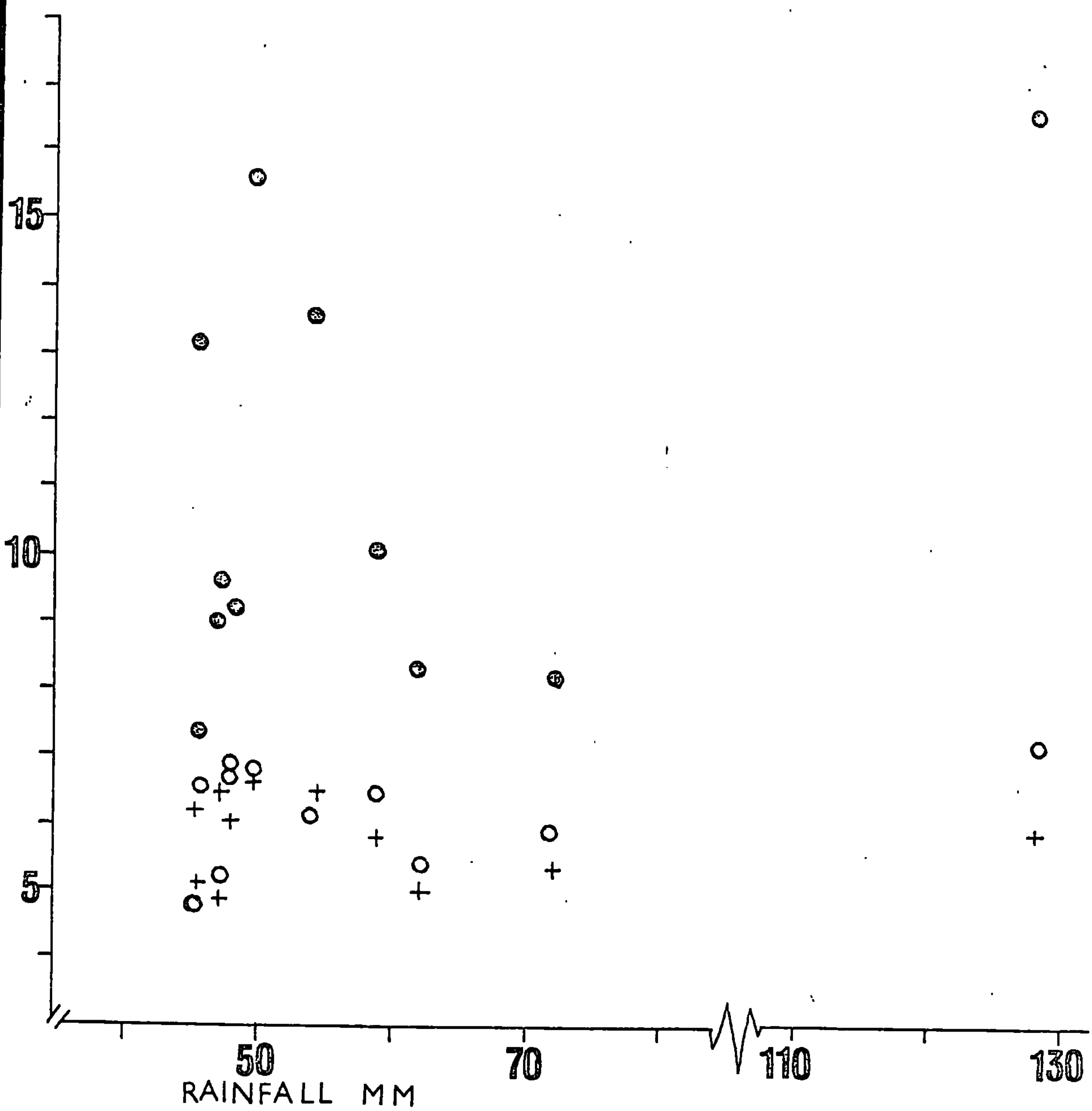


Fig. 37 Relationship between monthly rainfall figure (over 45 mm.) and available phosphate content in soil. Statistical analysis shows that this relationship is not significant.

was 16.6 ppm compared to 6.8 ppm in Zone 1a and 7.25 ppm in Zone 1b in August 1971).

The overall results are similar to the finding of van der Paauw (1962) in a longer term experiment in Holland (September 1946 to October 1951) during which he concluded that the decrease of available phosphate is at least partly due to its considerable migration from the arable layer to the subsoil.

De Vires and van der Paauw (1937) also have demonstrated important vertical migration of phosphorus under the influence of leaching in similar humic sandy soils with a high content of water-soluble phosphate. Although the soils on Waldridge Fell are not humic sandy, the effects of leaching are found to be severe.

A very low correlation is obtained when plotting the contents of available phosphate in *Calluna* against the amounts of monthly rainfall (over 45 mm.) (Fig. 38). The correlation coefficient of Zone 1a is +0.34, Zone 1b +0.16 and Zone 2 +0.29. The lowest value in Zone 1b is probably due to the steep slope causing runoff of heavy rainfall, instead of downward translocation in the soil profile. The overall results (although low correlation) indicate that by increasing the soil moisture, higher values of phosphate appear in *Calluna*. This, again, is in line with the findings of Smith and Simpson (1957) who studied the effect of increasing soil moisture on uptake of fertilizer phosphorus by potatoes and discovered that the additional water increased the absorption of fertilizer phosphorus at three stages of growth of potatoes (Table 8.3).

Zone	r	r^2	level of sig.
+ 1a	+0.34	.11	not sig.
O 1b	+0.16	.02	not sig.
⊙ 2	+0.29	.08	not sig.

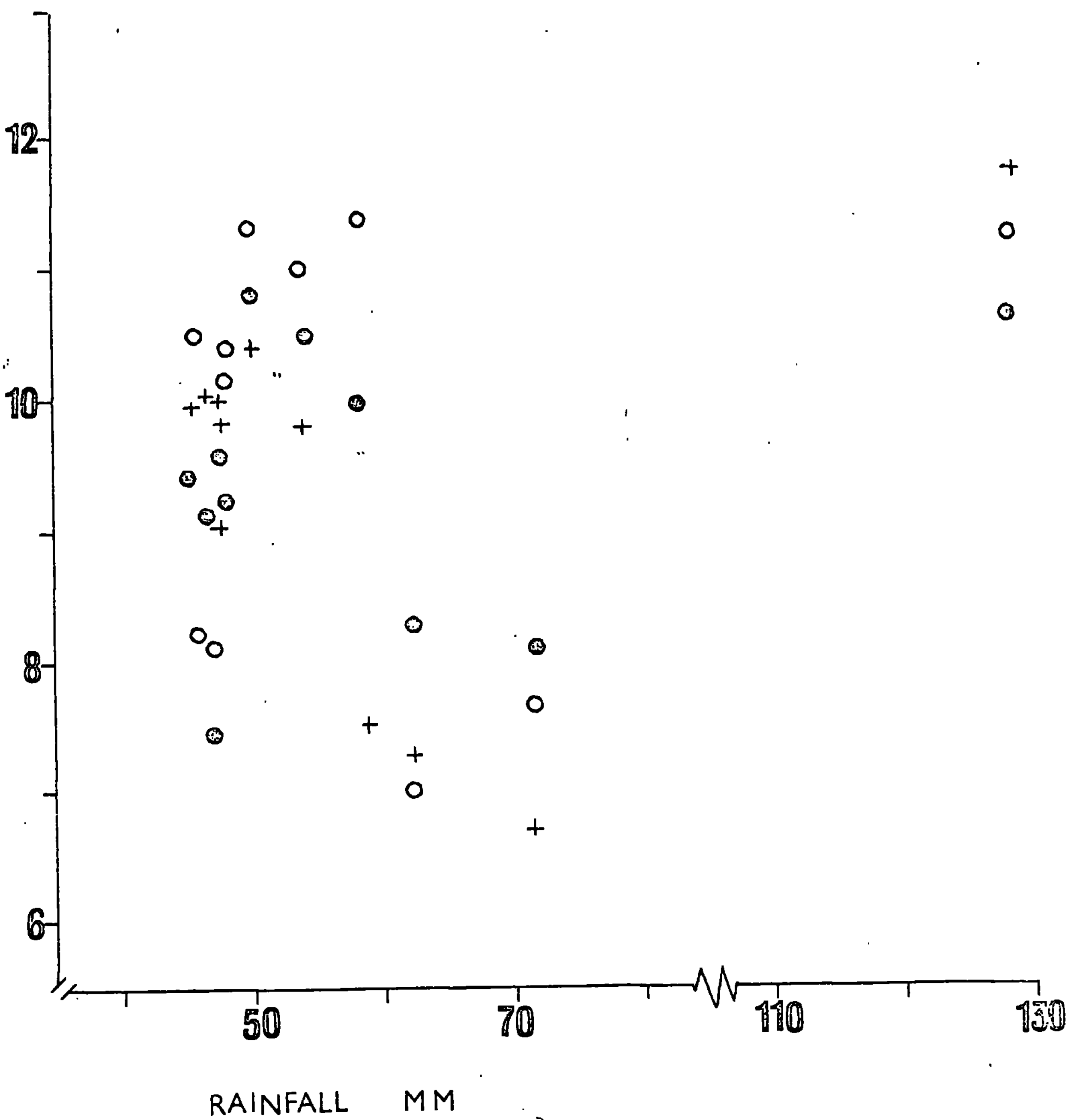


Fig. 38 Relationship between monthly rainfall figure (over 45 mm.) and phosphate content in <u>Calluna</u> tissue. Statistical analysis shows that this relationship is not significant.

Sample	P_2O_5 applied - Kg/ha			
	67.28		135.45	
	Normal	Irrigated	Normal	Irrigated
1	1.46	2.03	1.46	3.14
2	3.48	5.27	6.95	8.30
3	5.27	6.72	8.30	10.87

Table 8.3 Effect of increasing soil moisture on uptake of fertilizer phosphorus by potatoes (source:- Smith and Simpson 1957).

Chemical studies have generally indicated an increase in soluble phosphorus compounds when the soil is flooded. Paul and De long (1944) found that organic-acid- soluble phosphorus in a clay soil increased from 8 ppm to 40 - 50 ppm on flooding. In spite of this, the availability of phosphate to the plant is not consistently retarded by flooding. Nevertheless, the lower uptake in waterlogged conditions (Zone 2) could be explained by the anaerobic condition which affected the root growth as well as the mechanism of their absorption. This was the reason why the *Calluna* in Zone 2, which became waterlogged after heavy rainfall, had a lower value of phosphate although the available phosphate was higher in the soil compared to the other zones. This was exemplified in the comparatively low readings of tissue analysis recorded in Zone 2 in January 1971 (7.42 ppm) and December 1971 (7.6 ppm). Williams and Simpson (1965) claimed that a conversion of phosphate to non-available forms occurred even during a short period of anaerobic conditions. It was further discovered (Simpson and Williams, 1970) that the decrease in phosphate availability was closely associated with the reduction of iron during the anaerobic phase and its subsequent oxidation.

From the above results, it can be concluded that the contents of available phosphate in soils and *Calluna* tissues have higher correlations with monthly temperature than monthly rainfall, and it is assumed that the smaller uptake by *Calluna* in cool wet seasons was an effect of temperature and not of moisture.

Simpson (1956) in south-east Scotland, studied the relationship between rainfall and the response to phosphorus fertilizers by several crops (swedes, oats and potatoes) and found out in dry and warm years little of the fertilizer phosphorus applied was recovered and high yields were obtained without fertilizer phosphate, even on soils very low in soluble phosphorus. Soil phosphorus therefore, appeared to be more useful in the dry and warm seasons rather than in the cooler, wetter seasons as it was not considered that these crops were limited by the lack of rainfall even in dry years.

8.4.3 Exchangeable potassium

(1) Correlation between exchangeable potassium and temperature

The seasonal pattern of exchangeable potassium both in the soil and plant are shown in Fig. 39. A low correlation between the contents of potassium in *Calluna* and the monthly temperature values (Fig. 40) is found. The correlation coefficient in Zone 1a is +0.37, Zone 1b +0.43 and Zone 2 +0.33. These low figures are probably the result of other factors, such as rainfall, governing the availability of the potassium content. The lowest correlation in Zone 2 is attributed to the waterlogged condition of the soil and competition of other plant species (mainly *Molinia caerulea)* which affect absorption. However, it is generally accepted that good weather conditions (high temperature and high light intensity) are more favourable for potassium absorption by plants.

