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WELSH SOILS DISCUSSION GROUP

CYMDEITHAS TRAFOD PRIDD

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Report No. 20

Edited by:

R. J. W. Dight

Welsh Office Agriculture Dept.
TRAWSGOED, Aberystwyth

and

E. M. Bridges

University College of Swansea

Copies of this report are available from:

P. S. Wright, Publication Manager, W.S.D.G.
Soil Survey of England and Wales, U. C. Swansea,
Singleton Park, Swansea, SA2 8PP.

CONTENTS

*The following comprise a selection of the papers which were presented on the theme of 'Soils and Upland Management' at Trawsgoed on 25th October 1978 and at UCNW Bangor, on 14th March 1979. (*Written paper not presented).*

PROBLEMS OF HILL AND UPLAND SOILS

P. Newbould and M. J. S. Floate
Hill Farming Research Organisation,
Bush Estate, Penicuik, Midlothian

Hill and upland soils cover more than one-third of the total land area of the United Kingdom. Over 70 per cent of this area (6.5 M ha) is covered with unimproved native grassland or rough grazing, while forestry presently occupies 1.75 M ha. Hill and upland land is not completely defined by altitudinal ranges, since rough grazings can occur at sea level in exposed north-western coastal areas but, in general, its distribution relates to that of the relief of the United Kingdom. Thus, they occur predominantly in Scotland, Wales, the Pennines and North of England, part of South-west England and the upland area of Northern Ireland.

The primary uses of this large area of land are agriculture, forestry, sporting estates and recreation, with mining, water collection, nature conservation and military training being prominent in a few specified localities. Many of these uses conflict in requirements for land and in mutual interference and incompatibility.

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Problems arise both because of the inherent nature of the soils and the ways in which they are used. This paper discusses these two main types of problem with emphasis on the more technical aspects. It describes how some of the problems can be resolved in general terms and concludes with a case description of a successful integration of use between agriculture and forestry which illustrates the important role of soil science and survey in making decisions which affect the management of the uplands.

Hill and Upland Soils

The main factors which have influenced the formation of these soils are climate, parent material, topography and biotic events, e.g. grazing and/or burning. The dominant influence has been and still is climate which is generally cool, wet and windy and which deteriorates rapidly with rise in altitude. The chief features which delineate upland climatic zones and where these occur are shown in Table 1. An important consequence for the growth of both trees and plants is that the season of growth is much shorter than in lowland situations varying from 180-220 days and that it declines with altitude, being zero days at the top of Ben Nevis (1340 metres).

The theme of today's meeting is Soils and Upland Management and yet we have entitled our paper problems of hill and upland soils. Is there then a clear distinction between the soils occurring in these two regions? If not, why use this form of title? Where does hill begin and upland end, and vice-versa? The sub-division of the uplands rests primarily on the characteristics of farming systems within the major land use, i.e. agriculture. In summary it can be stated that hill and upland farms occur predominantly in regions of mountains, hills and heather.

Table 1. Upland climatic zones

Description	Location	Mean annual Temp. (°C)	Rainfall (mm)
Very cold and very wet	Scotland 700m	4	> 4000
Cold and wet	High Wales and SW England Pennines Lake District W Scotland	4-8	> 1000
Fairly warm and wet	Wales SW England	> 8	> 1000
Cool and fairly wet	N Yorks Moors Eastern Pennines Eastern Scotland	< 8	< 1000

The growing season is short and cool and all the soils are of poor to average fertility. The enterprise is to breed and rear sheep and cattle and, more recently, red deer; there is no dairying, little fattening and few crops. Within this broad category the hill farms are predominantly rough grazing with only a small percentage of enclosed land and with few possibilities for conservation of grass. Upland farms, by contrast, are predominantly enclosed permanent pasture but often with more than 50 per cent rough grazing and some conservation is possible although it is very constrained by weather and/or topography.

Thus, there is no clear division between hill and upland soils although the latter tend to be more mineral and to have more problems due to impeded drainage. In terms of the climatic regions shown in Table 1 the main soils associated with the very cold wet region are skeletal soils and peaty rankers; with the cold and wet region are acid peats, peaty gleys and peaty gley podsols; with the fairly warm and wet region are brown rankers, brown podsolic, acid brown earths and non-calcareous gleys, while in the cool and fairly wet region the humus iron podsol predominates.

Detailed descriptions of hill soils and their classification have been given by Crompton (1958), Avery (1973), Ragg and Clayden (1973), Floate (1968, 1977) and Ball (1978). For simplicity it is possible to divide them into four major soil groups as in Table 2; the main associated vegetation types are also broadly described although in practice there are a wide variety of types whose nature is determined by soil nutrient level of which pH is a useful index, by soil drainage class and by biotic history.

Table 2. The main hill soils and vegetation types

Soil	pH	Vegetation
Brown earth	5.2-5.5	Acid grassland (sp. rich)
	4.6-5.2	Acid grassland (sp. poor)
Gleys, peaty gleys	4.0-5.2	Grass heath
Podsols, peaty podsols	3.8-4.5	Shrub heath
Blanket peat	< 4.0	Bog

Problems - Technical

Hill soils are generally acid and short of available phosphorus and are often of poor physical structure (Floate, 1968; Reith, 1973). An important feature of many of them is the increasing accumulation of organic matter - either within the profile, or on the surface as peat - the depth of the latter often increasing with elevation.

This is due to increasingly severe conditions for decomposition of OM, e.g. temperature, acidity and moisture - probably in that order of importance and all affecting the presence and activity of micro-organisms. Increasing acidity develops partly as a result of increasing leaching and loss of bases, but also as a result of increasing OM and associated CEC, without the necessary weathering and release of bases to satisfy exchange sites - the result is progressive base unsaturation and the development of acidity associated dominantly with Exchangeable Al^{3+} in mineral soils and increasingly with H^{+} in more organic soils.

The accumulation of organic matter has important consequences to the distribution and availability of nutrients for plant growth; the increasing amounts of organic matter, the slow rate of its decomposition and mineralisation of nutrients, and the fixation of P (associated with acidic weathering products especially Fe and Al) are responsible for what is usually described as the "low fertility" of hill soils.

This does not mean that the total fund of nutrients is small, or lower than in lowland soils - see Table 3 (Floate, 1977) but rather that the amounts available for plant growth at any instant in time are small, and the rate of replenishment is very slow.

Table 3. Average organic matter and nutrient status of hill soils (0-20cm) (after Floate, 1977)

	%	kg/ha	ppm
Organic matter (C)	9-36	114,000 (av)	
NITROGEN: Total	0.4-1.4	4000-10000	
Organic	99.9		
Inorganic	0.1		
NH_4^+			10-15
NO_3^-			0-1
PHOSPHORUS: Total	0.07-0.12	400-2000	
Organic	60-80		
Inorganic	40-20		
'Available'		2-10	1-5

Important aspects of soil improvement are concerned with releasing and mobilising the reserves of nutrients held in organic matter, and promoting more efficient recycling of these nutrients via grazing animals (Floate, 1970). The above-ground recycling of nutrients via animals and the accelerated decomposition of plant materials after they have spent a period of time in the rumen of grazing animals can be manipulated in improved grassland situations to substitute for the deep rooting and biological pumping of nutrients by a former woodland cover. Moreover, increased levels of pasture utilisation by ruminants enhances

nutrient cycling. To some extent these processes can be harnessed to reduce the potentially excessive leaching of nutrients and bases which often occur in the hills and uplands. Extra removal of nutrients in increased livestock products does not lead to a run-down in 'fertility' - partly because cycling is more efficient (Floate, 1970) and partly because removals are largely made good by income in rainfall (Newbould and Floate, 1977).

A summary of some of the technical problems of hill and upland soils is given in Table 4. The first category is described as permanent since little can be done to alter them but many of the so-called temporary problems can be alleviated (see later).

Table 4. Some problems of hill and upland soils

CAUSED BY WHERE THEY ARE (PERMANENT)
Climate, slope, erosion, depth, stones, poor drainage, parent material, resistant to weathering, podsolisation, accessibility, allophanic clays.
CAUSED BY WHAT THEY ARE (TEMPORARY)
HIGH organic matter, water holding capacity, pH dependent change, capacity to 'fix' P.
LOW calcium, available phosphorus, nitrogen and trace elements, microbial and soil fauna activity, pH.

Problems of Use

A plethora of problems outwith the purely soil chemical affect hill soils, primarily because of their location, and conflict about what they should be used for. Because of the general theme of this meeting, i.e. upland management, it is appropriate to dwell briefly on some of these.

Agriculture, the main user, has about 80 per cent of the uplands, i.e. one-third of the agricultural land of the UK from which it produces only 7.7 per cent of the total gross agricultural output (worth about £50 M in 1978). However, hill and upland farms contribute a quarter of the value of the total output of cattle and nearly half of sheep and wool produced in Great Britain (Table 5).

Table 5. Hill and Upland Farming in the United Kingdom

	Gross output (in £) for 1978 (Forecast)		
	Hill and Upland	UK Total*	Hill and upland as % of total**
Cattle	327	1310	25.0
Sheep and wool	174	355	49.0
Other (pigs, poultry and milk)	31	3120	1.0
Total livestock	532	4785	11.1
Crops and misc.	27	2470	1.1
Total farm	559	7255	7.7

* Ann. Rev. of Agric. 1979.

** NEDO 1973; Dyfri Jones, 1978

The country is 56 per cent self-sufficient in sheep (lamb/mutton) production which is important in relation to a total annual food import bill of about £6,000 M. The White Paper 'Food from our own resources' (HMSO, 1975) suggested that an increase of mutton and lamb production of 47,000 tons by 1980 was possible with much of this from the uplands. Overall it was suggested that the net product of agriculture should expand by about 2½ per cent per year on average; this would save £550 M of imports in five years. This estimate of saving was revised upwards by NEDO in 1977 to £670 M. Actually there has been no change in production since 1975, primarily due to climatic reasons and the most recent White Paper sets no quantitative targets but concentrates on a statement of intent only (HMSO, 1979).

Forestry occupies about 7 per cent of the uplands and the country is about 8 per cent self-sufficient in timber products. The total annual import bill for timber products is approximately £2000 M. There is a broad Government or Forestry Commission target to raise the level of self-sufficiency to 11 per cent by the year 2000 (British Forestry, 1974) but there is no agreed target for the additional amount of upland to be afforested. Estimates vary from 0.5-2 M ha (Locke, 1976; Stewart, 1977). It has been shown by Cunningham et al (1978) that any increase of planting within this range which would occur predominantly in Scotland, would affect hill sheep farming significantly.

Thus the possibility of conflict exists at the National level and it is often particularly sharp at the individual farm level. Government requires more sheep and trees but provides little guidance as to how to achieve both aims. There are also conflicts with the sporting estate users, and with amenity and conservation groups.

The lack of a clear policy is probably not surprising in view of the large number of uncertainties about the future which may affect the allocation of upland to uses which have to last many years. These have been described in detail by Coppock (1976). One of the key factors is climate. Climatologists differ as to whether the climate is warming up or cooling down. A change either way could have large implications to the growth of both trees and pasture on our hills. The size and life style of the population may affect the demand for food and timber. The development of a biodegradable medium for newspaper production not requiring timber pulp would have enormous effects on the demand for forestry. Similarly, the perfection of soya-bean protein based substitutes for meat might affect the demand for sheep and cattle meat. The price of land, capital transfer and wealth taxes and the Community Land Act may alter the price relativities between agriculture and timber. The increasing cost of energy which affects the cost of fertilisers and of petrol affect land improvement directly and may either diminish or enhance the number of town dwellers seeking recreation in the countryside. The political parties offer a wide spectrum of views on control of land use, from full nationalisation to complete laissez-faire. The present system of deciding land use has been described as zoning (OECD, 1976) but there are no published criteria to state what the decision makers take into account except the very general statements for Scotland (HMSO, 1972).

Other Limitations to Production from Hill Land

The limitation of production, whether of trees or pasture (and ruminant animals) imposed by the technical problems of hill and upland soils is not the only source of difficulty. Using agriculture, and hill

sheep farming in particular, as the example, although similar categories of problems apply to forestry, the main limitations to production can be summarised as due to climate, site, soil, vegetation and management (Fig. 1). The nature of the limitation can either be modified by man, when it is described as temporary, or is almost unalterable or permanent.

Figure 1. The main limitations to production from the uplands

LIMITATION	NATURE	
	PERMANENT	TEMPORARY
CLIMATE	Temperature, rainfall	Wind (shelter)
SITE	Topography, rockiness, access	Wetness (drainage)
SOIL	Stoniness, texture, parent material	Acidity (+ lime), Fertility (+N, P, K & trace)
VEGETATION	Weeds, eg. rush seeds	Low yield, poor quality (Replace + better species)
MANAGEMENT	Farm size - Business more often than area	Traditional - year-round set-stocked (Change by strategic control of grazing and breeding times with fence: feed: veterinary medicines)

( ) means of removing temporary limitation.

The relative size of the permanent and temporary parts of the histograms indicate that for hill sheep farming the limitations of traditional management is the least, and climate the most permanent of the five main areas of limitations.

Solutions

From the point of view of agriculture and hill sheep systems, which alone are dealt with in this paper, work at the Hill Farming Research Organisation (HFRO) has shown how the management limitation can be reduced using new strategies of grazing control which have become commonly known as 'two-pasture' systems (Eadie, 1970). The principle of the system is to improve a small area of the hill pasture and to graze this area intensively during lactation and early lamb growth (April-June) and prior to mating (August-November). The large area of unimproved rough grazing is used from June to August and from November onwards. It is also necessary to feed the pregnant ewe supplementary concentrate food in the six weeks (February-April) prior to parturition. These ideas have been tested successfully in several hill environments (Eadie et al, 1976a, b). Thus, it is necessary to alleviate some of the other 'temporary' technical disadvantages of hill and upland sites (see Table 4) so that the production of high quality herbage can be increased. This process is usually called land improvement. For example, lime can be added to raise the pH and provide calcium, fertilisers can be used to provide nitrogen, phosphorus, potassium and trace elements, missing or ineffective micro-organisms, e.g. Rhizobium, and soil fauna, e.g. earthworms can be introduced. Drains can be provided, pans can be broken by ploughing or sub-soiling, the surface layers of soil organic matter can be mixed with the underlying mineral soil by cultivation. The existing

vegetation can be destroyed and replaced by other species. Moreover, the impact of some of the permanent problems can be lessened by judicious selection for improvement of the less stony, moderately sloping, drier, more accessible areas of soil with favourable aspect and altitude for plant growth. All these treatments are expensive and their use is only justified if the responses in pasture production and quality are reflected in extra animal output and hence increased financial returns.