A higher correlation between the contents of available

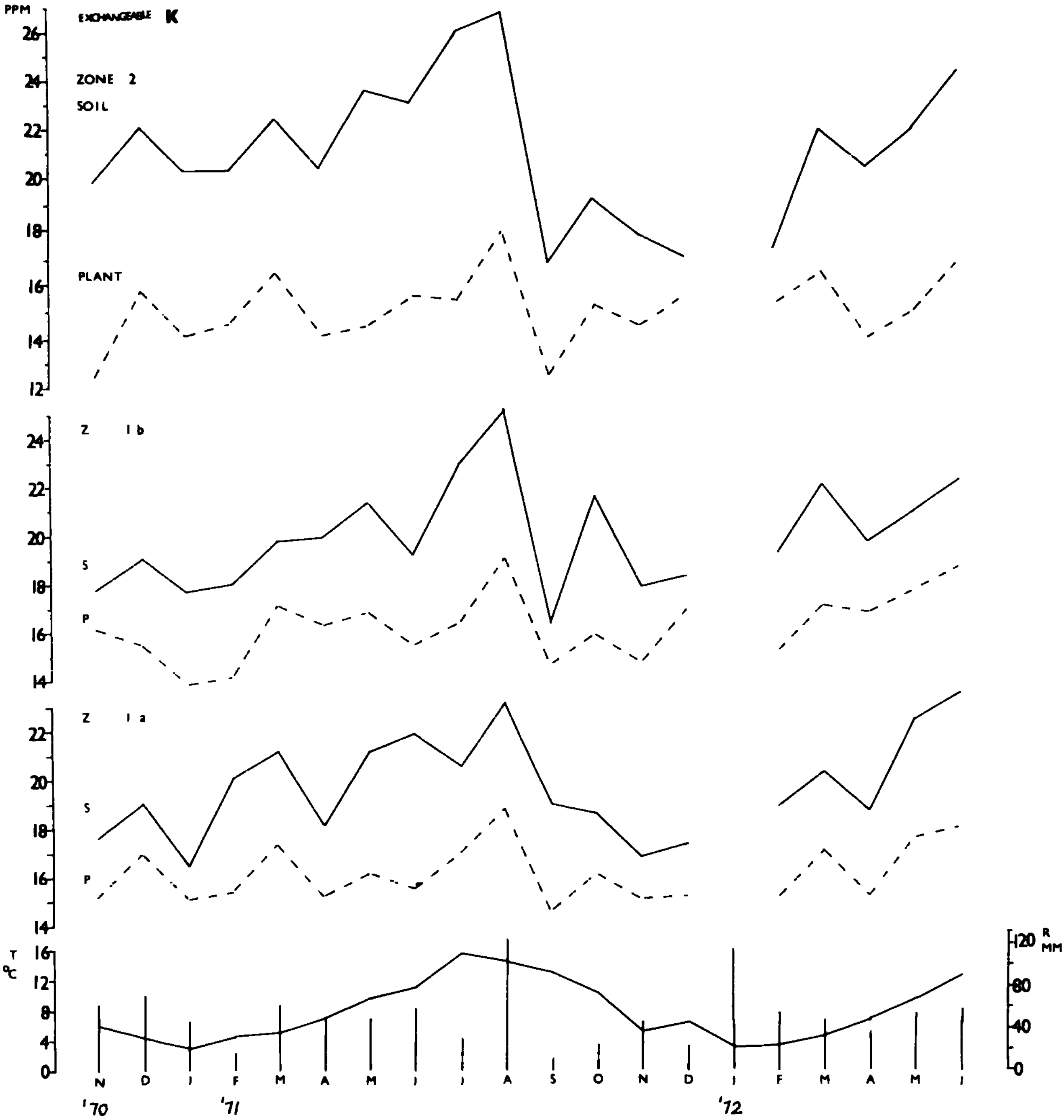
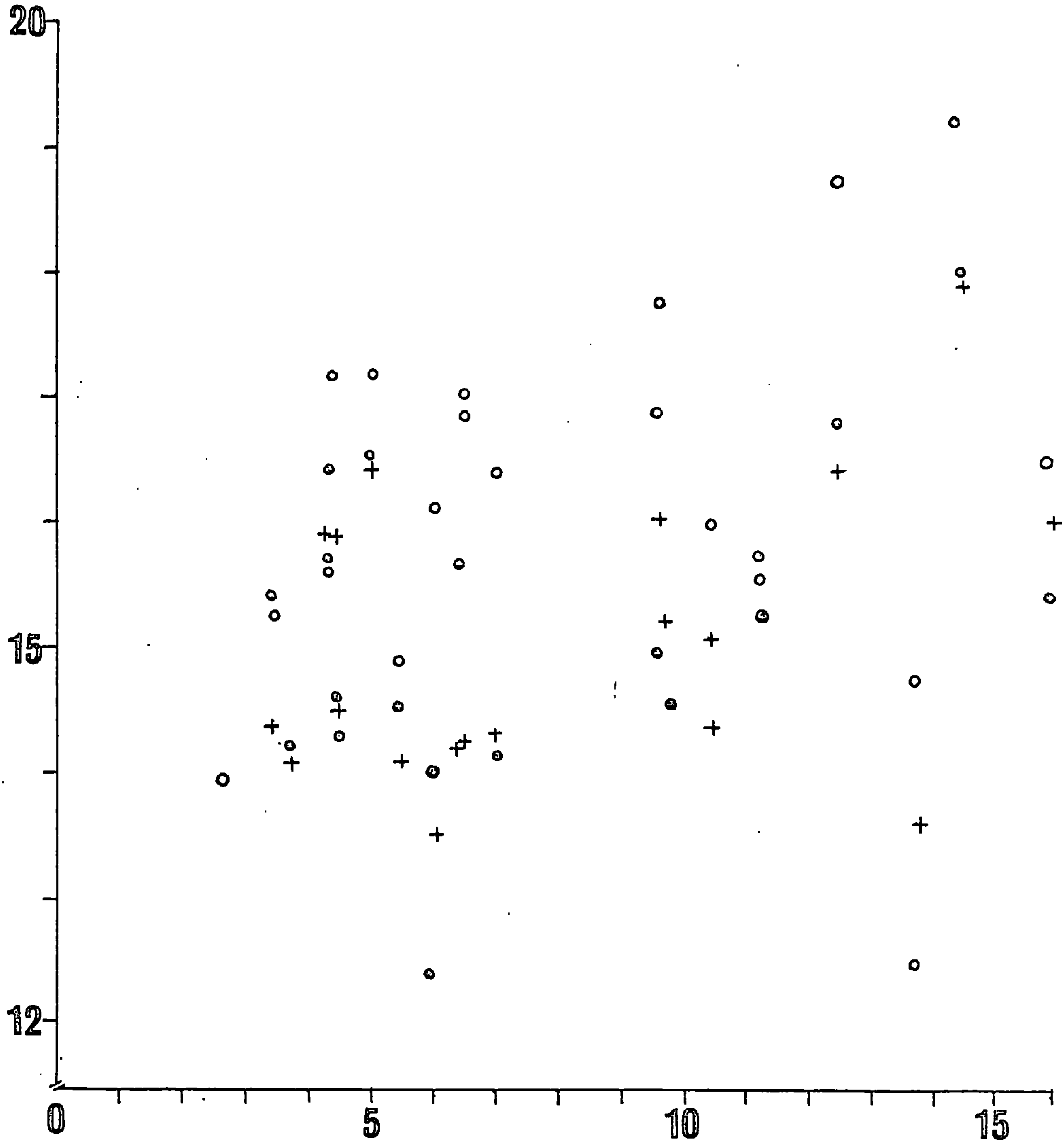


Fig. 39 Seasonal fluctuations of exchangeable potassium contents in soil and *Calluna* uptake.
(2-10 cm)

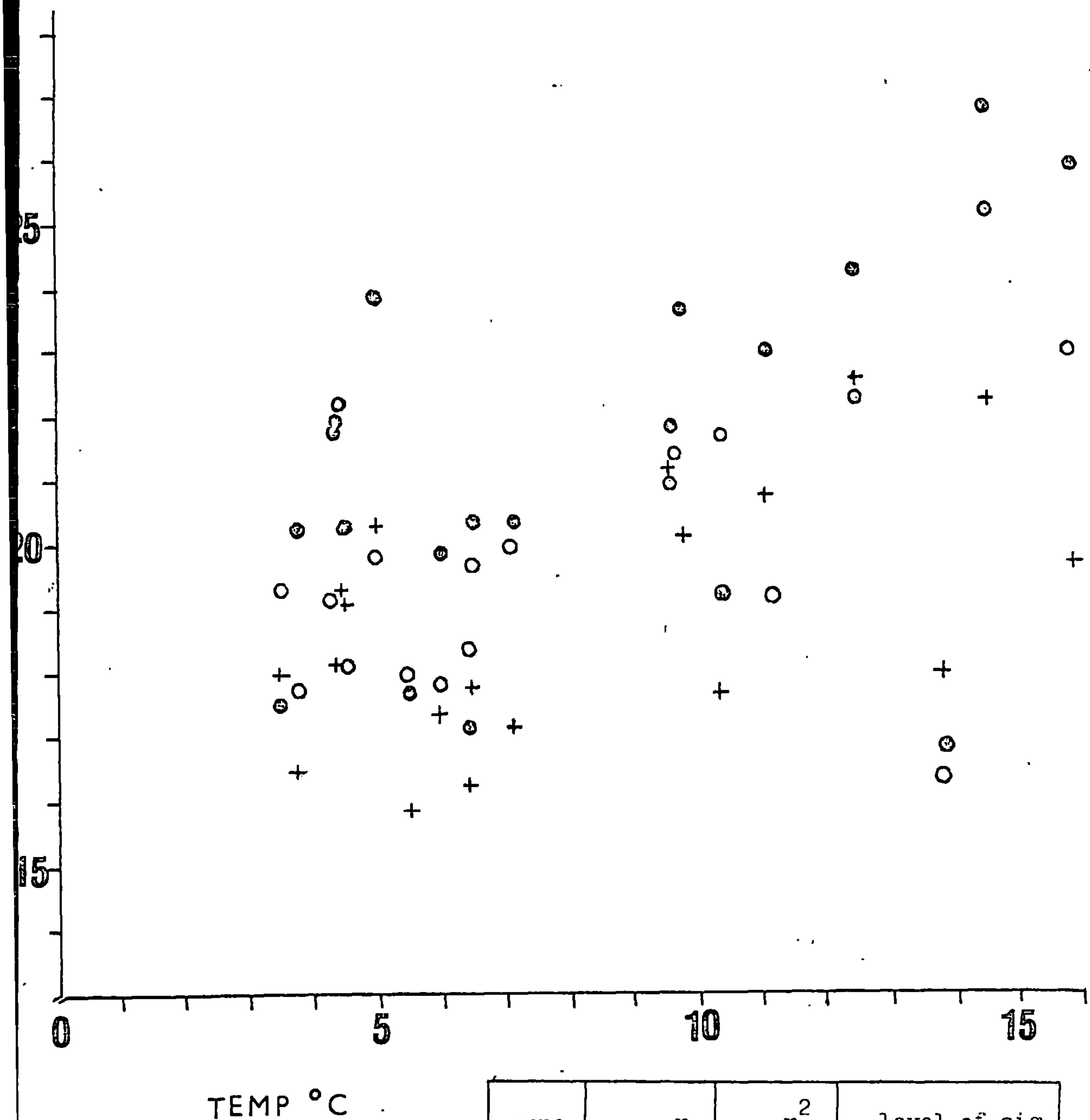


zone	r	r^2	level of sig.
+ 1a	+0.37	0.13	.1
o 1b	+0.43	0.18	.05
⊙ 2	+0.33	0.10	not sig.

Fig. 40 Relationship between monthly temperature figure and potassium content in Calluna tissue.

potassium in soil and the monthly temperatures is indicated in Fig. 41. The correlation coefficient in Zone 1a is +0.57, Zone 1b +0.51 and Zone 2 +0.47. As 90 - 98% of potassium exists in mineral form, weathering of soil minerals is the major source of potassium used by crops. The higher temperatures have the effect of speeding the rate of weathering as the speed of most chemical reactions increases when applying heat, e.g. in tropical regions the soil temperatures are high during the entire year, the higher temperatures of the soil increases the rate of chemical reactions from two to four times (Jackson and Sherman 1953). Stephens (1949) relates the Szymkiewicz (1947) air temperature index (T) shown in the equation:- $(T) = 2.5^{t/10}$ in which t is the air temperature in degrees centigrade, to the rate of chemical weathering. Stephens was able to correlate this temperature index (T) for a range of about 2 to 10 with the weathering of rocks and noted that the index value is normally under 3 in temperate regions.

While nearly half the phosphorus in the topsoil may be in organic combination, only a small fraction of potassium is held by organic compounds. However, Roberts (1968) claimed that in soils containing 4% or more of organic matter, the non-exchangeable potassium associated with organic matter was an important source of supply of potassium entering the exchangeable form. He also believed that the release of potassium was due to the same chemical and physical disruption of plant and microbial cell material that Birch (1958, 1959) considered responsible for the first stage in carbon and nitrogen mineralization. Birch showed that drying and heating increased the amount of soluble organic matter and that this organic matter was decomposed during a subsequent flush of microbial activity when the



zone	r	r^2	level of sig.
+ 1a	+0.57	0.32	.01
O 1b	+0.51	0.26	.02
⊙ 2	+0.47	0.22	.05

Fig. 41 Relationship between monthly temperature figure and exchangeable potassium content in soil.

soil was rewetted. It has been also demonstrated by Bolton and Coulter (1964) that organic matter content, especially readily decomposable organic matter content, is positively associated with potassium release. This was confirmed by the exchangeable cation contents of the A_1 and B_1 horizons being higher than those of the A_2 and B_2 horizons reflecting differences in cation exchange capacities which were determined primarily by the amounts of organic matter (Bolton and Coulter, 1964).

(2) Correlation between exchangeable potassium and rainfall

The highest values of potassium in soil appeared after periods of high rainfall while the lowest values were obtained after the heavy leaching of rainwater. Water as an agent in chemical weathering has two distinct roles. Firstly, hydration of minerals causes an increase in volume and it is therefore an important factor in the decay of coarse-grained igneous rocks (Reiche 1950). Secondly, water acts as a leaching agent to the extent that external drainage and the supply of water permit its passage through the soil profile.

The correlation coefficient (with over 45 mm. monthly rainfall) in Zone 1a is +0.47, Zone 1b +0.65 and Zone 2 +0.64 (Fig. 42). The lower value in Zone 1a is probably due to the higher content of sand and lower content of silt and clay which favour the process of leaching. Although the soil texture in Zone 1b is similar to Zone 1a, the process of leaching is less severe due to the slope causing runoff of rainfall instead of downward movement through the solum. By receiving such runoff water and higher content of silt and clay in Zone 2, the effect of leaching is also less than Zone 1a and therefore, a comparatively high correlation between potassium content and rainfall is also obtained.

Zone	r	r^2	level of sig.
+ 1a	+0.47	.22	.1
o 1b	+0.65	.42	.02
⊙ 2	+0.64	.40	.02

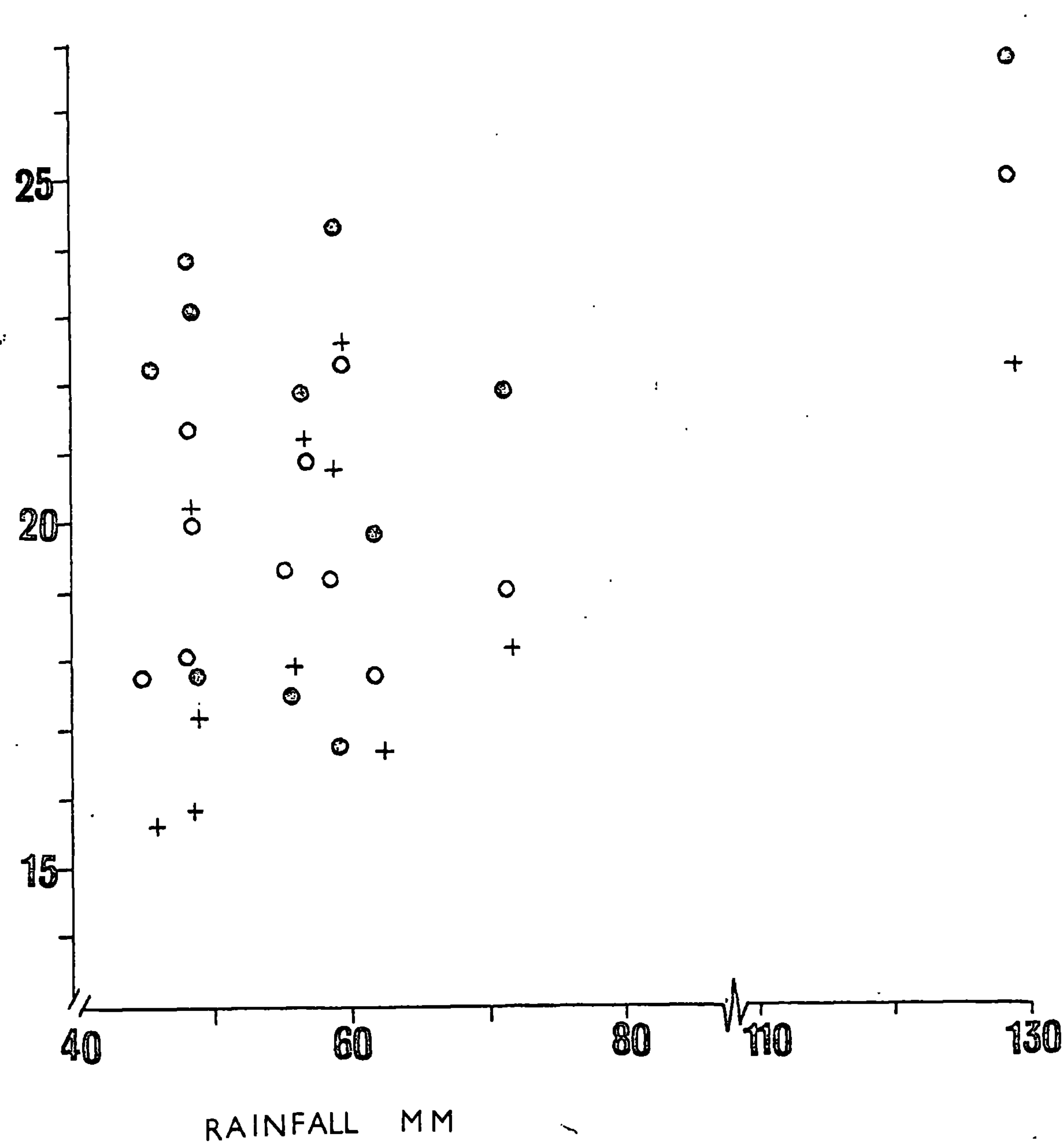


Fig. 42 Relationship between monthly rainfall figure (over 45 mm.) and exchangeable potassium content in soil.

The nutrient content of rainwater could be regarded as an important source of input especially Ca, Mg, and K, since rainfall is known to contain a significant amount of nutrients (Ovington 1962, Robertson and Davies 1965). The higher contents during the wet months could be partially explained by such phenomena.