The main procedures to improve hill and marginal land have been known for many years as we will hear in the papers describing work on Exmoor (Horn, Maltby) and in Wales (Gwyn Jones) at this meeting. In the past much stress was laid on ploughing but since this tended to result in a big increase in the population of rushes, interest has increasingly centred on methods using surface seeding or minimum cultivations. This trend has been assisted by the development of better herbicides and by the desire to keep costs to a minimum.

A large number of techniques are available to ameliorate the condition of upland soils and to change to better species of grass (NOSCA, 1972; Frame, 1973; Newbound, 1974, 1975, 1976). They range in cost, speed of response and persistence of improvement from the provision of a fence alone to the latter plus full cultivation and the addition of lime, fertilisers and seeds (Table 6). On brown earth soils supporting acid grassland all the options are open depending on the availability of finance and the rapidity of response required: on deep peat soils with blanket bog vegetation only one improvement technique is usually possible. The indigenous vegetation is destroyed by burning,

flailing off or grazing, a fence is erected and grass and white clover seeds are oversown and trodden into the soil surface by the feet of animals after applying lime and fertilisers.

Table 6. The main processes of hill land improvement and their relative cost

Fence to control grazing	Cost relative to fencing
Alone	1.0*
+ herbidide - Dalapon (to reduce Nardus)	1.3
- Asulam (to control Pteridium)	1.7
+ lime and phosphorus	2.1
+ lime, phosphorus and white clover seed	2.2
+ lime, phosphorus, nitrogen, potassium, white clover and grass seed -	
by oversowing	3.2
by light cultivation	3.7
by ploughing	4.4
+ deep tile drainage	7.6

* The baseline was taken as £85, i.e. the gross cost per ha of enclosing an area of 8 ha with a cheap mains electric fence costing 60 p/m.

It is impossible to specify precisely the response to be expected in different situations because of the major impact of utilisation practices and their interaction with soils and climate etc. which vary from farm to farm and from paddock to paddock. However, an attempt to illustrate the likely effects on the main hill soil types is shown in Table 7. This illustrates the consequence of the low levels of utilisation (5-20 per cent on average) of unimproved hill vegetation in traditional systems of grazing management and the small responses in production and quality, to control of grazing at the better end (Agrostis-Festuca sp. poor) and the lack of response at the poorer end of the indigenous spectrum of hill vegetation (deep peat). Large responses in yield and quality from replacement of the indigenous vegetation by sown pastures occur irrespective of the starting vegetation.

Table 7. Likely responses of four indigenous hill vegetation types to pasture improvement by moderate grazing control alone or to the establishment of sown pasture with good control of grazing. Estimated average annual levels of DM (kg/ha) and seasonal range of digestibility (DDM %).

Indigenous sward	No fence		No fence		+ Fence and sown pasture	
	Yield	DDM	Yield	DDM	Yield	DDM
Acid grassland (sp. poor)	2500	76-40	2800	76-50	6000	78-66
Dry shrub heath (Calluna)	2000	60-40	2000	60-50	5000	78-66
Wet grass heath	1500	70-35	1600	72-55	4500	78-66
Bog	1400	68-40	1400	68-40	4000	78-66

after Newbould (1976)

There is considerable discussion on which grass species and varieties to have in the seeds mixture for hill land improvement and this will be discussed further by Munro (1978). However, it is widely accepted (Munro, 1970; Newbould and Haystead, 1978) that white clover is an essential part of the seeds mixture. This follows both because of the important contribution of the nitrogen fixed from the atmosphere (100-150 kg/ha/yr) and because the presence of white clover enhances the intake and nutritive value of the diet of grazing ruminants (Thompson and Raymond, 1970; Armstrong and Eadie, 1973; Thompson, 1979). To grow white clover in hill soils it is necessary to alter soil conditions as already described, and to ensure the correct Rhizobium are present, especially in deep peat soils (Mytton, 1975). Recent work suggests that the plant may also benefit from the presence of a matching mycorrhizal fungus in some situations (Hayman, 1978).

It would seem axiomatic that pastures improved at high cost by the methods described above, always should be maintained in a productive state for as long as possible. However many farmers wait until definite signs of sward deterioration, i.e. poor vigour and quality of herbage, loss of sown species, and/or weed incursion, before taking action. This is too late, extending the time of sward recovery and leading to additional losses of nutrients by leaching, and of course to loss of production, and reduction in herbage quality, for the grazing animals. From the management side, careful control of grazing to prevent the grasses heading, to provide a mid-season rest and to avoid excessive grazing in early spring and in late autumn are required. Fortunately, the strategy of the 'two-pasture' system which was designed primarily to meet the requirements of the grazing animal accords with this scheme of management. In addition it is necessary to maintain a soil pH of 5.5-6.0 by liming,

and sufficient available phosphate and potassium to retain the sown species of plants and particularly white clover. On average 5 tonne lime/hectare 3-7 years and 40 kg P and 40 kg K per hectare 2-5 years after the initial application are required; the variations in time depending on the initial nature of the soil and the annual rainfall. In some situations where white clover is slow to establish and to commence fixation of nitrogen it may also be necessary to add some nitrogen fertiliser (40 kg N/ha) in the first spring after sowing. More quantitative information is needed on the amounts of lime and phosphate required in upland environments to retain adequate levels of fertility for white clover and better grasses in improved pastures.

An example of the use of Soil Survey and analysis in Upland Management

The importance of using knowledge of soils and their potential for improved production of herbage either to enhance agricultural production or to ensure that 'pastoral farming and forestry' are brought together in such a way that benefits are obtained which would not otherwise be obtained (Cunningham et al. 1977) is well illustrated by work at the Lephinmore Field Research Station of HFRO.

The Mid-Hill and Barnacarry/Feorline projects at Lephinmore illustrate how some of these solutions can be applied in practice. Many other examples could have been quoted, especially those at Redesdale and Pwllpeiran EHF's, but that at Lephinmore is more familiar to us, and the dominant soils (deep peat) and vegetation (blanket bog) are arguably one of the poorest possible starting points (see Table 2).

Hill sheep (Mid-Hill)

The Mid-Hill project has a long history which has been described in detail by Nicholson et al. (1968) and Eadie et al. (1972, 1976b). In essence there is a large flattish, relatively high altitude exposed area of deep peat soil, a smaller steeply sloping area of shallow peat, peaty podsol and peaty gley soils, with a minute low-ground area of flat brown earth soil. There is no Land Use Capability map of Lephinmore as described by Bibby and Mackney (1972 and Bibby (1979) but if there were it would show small areas of Class 4 and Class 7 land, with the bulk falling into Classes 5 and 6. Use of the latter classes is often limited by slope, poor soil, altitude and wetness. A changed management system of the type already described has been applied in several phases, based on the enclosure of large areas of the Class 5 and 6 land in which the potentially most responsive soils in accessible dry positions, were treated with lime and P and the existing vegetation replaced by sown grasses and white clover to form a mosaic of improved pasture. Data collected by Bibby et al. (1976) indicated that in this situation the peaty podsol produced more herbage dry matter after this process of improvement than the peaty gley and both showed twice the response of the deep peat (Table 8).

The response to these improvement processes and the 'two-pasture' strategies of grazing management was shown both in animal production (Table 9) and in economic terms (Eadie et al., 1976b; Maxwell et al. 1976). The net internal rate of return on invested capital being about 17 per cent, which compares favourably with much of British industry where the rate is less than 10 per cent.

Table 8. Response in mean pasture production (kg DM/ha/yr) for three years (1973-75) to the establishment of sown pastures on the three major soil groups at Lephinmore, Argyll. (After Bibby et al. 1979).

	Peaty Podsol	Peaty Gley	Deep Peat
Indigenous	3007 ± 479	2979 ± 339	1532 ± 45
Sown pasture[1]	5413 ± 112	5032 ± 244	2084 ± 74
Response	2406 **	2053 ***	552 ***

** Significant at P > 0.01

*** Significant at P > 0.001

[1] Following application of:

Lime 7.5 t/ha: N 40 kg/ha: P 80 kg/ha: K 112 kg/ha: Cu 20 kg/ha : Co 2 kg/ha: Mo 0.1 kg/ha: with 20 kg/ha rye grass and 3 kg/ha white clover seed.

Table 9. Summary of production data from mid-hill project at Lephinmore

Total land (mainly blanket bog) = 444 ha
Improved pasture (separately enclosed) = 25 ha
Improved pasture (mosaic basis) = 20 ha (out of 96 ha)

	1969	1976
Ewe (Scottish Blackface) No.	339	458
Weaning percentage	85.0	91.3
Total weight (kg) :		
weaned lamb	7207	9701
wool	652	915
Weaned lamb (kg/ha)	16.2	21.8

after Eadie, Maxwell and Currie (1976b).

Hill sheep and forestry (Barnacarry/Feorline)

Prior to 1975 the area of the Lephinmore Field Research Station called Barnacarry was extremely difficult of access (Fig. 2). A flock of hill sheep was grazed there in the traditional manner but on a minimum attention basis. In 1975 the Forestry Commission acquired the neighbouring farm of Feorline (see Fig. 2). A soil survey of both farms, together with the types of responses to land improvement as

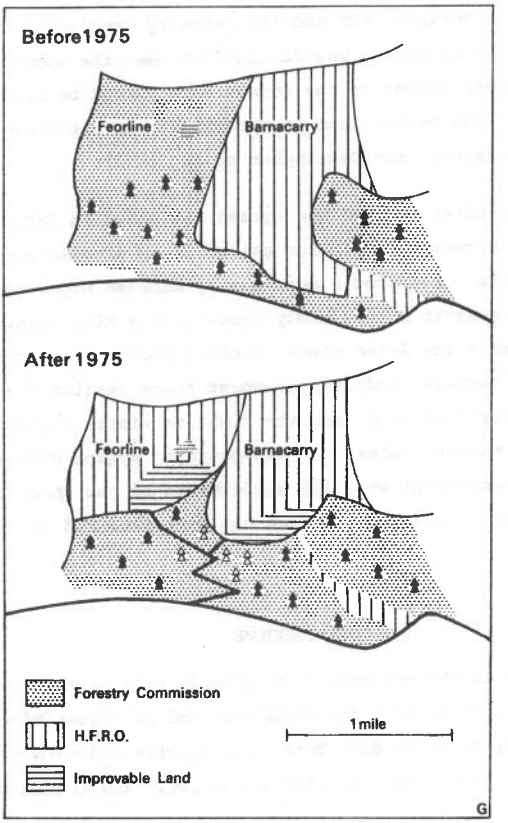

Fig. 2. Scheme of integration at Lephinmore, Argyll, agreed between H.F.R.O. and F.C. in 1975.

shown in Table 8 were used to help prepare a scheme of integration after full discussion between HFRO and the Forestry Commission (Maxwell and Eadie, 1979). This scheme was designed to meet the important criterion that the economic output of the integration should be better than the separate parts and better than if the whole area has been all agriculture or all forestry (see Cunningham et al. 1977).

A transfer of land was agreed as shown in Table 10 and Fig. 2). The Forestry Commission gained 21 ha of plantable land, saved on fencing costs and gained a more easily managed block of forestry. HFRO gained access to a previously inaccessible hill, saved some fencing costs, obtained a low-lying piece of peaty podsol (i.e. the highest potential for herbage production amongst those available in this area), obtained shelter from wind, and the right to winter sheep under cover of a stand of mature timber. A 'two-pasture' system will be set up following land improvement when the performance of the sheep flock under the traditional management practice has been measured to form a base line.

TO RESOLVE

Despite the evidence from schemes such as that described here, that soil problems of both the technical and political kind can be overcome, much remains to be done both to publicise and gain wider adoption of such practices and to make them more widely applicable and of lower initial cost.

Table 10. Integration of Agriculture and Forestry.
Land transfer and compensation arrangements between HFRO and FC at Lephinmore, Argyllshire.

TRANSFER OF LAND

151 ha Feorline (71 plantable) to HFRO

95 ha Barnacarry (92 plantable) to FC

Value Unplantable Land = 0 : Plantable Land = £200/ha

FC GAIN £4,200 of Plantable Land.

COMPENSATION

(1.8 km Extraction Road in existing timber 7 years early	£2,360
0.3 km Farm Road Access to Feorline) Access to Barnacarry)	£1.840

OTHER ARRANGEMENTS

FC to lease 27 ha of timber for winter shelter

Downfall to be left for sheep movement

Each party responsible for fencing on 'new' land

Maxwell and Eadie, 1979.

There is still a need to quantify the biological responses to land improvement over the range of hill and upland soil and vegetation types. It is particularly important to learn how to achieve and maintain land improvement by use of the minimum cost effective additions of lime, phosphorus and other fertilisers. Much remains to be clarified as to the plant material to introduce as Munro will describe, and the process of nitrogen fixation by white clover or alternative legumes needs to be optimised. The benefits of drainage to enhance utilisation of pasture are well known but there is little evidence to show its effect on plant production. Some new problems have occurred following the application of lime in that trace element imbalances, particularly of copper and selenium have come to light. These must be understood and ways of avoiding them devised.

Further information is required on the distribution of hill and upland soil types so that the relative potential for response to improvement for different land units can be ascertained. The methods to be described by Bibby (1979) will be appropriate here and it is encouraging that schemes to survey large parts of the uplands of England, Wales and Scotland are now in progress. The application of Land Use Capability mapping for Agriculture and Forestry as a follow-on to the soil vegetation surveys will be of great value to planners. This regional or national activity does not eliminate the need for an individual farm or site survey by experts to assist frarmers plan two-pasture systems or devise schemes of integrated land use.

Politically, ways must be found to give farmers and others who live and work in the uplands confidence in the future so that they can be persuaded to borrow money and raise the productivity of individual farms, estates and valleys so benefiting the nation by increasing self-

sufficiency in sheep meat and wool production. Clear national targets for both forestry and agriculture production are required, together with a clearly stated policy on how and where these should be achieved. The Department of Agriculture for Scotland now holds back small parts of farms, primarily the enclosed permanent pasture or in-bye, from forestry so that they can be added to other areas when they come on the open market to form viable farms. There is need to make this a definite policy and to provide further funds for such a land holding body on a Great Britain basis. There is need to devise schemes, especially in National Parks or other areas of natural beauty or scientific interest, to compensate farmers who are unable to apply and benefit from modern land improvement procedures. This may be particularly appropriate in areas like Exmoor as will be described by Horne (1979). The problems of common land in England and Wales and of crofting tenure in Scotland also need to be resolved.

Conclusions

Hill soils have problems, both of the technical and the socio-political land use type. Many of the former can be alleviated, resulting in sizeable increases in the production of store animals based on the efficient, more intensive use of pasture or in the quality and yield class of timber. Increases of this type in the output of agriculture and forestry occur over very contrasted time scales. Since both activities are in competition for the more responsive hill soils it is extremely difficult to choose between them. However, a policy to intensify hill farming and to integrate agriculture and forestry in the manner described here should enable other uses of hill land (amenity, tourism, water collection and conservation) to co-exist because of the

maintenance of a viable social infrastructure in the remoter upland areas of the UK. This will need to be supported by clear criteria and rules for permitting change of use from agriculture to forestry, by the acquisition of physical resource information, especially about soils, and the setting of targets for production of both trees and agricultural products. The planners may need the power to purchase and hold hill land until viable agricultural units can be formed by amalgamation. The achievement of these objectives should allow the uplands to be used for production of food and timber, to provide recreation and full enjoyment of natural beauty without damaging the environment and without prejudice to the options of future generations.

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SOIL SURVEY AND ITS INTERPRETATION FOR AGRICULTURE IN THE WEST HIGHLANDS

J. S. Bibby
Soil Survey of Scotland

Introduction

Soil survey is essentially concerned with investigating the distribution of soil characters and subsequently displaying them for those interested in the nature of our most important natural resource, land. The number of ways in which data can be stored and displayed is increasing rapidly and changes in soil survey techniques are occurring as a consequence. This paper is concerned firstly with describing the methods of survey currently in use in an area of mountainous terrain (Western Scotland) and secondly explaining how the results of soil survey are being interpreted for use in land planning.

Soil Survey in the West Highlands

If soil characters were arranged in a random, unrelated manner, soil survey would adopt very different methods to those traditionally used. Fortunately, however, many of the principal soil characters are linked and these links are expressed in the landscape as pattern. Landscape patterns have been studied for many years from a variety of

points of view (the literature is voluminous), and are frequently used in traditional or free soil survey procedures for placement of soil boundaries. Many landscapes exhibit fairly simple patterns; the lowlands of England (except in areas where there has been particularly complex geomorphological history usually involving fluvial or marine processes) and hill areas such as the Southern Uplands are examples. In the Western Highlands of Scotland, soil characters change drastically within short distances reflecting landscape change and cannot often be resolved even at map scales as large as 1:10,000. Yet, nevertheless, it is possible to detect some overall patterns, even though the detail is complex, and these patterns are capable of identification on air photographs. A recognition of the major patterns of the West Highland landscape using the criteria listed in Table 1 and the rapid translation of such units to a map by air photo interpretation is the first stage in mapping.

Table 1. Criteria used in establishing soil complexes

Rock type Drift type	———	Parent material
Nature of surface horizons	———	Organic or Mineral
Major soil subgroup Associated major soil subgroups		
Slope	———	$>15^{o}$ or $<15^{o}$
Amount of rock outcrop	———	Rock classes (USDA 1951)
Climatic zone	———	Bioclimatic maps (Birse 1971)

Table 2. Percentages of Major Soil Subgroups in three complexes on basalt

	Brown Forest Soils Free & Imperfect Drainage	Podzol		Gley		Ranker		Peat	Alluv.	Rock	Other	
		Humus Iron	Peaty Gley	Humic	Peaty	Brown	Peaty	>45cm				
Knockan Complex	76	2	1	1	1	11	0	1	3	2	2	149 sites
Mishnish Complex	3	39	16	2	16	3	7	2	2	3	2	61 sites
Cruachan Complex	0	0	14	1	25	1	7	45	0	7	0	167 sites

Table 3. Percentages of major soil subgroups included within Knockan complex

	Brown Forest Soils Free and Imperfect drainage	Podzol		Gley		Ranker		Peat	Alluv.	Rock	Other	
		Humus Iron	Peaty Gley	Humic	Peaty	Brown	Peaty	> 45cm				
Isle of Mull Grid	76	2	1	1	1	11	0	1	3	2	2	149 sites
Isle of Mull Sample Area	65	0	2	1	2	20	2	2	3	3	0	140 sites
Morvern. Sample Area	63	5	0	3	3	17	5	1	1	1	1	100 sites

Table 4. Comparison of similar complexes on different rock types

	Brown Forest Soils Free and Imperfect drainage	Podzol		Gley		Ranker		Peat	Alluv	Rock	Other
		Humus Iron	Peaty Gley	Humic	Peaty	Brown	Peaty	> 45cm			
BASALT (Knockan cx)	63	5	0	3	3	17	5	1	1	1	1
GRANITE (Tearnait cx)	23	23	5	4	14	8	7	3	7	6	0
GRANITE (Funtack cx)	0	2	9	0	38	0	10	39	2	0	0
SCHIST (Asapol cx)	0	4	17	0	38	0	13	27	1	0	0

More detailed work is required to demonstrate the difference between various patterns and to describe them in soil terms. The obvious way of proceeding is by a statistically-based investigation; during the survey of the Isle of Mull 893 sites were visited on a 1km grid pattern. Table 2 indicates the results obtained for three soil complexes belonging to one soil association* (Darleith Association). The complexes are significant different at the 0.1% level.

A check was conducted for any bias introduced into the data due to the method of amending air photo interpretation lines at the same time as collecting the grid data. Knockan complex was selected for the trial and all 1km National Grid squares containing more than 50% of the complex listed. Seven areas were selected randomly and twenty points within each, again randomly distributed, were identified in the field. Soil and site data was collected from each site. Table 3 provides a summary of the major soil subgroups. Data for further sample area work undertaken on nearby Morvern are also included. No significant differences occur between the grid samples and the sample area methods.

Interpretation of aerial photography and the application of statistical techniques to map units gave some interesting results when it was extended to a wider range of parent materials (Table 4). A comparison between the complexes which show the greatest development of freely drained soils on a basic parent material (basalt) and on an acid one (granite) indicates a sharp increase in podzolic soils in the latter. Indeed many of the soils classed as brown forest soils on the granitic parent materials are brown podzolic rather than the more usual

* *A Soil Association is defined as a group of soils derived from similar parent material but varying in profile morphology as a result of other soil-forming factors.*

brown forest soil of the basalts. An increase in the amount of peaty gley and of rockiness in the granite is also apparent.

Two complexes essentially peaty in nature and both on acid parent materials are compared in the lower part of Table 4. It can be seen that both are very similar in content of major soil subgroups except that the granite has a higher peat percentage and the schist a higher podzol content. This is a reflection of the ridged nature of the pattern in the schists compared with a smoother more tabular form of weathering in the granite, which shows in analyses of site factors.

The range of soil types is greater in the two complexes shown in the upper part of Table 4 than in the peaty complexes of the lower part. This is a consistent feature of similar types of soil complexes from a wide range of parent materials. Although peaty soils develop in hollows and flush channels in the lower areas of the landscape where mineral surface soils are common, especially where drifts are derived from acid rocks, mineral soils are not often found even as minor components in the zones where peaty soil complexes are dominant.

The mapping units found on any rock type and its derived drifts (soil association) depend on a variety of geological, geomorphological and climatic relationships and give strong and consistently recognisable patterns. The recognition and investigation of these patterns forms an integral part of soil survey in the Western Highlands. Information is becoming available on the distribution of the major soil groups and subgroups between and within mapping units (soil complexes or soil-landscape units) and on the variation of morphological characteristics within each major soil subgroup. The relationships between these characteristics and site factors can be more fully described to aid prediction.

Interpretation

Land capability classification was introduced in the lowlands of Scotland in 1966, subsequently adopted as part of the soil survey programme and extended to map sheets currently nearing completion. Three sheets were published in 1969 and of these the Carrick-Girvan sheet (Bown and Heslop 1969) covered appreciable areas of hill ground. It is clear that from the beginning the land use capability system for agriculture has been used to classify hill land and in the monograph (Bibby and Mackney 1969) illustrations show its application to hill land.

For some time the keys which accompanied the land capability maps were simple in form. In view of the interest of bodies such as the Highlands and Islands Development Board in using capability interpretations to act as an input in the formulation of development plans for the Island of Mull (H.I.D.B. Special Report 10, 1973), attention was focussed on land suitable for reclamation and on the quality of hill grazings. Criteria were introduced, based on the physical characters likely to affect management during and after reclamation and on the composition and distribution of plant communities, which would assist planning authorities to make more informed judgments on the potential of such land. Table 5 reproduces the key to the land capability map of the Isle of Mull. The definitions and description of classes are those contained in Technical Monograph 1, Land Use Capability Classification (Bibby and Mackney 1969). In the hill land areas of Scotland the principal involvement is with Classes 4 to 7.

Land included in Class 4 is that in which an arable element is possible although the economy is principally dependent on grass production. In hill areas of Western Scotland such land is easy to

Table 5. Land-Use Capability for Agriculture

Class	Sub-Class	Management Characteristics		Area (hectares)	Sub-Class (% of total)	Class (% of total)
4. Land suited to the growth of arable crops and grass in rotation	s	Sandy or gravelly soils with poor fertilizer retention capacity or loamy soils with rooting depth limitations. Some risk of winter poaching by stock	Moderately suited to arable use	1000	1.1	1.6
	w	Soils with imperfect and poordrainage which affect timing of cultivations and are liable to poach		400	0.5	
5. Land suited to use as grassland and improved pastures	gs	Intense patterns of rock and shallow soils cause cultivation and harvesting difficulties. Small areas (<2 hectares) are cultivable	Highly suited to reclamation	13100	14.5	21.6
	s	Very gravelly soils unsuitable for regular cultivation. Harvesting difficulty less than 5gs but fertilizer retention and available water capacities are low.		400	0.4	
	se	Sandy soils (machair) unsuitable for regular cultivation and with low fertilizer retention and available water capacities. Severe wind erosion risks		300	0.3	
	gw	Intense variation in pattern of soils, rock and slope. Organic surfaces subject to poaching	Moderately suited to reclamation	800	0.9	
	w	Organic surface soils and wet subsoils give severe poaching risks and grassland management problems. Field drainage necessary for effective control		300	0.3	
	wg	Rocky outcrops, peaty surfaces and wet subsoils provide vere severe management problems. No field drainage possible.	Marginally suited to reclamation	4700	5.2	

Table 5. Land-Use Capability for Agriculture (continued)

Class	Sub-Class	Management Characteristics		Area (hectares)	Sub-Class (% of total)	Class (% of total)
6. Land with severe limitations which confine its use to rough grazings	g	Slopes too steep for mechanised improvement practices. Bent-fescue grassland with frequent bracken infestation	High hill-grazing value	4900	5.4	71.4
	gw	Slopes too steep for mechanised improvement. Mixed vegetation communities with Atlantic heather moor, bent-fescue grassland and subsidiary bog heather moor.	Moderate hill-grazing value	9100	10.0	
	ec	Hill summits and slopes between 425-675m. Severe erosion risks. Exposure limits grazing season. Mountain heath rush-fescue grassland and upland blanket bog communities		3300	3.7	
	sg	Rocky land with moist Atlantic heather moor on knolls and bog communities in hollows. Some patch-reclamation may be possible	Low hill-grazing value	3500	3.9	
	wg	Severe wetness and patterns of rock and soil. Blanket bog and bog heather communities dominant. Some patch-reclamation may be possible.		31300	34.6	
	w	Peat soils > 50cm deep have severe wetness problems. Bog communities dominate but some locally better grazing may be available in flushes.		12500	13.8	
7. Land of little agricultural value	s	Rock, cliff and active scree. Patchy vegetation cover.	Little grazing value	4700	5.2	5.3
	e	Sand dune communities or oroarctic dwarf shrub and moss heath communities - mainly brown bent-woolly fringe moss heath		100	0.1	

define on soil and site characteristics except in some areas were pattern limitations (e.g. rock) occur in otherwise useful soils. For 1:50,000 scale mapping purposes an additional guideline has been introduced that any area of land mapped within Class 4 should be at least 2 hectares (5 acres) in extent.

Class 5 is defined as land on which reclamation is possible. The definition of reclamation is open to some debate but as used in land capability classification the use of machinery must be feasible for the reclamation process. This can cover a range of techniques from full cultivation to surface seeding. The principal problem involved in judging what is feasible involves assessing the technical possibilities, the costs and, most importantly, whether a good manager would commit resources to it within the context of trends within the industry in the past ten years and the possibility of developments in the next ten. Discussions with agronomists and other members of the farming community are necessary in coming to a decision and often involve the establishment of local rather than national guidelines. Those used in the Mull survey were that reclaimable land would lie below 750 feet (228m) and have less than 70 inches (1778mm) rainfall. Slopes would be less than 15^{o}. These guidelines have been elaborated during the more recent work in Ardnamurchan and Morvern. Suitability for reclamation is expressed in three broadly based groups as highly, moderately and poorly suited. The differences between the groups are based on soil drainage and site characteristics which in areas of high rainfall reflect costs of establishment, continuing maintenance and risk of damage by stock trampling. Freely drained soils are, in general, highly suited for reclamation and poorly drained and peaty soils are poorly suited.

On land defined as not reclaimable (Class 6) grazing is governed by current vegetation cover. Although it is possible by fencing and grazing management techniques alone to encourage some species at the expense of others, such methods are not extensively used in the West Highlands and it was decided not to include land where this was the sole possible method of improvement in Class 5. It is obvious that the basis of any assessment of grazing value is a sound phytosociological classification; the botanical section of the Soil Survey of Scotland has been researching appropriate classification methods for many years. Their work, together with that of McVean and Ratcliffe (1962) is of increasing value. An interpretation of each of the major plant communities, termed relative grazing value, was established using a method devised by Klapp, König and Stählin (1953). Each species in a given community is allocated a rating based on an assessment of its dry matter production, digestibility and palatability. The rating is multiplied by its percentage presence in the community (an average of many site recordings) and the totals summed and divided by 100 to arrive at the relative grazing value.

In view of the lack of vegetation maps in Scotland, instruction and guidance is given to soil surveyors in the recognition of the major plant communities. The botanical assessments and their interpretation are checked by the botanists during correlation visits. The expression on the map is in terms of three groups of relative grazing values >4, 4-2, <2 termed good, moderate and poor. A good correlation between these methods and the views of the agricultural community and research workers has been realized, although further work on refinement is necessary.