The fluctuation of potassium content in the *Calluna* tissue was due to the leaching from plant tissue as potassium is known to be very mobile in plant tissue (Smith 1962). It is readily leached from living tissue and even more from dead material. This is supported by the rather high value of correlation coefficient (over 45 mm. monthly rainfall) in Zone 1a +0.62, Zone 1b +0.63 and Zone 2 +0.69 (Fig. 43).

Carlisle et. al. (1967) measured the quantities of some elements washed by natural rainfall from the vegetation of an oak woodland with a *Pteridium aquilinum* ground cover. They found that Na and K were leached in the greatest quantity with 38.6 and 26.9 kg/ha/year respectively. The foliage of ryegrass, wheat, red clover and lucerne were leached with simulated rain by Clement et.al. (1972) and it was calculated that a single period of heavy rain (15 mm in 1h) or 8 hour of light rain (1.25 mm/h) could transfer the equivalent of at least 1.5 kg K/ha from ryegrass to the soil.

Therefore, it can be assumed that the leaching of K in the present experiment resulted from heavy rainfall. For example, the comparatively low values obtained in September 1971 after the heavy rainfall in August are as follows:- soil - Zone 1a 18.0 ppm. Zone 1b 16.4 ppm and Zone 2 16.9 ppm; plant - Zone 1a 13.6 ppm, Zone 1b 14.8 ppm and Zone 2 12.5 ppm (Fig. 39).

However, elements leached from foliage may be readily reabsorbed

Zone	r	r^2	level of sig.
+ 1a	+0.62	.38	.05
o 1b	+0.63	.39	.02
⊙ 2	+0.69	.47	.01

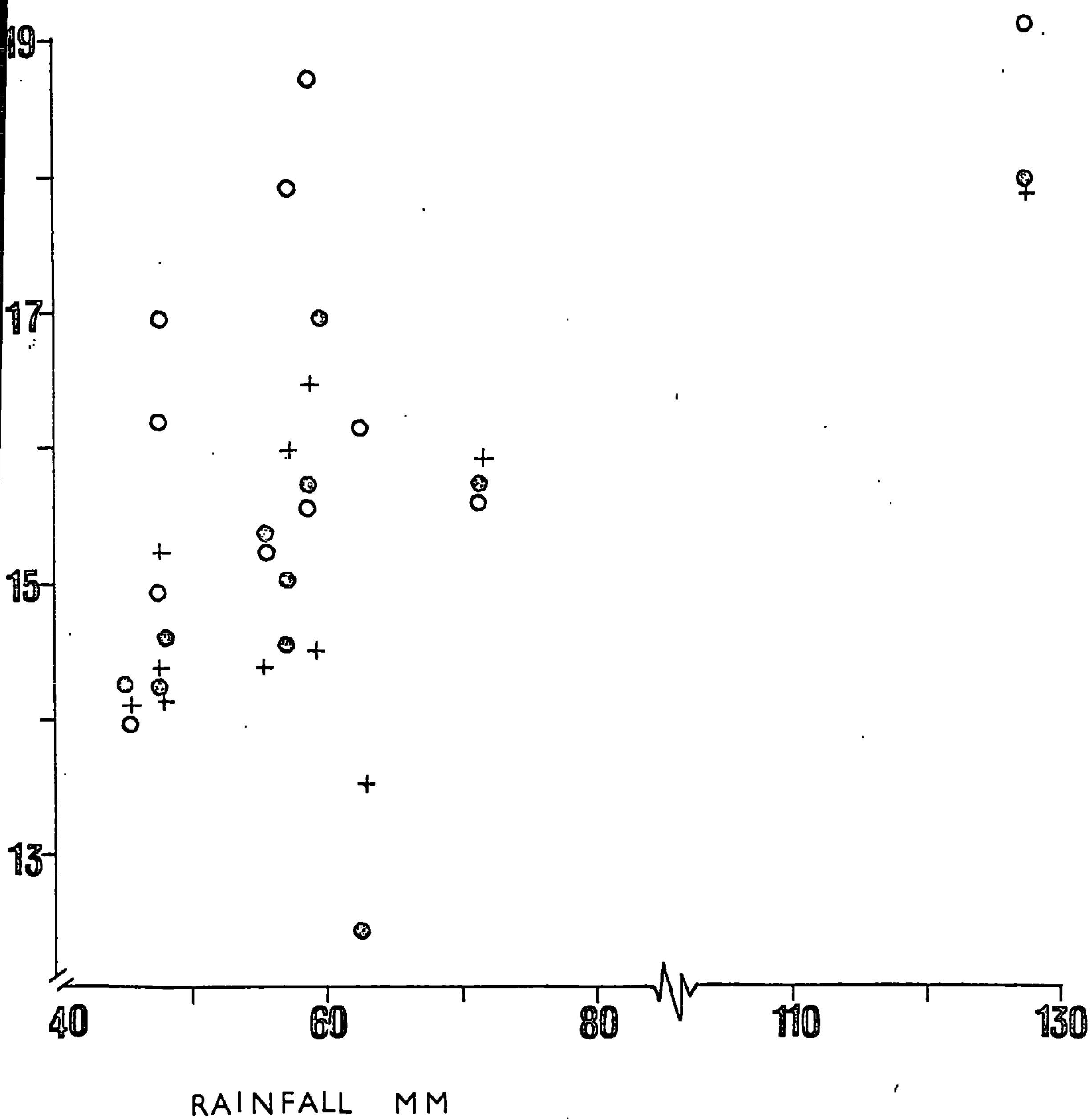


Fig. 43 Relationship between monthly rainfall figure (over 45 mm.) and potassium content in *Calluna* tissue.

by roots (Tukey and Mecklenburg 1964). It is known that the mechanisms of such leaching are related to the wettability of the surfaces of leaves, and extensive evidence suggests that wax formations on leaf surfaces influence wettability (Martin and Batt 1958, Clement et.al. 1972). Low wax contents on the leaves of *Calluna* suggest a possible reason for the susceptibility to leaching. Such mechanisms also operate at different levels according to the physiological age of the plant. For example, young actively growing plants are relatively resistant to leaching, whereas more mature tissue approaching senescence is very susceptible (Tukey, 1970). The lower values of plants in winter were due to the losses through litter (Loach, 1968, Frankland, Ovington and Macrae 1963). Also, since potassium was rapidly circulated between the plant and the soil, a site supporting a low plant biomass as in valley bog (Zone 2) may have had relatively more potassium in the soil and less in the standing crop than in more highly productive sites.

Therefore, the lower content of plants found in Zone 2 was again expected as the effect of the waterlogged condition. This was attributed to the poor aeration, and the low oxygen content which affected the mechanism of absorption as well as root growth although the content in the soil was comparatively high (Fig. 39).

Being a cation, potassium loss by leaching is higher than phosphate. This has been demonstrated by the higher correlation between available potassium contents both in the soil and *Calluna* and the amounts of monthly rainfall - the rise and fall of the contents correspond to the rise and fall of the rainfall. The amount of K^+ lost by leaching in humid regions exceeds the amount of K^+ removed in crops (Thompson 1957). This raises an important question of exhaustion of potassium potential in areas of excessive rainfall such as moorland.

8.5 CONCLUSION

The simplest and most important effect of the weather on the amounts of nutrients in soils, is the leaching of soluble nutrients, e.g. whenever there is drainage through the sub-soil, nitrate in topsoil is liable to be lost. Leaching also removes phosphate and potassium although phosphate loss is less severe than potassium. The effects of both rainfall and temperature on the amounts of nitrogen mineralized from organic matter, and the amounts of soluble phosphorus and potassium in the soil solution are more complex. Furthermore, weather not only governs the need for nutrients for crop growth, but it may also affect the physiological process by which ions are taken into roots.

Any assessment of the implications of weather change on the performance of a biological system must surely rest on an understanding of the quantitative responses of that system to the climatic complex over the range experienced. Weather effects are of paramount importance in determining yield, and it is characteristic of the agricultural industry that output varies enormously from year to year.

However, van der Paauw (1962) stated that it was theoretically possible to eliminate yield fluctuation in high-producing systems by appropriate fertilizing and soil management. This should become increasing possible in practice as our understanding of the effects of weather on crop yields and on soil fertility improves.

CHAPTER NINE

ASSESSING SOIL PRODUCTIVITY BY FIELD AND LABORATORY METHODS

9.1 INTRODUCTION

Soil fertility (including both physical and chemical properties of soil) is concerned with the ability of soil to supply enough nutrients and water to allow the crop to make the most of a particular site. The long term (20 months) seasonal variations of the major nutrients (total nitrogen, available phosphate and exchangeable potassium) have been analysed in the previous chapter.

The first experiment of this chapter gives an account of the assessment of soil productivity in the field - a property which integrates both the climatic potential of the site, and the fertility of the soil. The second experiment measures soil productivity from the different zones in laboratory to eliminate the factors of climate, topography, moisture conditions, aeration and biotic factors (i.e. burning, grazing, trampling). The results of these experiments are used to determine the various factors regulating the productivity of *Calluna* on Waldridge Fell. It is hoped that these results will be some use for the future development of farming systems in the moorland.

9.2 ASSESSING SOIL PRODUCTIVITY IN NATURAL ENVIRONMENT

9.2.1 Method

Five subsamples (0.25 m^2 each) of *Calluna* were taken randomly from each of Zones 1a, 1b, and 2. The vegetation was clipped to leave a stubble of approximately 2cm. by using a pair of scissors at 3 - monthly intervals from December 1970 to June 1972.

The samples were dried in a drying cupboard at 105°C for approximately 42 hours and their dry weights were measured.

9.2.2 Results

The seasonal changes of above ground dry matter production (dry weight gm/m^2) of *Calluna* are shown in Fig. 44 and Table 9.1. There was

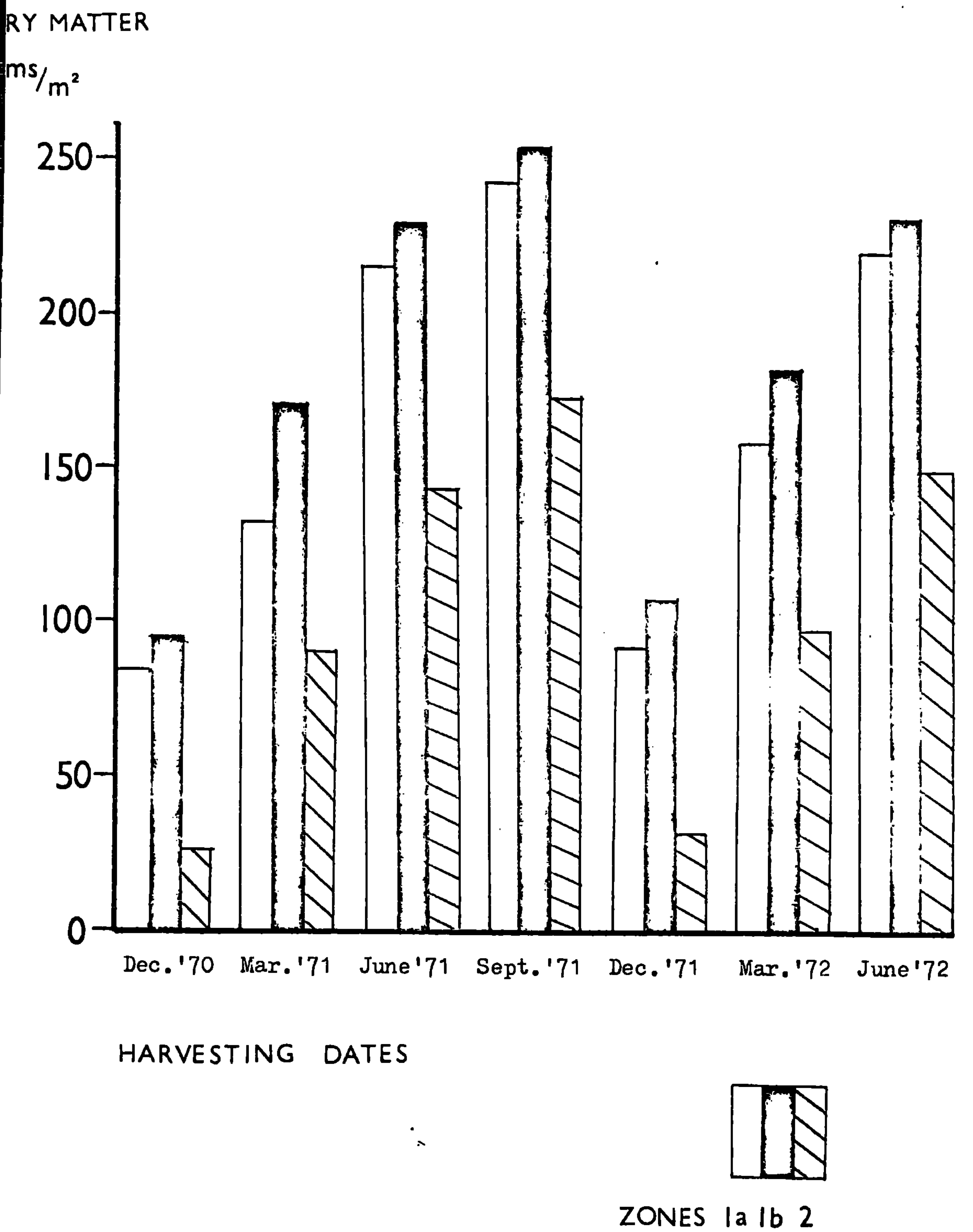


Fig. 44 Dry matter production of Calluna vulgaris on Wadlridge Fell.

a steady increase of dry matter production from December 1970 upto the maximum in September 1971. After declining to another low value in December 1971, a similar pattern reoccurred in 1972 according to the seasons. Zone 1b had the highest average yield 177.82 gm/m^2 while 1a was slightly lower with 162.45 gm/m^2 and Zone 2 was the lowest with 98.67 gm/m^2.

Date of harvest	Zones 1a	1b	2
Dec. 1970 (gm/m^2)	84.22	90.01	25.86
Marc.1971	132.16	170.41	80.32
Jun. 1971	216.34	226.60	142.11
Sep. 1971	239.82	250.21	171.07
Dec. 1971	90.05	106.66	29.79
Mar. 1972	156.65	180.04	95.00
Jun. 1972	217.97	220.84	146.57
Mean	162.45	177.82	98.67
Stand. deviation	$\pm$ 66.75	$\pm$ 61.47	$\pm$ 57.48

Table 9.1 Dry matter production of *Calluna* of different zones on Waldridge Fell. (gm/m^2)

9.3 ASSESSING SOIL PRODUCTIVITY UNDER LABORATORY CONDITIONS

9.3.1 Method

The potential of the soils from Zones 1a, 1b and 2 were assessed as a medium for plant growth under the laboratory environment. Five soil samples at 2 - 10 cms. were taken from each zone randomly. The five soil samples from each zone were then mixed thoroughly and placed in 6 five-inch, distilled washed, plastic flower pots. Six control pots were filled with approximately 20 pieces (1 cm^3 each) of distilled water washed polystyrene (as plant growth medium). All pots were sown with 8 seeds of *Lathyrus* spp. (pea). (*Lathyrus* spp. was chosen because the seeds have a high efficiency both in germination and growth).

The pots were then placed in the laboratory with a relatively constant temperature (19-22^{o}C). The pots containing soil were watered regularly with distilled water and the control pots with a complete culture solution formulated after Hewitt 1952, and Rieley 1967 (Appendix A.4).

9.3.2 Results

The results (Table 9.2) shows a marked contrast in the productivity of the crop of *Lathyrus* spp. with the productivity of *Calluna vulgaris* growing in the field. The dry matter production of *Lathyrus* spp. growing in the soil from Zone 2 was 364 mg., compared to 531 mg. of the control pots. Soils from Zones 1a and 1b gave much lower dry matter production though the results for these zones were comparable (174 mg. and 196 mg. respectively).