Land unsuitable for grazing is grouped in Class 7. The principal limitation operating in hill areas is one of climate governing the distribution of vegetation communities. The climate map series of Scotland (Birse et al 1970, 1971) show the distribution of the most severe conditions. The limit of Class 6 has been established at the lower limit of the oroarctic zone (Birse 1971, King 1977), which is dominated by moss, rush-heath and dwarf shrub communities whose biological productivity is very low, the growth season short and exposure severe. Class 7 is also used in other instances, for example, where rockiness is very severe, danger to stock exists or industrial dereliction occurs.

This brief review of soil mapping and interpretative procedure in the Western Highlands has outlined the development of a system of air photo analysis of complex patterns of soil, site and vegetation characteristics to form adequate mapping units for the production of maps at 1:63,360 or 1:50,000 scales, and the subsequent investigation of these patterns. Since soils which cannot be mapped separately at large scales present insuperable difficulties for farmers to manage separately, several soils must be utilized together as a management unit. Such management units have close relationships to the soil complexes and the mapping units have direct practical significance which is reflected in the land use capability interpretation. Although land suitable for production of conserved grass and forage crops and land which can be reclaimed to give improved grass production is vital to the future of agriculture in the hills and uplands, this must necessarily be coupled with the better areas of natural grazing. The method used for assessing relative grazing value has been described. User organisations in Scotland have been extensively consulted and professed themselves satisfied with the systems used. As work progresses better guidelines and more accurate

assessment procedure are continually being developed. The evaluation of land capability classification in the hill areas is a continuation of the system developed for low ground and harmonious with it.

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REPORT of the field meeting 31 May 1979 Pwllpeiran

W.S.D.G. ANNUAL REPORT 20.

PASTURE PLANT BREEDING AND HILL LAND IMPROVEMENT

J.M.M. Munro, D.A. Davies, T.E.H. Morgan and N.R. Young

Welsh Plant Breeding Station, Aberystwyth

Background

Land improvement, with its considerable nutritional, visual and economic benefits, has been one of the main features of the Welsh hill farming scene for many years and its impact is becoming more apparent. During the last 25 years alone, over 100,000 hectares of rough grazing, 10 per cent of the total hill area in Wales, have been improved (MAFF, 1952-77) and largely as a consequence, sheep and beef cattle numbers have increased overall by some 300 per cent. Comparison with Scotland shows that there are now more hill ewes in the Principality on less than one quarter of the land resource (Table 1).

Table 1. Land improvement and hill livestock numbers, 1977.

Country	Hill area million ha	% improved grazing	Hill ewes million	Hill cows million
Wales	0.81[‡]	52[‡]	2.5*	0.15*
Scotland	3.74[‡]	6[‡]	2.3[o]	0.46[o]

Source: [‡]National Economic Development Office (1973);
*Welsh Office Agricultur Department (1978);
[o]Department of Agriculture and Fisheries for Scotland (1978).

With good future prospects in the sheep industry (HMSO, 1979) continued expansion in land improvement will undoubtedly take place, although with changed emphasis. Because of a declining area of unimproved drier soils, new development will be based on more intensive use of existing ploughed and reseeded land through increased fertiliser use and better management accompanied by pioneer surface seeding of higher, wetter mountain areas (Munro, 1973a; Jones, 1979; MAFF, 1979).

Because of the importance of hill farming in the Welsh economy, the Plant Breeding Station has had an involvement with many aspects of land improvement for 60 years. Before founding the Station in 1919, Sir George Stapledon conducted an ecological survey of 400,000 ha of grassland in north Cardiganshire, from which he formulated new ideas in management and plant breeding which have had a world-wide effect on pasture improvement and livestock production. The Station ran the Cahn Hill-Improvement Scheme (Griffith, 1937), based on land now partly included in the Ministry of Agriculture Pwllpeiran Experimental Husbandry Farm, between 1933 and 1947, demonstrating for the first time that large scale reclamation was a practical proposition. From 1947 to 1963, hill research was restricted by financial stringency but one major animal production trial was completed (Jones, 1967) which showed that, over 14 years, a reseeded sward, based on Aberystwyth grass and clover varieties produced 175 per cent more animal liveweight gain than an unfertilised native *Festuca/Agrostis* pasture.

Preliminary Screening of Species and Varieties

In the thirties, breeding of a complementary range of varieties was in vogue and hill trials were carried out in the Aberystwyth area with a wide range of species including *Lolium, Dactylis, Phleum, Festuca, Agrostis, Holcus, Poa, Alopecurus, Anthoxanthum, Trifolium* and *Lotus*

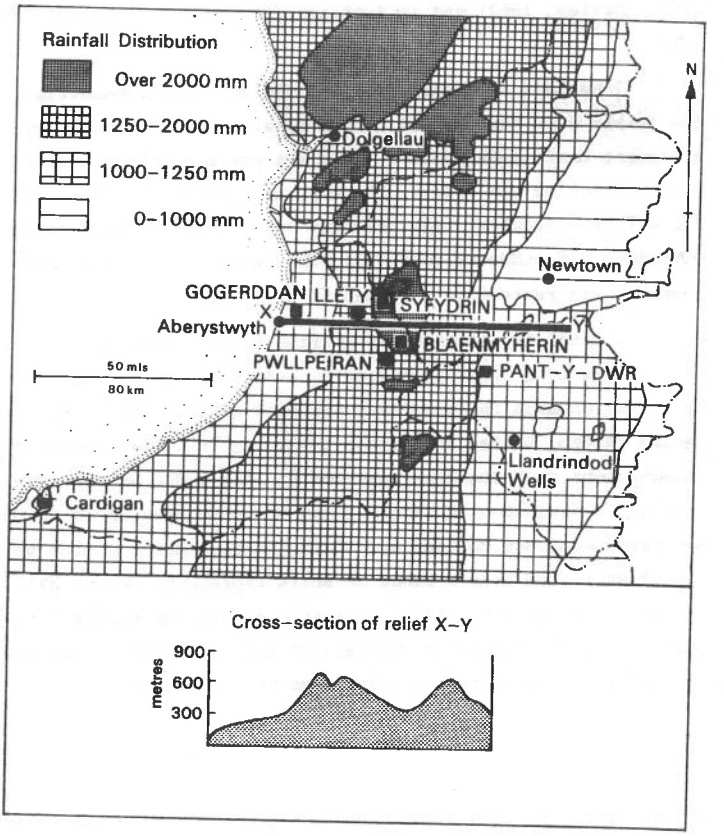

Fig. 1. Testing centres in mid-Wales

(Thomas, 1936; Davies, 1940). Value ratings were given (Table 2). Further evaluation took place after the war both in Wales (Walters, 1953; Davies, 1962) and in Scotland (Hughes and Nicholson, 1962; Hunt, 1964).

Methods of seeding and the native plant communities on which the trials were carried out varied considerably but there was general agreement that, under wetter, more extreme conditions, perennial ryegrass was inferior to red fescue, timothy and tall fescue. Because of the variation in results, high priority was placed on the monitoring of environmental factors affecting growth (Hughes, 1963) when hill land research was revived in the Station in 1961.

Initially testing was carried out at three small sites on farms with contrasting climatic and soil conditions (Hughes and Munro, 1964). From 1963 onwards the programme has been centralised at Pant-y-dŵr Hill Centre (Munro, Davies and Morgan 1973) near Rhayader in Powys (Fig. 1). Observations on herbage performance at Pant-y-dŵr now cover a total of nearly 250 varieties of 19 grass and 6 legume species of European, Mediterranean, New Zealand and North American origin. The varieties have been tested over a range of soils representative of hill types in mid-Wales (Rudeforth, 1970). Climatic conditions experienced cover 18 years including the severe winters of 1962-63, 1968-69 and 1969-70 and more recent mild winters and dry summers (Fig. 2).+

+ The winter of 1978-79 has been the coldest since 1962-63 and the spring amongst the latest in this century.

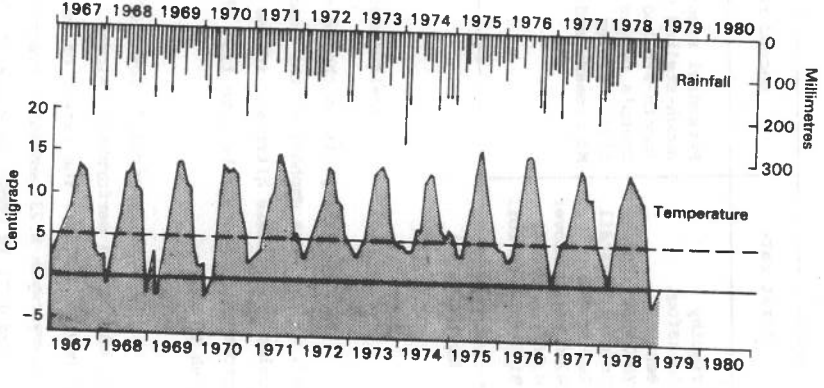

Fig. 2. Rainfall and temperature. Pant-y-Dwr 1967-79.

Table 2. Ratings of species for use in hill reseeding mixture (1937-40 trials)

First rate	Second rate	Third rate
Timothy Cocksfoot Bent Yorkshire fog Crested dogstail Red fescue Wild white clover Wild red clover Birdsfoot trefoil	Perennial ryegrass Rough-stalked meadow grass Smooth-stalked meadow grass Sheep's fescue Alsike clover Montgomery red clover	Italian ryegrass Meadow fescue Tall fescue Meadow foxtail Sweet vernal Canary grass Other red clovers Subterranean clover

Davies, 1940

Environmental Limitations

Previous reports to the Welsh Soils Discussion Group (Munro, 1967, 1973b) have emphasized the importance of soil limitations, particularly available nitrogen, in the success or failure of hill land improvement. A comprehensive list of environmental limitations is given in Table 3.

Climate, especially low soil temperature, is the major restriction on pasture performance (Alcock, Lovett and Machin, 1968; Munro and Davies, 1973). The extent of annual variation in yield of swards of Aberystwyth S.23 perennial ryegrass receiving 270 kg N/ha between 1967 and 1971 is shown in Figure 3. On freely drained brown earth soil at Pant-y-dŵr, yield ranged from 4000 to 6900 kg dry matter/ha, reflecting the influence of winter frost damage, late springs and summer drought (Munro, Davies and Morgan, 1973). On stagnogley, the equivalent

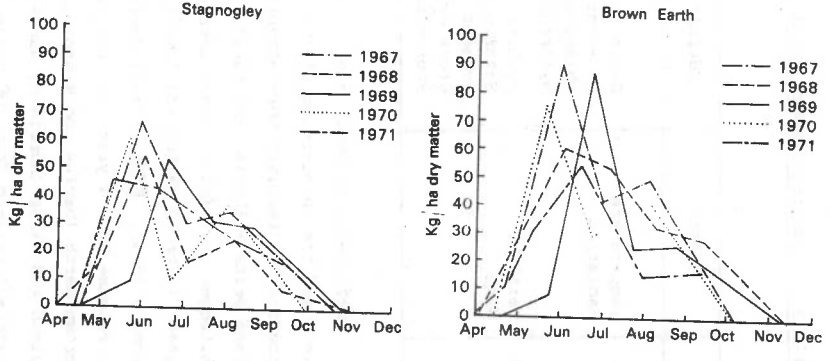

Fig. 3. Growth of S.23 ryegrass. Pant-y-Dwr 1967-71.

range was 3500 to 5000 kg/ha. The highest yields recorded were in 1978, a year of abundant summer rainfall and mild winter (8200 kg and 7200 kg on the respective soils).

Table 3. Limiting factors in hill environments

	Climatic	Edaphic	Biotic
Low	Temperature Radiation	Depth Nutrients Rhizobium Mycorrhiza	Stocking (summer) Fertiliser input
High	Rainfall Wind	Acidity Waterlogging Drought Frost heaving Stoniness	Stocking (winter/spring) Diseases and pests

Deficiency of available nitrogen is the key soil factor affecting yield and the interaction of soil, clover and fertiliser nitrogen contribution has received more attention at Pant-y-dŵr than elsewhere in upland Britain (Davies and Munro, 1974; Munro and Davies, 1974). Soil nitrogen availability decreases with increasing waterlogging and is highest in brown earths and lowest in stagnogleys (Munro, Davies and Thomas, 1973). From a newly reclaimed gley at Pant-y-dŵr, average annual release over 4 years was only 2 kg N/ha compared with 62 kg from brown earth (Davies and Munro, 1974). Under lowland conditions in England and Wales (Morrison, Jackson and Williams, 1974; Richards, 1977) average release from 108 sites was 101 kg N/ha with a maximum of 275 kg N.

Until recently, inadequate maintenance fertiliser dressing has been the main factor under farmer control contributing to rapid deterioration of reseeding on poorer soils (Ellison, 1946; Davies, 1968a; Reith, 1973). With good economic returns from hill products in the last few years, this problem has become less acute although lime, phosphate and potash application need constant monitoring. According to the Survey of Fertiliser Practice, 1942-1976 (Church and Lewis, 1977) appreciable increase has taken place in nitrogen use on upland farms in England and Wales from 2.5 kg N/ha in 1950-1952 to over 50 kg at present. Trends in overall fertiliser use are shown in Fig. 4.

Evaluation and Selection Characteristics

In a recent review, Newbould (1974) has conveniently listed the main agronomic and nutritional characteristics required in plants for use in hill land improvement. Over the years workers have placed emphasis on establishment vigour, winter-hardiness, tolerance of low soil fertility and extremes of wetness or drought, evenness of growth and high feeding value. All these criteria have been used in evaluation at Pant-y-dŵr (Munro, in press) and as a result many species and varieties have been eliminated from further consideration.

Slow seedling establishment was the principal reason for eliminating tall fescue, smooth-stalked meadow grass, canary grass, red clover and trefoil (Munro and Hughes, 1968). Lack of winter-hardiness resulted in the rejection of cocksfoot varieties, Mediterranean tall fescues, Yorkshire fog, rough-stalked meadow grass and Italian ryegrass on wetter soils.