Pot	Zone 1a	Zone 1b	Zone 2	Control (culture solution)
1	161 mg	199 mg	401 mg	485 mg
2	181	235	387	501
3	231	201	365	534
4	153	175	372	493
5	134	212	304	564
6	186	157	356	614
Mean	174.50	196.50	364.16	531.83
S.D.	± 13.77	± 12.65	± 14.96	± 14.26

Table 9.2 Dry matter production (mg./pot) of *Lathyrus* spp.

9.4 DISCUSSIONS AND CONCLUSIONS

The increase and decrease in dry weight of *Calluna* have been paralleled with changes in the contents of nitrogen, phosphorus and potassium in the aerial portions. In almost every case tissue concentrations were highest in Zone 1b, slightly lower in 1a and lowest in 2, and since their differences were in general associated with high and low dry matter yields respectively, they probably provide a true measure of the relative abilities of the soil in the different zones to supply nutrients to *Calluna*. The reason for slightly higher values being obtained in Zone 1b (slope 30-35^{o}) than 1a are probably due to better growth of *Calluna* under more sheltered conditions, less trampling and an absence of grazing by ponies, for other environmental factors were essentially the same. However, the results of the culture experiment showed that, under conditions of similar microclimate and better drainage and aeration, the crops in soil from Zone 2 had significantly better performance when compared to the others. In the field, the available nutrient deficiency in the valley gley soil (Zone 2) was caused by the effects of waterlogging on root growth and nutrient uptake. The growth of *Calluna* was further retarded by the well-adapted (deep-rooted) species - *Molinia caerulea*. Loach (1968) found that *Calluna* had low cover when growing in association with *Molinia*, but after being isolated from such competition it grew and survived.

With all the knowledge acquired from earlier and present experiments, the factors related to the productivity of *Calluna* are now clear and can be concluded and expressed diagramatically as in Fig. 45. The various factors are outlined as follows:-

A. Biological factors

(1) Genetic variables

Hereditary control of growth potential of plants affects the variation in ultimate sizes, growth rate and the adaptability of different genera and species. The vigourous growth of *Calluna vulgaris*

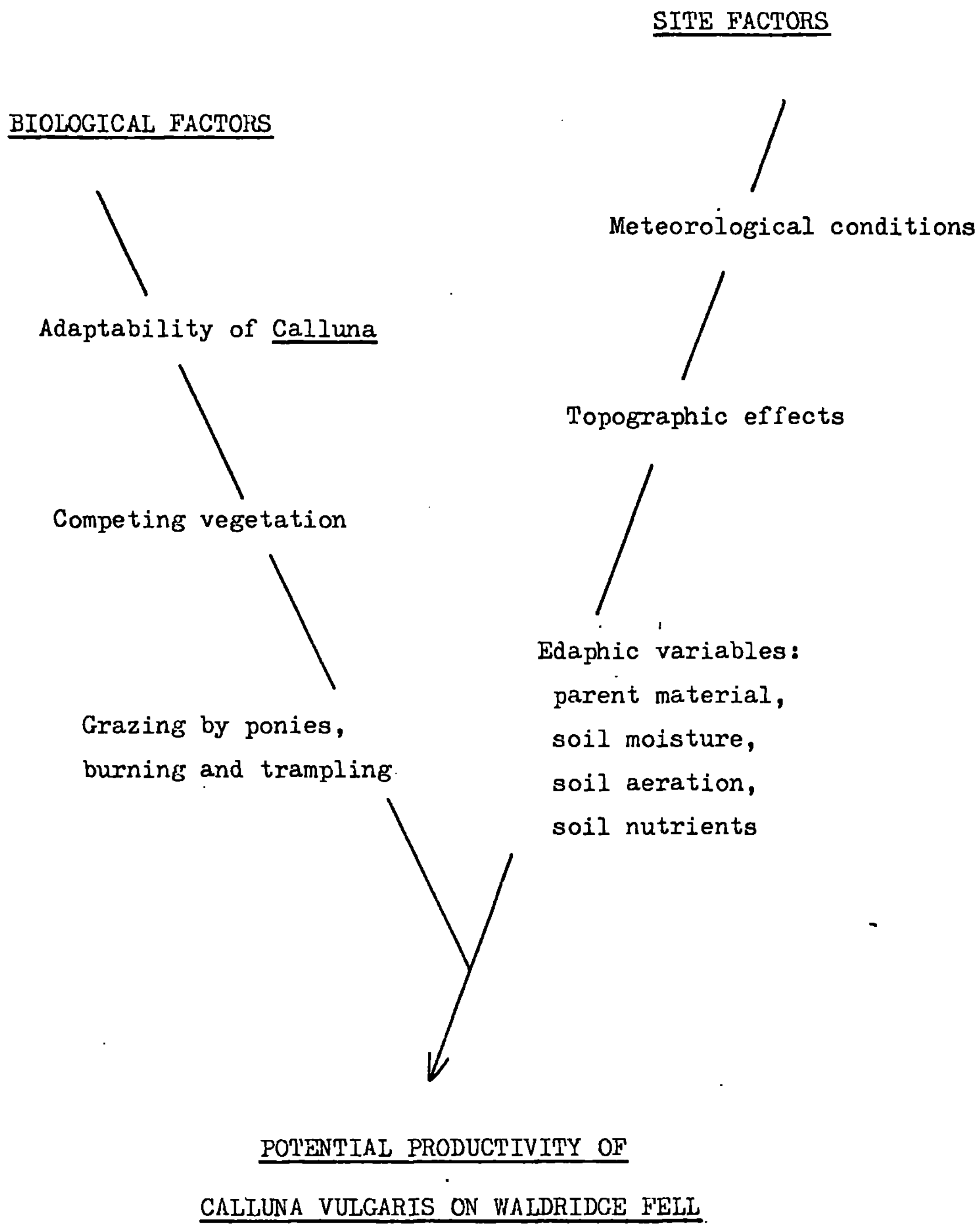


Fig. 45 Major factors regulating productivity of *Calluna vulgaris* on Waldridge Fell.

on Waldridge Fell can be reflected by its high stand density or cover abundance. *Calluna* also has different performance for adaptation in various habitats, e.g. growth form on podzolic soils on Wanister Hill is characterized by erect stems and few branches. On sloping ground, the tall stems tend to become recumbent, their bases buried in the moss layer and the plant straggling in the downslope direction. On Wanister Bog, a weak sprawling form results, often with buried prostrate stems and poor flowering.

(2) Competing vegetation

The influence of competing vegetation enters into crop yield considerations in two significant ways:- competition for soil nutrients and water, and for space, e.g. there is high competition between *Calluna vulgaris* and *Deschampsia flexuosa* on the top of the Wanister Hill, *Vaccinium myrtillus* on the slope; competition between *Calluna* and *Molinia caerulea* is severe at the edge of the bog area.

(3) Burning

Regular and rotational burning are used as effective management on Waldridge Fell as well as other moorlands. Under controlled burning, new young growth of *Calluna* can be promoted and hence high productivity maintained. However, a severe unexpected fire can cause damage to the dominance of *Calluna*.

(4) Grazing

Grazing pressure is mild on Waldridge Fell although several horses are grazed regularly on the Fell. Under such mild grazing, new young growth of *Calluna* is stimulated.

(5) Trampling

Trampling was not only harmful to the aerial portion of *Calluna* but also modified the soil environment adversely for root growth due to soil compaction. Under such circumstance, root penetration is affected and leads to poor production.

B. Site factors

(1) Meteorological variables

The effect of the meteorological variables on soil fertility and crop yield were found to be profound and continuous. More nutrients were available for plant growth under higher temperature mainly due to the more efficient decomposition of organic matter. Uptake of nutrients by *Calluna* was also accelerated. Leachings of nutrients both from soil and *Calluna* were found to be severe after periods of heavy rainfall.

(2) Topographic variables

Topographic distinction may be useful in predicting variation in site quality as soil-water relations may be altered by rather subtle changes in surface elevation. Furthermore, they have an important effect on meteorological variables, for instance Wanister Bog has lower temperature and higher moisture than Wanister Hill due to the thick peat layer (refer to 6.2.1 temperature) and topography (receiving runoff rainfall).

(3) Edaphic variables

a. Effect of parent material

Soil texture and amount and rate of release of minerals are related to the texture and chemical composition of parent material. Soil drainage and root penetration below the solum are affected by size and orientation of structural cracks. The parent material of Waldridge Fell was laid down at the end of the Pleistocene Glaciation. The low base status of the parent material, together with factors like moderate wet, cool climate created the podzolic nature of the soils which hinder the nutrient availability (due to leaching) for plant growth.

b. Soil moisture variables

The topography, as well as soil texture, affects surface runoff and seepage of water, while it also has an effect on soil texture. This is especially true in the selected investigated transect where the moisture content of the soils increase from the Wanister Hill (light soil) downslope to the maximum of the Wanister Bog (heavy soil).

c. Soil aeration

Since limitations in movement and supply of air occur when soil voids are occupied primarily by water, the soil moisture is intimately related to soil aeration. Although no measurement of soil aeration has been made for the present investigation, it is to be expected that the aeration of Wanister Bog is extremely poor due to the waterlogged condition.

d. Soil nutrients

The soil nutrients and their availability to *Calluna* have been demonstrated. The availability of the three major nutrients on Waldridge Fell is low although the organic matter has a considerable reserve of such nutrients. The circulation of soil nutrients in the ecosystem can be illustrated in Fig. 46. There are two complementary pathways of nutrient circulation:- The first one is via the direct decomposition of plant litter which is derived from herbage untouched by the grazing animals. The second one is via the consumption of herbage by the animals and the return of excreta to the soil surface. Therefore, more efficient utilization implies the increasing return of nutrients to the soil by the second pathway. According to Ovington 1962, Robertson and Davies 1965, rainfall brings a considerable amount of nutrients. However, large amounts of available nutrients are subject to loss by leaching which causes the exhaustion of soil fertility in the area.

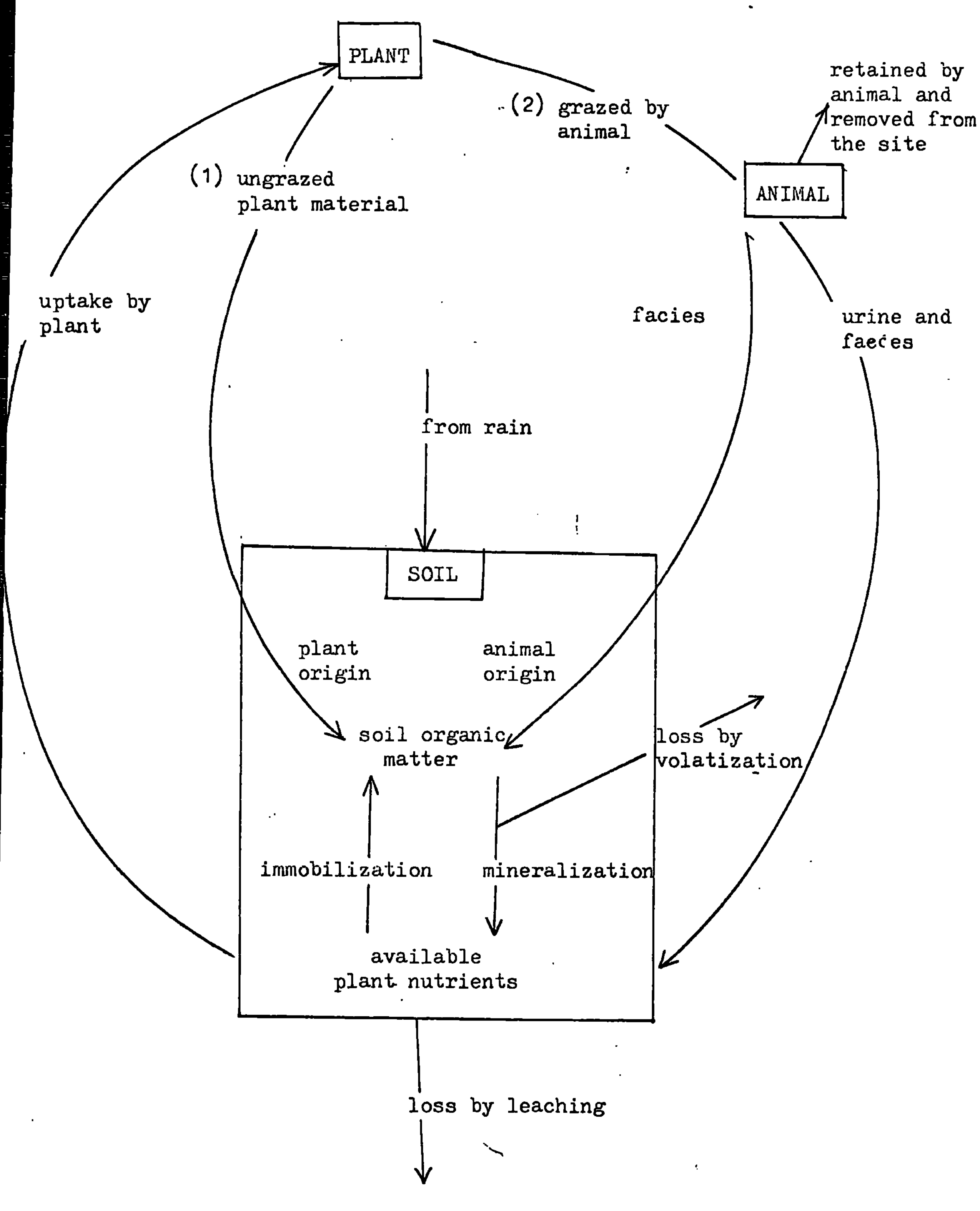


Fig. 46 Nutrient cycle on Waldridge Fell.

CHAPTER TEN

SOIL FERTILITY AS A PARAMETER IN LAND EVALUATION

10.1 INTRODUCTION

Soil does not have a complete influence on the agricultural productivity or capability classification of land; at best it is only one of a number of physical factors affecting it. The aim of this chapter is to try to discuss the possibility of using soil nutrient status as a parameter in agricultural land evaluation. The main conclusions of the whole thesis are also given at the end of this chapter.

10.2 THE VARIABILITY OF NUTRIENT STATUS

10.2.1 Spatial variation

The heterogeneity of soil is often stressed and relatively large differences in the chemical composition or pH of a soil over distances of only a few centimetres may occur (Ferrar and Vermeuleu 1955). It has been estimated that the error of sampling is at least ten times as much as the laboratory error of analysis (Robertson and Simpson 1954). This is because soil is normally a most heterogenous material and it has sometimes been extremely difficult to convince those taking samples of the importance to be attached to securing a sample reasonably representative of the data in question. Many pedological and ecological investigations employ the 'type profile' approach in which one or more characteristic profiles are sampled, the subsequent analyses being taken to be representative of a homogeneous soil area. Where spatial variability within a soil type has been found to be large, this has usually been ascribed to inherent heterogeneity in the parent material (such as textural variations in glacial drift) or to residual effects of fertilizer applications. Therefore, 'homogeneous' non-fertilized soils as on Waldridge Fell, should exhibit a greater degree of uniformity.

For the study area of the present investigation, the findings of the vegetation analysis delineated the studied transect into four zones which are correlated to the soil types, their morphological characteristics and drainage status (Chapters 7.2 and 7.4 Table 7.2). The types of dominant vegetation and their performance are further found to be correlated with the topography, pH, soil moisture regime and content of soil nutrients between zones (Chapter 7.4, Fig. 31). The statistical data was made by calculating the 95% limit confidence of the mean values (Fig. 32) and the coefficients of variation (Tables 7.3 and 8.1) on each set of data on each zone. The results show that values of exchangeable potassium and available phosphate are comparatively variable in Zones 3 and 4 although other soil properties such as air-dry moisture, loss on ignition, pH are rather more constant within all zones.

Table 10.1 (derived from Table 7.3 and Table 8.1) gives the comparisons of CV values of individual soil properties of different zones. The overall values of CV decrease in the following order:- Zone 3 > Zone 4 > Zone 2 > Zone 1a > Zone 1b.

Soil property	Coefficients of variation %				
Exchangeable K	Z3: 16.75	Z4: 12.76	Z2: 8.53	Z1a: 7.23	Z1b: 6.93
Available P	Z3: 19.15	Z4: 16.86	Z2: 7.50	Z1a: 6.40	Z1b: 5.16
Total N	Z3: 18.00	Z4: 13.13	Z1a:6.11	Z2: 5.73	Z1b: 5.16
Loss on ignition	Z3: 5.10	Z4: 4.16	Z2: 4.10	Z1a: 3.66	Z1b: 2.96
Air-dry moisture	Z4: 6.93	Z3: 3.65	Z2: 3.50	Z1a: 3.46	Z1b: 3.06
pH	Z3: 3.20	Z4: 3.00	Z2: 2.63	Z1a: 2.03	Z1b: 1.83

Table 10.1 Comparisons of CV values of individual soil properties of different zones.

The possible causes of variability of soil properties along the studied transect are listed as follows:-

(1) Parent materials

Parent materials may vary over short distances, as solifluc ted materials or the deposits of a braided stream, or more gradually across the outcrop of a sedimentary rock. However, the variability of soil characteristics caused by the parent material factor is not particularly great (see the results of mechanical analysis, Chapter 7) as the soils along the transect are derived from the same parent material. Consequently this factor has little influence on variability.

(2) Climate

As continental gradations in climate only produce gradual changes in soil , a high variability of soil properties is not expected in a small area. The variability of soils within zones along the transect caused by this factor is slight although differences of temperature will undoubtedly exist between zones due to topography and texture of soils.

(3) Topography

Regional contrasts in topography produce regional differences in soil properties. There are no conspicuous micro-relief differences and no substantial changes in macro-relief within each zone of the study area. However, the zones themselves are topographically dissimilar and have marked influences on drainage status between zones (refer to Chapter 6.3 and Fig. 16).

(4) Biological activity

It has been noted that biological activity increases local variability. For example, the localized uptake of nutrients and water may influence the vegetation patterns or the local effects of burrowing or wallowing worms and insects may cause variations in the soil. However, these are not the causes of soil variability within the studied area as the vegetation patterns tend to be uniform within zones and there is a conspicuous lack of burrowing or wallowing worms or insects due to the high soil acidity. However variability of soil properties in Zone 3 and 4 may be due to the effects of trampling and grazing. The latter produces dung or urine patches, rich in potassium or phosphorus respectively.

10.2.2 Seasonal variability

In addition to spatial variability of soil, there is also seasonal variability due to weather differences. This has been demonstrated by the long term experiment in Chapter 8 in which temperature and rainfall are found to correlate with nutrient contents both in the soil and *Calluna* tissue. To achieve a high enough precison to detect minor seasonal changes would require more intensive sampling as the nutrient contents in soil tend to be subordinate to spatial variation. As a consequence it can always be claimed that the results of the long term experiment of the present investigation are never sufficient to allow any detailed conclusions to be reached because of the time factor. Such a difficulty can only be reduced by ensuring that larger numbers of samples are randomly selected for the future studies of the same kind. However, the more heterogeneous sites have been avoided in the present work, and the results give a fair indication of the fluctuations of nutrients both in the soil and plant according to seasons.

Seasonal fluctuations in the properties of soils are frequently reported, but there is considerable disagreement on the timing and magnitude of these changes. The soil surveyor who wishes to record the chemical and physical properties of the soil in relation to a particular problem is usually confronted with a number of queries on how and when to sample.

According to the present investigation, a general lower level of the available phosphorus and exchangeable potassium occurred in the autumn and winter months while higher values were recorded in spring and summer. This is possibly because of the exhaustion of the easily available phosphorus and potassium in the soil at the end of the summer by the growing plants while there is release of freshly available phosphorus and potassium from the soil minerals during spring and early summer due to the higher temperatures. Organic decomposition is also important during these seasons. Analyses of soils sampled at the end of the growing season (in autumn/winter) may indicate lower levels of readily soluble nutrients because of the uptake of nutrients by crops during their growing season. The same soil sampled in the spring might have a higher level because of release from relatively soluble forms during the late winter and early spring. In cultivated areas, where crops are removed at the end of each growing season, the deviation will be greater. Therefore, standardization of the time of analysis for soil nutrients on any site might be considered.

Measurement of nutrients in soils, and of pH are of importance in planning land usage, particularly for agriculture. In terms of actual management, absolute values are only of importance at a particular time for they can be easily altered by supplying lime and fertilizers. The physical properties of soil, chiefly depth, texture, structure, stoniness and drainage, affect the fertility of any soil but they are regarded as more difficult and more expensive to change than chemical properties. It can be assumed that physical soil factors are of more importance than chemical factors in assessing the potential value of the land. If the more permanent characteristics of depth, texture, drainage, etc. are satisfactory, then the nutrient status of an inherently poor soil may be built up. Moreover, a map of 'natural soil fertility' judged according to the amounts of plant nutrients, even in unimproved soils, is of little value in predicting crop yields.

10.3 Nutrient contents in soils and Calluna tissues related to productivity

Besides variability, another difficulty arises when using nutrient status in assessing the agricultural value of the land. Methods are required to distinguish between total nutrients in the soil and those which would probably become available to the plant in the course of the growing season. It is doubtful if any simple laboratory method can indeed be devised to account for the numerous factors concerned in the extraction of nutrients by plants over a lengthy period, subject as it must be to all the changes in moisture, air and temperature of the soil and to the action of the micro-organisms and active roots. Furthermore, these factors are all independent in the natural environment. Therefore, the most that can be expected, is an estimate of the available nutrients, reasonably close to the truth and suitable for guidance in predicting productivity.

To study the nutrient contents in *Calluna* tissues and soils as indications for assessing soil fertility, total nitrogen, available phosphate and exchangeable potassium both in soils and *Calluna* leaves are compared with the data of *Calluna* productivities. The results are presented in Figs. 47-52 respectively.

The correlations between total nitrogen contents in *Calluna* tissues and dry matter productions are comparatively high with r =+0.73 in Zone 1a, +0.80 in Zone 1b and +0.94 in Zone 2 (level of significance: p = 0.05, 0.02 and 0.001 respectively) whilst other correlations

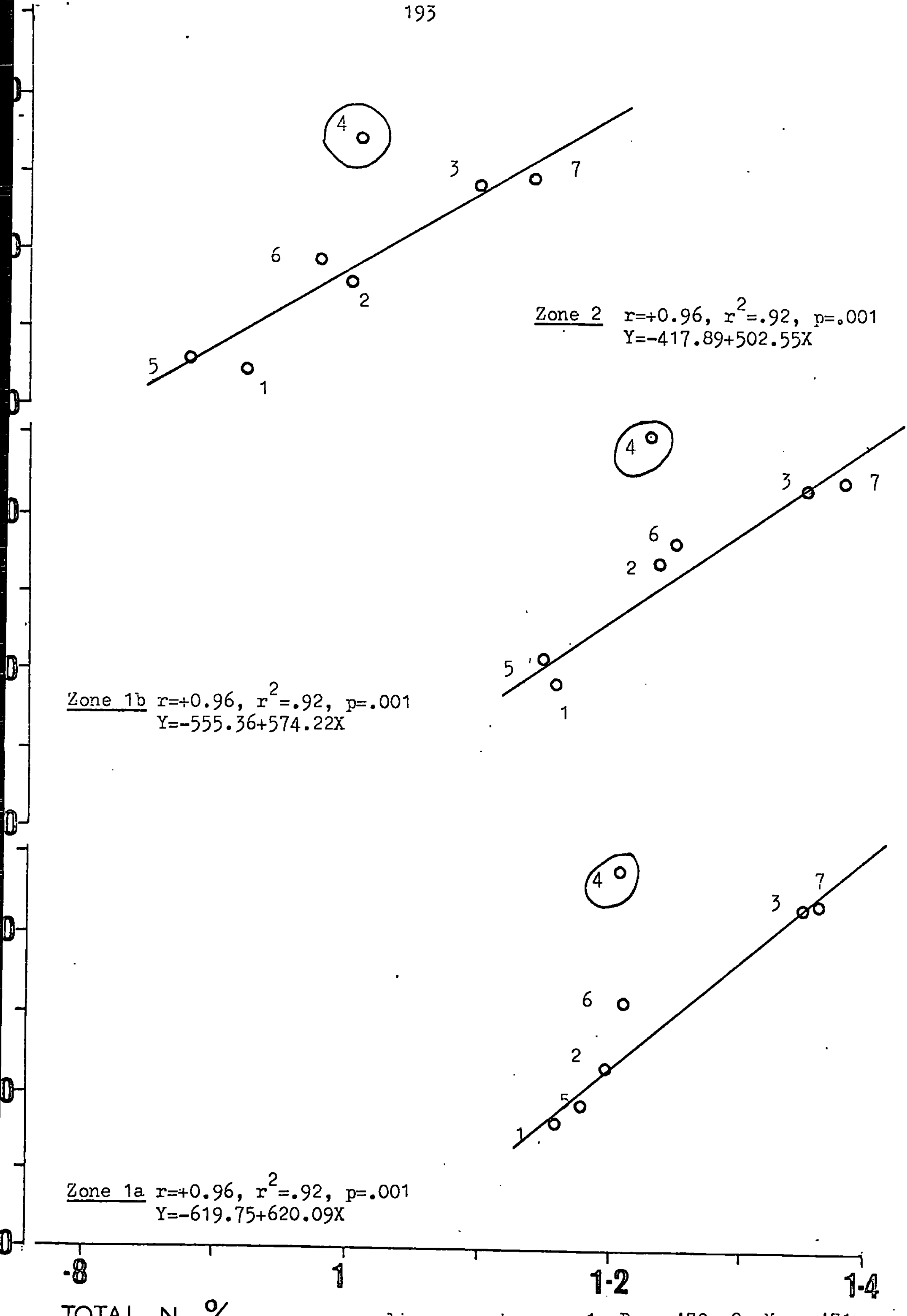
(correlations between total nitrogen in soil; available phosphate both in plants and soils; exchangeable potassium both in plants and soils and productivities) are comparatively low. The high correlation is probably due to the stability of total nitrogen and the large proportion of this content in the *Calluna* tissues (0.8 - 1.4% in the present investigation).

However, better correlations between nutrient contents and productivities occur if one of the sampling occasions (September 1971) is omitted (Table 10.2 and Figs. 47-52).

	Zone	Correlation between nutrient content in plant and productivity		Correlation between nutrient content in soil and productivity	
		r	level of sig.	r.	level of sig.
Tot. N.	1a	+ 0.96	0.001	+ 0.86	0.02
	1b	+ 0.96	0.001	+ 0.78	0.05
	2	+ 0.96	0.001	+ 0.88	0.01
Avail.	1a	+ 0.94	0.001	+ 0.95	0.01
P.	1b	+ 0.96	0.001	+ 0.79	0.05
	2	+ 0.35	not sig.	+ 0.86	0.02
Exchange	1a	+ 0.51	not sig.	+ 0.68	0.1
K.	1b	+ 0.34	not sig.	+ 0.57	not sig.
	2	+ 0.11	not sig.	+ 0.87	0.02

Table 10.2 Correlations between nutrient contents and productivities (samples of September 1971 excluded).

September 1971 had 12.8 mm of rainfall values in the month which was only one quarter of the long term average (50.6 mm.) for the month. Three quarters of this fell in three days, and the total was the lowest September rainfall since 1910 when 9.5 mm. was recorded. The mean



sampling occasions:- 1 Dec '70, 2 Mar '71, 3 June '71, 4 Sept '71, 5 Dec '71, 6 Mar '72, 7 June '72

Fig. 47 Nitrogen contents in *Calluna* tissue related to productivity.

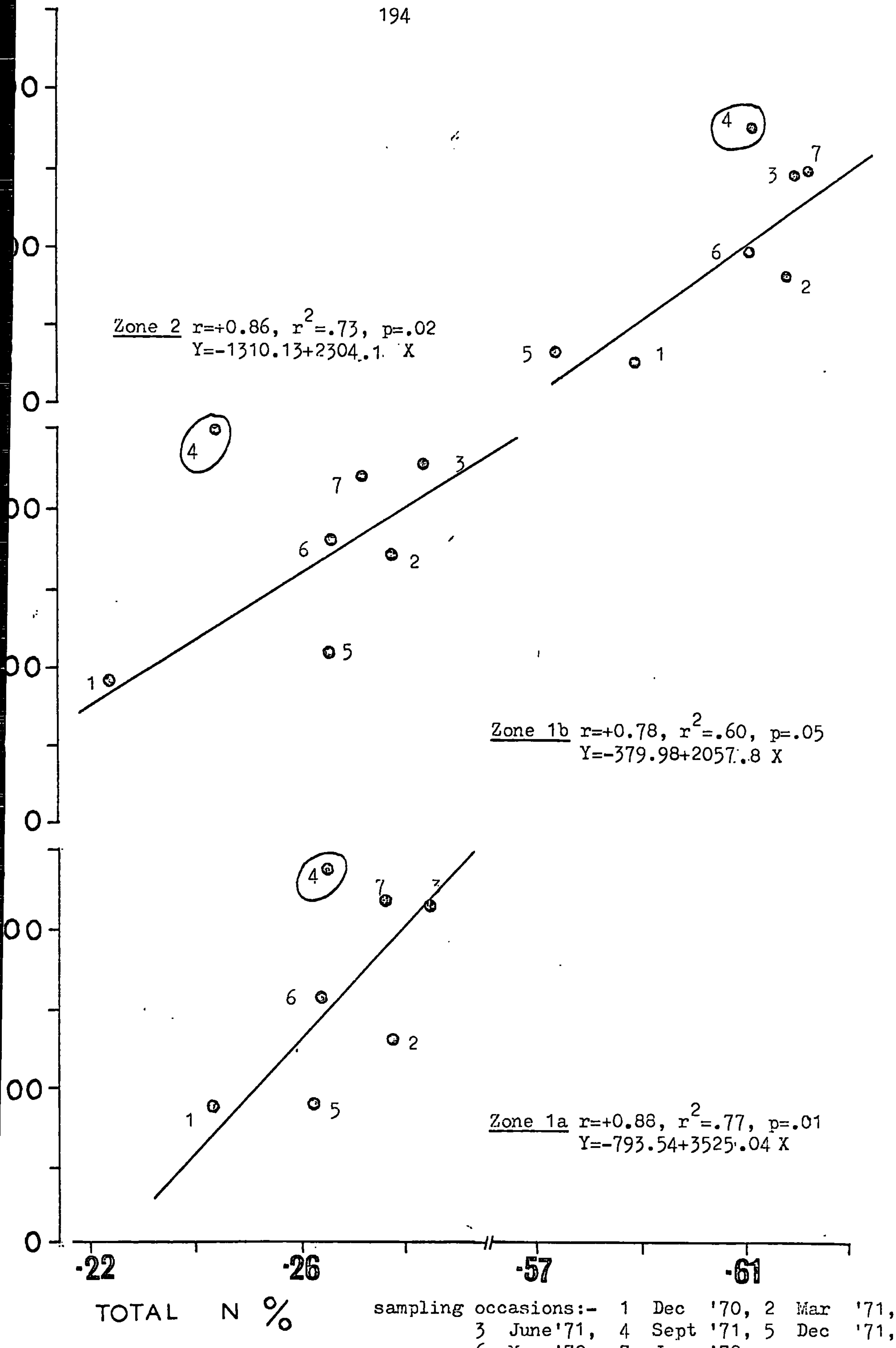


Fig. 48 Nitrogen content in soil related to productivity (*Calluna*).