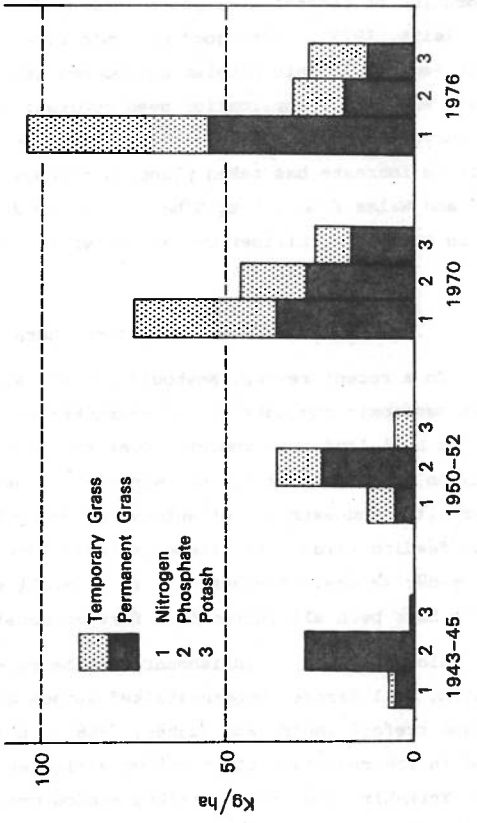

Fig. 4. Fertiliser use in the uplands.

In hill sheep farming systems, good early spring growth of grass is vital to the whole cycle of animal nutrition (Russell and Eadie, 1968; Russel, Doney and Eadie, 1978). The dominant indigenous species in Wales, *Molinia*, does not commence active growth until June and only continues growth for 3 months. Existing varieties of most grasses found on better hill soils, ie. bent, sweet vernal, crested dogstail and smooth-stalked meadow grass, were also markedly seasonal; producing less than 250 kg DM/ha in early May (Table 4).

Table 4. Tiller survival and spring production 1962

Species	Syfydrin			DM production (kg/ha) 4 May 1962
	Variety	Tillers/m^2 Aug.1961	May 1962	
Agrostis tenuis	Br	3770	7880	200
Alopecuris pratensis	S.55	1220	2840	510
Anthoxanthum odoratum	Bs2811	5340	7720	100
Cynosurus cristatus	N.Zealand	2630	3580	-
Dactylis glomerata	S.37	1840	400	-
Festuca arundinacea	S.170	1750	2730	690
	Mediter.	3250	540	-
Festuca rubra	S.59	2420	6740	600
Holcus lanatus	Commercial	6150	7220	-
Lolium multiflorum	S.22	3530	1440	110
Lolium perenne	S.23	3350	6270	270
	S.24	3800	3120	460
Phleum pratense	S.48	4400	5240	1010
Poa pratensis	S.63	2340	6420	190

Source: Hughes and Munro (1963)

By contrast S.59, a red fescue bred at Aberystwyth, produced 600 kg/ha, more than most of the perennial ryegrasses tested, while S.48 timothy exceeded 1000 kg/ha.

Although pest and disease incidence among pasture plants in the hills is less common than in the lowlands, leaf spots (*Selenophoma* and *Drechslera*) were prevalent on bent and crested dogstail. Animal acceptance was low on dogstail, sweet vernal and certain overseas varieties of red fescue.

Yield Consistency

As a result of preliminary screening and previous experience in Wales and Scotland, emphasis on species for further evaluation for surface seeding has been concentrated on red fescue, timothy and ryegrass, together with white clover. Less stringent criteria were used in the assessment of material for conservation and grazing on drier, lower land and these will be discussed later.

In the earliest detailed studies, carried out at Syfydrin, S.59 red fescue gave higher yields than S.23 ryegrass and S.50 timothy at three levels of lime application (2.5, 5.0 and 7.5 t/ha) (Table 5). From 1966-69 at Pant-y-dŵr, S.59, S.23 and S.48 timothy were compared for yield and chemical composition at three levels of nitrogen application (0, 135 and 270 kg N/ha) on brown earths and stagnogley. The red fescue gave the highest yield each year at all nitrogen levels (Fig. 5) and also had the greatest proportion of spring and autumn production (Table 6). These results, reflecting the wide tolerance of red fescue to adverse climate and soil conditions are substantiated by ecological studies at the Hill Farming Research Organisation (Rogers, King and Davies, 1974).

Table 5. Comparative yields at 3 lime levels

(S.59 high lime yield = 4000 kg DM/ha).

	Low lime	Intermediate lime	High lime	Mean
S.59 Red fescue	72	99	100	90
S.50 Timothy	56	62	77	65
S.23 Ryegrass	53	74	73	67

Source: Munro (1966)

Table 6. Seasonal yield as a percentage of annual production

	Brown Earth			Stagnogley		
	Spring	Summer	Autumn	Spring	Summer	Autumn
S.59 red fescue	27	45	28	24	48	28
S.23 ryegrass	21	54	25	18	57	25
S.48 timothy	26	51	23	22	54	24

Source: Davies (1971)

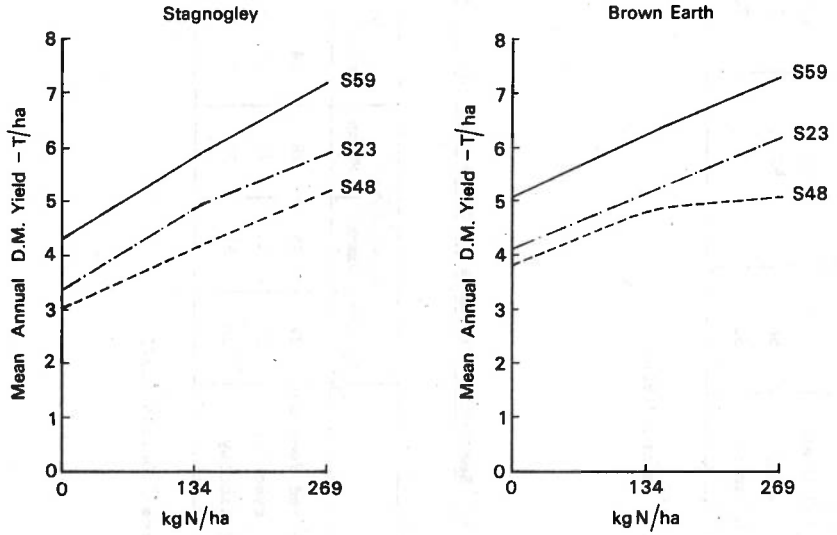

Fig. 5. Grass production. Pant-y-Dwr 1967-69.

In addition to species differences there are wide varietal differences in annual yield. Among 20 perennial ryegrass varieties recommended by the National Institute of Agricultural Botany and new Station material, harvested over the 5 years 1974-78 at Pant-y-Dŵr, average yield varied from 4540 to 6000 kg/ha with the coefficient of variation of yield within a variety ranging from 37 to 61 per cent (Table 7). More emphasis must be placed on consistency of yield under hill conditions as it will become of vital importance as systems become more intensive in the future.

Table 7. Yield of perennial ryegrass varieties

Variety		Mean DM yield (kg/ha)	Index S.23=100	Range (kg/ha)	C.V. (%)
Early	S.24	5850	105	3690-9820	41
	Premo	5780	104	4010-9800	41
	Cropper	5730	103	3610-9360	40
	Gremie	5490	99	3220-9790	48
	Barvestra	5110	92	2500-9480	52
Medium	S.101	5930	107	4100-9530	37
	Ba8679	5900	106	3570-9950	41
Late	Perma	6000	108	3500-10030	41
	Mascot	5590	101	3590-9220	38
	S.23	5550	100	2960-9640	46
	Cawdor	5540	100	3500-9820	45
	Silian	5460	99	3540-10130	49
	Melle	5460	99	3100-9450	44
	Midas	5420	98	2880-9150	43
	Barpastra	4540	82	1360-8970	61

Herbage Quality and Animal Production

The agricultural value of any herbage plant lies in its capacity to supply the nutritional requirements of the animal. This is particularly important in the hills where the natural vegetation is adapted to an impoverished environment and the dominant species are low in energy, protein, digestibility and most minerals (Munro, Davies and Morgan, 1973; Black, 1967; Trinder, 1975; Grant and Campbell, 1978).

At any early stage in variety evaluation, in small plot cutting trials, *in vitro* digestibility, nitrogen and content of the major minerals, Ca, Mg, K and Na are assessed. This preliminary screening highlighted possible shortcomings in red fescue. In 1967, average digestibility (DOMD) of monthly cut herbage of S.59 was only 64.5 per cent compared with 69 per cent in S.48 timothy and S.23 ryegrass and 74 per cent in mixed ryegrass/clover swards. The seasonal pattern is shown in Fig. 6.

Considerable resources are required for meaningful animal production studies and only two major experiments have been conducted at Pant-y-dŵr. In both, herbage intake has been assessed on a weekly basis under a pre- and post-grazing sward sampling technique (Walters and Evans, 1979). Analysis of the samples for digestibility, water-soluble carbohydrate and mineral content followed. Ewe and lamb performance was measured by regular weighing.

In the first comparison, of S.59 red fescue and S.23 ryegrass (Davies, 1975a, 1975b), poor gains on the fescue in mid-summer after a good start in spring were associated with a rapid fall in digestibility assocuated with early heading and stem formation. Over the period 16-30 June 1969 intake of digestible organic matter was 12 per cent lower than on ryegrass. Over the 130 day trial period, lamb liveweight gain

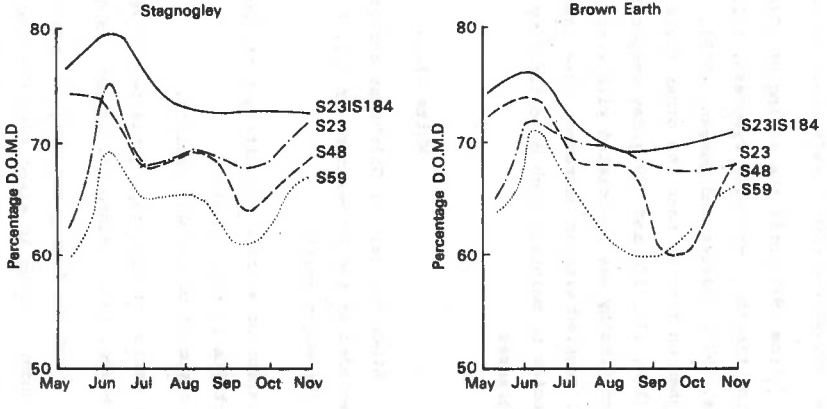

Fig. 6. Seasonal pattern of digestibility. Pant-y-Dwr 1967.

was similar on the two species but ewes on fescue lost 50 g/day compared with a 15 g gain on ryegrass. Levels of water soluble carbohydrate, sodium and cobalt were lower in the fescue.

From 1975 until the spring of 1978, a second trial took place comparing timothy, perennial ryegrass, tall fescue and cocksfoot (Davies, 1977; Davies and Morgan, 1979). Daily lamb liveweight gain was higher on timothy than the other three grasses in each year of the trial (194, 170, 170 and 159 g/day respectively (Fig. 7). Good performance on timothy was associated with winter hardiness and early spring growth, coupled with an extremely late date of heading, which enables the species to maintain high digestibility over a longer period than the other grasses.

White Clover

Since the days of Gilchrist and Stapledon, white clover has been regarded as the cornerstone of hill land improvement in Britain. It has two major roles:

1. Fixation of atmospheric nitrogen through symbiosis with *Rhizobium* bacteria in root nodules.
2. Improvement of herbage quality.

Quantification of both aspects has been given high priority at Pant-y-dŵr. (Munro, 1970; Munro and Davies, 1974; Munro and Young, 1978).

Over the four years 1967-70, the contribution of S.184 white clover under grazing in mixed ryegrass swards was measured at just under 100 kg N/ha per annum. This level is similar to that recorded in Scotland (Haystead and Lowe, 1977) and closely approximates the theoretical amount calculated from temperature (Munro and Hughes, 1966).

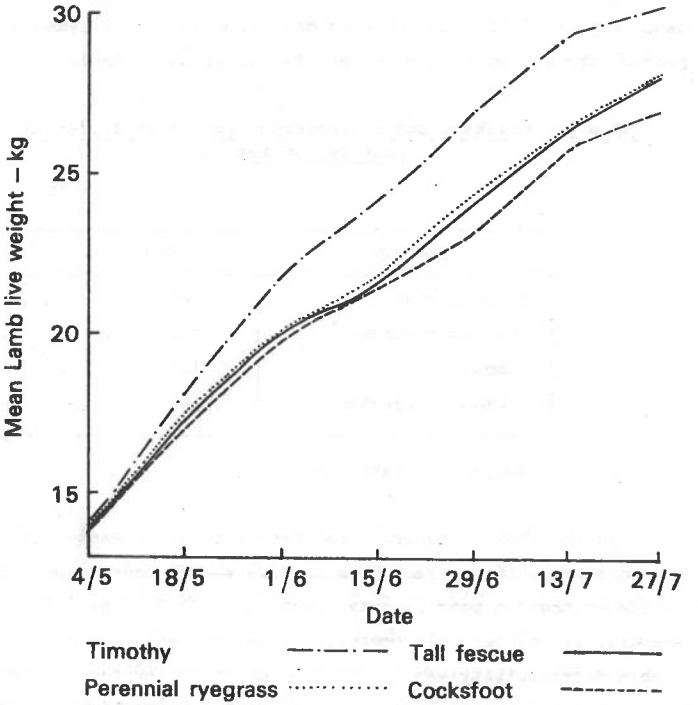

Fig. 7. Lamb liveweight from four grasses. Pant-y-Dwr 1975-77.

Early experiments at Aberystwyth (Stapledon, 1933) and Bangor (Roberts and Williams, 1940) showed marked effects of clover in liveweight gain in sheep and more recent Australian, New Zealand and British work (Thomson, 1977) has associated these responses with improved digestibility, intake and utilisation of digested energy. In New Zealand, Ulyatt (1970) has collated data from several grazing experiments to produce the following indices of liveweight gain (Table 8).

Table 8. Relative sheep liveweight gain from different pasture species

Species	Index
White clover	186
Italian ryegrass	160
Timothy	129
Perennial ryegrass	100

Source: Ulyatt (1970).

In the 1969/70 ryegrass/red fescue trial at Pant-y-dŵr, lambs gained on average 16 per cent more on S.23 swards containing S.184 white clover than on pure ryegrass receiving 150 kg N/ha. Although on average, the clover only contributed 14 per cent of the pasture available digestibility was raised from 66 to 70 per cent. Obviously there are great advantages in having as high a proportion of clover in hill reseeding as possible. Current research is aimed at maximising contribution through better varieties and management. Trials in 1977/78 (Young, unpublished) have shown that improved *Rhizobium* strains and

spray inoculation techniques can greatly increase establishment and subsequent growth. Increasing the level of potassium fertiliser from 60 to 120 kg K_2O/ha raised the yield of mixed swards by 11 per cent over 5 years (Young, unpublished).