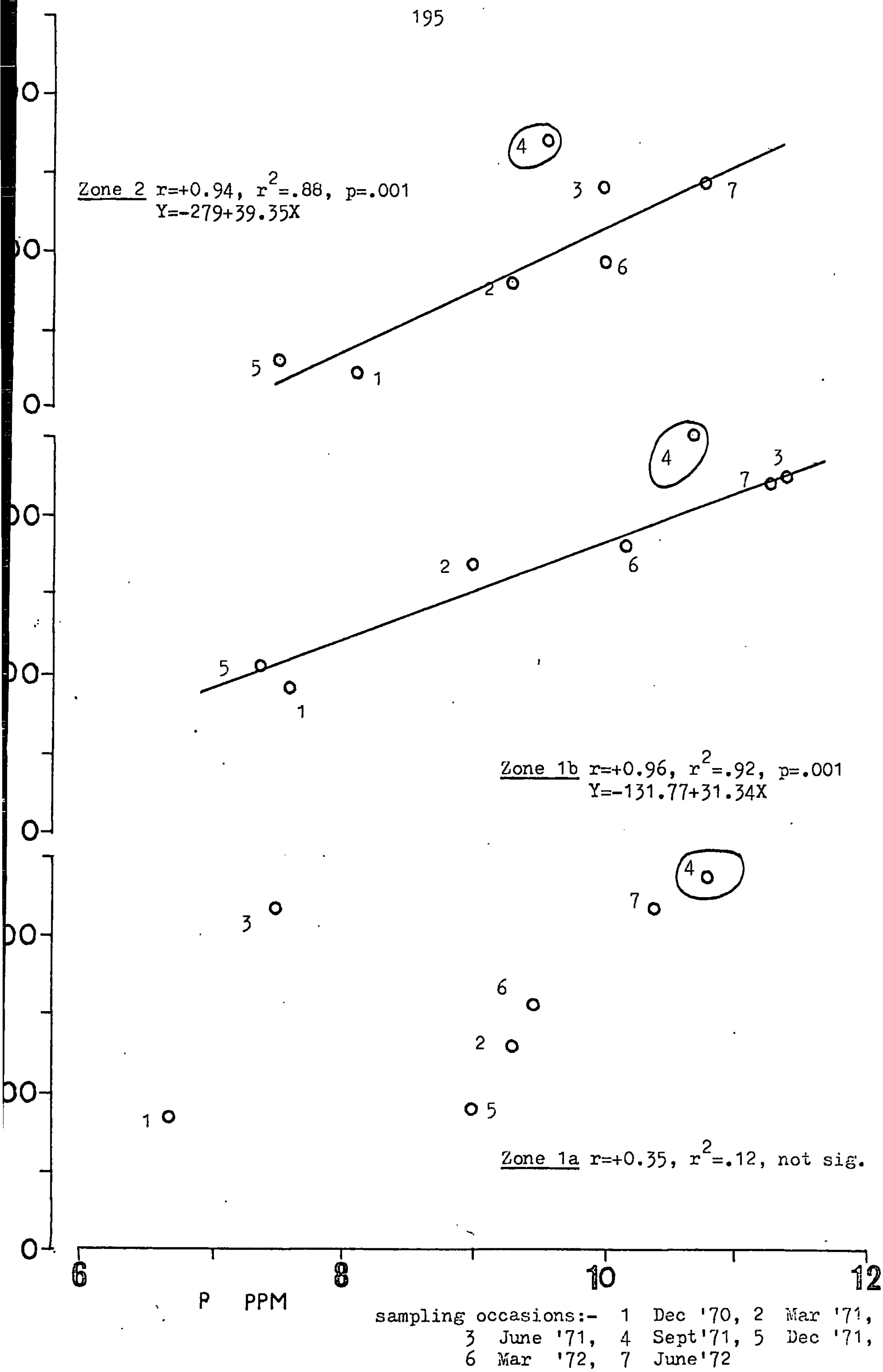
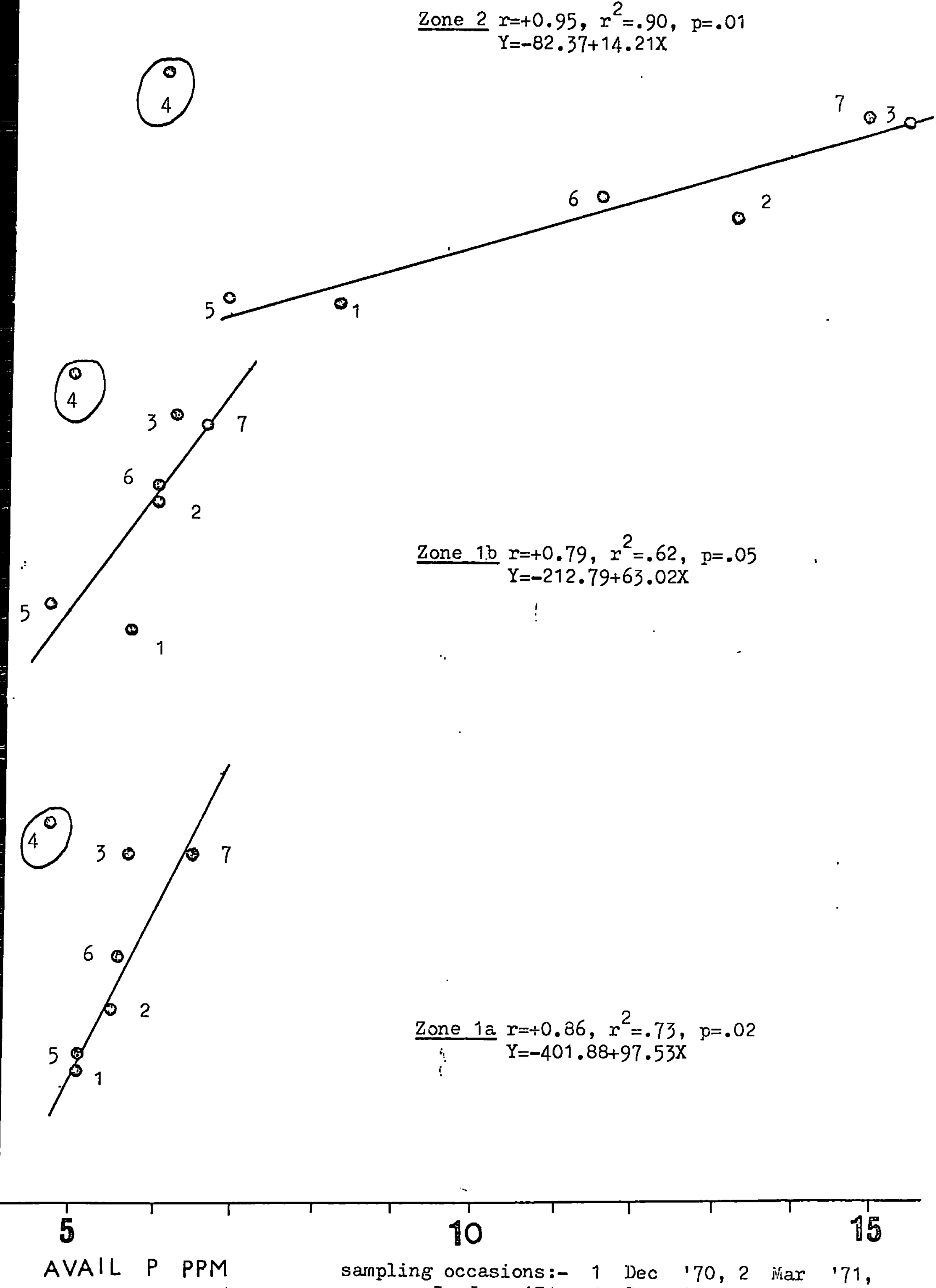
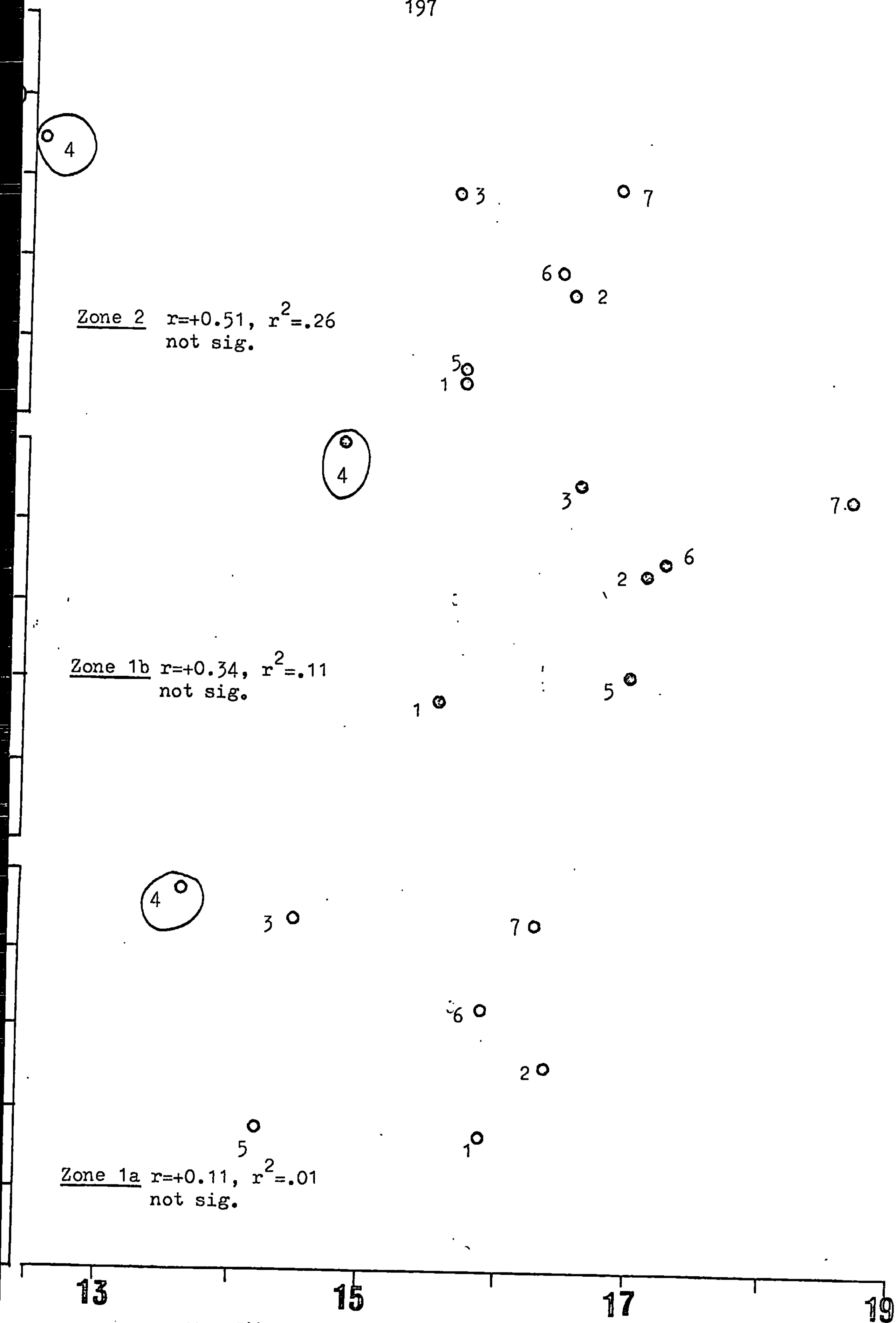


Fig. 49 Phosphate content in Calluna tissue related to productivity.



sampling occasions:- 1 Dec '70, 2 Mar '71, 3 June '71, 4 Sept '71, 5 Dec '71, 6 Mar '72, 7 June '72

Fig. 50 Available phosphate content in soil related to productivity (Calluna).



sampling occasions:- 1 Dec '70, 2 Mar '71, 3 June '71, 4 Sept '71, 5 Dec '71, 6 Mar '72, 7 June '72

Fig. 51 Potassium content in Callùna tissue related to productivity.

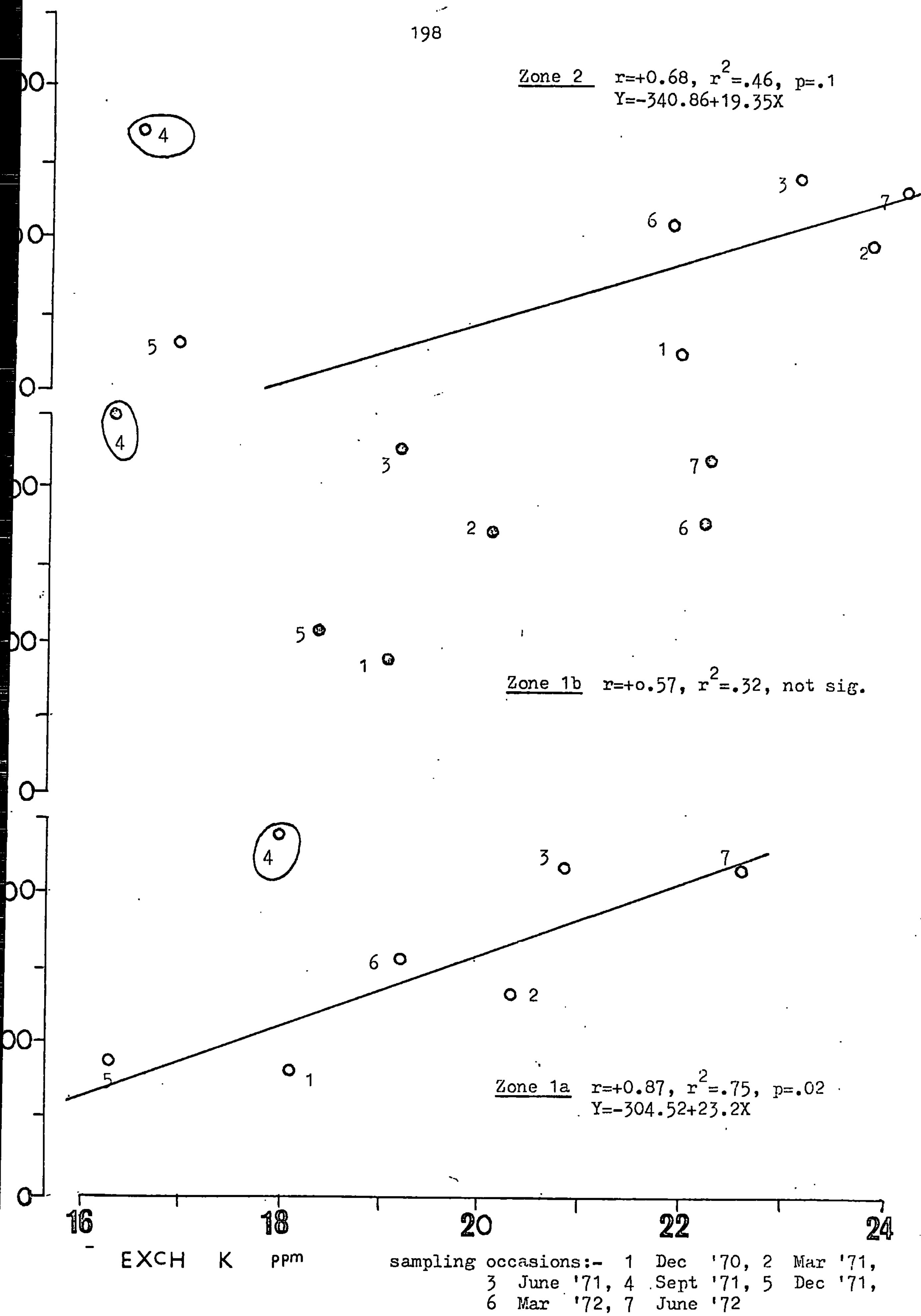


Fig. 52 Exchangeable potassium content in soil related to productivity (Calluna).

monthly temperature with 13.7°C was above the long-term mean (11.3°C), and on seven occasions, the mean daily maxima was recorded above 20°C (Durham University Observatory 1971). The mineralization of soil minerals as well as decomposition of organic matter must have been retarded due to the combination of comparatively high temperature and lack of moisture. The mechanism of nutrient absorption of *Calluna* and its metabolism could also have been disturbed in this dry weather. The high productivity measured in this month, however, could be explained by the residual effect of the early favourable growing period.

Nevertheless, the correlation between exchangeable potassium (both in *Calluna* tissue and soil) and productivity is still comparatively dubious even if the samples taken in September 1971 are omitted. This can be explained by the higher variability of exchangeable potassium contents in the soil as explained in 10.2.1.

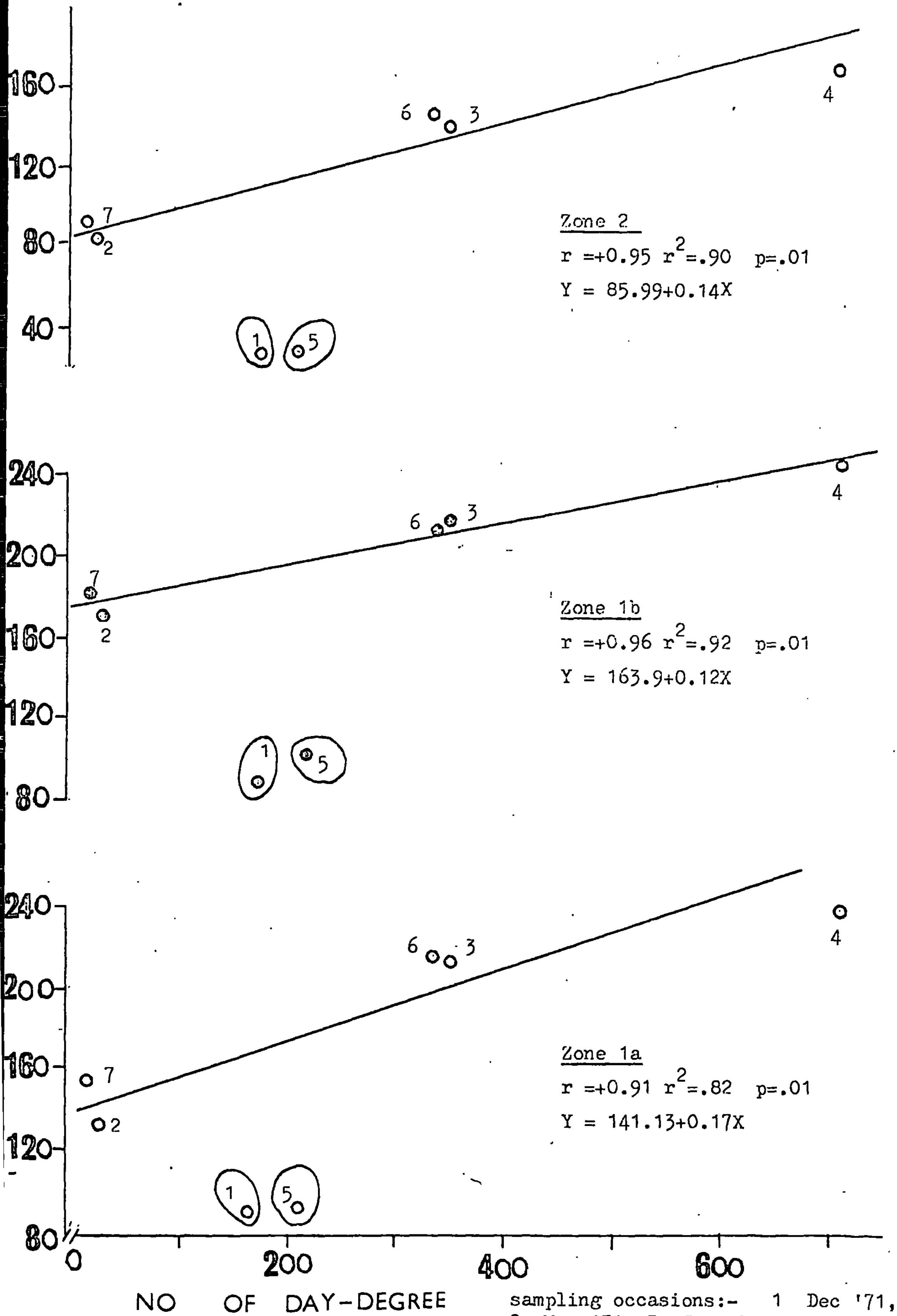
Bould (1965) stated that the concentrations of nutrients in leaves at specific stages of growth are related to the performance of the crop. He also concluded that 'experience shows that leaf analysis, correctly used, reflects the ability of a crop to obtain nutrients from the soil under a given set of environmental conditions; whereas soil analysis can, at present, only indicate the potential availability of soil nutrients for plant uptake.' There is an extensive literature on the composition of crops in relation to their nutrition and its implication in planning fertilizers. In the present study, considering the comparatively high correlation between total nitrogen content in *Calluna* tissue and productivity, it is suggested that the value of total nitrogen contents in plants can be used as one of the criteria for assessing the fertility of a soil. However, careful standardization of the part of the plant that is sampled and of the stage in the season when the sample is taken, will be needed.

10.4 WEATHER, NUTRIENT CONTENTS AND PRODUCTIVITY

Any assessment of the implications of changes in the weather on the performance of a particular crop at a given site must be based on an understanding of the quantitative responses of that crop to the climatic complex over the range experienced. According to the long term experiment (Chapter 8), it has been noted that the periodic fluctuations of nutrients both in soil and *Calluna* uptake were due to the meteorological periodicities. It is assumed that the periodic changes in soil chemical fertility factors have been affected by the alteration of periods of rainfall and temperature. It is further assumed that rainfall and temperature are correlated to the yield of *Calluna*.

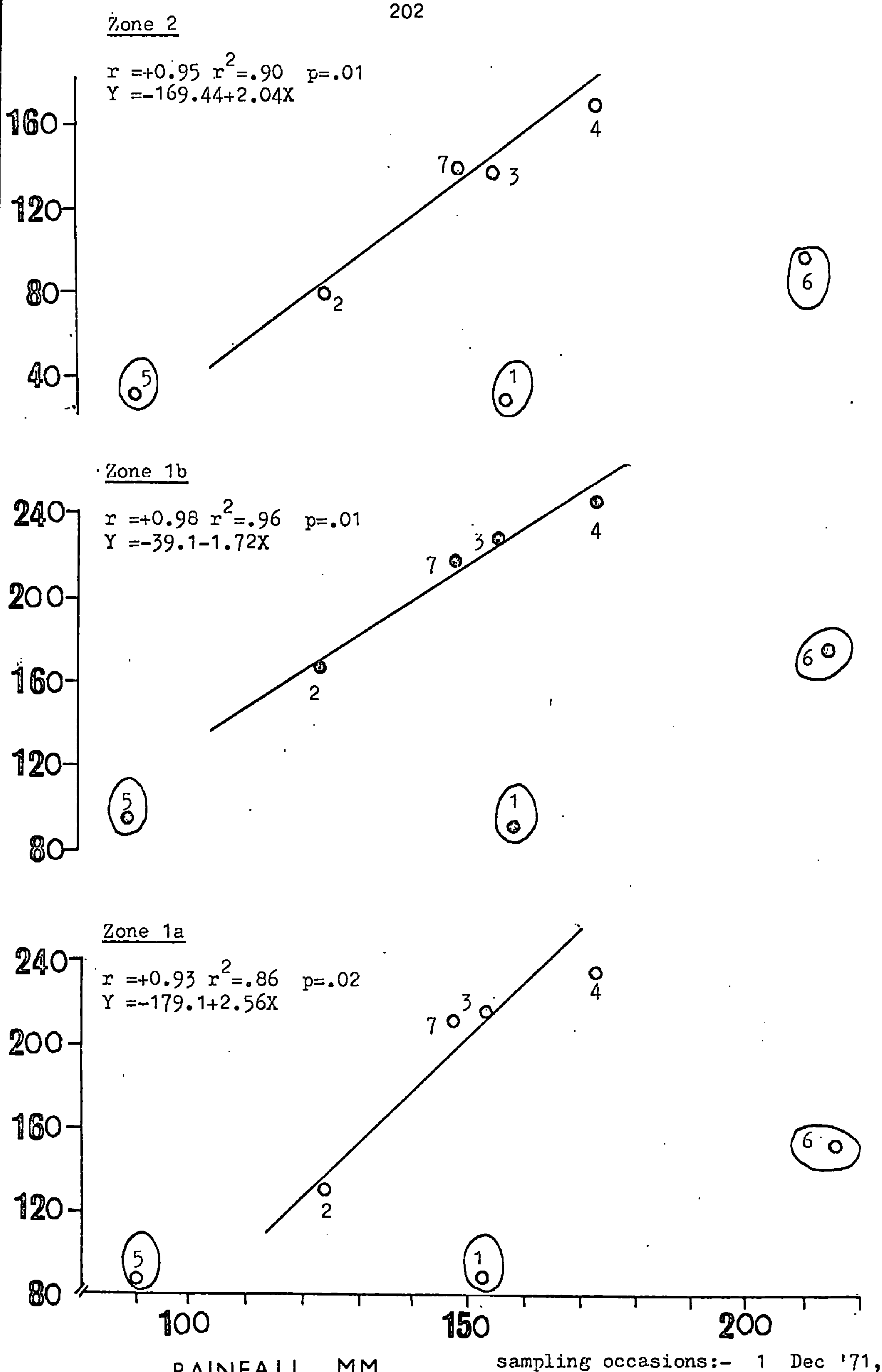
In order to pursue the above suggestion in greater detail it is necessary to relate the productivity data (obtained in Chapter 8) and the climatic parameters. The total number of day-degrees (taking 6°C as the threshold temperature for the onset of growth of *Calluna vulgaris* the number of day-degrees of accumulated temperature for one day was obtained by subtracting 6°C from the actual mean temperature for the day) and the total monthly rainfall of the sampling month and the two months prior, were taken into account. The results are presented in Figs. 53 and 54.

According to Figs. 53 and 54, the values of *Calluna* yield obtained in the two occasions, December 1970 and December 1971 were comparatively low with 84 gm/m^2 and 90 gm/m^2 in Zone 1a, 90gm/m^2 and 106 gm/m^2 in Zone 1b, and 25 gm/m^2 and 29 gm/m^2 in Zone 2 respectively) although the weather conditions were reasonable for plant growth (total number of day-degrees: 171.9 and 223.65, total monthly rainfall : 156.96 mm.



sampling occasions:- 1 Dec '71, 2 Mar '71, 3 June'71, 4 Sept'71, 5 Dec '71, 6 Mar '72, 7 June'72

Fig. 53 Relationship between productivity (Calluna) and temperature figures (measured by number of day-degrees).



sampling occasions:- 1 Dec '71, 2 Mar '71, 3 June'71, 4 Sept'71, 5 Dec '71, 6 Mar '72, 7 June'72

Fig. 54 Relationship between productivity (Calluna) and rainfall figures (measured by monthly rainfall).

and 90.1 mm. respectively). The lower productivities on these two occasions can possibly be explained by the large amount of litter fall of *Calluna* which commenced in the early part of October. If these samples are omitted, better correlations between productivity and temperature (accumulated temperature) would have occurred, e.g. the correlation coefficients are as follows:- Zones 1a +0.91, 1b +0.96, and 2 +0.95 (level of sig. p=0.01). However, the correlations between productivities and rainfall remained dubious even if the two sampling occa sions (December 1971 and December 1972) were ommitted. This could be explained by the abnormally wet period between January and March 1972. Rain fell on 28 days during January 1972 with 116.0 mm. which was the highest monthly total value of January since 1948 (188.0mm.). The monthly total rainfall records of February and March 1972 were also above the long-term average with 56.0 mm. and 51.9 mm. compared with 38.1 mm. and 44.9 mm. respectively (Durham University Observatory 1972). If this sampling occasion is also excluded, the correlation coefficients between productivity and rainfall (total monthly rainfall) would have occurred as follows:- Zones 1a +0.93, 1b +0.98, 2 +0.95 (level of sig. p = 0.02, 0.01 and 0.01 respectively).

However, it is unreasonable to claim a direct causal effect of preceding alternating climatic periods on the yield of *Calluna*. The fertility status of the soil should be regarded as an intermediary between the fluctuations of weather and crop yields, as the fluctuations in soil fertility induced by cumulative effects of periods of different rainfall and temperature are important for the control of crop yield.

It may be concluded that the periodic changes in yield are affected by changes of the nutrients in the soil and the modifications imposed by soil physical properties, for example, moisture conditions and aeration. Microorganisms in the soil may also depend on the physical and chemical changes and in turn affect the fertility status and crop yield.

The climatic factors, therefore, are extremely important in terms of crop yield. A region that has a short growing season, as has Waldridge Fell, is under great handicap, for crops cannot mature in the time available. High rainfall and low evaporation encourage leaching of nutrients where areas are freely drained, while areas that are poorly drained are subjected to waterlogged conditions. These are perhaps the greatest deterrents to the future extension of agriculture in moorlands.

Nevertheless, productivity increases are as likely to be achieved by plant breeding, as by soil knowledge. To achieve this, more attention should be given to identifying and breeding strains adapted to the adverse climatic conditions and specific soils. This will need knowledge of physiological and genetic analysis of crop species together with a detailed study of the field environment, before varieties of crop species can be developed to adapt such adverse conditions.

10.5 GENERAL CONCLUSIONS

Crop yields on any site depend on management, weather and soil. It is of course, possible to carry out management practices which modify some aspects of soil character - drainage, texture, even depth for example. Some of these changes can be drastic and may be very costly such as greenhouses or desalination and, while feasible economically on a limited scale, these modifications cannot be practised on any extensive scale in modern farming.

Weather is a factor which man cannot control to any appreciable extent except to irrigate crops. The variations in climate from season to season at any site are often as great as the variations between sites as demonstrated in different soils on Waldridge Fell. Even small altitudinal effects produce differences in crop yield on soils which are classified as the same pedologic series. Climatic interactions are complicated because the climate over a long period has influenced the course of soil development, while the weather in any one season affects crop growth both by direct action on the plant and through the inherent soil characteristics, e.g. in the question of nutrient storage and availability as shown in the present investigation (Chapter 8).

The theoretical soil fertility (measured by crop yield) of a soil under given climatic conditions is largely controlled by its suitability as a rooting medium, and by the ability of the horizons, penetrated by roots, to store water and nutrients in available forms to plants. These, in turn, result from the interactions of all the characteristics of the soil horizons. The actual yield of a particular crop is further determined by the interactions between soil qualities, seasonal climatic conditions and management practices.

In order to understand the crop performance related to the specific soil types, the soil-crop relationships should be investigated in detail and need to be supplemented by adequate meteorological data, and by comprehensive morphological, physical, chemical and mineralogical data on the soils. In view of the importance of rainfall and temperature as limiting factors on nutrient availability, data on the seasonal rainfall and temperature regimes are of particular significance. Given increased understanding of soil-crop relationships, not only soil suitability, but also soil classification and hence subsequent land capability interpretation for agricultural production could be improved. The building blocks of land capability classification schemes are 'soil mapping units' and these units should be 'nearly alike in suitability for plant growth and respond to the same kind of management' being grouped into 'capability units'.

There is no doubt that from the agricultural point of view the quality of the land of Waldridge Fell is poor, and is typical of other moorlands having the same hazards, (i.e. adverse climate, topography, soil acidity, aeration, moisture and nutrients) for the agricultural development in the future. If these difficulties may be modified by ploughing, liming, fertilizing and planting crops that can adapt to such climatic conditions, the agricultural production and hence, the economy of the whole nation, will be increased.