Variety trials have clearly shown that the small-leaved wild white type of clover is most suited to the hill farm environment. Several other white and alsike clovers (*Trifolium hybridum*) have been tested but none approach S.184 in persistence (Table 9). A wide range of other varieties are now under test.

Table 9. Percentage clover ground cover after 4 years

Variety	Pant-y-dŵr 1974 % Ground cover
S.184	20
S.100	11
N.Z. Huia	6
Alsike	less than 1

Source: Munro, Davies and Morgan (1975).

Varieties for Conservation

The improvement of higher mountain pastures by surface-seeding can result in less prolonged spring grazing of lower fields and earlier closing for silage crops. Persistence is less important and more scope is available for the use of Italina ryegrass and hybrids with perennial

ryegrass or meadow fescue. In 1976 and 1977, new varieties yielded above 10 t DM/ha at Pant-y-dŵr in May and July harvests compared with 7.7 t from the best perennial ryegrass. Similarly in 1977 and 1978 new tetraploid red clover varieties gave 10 t/ha without fertiliser nitrogen.

Future Breeding Objectives

Twelve years of research at Pant-y-dŵr Hill Centre have demonstrated the value of S.59 red fescue, S.48 timothy, S.23 ryegrass and S.184 white clover in animal production. The combination of these varieties in mixtures for surface seeding has proved successful in the large-scale mountain improvement scheme at Pwllpeiran (Roberts, 1973; MAFF, 1979) and on private farms throughout Wales.

Special purpose breeding is an expensive undertaking and the Station has concentrated on varieties with wide adaptation (Breese, in press). This policy is now under scrutiny. Possibilities within the four main species used on hill farms are as follows:

Perennial ryegrass Increased emphasis on winter hardiness and yield stability are of highest priority. These objectives are in line with lowland requirements for the north of England and Scotland for which the Station now has responsibility (MAFF, 1977).

Red fescue Selection has resulted in lines 7 and 14 days later in heading than S.59 with higher digestibility and better compatibility with clover. The possibility of a dual purpose variety for amenity and hill use is being investigated.

Timothy S.48 timothy meets most of the requirements. Selection for higher persistency and mineral content (particularly sodium and magnesium) could be investigated.

White clover S.184 is an ideal variety in most respects but falls down in seed production and high initial cost. At Newcastle University (Ollerenshaw, Stewart and Baker, 1977) research has begun on the improvement of spring growth in white clover and some Norwegian and Scottish ecotypes show advantages over S.184. The Station is involved in this project.

A general breeding objective which requires more urgent scrutiny is the possibility of selection for adaptation to mineral stress, particularly tolerance of excess aluminium, and more efficient uptake of nutrients. Work carried out on aluminium tolerance in perennial ryegrass at the Station several years ago (Vose, 1963; Vose and Randall, 1962) showed promise but was terminated because the plants were poor in other agronomic respects. Current effort is centred on increasing nitrogen uptake efficiency in perennial ryegrass (Goodman, 1977). In American considerable success has been achieved with various nutrients in such diverse crops as wheat, cassava, tomatoes, maize, rice, barley and tropical legumes (Wright, 1977). With nearly 90 per cent of all world soils suffering from various stress factors closer cooperation will be required in the future between breeders, soil scientists and agronomists to make the optimum use of resources.

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DISCUSSION

Gwynn Jones (ADAS) asked about the interaction of lime and phosphate and their use in upland improvement.

Dr. Newbould (HRFRO) replied that because of the decline in availability of basic slag they were looking into the effectiveness of alternative sources of phosphate as a replacement of basic slag. Pot experiments (Dr. Floate, unpublished) indicate that a SO:SO mixture of superphosphate and rock phosphate was effective, supplying phosphate for the immediate reseed and in the longer term. The response to phosphate was less when lime was added.

Dr. Sandford (UKF) asked Dr. Bibby if the relationship between soil type and vegetation type is close and if so could not aerial surveys make soil mapping easier and cheaper.

Dr. Bibby said he did use aerial photographs but one required a ground control. The rate of mapping had been 100 sq. miles per man on standard survey. This year on the quarter million survey a team of three has mapped 1,120 sq. miles. The relationship between soil and vegetation is not always good. For example, the agrostis, fescue swards are usually associated with brown earths but can be found on peat if the drainage and slope characteristics are present, so it is essential to have ground control to complement the aerial surveys.

B. Clayden (Soil Survey) observed that in Dr. Bibby's slides of map units brown forest soils with free and imperfect drainage were described and peaty and humic gleys, but there were no gley soils without humose or peaty tops.

Dr. Bibby replied that in conditions of high rainfall and cool climate in the west only humic and peaty gleys occur. Further south in lower rainfall areas such as Kintyre non humic gleys occur on glacial till.

Edryd Jones (ADAS) asked what starter nitrogen was recommended on shallow peat soils such as the Hiraethog series and whether any comparative work had been done because in practice there is a wide range, from between 50 to 150 kg/ha N, applied.

Dr. Newbould replied that in Scotland 40 to 60 kg/ha N is traditionally used to get the grass growing and too much nitrogen may reduce the establishment of clover. Current experimental work by Dr. Hasted applying four rates of nitrogen at different times has indicated that 90 kg/ha N is best for clover establishment and 120 kg/ha best for grass, both applied one week after sowing.

H. Munro (PBS) said most work had been done on the Ynys series and indicated that 90 to 120 kg/ha N was needed. The Hiraethog, on which less work had been done, was a better soil type releasing 30 to 40 kg/ha and so the nitrogen requirement could be less. The SURVEY OF FERTILISER PRACTICE has revealed that nitrogen use on permanent pasture in 1352 of 2 kg/ha has risen to over 50 kg/ha.

Dr. Sandford (UKF) said 90 kg/ha checked cover establishment in one trial out of four and he was currently recommending 60 kg/ha N for reseeding. It is important to get the reseed established quickly.

M. Jarvis (Soil Survey) commented that Dr. Bibby had described complex map units and asked how well these related to capability classes, and could they be used for other purposes such as recreation?

Dr. Bibby said complex units such as Mish-mish were not easily assessed for Land Capability, but they might be used for scenic assessment; the percentage rock outcrop, steepness and proximity to water are implicated in the attractiveness of an area.

CHANGES IN SOIL PROPERTIES AND VEGETATION RESULTING FROM RECLAMATION ON EXMOOR

E. Maltby
Geography Department
University of Exeter

Introduction

Earlier interests in the improvement of upland areas for more intensive agricultural use have concentrated on the practical problems of technique and overall changes in sward productivity (e.g. Ellison 1951; Gardner et al. 1954, 1957; Robertson 1957; Grant et al. 1958; Heddle and Young 1965). More recently attention has focussed on the environmental factors, including soil, which influence productivity in the uplands and potential land use (e.g. Munro, 1973; Munro & Davies, 1973; Munro 1979). However, effects of upland management strategies on soil properties, profile morphology and longer term pedogenesis has been largely neglected. A notable exception is Crompton who in 1953 suggested alternative pathways of soil development which led in one case to the accumulation of peaty surface horizons and in the other to the formation of mull humus and a 'deep granular topsoil'. Crompton recognised most clearly the importance of management influences in controlling these alternative pathways but was unable to attach any precise timescales to the changes effected by particular farming operations.

It is the intention of the present contribution to outline briefly the modifications to vegetation and to detail some of the changes in soil characteristics brought about by reclamation on Exmoor since the nineteenth century.

The Study Area

Land within the boundaries of the present upland parish of Exmoor Forest (fig. 1) provides an ideal basis for investigating the effects of moorland reclamation on vegetation and soil development. Before 1815 the area was protected under forest law and used primarily for the summer agistment of sheep, cattle and horses (MacDermot, 1911). Probably from Saxon times and possibly even earlier up to the enclosure and eventual sale of the major part of the former Royal Forest in 1820 no cultivation was carried out within its boundaries. Any man-induced modifications to the land within this millenia was confined to some restricted fluctuations in stocking rates and burning activity. The significance, however, of grazing pressure and swaling (burning) on vegetation development and peat accumulation should not be underestimated (Maltby and Crabtree, 1976).

Under this land use regime vegetation dominated by *Molinia caerulea, Trichophorum caespitosum, Carex spp* and *Juncus spp.* developed over the broadly convex summits and lower crest slopes. *Calluna vulgaris, Vaccinium myrtillus* and *Nardus stricta* probably occupied drier areas on the upper valley slopes and shoulder position with *Festuca-agrostis* swards present on the steeper and often very well drained valley slopes. Pollen evidence suggests that heather declined significantly in the period before enclosure and heavy grazing pressure may have been at least partly responsible for this effect (Maltby and Crabtree, 1976).

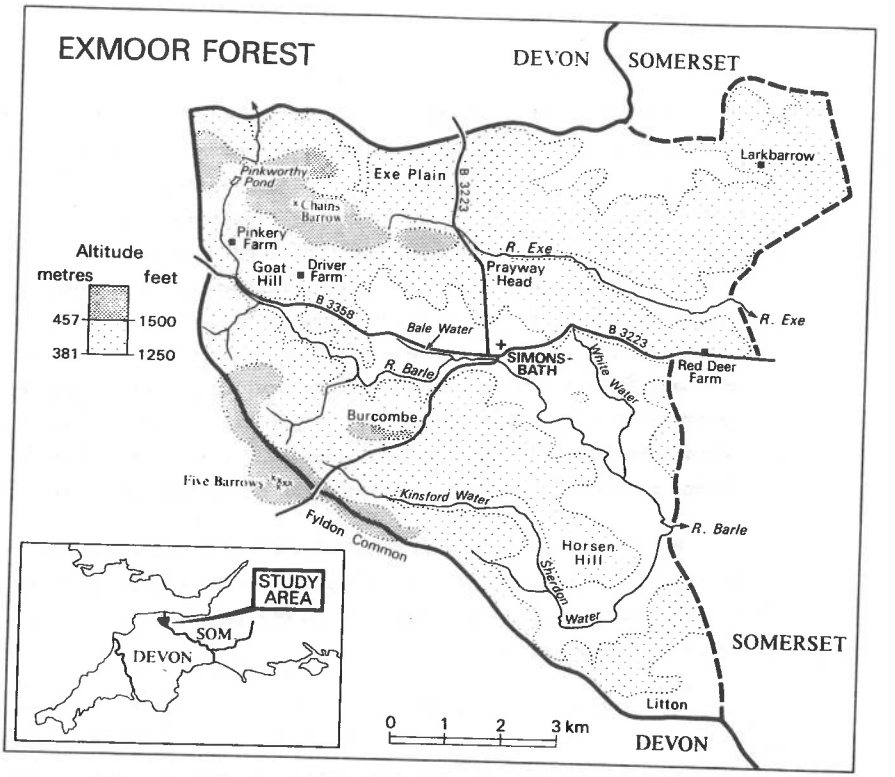


Fig. 1. *The location of field sites in relation to the boundaries of Exmoor Forest.*

Reclamation of moorland for agriculture was initiated soon after purchase of much of the area by John Knight who eventually bought 80% of the original Royal Forest (Orwin and Sellick, 1970). Nineteenth century operations concentrated on south-facing slopes and generally comprised (i) paring off 50-75mm of turf (ii) burning the dried turf (iii) spreading the ashes (iv) ploughing - frequently 'half-ploughing' (v) application of lime and slag (vi) reseeding. The various techniques and management procedures associated with reclamation are well documented by Orwin and Sellick (1970). Twentieth century improvements have omitted treatments (i) to (iii) and invariably include the addition of artificial nitrogenous fertilisers. Some recent schemes have substituted herbicidal treatment, rotovating and direct drilling for ploughing (see Horne, 1979).

Whilst originally varied mixtures were used for reseeding (including *Holcus lanatus, Cynosaurus cristatus, Dactylis glomerata* and *Phleum pratense*) modern schemes now tend to concentrate exclusively on rye-grass and clover varieties.

The generalised distribution of soils on south-facing slopes is shown in fig. 2. Stagnopodzols and stagnohumic gleys frequently occur in close association giving a complex pattern of profile forms on sub-summit slopes. Reclamation over the last 150 years has been directed in particular towards the improvement and modification of these soils and associated vegetation on the gentle gradients of the valley shoulder and lower crest slopes ideally suited to mechanical operations.

Investigations have concentrated on the changes occurring in two soil series units - the Ashcombe and Burcombe series mapped originally as a humic or peaty gley (stagnohumic gley) and thin iron pan peaty gleyed pedzols (thin iron pan stagnopodzols) respectively. Typical profile descriptions are given in Curtis (1971). Areas can be identified

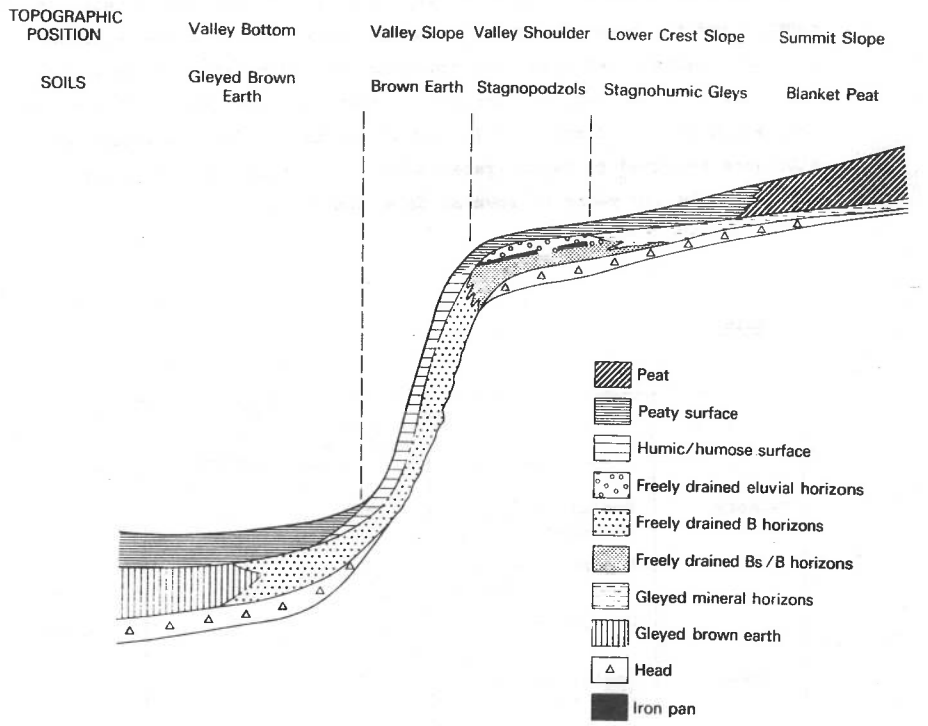


Fig. 2. Generalised distribution of soils on south-facing slopes in Exmoor Forest. (Modified from Curtis, 1971).

where land has been reclaimed at various dates between the nineteenth century and the present. The soil series units can be differentiated into unreclaimed, reclaimed and reverted land types which frequently demonstrate significant differences in profile characteristics and merit the recognition of distinct soil phases (Maltby, 1975). A number of sites are selected to demonstrate changes on a time scale ranging from approximately 130 years to several days (Table 1).