10.6 MAIN CONCLUSIONS OF THE THESES

(1) Moorlands make up 29 per cent of the total area of Britain, much of which are only extensively used and probably not producing to their maximum capability. Such areas have some potential for agricultural and forestry developments.

(2) The main factors down-grading the land of Waldridge Fell in terms of agricultural productivity are the cool wet climate, adverse topography and soil characteristics (including leaching, moisture content, acidity and nutrient status).

(3) Soil fertility (nutrient status) as a parameter in land capability classification is a variable concept being related to the prevailing weather conditions. Changes in the amount of rainfall and temperature give rise to considerable changes in nutrient availability and consequently affect crop yield.

(4) The major factors regulating productivity of *Calluna vulgaris* are analysed and categorized as (A) Biological factors (the adaptability of *Calluna*, competition with other forms of vegetation, burning, grazing, and trampling), (B) Site factors (meteorological

variables, topographic variables and edaphic variables - effect of parent material, soil moisture, aeration, and nutrients.)

(5) It has been noted that soil is very heterogeneous, with characteristics varying not only spatially and vertically but also seasonally. Questions arise concerning standardization of not only the sampling method but also the sampling time if any valid predictions are to be made.

(6) The yield of a particular crop on a particular site results from the combined influence of three groups of factors:- 1). Management, 2). Weather conditions and 3). Soil characteristics. Soil nutrient status is not necessarily reliable in predicting crop yield. However, testing of nutrient contents both in soil and leaf tissue will give a better indication in assessing potential productivity of a particular soil type.

APPENDIX

Appendix A.1 Direct Gradient Analysis - A transect along a single gradient (Source:- Whittaker 1967)

In this application of gradient analysis, vegetation samples are taken at equal intervals along an environmental gradient - for example, 50 m. elevation intervals up a long, even mountain slope. A field transect - that is, a series of such samples taken as one moves along a gradient in the field - can effectively show how densities of some major plant populations change along the gradient. Transects are of considerable importance in the description of vegetative change along an environmental gradient, or in relation to some marked feature of topography. The sample usually includes measurements of plant populations in quadrats and coverage measurements. Clearer results are possible when several samples represent each interval, and their population data are combined so that much of the sample irregularity may be averaged out. Five samples may, for example, be combined into a composite sample to represent each 100 m. interval along the elevation gradient. Field transects with one sample per interval were taken along specific elevation and topographic gradients to prevent the possibility that averaging groups of samples might blur population discontinuities, or otherwise alter apparent population relations from those existing in the field. The data is suitably represented, either by means of a graph or a histogram, of abundance of a species plotted against position on the transect.

Appendix A.2 :- van der Marrel's Group Analysis (1968)

A simplification of the summary of "Small-scale Vegetational boundaries, on their analysis and topography" is given below:-

Small-scale vegetational boundaries may be considered of special importance in a general approach to ecological boundaries, since they determine the basic structures in vegetation on which the entire structure of vegetation is built.

According to the Information Theory the difference between two quadrats may be measured as the heterogeneity in the set of two quadrats. Each species occurring in only one of the two quadrats contributes one bit of selective information or, preferably, half bit per quadrat. When quantitative data are available the heterogeneity contribution of a species may be approximated by dividing the difference of performance in the two quadrats by the maximum difference. This leads to:-

$$H = \frac{1}{2} \sum_{i=1}^{G} \left[p(g_i,a) - p(g_i,b) \right] / p \quad \max$$

Where H = heterogenity between two adjacent quadrats

G = no. of species

$p(gi,a)$ = performance of the i^{th} species in quadrat a

$p(g_i,b)$ = performance of the $_i$th species in quadrat b

p max = maximum difference of performance

The value p can be measured as frequency, coverage, abundance or with a combined scale, e.g. the Braun - Blanquet scale.

For qualitative data this formula reduces to:-

$$H = \frac{(Ga - Gc) + (Gb - Gc)}{2}$$

Where Ga; Gb = number of species in quadrats a and b respectively Gc = number of common species

The 'H' values obtained from this formula are then plotted against transect distance of the quadrats to yield a 'vegetation differential profile', along which disaparities in the system can be noted, and hence boundaries detected.

Appendix A.3. Analytical methods

(1) Soil

1. Moisture: determined by weight loss after drying at 105°C for 4 hours. All analyses were made on the air-dry 2 mm. fine earth fraction.

2. Soil texture: Bouyoucos Mechanical Analysis

3. pH: determined by pH meter using 10 gms. soil and 25 mls. distilled water.

4. Loss on ignition: determined by weight loss after ignition at 800°C for 2 hours.

5. Organic carbon: 14 samples were determined by Walkley and Black method, other samples were calculated by using Fig. 55 in which $Y = -7.85 + 2.08X$ where Y= % organic carbon, X = % loss on ignition (for relation between organic carbon and loss on ignition, refer to Ball 1964).

6. Total cation exchange capacity: based on the retention of ammonium by by the soil after leaching 5 gms. soil with 250 mls. N ammonium acetate.

7. Total nitrogen: Kjeldahl method with 5 gms. of soil, being digested by sulphuric acid using copper catalyst tablets.

8. Avaliable phosphate: extraction of water soluble available phosphate by ammonium molybdate in dilute hydrochloric acid. 10 mls. were used to extract 1 gm. soil.

9. Exchangeable potassium: extracted by 1N ammonium acetate and determined by flame photometer

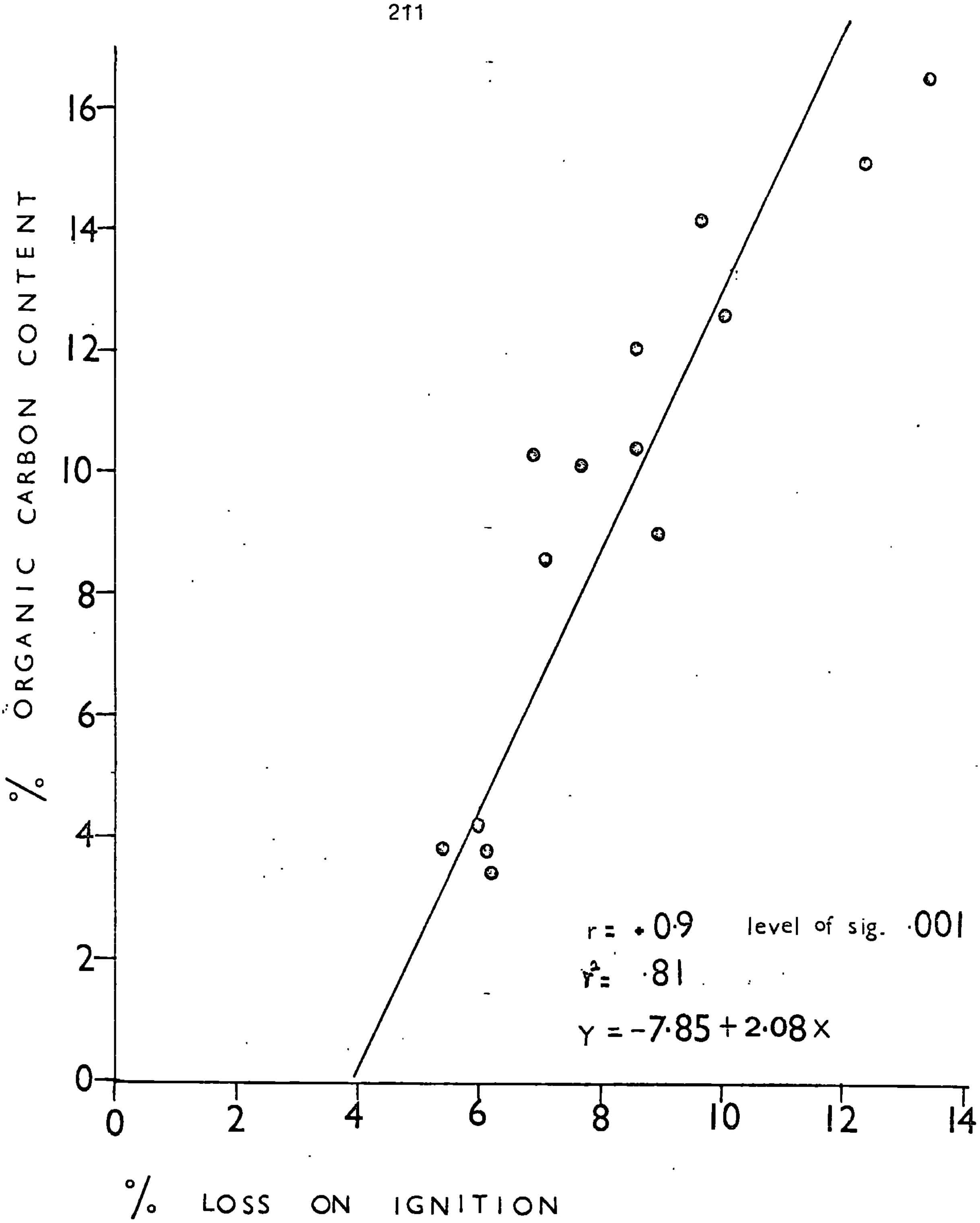


Fig. 55 Relationship between % loss on ignition and % organic carbon.

(2) Plant

A. Digestion of plant material

The dry plant materials were cut into small pieces and 1 gm. samples digested using wet oxidation method described by Jeffries and Willis (1964), but with change in the proportions of the acid used, as a more thorough and rapid digestion is obtained. Volumes of acids used to digest 1 gm. of plant tissue:-

Jeffries and Willis (1964)			Wong
Concentrated	HNO_3	20 mls.	20 mls.
Concentrated	HCl	20 mls.	20 mls.
60%	HClO	5 mls.	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 (Whatman filter paper No. 542) into 250 mls. volumetric flasks. The filtrate was then made up to 250 mls. with distilled water ready for analysis.

B. Analysis of the plant tissue digests

Same techniques were used as soil analysis for determination of total nitrogen, available phosphate and exchangeable potassium.

APPENDIX A.4 Culture Solution (after Hewitt 1952, Rieley 1967)

The components of culture solution are as follows:-

Elements	ppm
Ca	100
K	78
S	48
N	40
P	40
Mg	38
Na	30
Fe	5.6
Mn	1.1
Cu	0.13
Molybdenum	0.02

APPENDIX A.5 Analytical data (seasonal fluctuation of nutrients)

Year	Month	Total Nitrogen (%)					
		Soil (2-10 cm)			Plant		
		Zone 1a	Zone 1b	Zone 2	Zone 1a	Zone 1b	Zone 2
1970	Nov.	.257	.265	.608	1.11	1.14	0.88
	Dec.	.244	.224	.590	1.10	1.16	0.92
1971	Jan.	.263	.270	.615	1.16	1.20	0.97
	Feb.	.258	.255	.587	1.13	1.15	0.95
	March	.273	.278	.619	1.20	1.24	1.00
	April	.264	.273	.608	1.23	1.27	0.96
	May	.275	.279	.623	1.36	1.33	1.08
	June	.280	.285	.621	1.35	1.38	1.10
	July	.263	.268	.607	1.42	1.34	1.05
	Aug.	.275	.279	.625	1.37	1.35	1.09
	Sept.	.266	.245	.613	1.21	1.23	1.01
	Oct.	.240	.270	.612	1.19	1.23	0.95
	Nov.	.264	.250	.603	1.17	1.18	0.94
	Dec.	.263	.266	.575	1.16	1.15	0.88
1972	Jan.	ND	ND	ND	ND	ND	ND
	Feb.	.250	.245	.610	1.23	1.22	1.01
	March	.265	.266	.612	1.21	1.25	0.98
	April	.262	.253	.595	1.22	1.24	1.10
	May	.275	.275	.621	1.33	1.37	1.07
	June	.277	.273	.623	1.36	1.38	1.14

(ND = no data)

Year	Month	Available phosphate (ppm)					
		Soil (2-10 cm) Zones 1a	1b	2	Plant Zones 1a	1b	2
1970	Nov.	5.00	5.35	7.35	7.30	7.00	8.27
	Dec.	5.25	5.89	8.40	6.70	7.65	8.10
1971	Jan.	5.20	4.80	8.20	6.90	8.20	7.42
	Feb.	5.74	6.20	9.05	8.07	8.65	8.53
	March	5.53	6.25	13.40	9.33	9.00	9.30
	April	6.07	6.70	13.20	9.80	10.40	9.22
	May	6.44	6.80	14.35	9.03	10.15	9.55
	June	5.80	6.42	15.00	7.50	11.40	10.00
	July	6.00	6.37	14.28	11.62	12.30	10.65
	Aug.	6.80	7.25	16.60	11.80	11.30	10.70
	Sept.	4.80	5.20	6.20	10.84	10.70	9.61
	Oct.	5.34	Lost	8.40	9.60	7.50	9.05
	Nov.	4.78	5.20	7.72	10.05	8.06	9.10
	Dec.	5.20	4.79	7.08	9.00	7.42	7.50
1972	Jan.	ND	ND	ND	ND	ND	ND
	Feb.	5.53	5.40	7.40	6.30	8.24	7.00
	March	5.60	6.15	11.80	9.56	10.28	10.00
	April	6.20	6.50	13.10	10.00	10.51	9.44
	May	6.40	6.05	13.56	9.80	11.00	10.52
	June	6.67	6.80	15.60	10.40	11.32	10.80

(ND = no data)

Year	Month	Exchangeable potassium (ppm)					
		Soil (2-10 cm)			Plant		
		Zone 1a	Zone 1b	Zone 2	Zone 1a	Zone 1b	Zone 2
1970	Nov.	16.75	17.84	19.93	13.52	16.12	12.40
	Dec.	18.10	19.10	22.00	15.90	15.60	15.70
1971	Jan.	15.60	17.74	20.30	14.13	14.00	14.23
	Feb.	19.10	18.10	20.36	14.50	14.30	14.60
	March	20.30	19.80	23.90	16.40	17.20	16.50
	April	17.20	20.00	20.45	14.30	16.40	14.20
	May	20.20	21.40	23.70	15.20	16.90	14.54
	June	20.80	19.20	23.10	14.50	15.60	15.70
	July	19.80	23.00	26.00	16.00	16.50	15.40
	Aug.	22.30	25.20	26.80	17.90	19.20	18.00
	Sept.	18.00	16.40	16.90	13.60	14.80	12.50
	Oct.	17.70	21.70	19.30	15.10	16.00	15.30
	Nov.	15.90	18.00	17.70	14.10	14.90	14.53
	Dec.	16.30	18.40	17.20	14.20	17.00	15.70
1972	Jan.	ND	ND	ND	ND	ND	ND
	Feb.	18.00	19.30	17.50	14.36	15.30	15.33
	March	19.24	22.20	21.90	15.90	17.20	16.40
	April	17.80	19.70	20.40	14.25	16.90	14.03
	May	21.15	21.00	21.90	16.00	17.80	15.00
	June	22.60	22.30	24.30	16.40	18.70	16.80

(ND = no data)

APPENDIX A. 6 Weather Data (from the Durham University Observatory)

Year	Month	Total monthly rainfall (mm.)	Mean monthly temperature (°C)	Number of day-degrees
1970	Oct.	22.6	10.0	126.8
	Nov.	62.5	6.0	34.4
	Dec.	71.9	4.3	10.7
1971	Jan.	45.8	3.7	13.4
	Feb.	16.7	4.5	5.5
	March	62.0	5.0	16.3
	April	48.8	7.1	42.5
	May	47.7	9.7	149.3
	June	59.0	11.2	152.4
	July	32.3	15.8	309.6
	Aug.	127.7	14.5	250.2
	Sept.	12.8	13.7	150.2
	Oct.	20.9	10.4	142.6
	Nov.	47.7	5.5	41.7
	Dec.	21.5	6.4	39.3
1972	Jan.	116.0	3.2	3.4
	Feb	56.0	3.5	0
	March	44.9	4.4	18.3
	April	30.6	6.5	60.0
	May	57.3	9.6	117.4
	June	59.6	12.5	158.6

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