Table 1

Site	Land type	Date examined	Years since land use change	Residual improvement index
Pinkery	Reclaimed 1845-7 Reseeded 1945-6	1972	26	0.29
	Reverting since 1845-7	1972	125	0.08
	Unreclaimed	1972	-	0.00
Prayway	Reclaimed 1963	1974	11	0.32
Fyldon	Reclaimed 1965	1974	9	0.55
Red Deer	Reclaimed 1973	1974	1	0.80

Sites and methods

Four sites are examined and are located on fig. 1 at Pinkery, Prayway, Fyldon and Red Deer. Reclamation took place in 1845, 1963, 1965 and 1972 respectively.

All sites occur between approximately 400-460m on slopes commonly less than 4° and generally south-facing. They are mapped as either Ashcombe or Burcombe series but in reality comprise a complex mosaic of both profile forms. Each site can be stratified into two or three units depending on the presence or absence of zones of reversion, i.e. where formerly improved pasture has subsequently deteriorated back towards the original moorland condition. These strata establish the framework within which random vegetation and soil profile or surface samples were taken.

Vegetation was measured in terms of cover and cover repetition and three groupings identified:

Group a: Species sown in reclamation programmes and those used in earlier reseedings. This group includes *Lolium spp., Trifolium spp. Dactylis glomerata, Holous lanatus, Cynosaurus oristatus, Phleum pratense.*

Group b: Species not introduced by reclamation but of medium grazing quality includes *Agrostis spp. Festuca spp. Anthoxanthum odoratum.*

Group c: Species not introduced but characteristic of unreclaimed swards - generally of low grazing quality.

A simple measure of vegetation change was devised as: cover repetition of group 'a' species / cover repetition of all observations. This was termed the Residual Improvement Index. It has a value of zero in unreclaimed swards and a theoretical maximum of one in reclaimed pasture. In reality unity is rarely achieved because of the presence of stones and bare earth.

Morphological descriptions were made of random soil profiles and samples taken from all identifiable horizons and in some cases specific depth ranges. Analyses were made of selected physical, chemical and biological characteristics. Particular emphasis was directed towards the enumeration of four major groups of microorganisms : filamentous fungi, yeasts, bacteria and actinomycetes. The sampling and analytical procedures adopted have been detailed elsewhere (Maltby 1977).

General Trends in Vegetation

The decline in the residual improvement index with time is clear from Table 1 and suggests that the greater proportion of sward deterioration occurs within 10 years of improvement. Modifications of vegetation to a ryegrass-clover mix is a relatively unstable change. In the absence of intensive management maintaining sward quality there is a rapid invasion by non-sown species. Residual seed may also germinate and the progressive infestation of many recently reclaimed pastures by *Juncus effusus* is a very clear example of this effect. Without treatment in the past *Juncus* invasion has undoubtedly accelerated the reversion process by locally restricting grazing activity. Nothing new emerges from these data but the possible speed of sward deterioration observed by many workers in other Upland areas is clearly underlined. It is also

very clear that the improved sward is by no means a stable condition in the upland environment and its maintenance at a particular level of improvement requires significant and continual management inputs.

Effects on soil properties and profile development

In general mechanical operations have aimed at (a) the penetration and break-up of the iron pan which when present restricts rooting depth and causes waterlogging: (b) the improvement of drainage, aeration and ease of rooting by cultivation including originally the removal of some surface peat: (c) the preparation of a tilth suitable for the establishment of new pasture species and (d) the addition of nutrients which will ameliorate acidity and improve growing conditions for the introduced species.

Immediate effects of reclamation

Some of the immediate changes brought about by reclamation are illustrated by observations at the Red Deer site (1972) and part of the Pinkery site on Goat Hill (1974). These can be summarised as:

1. Inversion and mixing of the upper soil profile.

The extent to which the profile is affected varies according to ploughing depth and local variations in horizon thickness. Practices invariably result in the comminution of peaty horizons, mixing with bleached or gleyed mineral material (Ea, Eag, or Ag horizons) and occasionally incorporation of illuvial or Bg material. In some instances the vegetation may be buried virtually intact and may maintain locally high moisture levels. The ploughed and cultivated horizon is morphologically

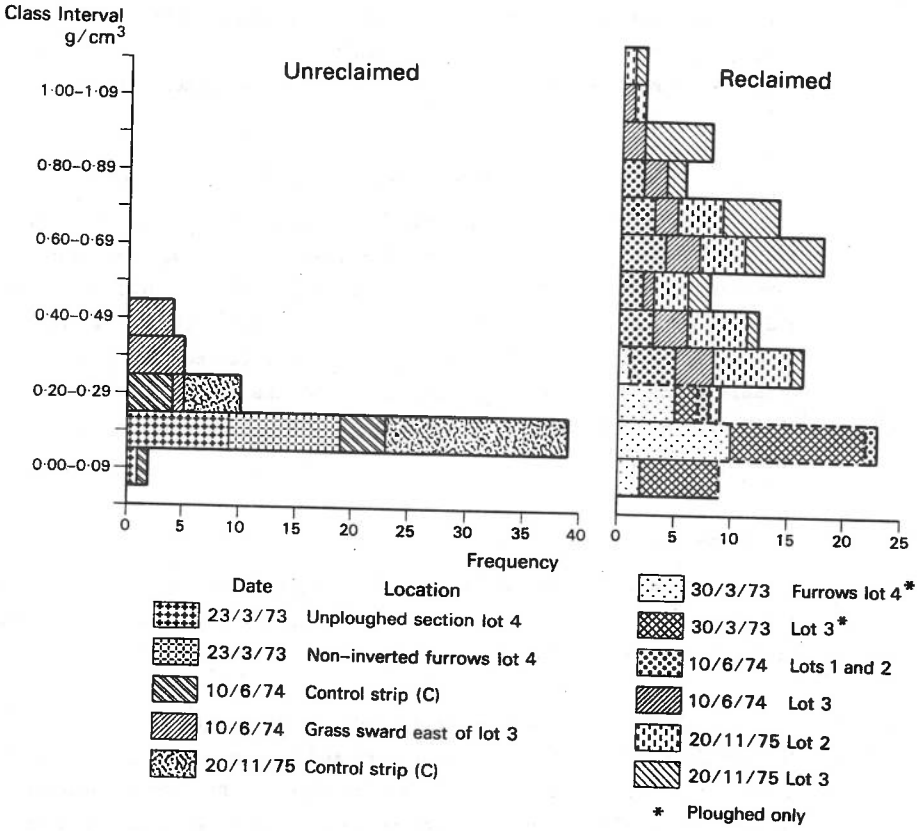


Fig. 3. Frequency distribution of bulk density measurements for surface 6.5cm Burcombe soil series, Red Deer.

heterogeneous and frequently comprises significant pockets of distinctive horizon materials from the earlier profile.

2. A general increase in surface stoniness and bulk density values. Figure 3 demonstrates, however, that the most obvious change is in the increased dispersion and apparent polymodality of observations. These data confirm the initial heterogeneity of the new Ap horizon imposed by coarse mechanical mixing of highly contrasted and originally spatially separated horizons.

3. The increase in variability of the soil surface is less pronounced for organic carbon. It is instructive, however, that whilst gravimetric results for this property suggest a decline in organic matter, expression of the data in volumetric terms indicates that the change is apparent rather than real (figure 4) and attributable to a dilution of the original organic surface.

4. Soil moisture values decline rapidly and significantly initially as a result of ploughing exposing peat and underlying mineral soil to desiccating conditions and subsequently by the general improvement in sub-surface drainage. The mean difference in moisture content (estimated gravimetrically at 105°C) between unreclaimed and reclaimed Burcombe series two years after cultivation, measured for the surface 6.5cm in June 1974, was 0.15g/cm^3 equivalent to 97.5 t/ha soil water. Even under winter conditions differences equivalent to 32.5 - 65.0 t/h have been estimated.

5. Immediate increases in surface pH to values exceeding 6.0 are not unusual but do not necessarily reflect anything more significant than the inclusion of lime particles in the sample under analysis. Figure 5

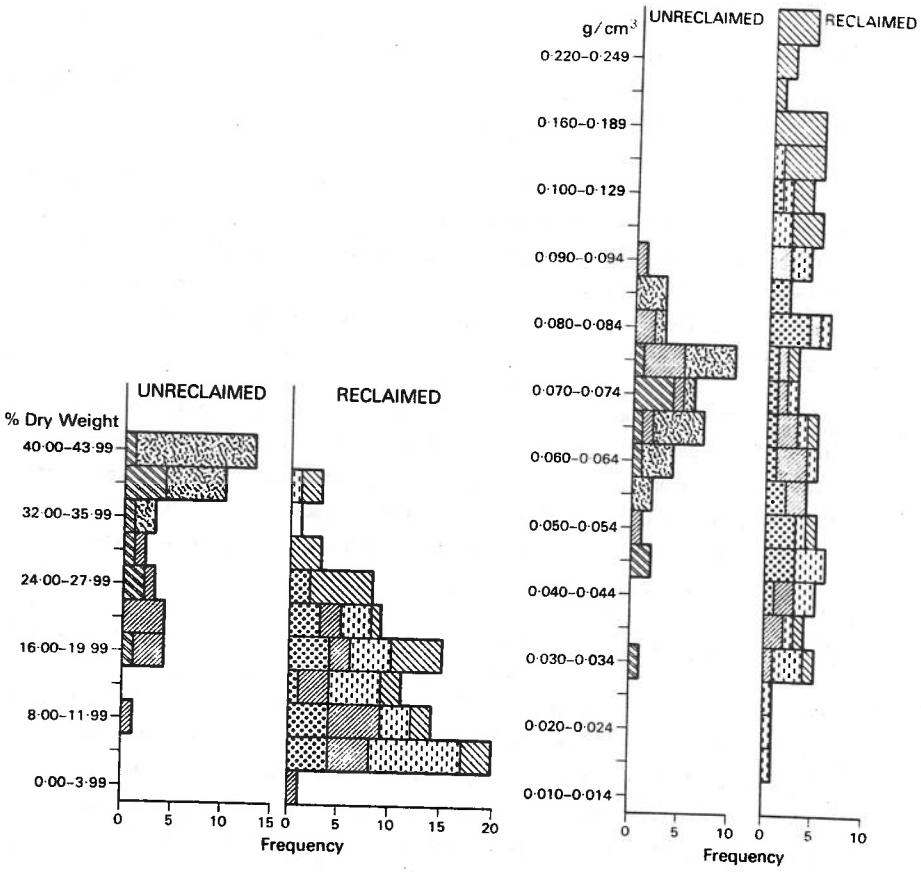


Fig. 4. Frequency distribution of "easily oxidisable" organic carbon measurements for surface 6.5cm. Burcombe soil series, Red Deer.

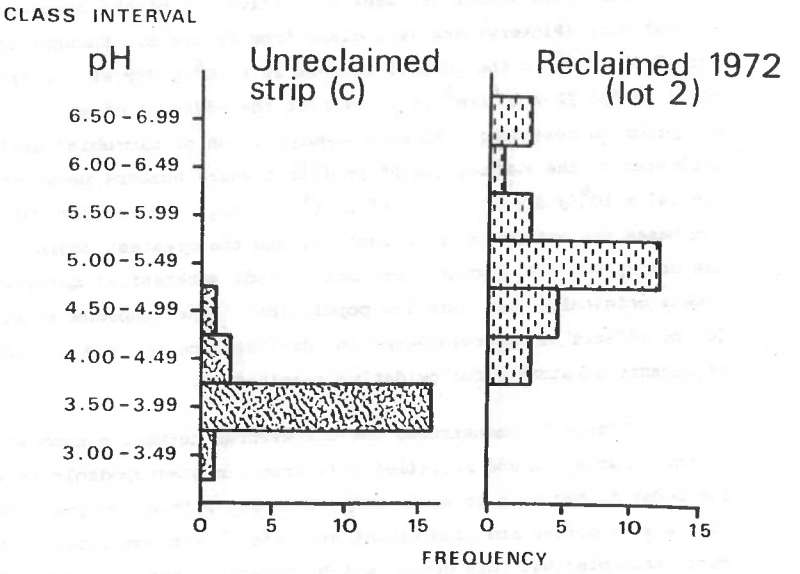


Fig. 5. Frequency distribution of pH values for surface 6.5cm. Burcombe soil series, Red Deer.

compares pH between reclaimed and unreclaimed sectors of the Red Deer site 53 months after treatment when surface lime and slag particles were no longer visible. At this stage the additions have been closely incorporated with the soil fabric and the amelioration of acidity can be considered as a real property change.

6. Very large increases occur in microbial numbers. The effects on the microflora within one week of cultivation of the stagnohumic gley at Goat Hill (Pinkery) are very clear from figure 6. Numbers increase from 8.05 x 10^6 in the control to 1588.12 x 10^6/g dry wt. in profile A (1.21 to 238.22 x $10^6/cm^3$ soil) without the addition of mineral fertilizers and prior to reseeding. An even greater flush of microbial activity is indicated in the surface 2cm of profile B where numbers were estimated at 3283.41 x 10^6/g dry wt. (647.68 x $10^6/cm^3$ soil). More than 99% of these increases are attributable to bacteria and the greatest change occurs in the new Op horizons though these may include substantial material from levels originally with very low populations. The response is attributed to the effects of improved aeration, drainage and the sudden availability of organic substrates for oxidative respiration.

Figure 7 demonstrates the differences between microbial numbers in the unreclaimed and reclaimed thin iron pan stagnopodzols at Red Deer. The boost to bacteria is still very clear but within two years there has been also a marked and significant increase in actinomycetes. It is quite probable that this group, which characteristically comprises relatively slow growing organisms but including species capable of breaking down highly complex organic substrates, is adapting more slowly towards new soil equilibrium conditions.

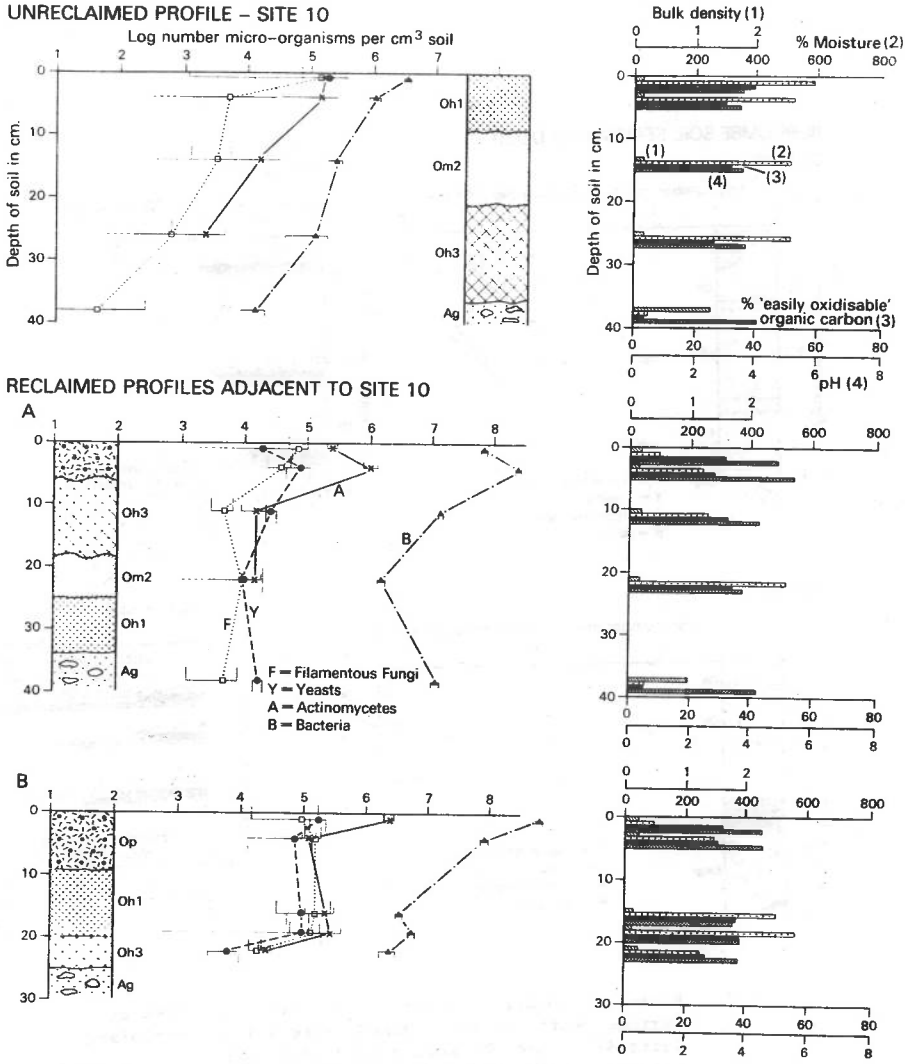
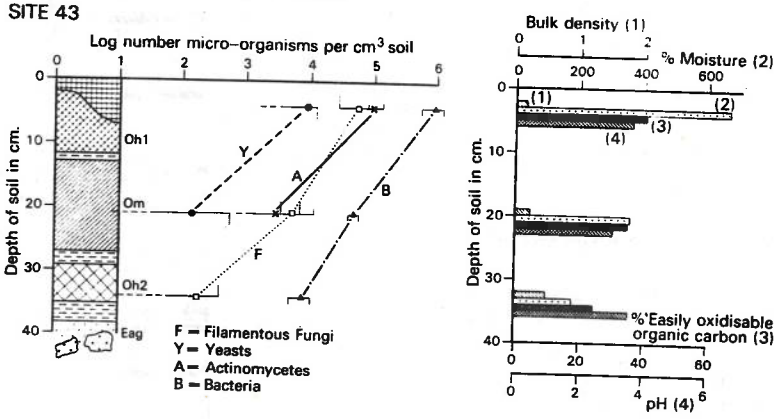


Fig. 6. Microbial numbers and associated soil properties at various depths at site 10 (unreclaimed Ashcombe soils) and at adjacent recently reclaimed sites, Goat Hill Pinkery. Sampled 20 June 1974.
Horizontal bars indicate 95% confidence band.

BURCOMBE SOIL SERIES (RED DEER)

SITE 43



SITE 45

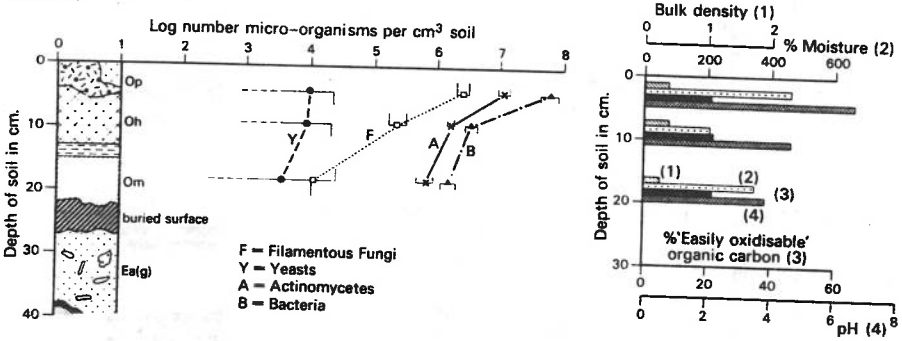


Fig. 7. Microbial numbers and associated soil properties at various depths in unreclaimed (site 43) and reclaimed (site 45) Burcombe soil series, Red Deer. Sampled 24 and 31 May 1973. Horizontal bars indicate 95% confidence band.

In summary the rearrangement and mixing of highly contrasting horizon material results in a heterogeneous cultivated surface with new physical and chemical properties which stimulate microbial numbers. The greatest change occurs in bacteria which react within days of cultivation. Actinomycetes respond within months whilst no large or consistent directed change is apparent in filamentous fungi and yeasts within two years of reclamation.

Longer term effects of reclamation

These are evaluated 125 years after reclamation at the Pinkery site where three distinct soil phases corresponding to unreclaimed, reclaimed and reverted land occur in close juxtaposition. Some 12-14 years prior to reclamation a small canal structure was excavated contouring the subsequently reclaimed slopes. Mineral spoil has buried and preserved the original soil profiles which vary between thin iron pan stagnopodzol and stagnohumic gley forms (Maltby and Crabtree, 1976). The buried profiles are directly analogous to the contemporary Ashcombe and Burcombe series which characterise adjacent unreclaimed land. They provide an extremely important base-line for the evaluation of changes which relies on a substitution of space for time in the comparison of unreclaimed, reclaimed and reverted land.

The morphological differentiation of these three phases is illustrated in the generalised profile forms in figure 8. The main feature of the reclaimed phase is the development of a relatively homogeneous Ap horizon extending to some 15cm. Peaty material and relatively inorganic A and B horizon fractions originally coarsely mixed by mechanical techniques have been subjected to mineralisation, dispersion and redistribution to yield an intimate association of organic and inorganic fractions

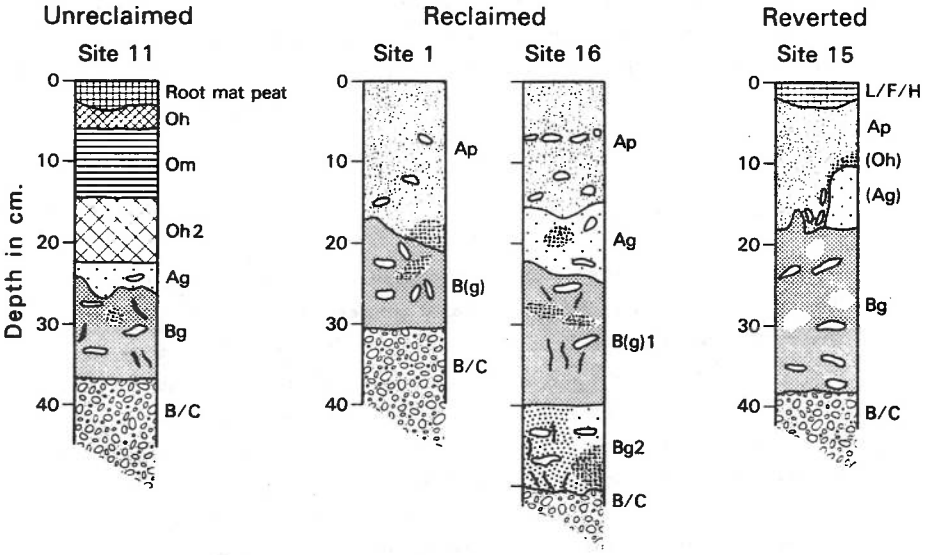


Fig. 8. Diagrammatic representation of generalised profile forms of unreclaimed, reclaimed and reverted land types in Ashcombe series mapping unit, Pinkery.

typical of a 'mull' horizon. The transformation must be attributed largely to the operation of biological processes and in particular to the activity of microorganisms and soil animals (especially earthworms and moles). Organic carbon content of the survace 6.5cm has been reduced from 43-48% to 4-7% dry weight or alternatively 3.9-4.5kg/m^2 to 3.3-3.6kg/m^2 for each horizontal cm slice of soil volume. The profile as a whole has lost up to 11 kg/m^2 organic carbon since reclamation 125 years earlier. About 4kg/m^2 can be explained by initial burning of surface peat but the rest is due to mineralisation.

Profiles in the reverted land at Pinkery commonly exhibit inherited features of the pre-reclamation profile, particularly pockets or discontinuous bands of peaty and pallid Ea(g) or Ag material. It is suggested, therefore, that reversion probably began soon after ploughing when less attention was directed towards the continued improvement of land furthest from the farm. The contemporary manifestations of reversion towards the original moorland conditions are suggested by (a) inclusion of species in the sward such as *J. squarosus, N. stricta* and *Malinia caerulea* (b) prominent development of a dense root mat and fermentation horizon, and (c) development of high organic carbon levels at the top of the profile.

The profile in the reverted phase contains a mean of 11.34kg/m^2 organic carbon which represents an increase of 1.67kg/m^2 over the reclaimed profile.

The contrast in microbial and earthworm numbers between the three land types has been examined in detail elsewhere (Maltby 1975). Figure 9 and Table II are representative of the level of differentiation of these important soil biological properties. Overall the 'total' microflora increases from 1.44 x $10^6/cm^3$ at 3-5cm in the unreclaimed phase to 35.56 x 10.6cm^3 at the same level in the reclaimed phase. Filamentous fungi exhibit no marked change but yeasts, antinomycetes and bacteria all increase significantly with the latter group predominating

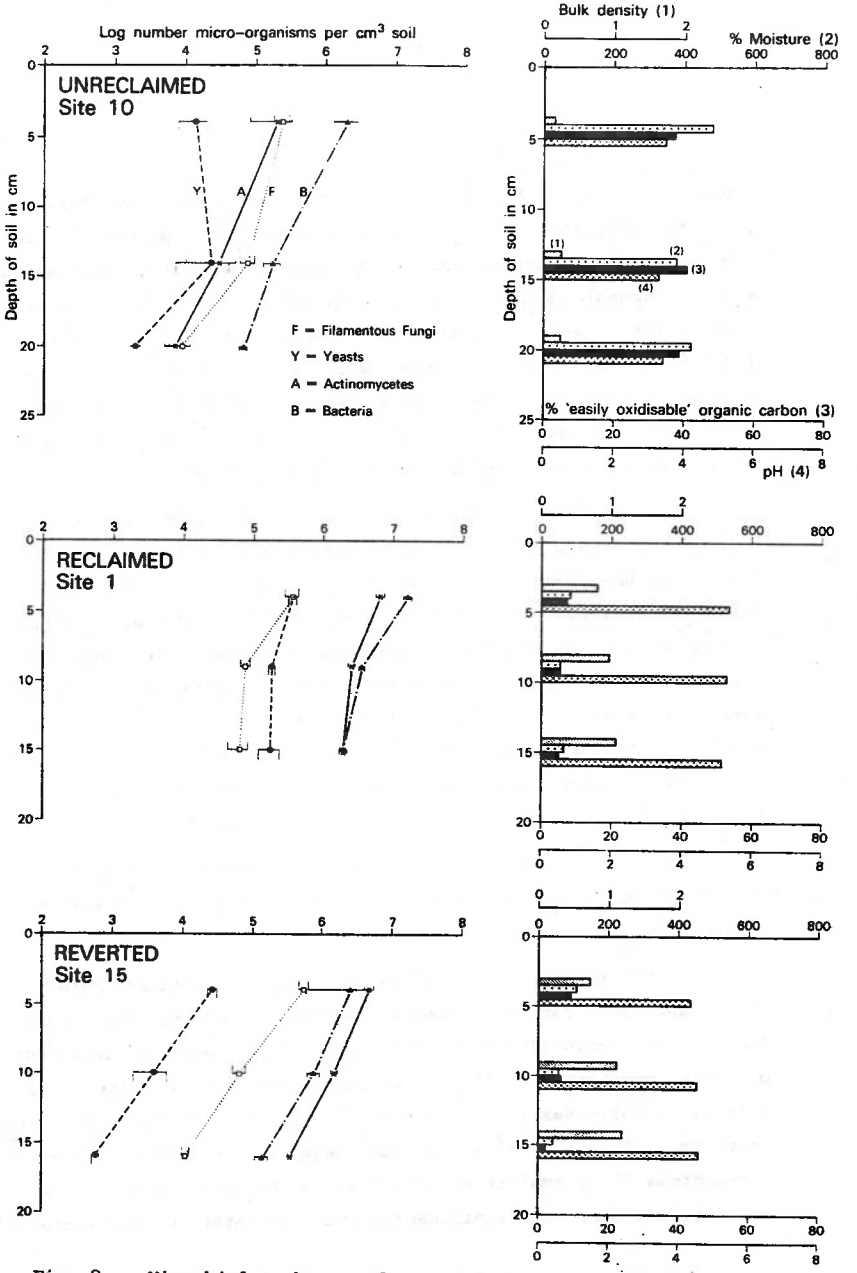


Fig. 9. Microbial numbers and associated soil properties at various depths in the Ashcombe soil series, Pinkery. Samples taken 10 December 1972. Horizontal bars indicate 95% confidence band (From Maltby, 1975).

in numerical terms. Microbial numbers are generally lower in the reverted phase unless lime or fertilizer has been added recently. A 'total' count of 10.6 x $10^6/cm^3$ at 3-5cm was estimated in the unlimed reverted land at Pinkery. Of greatest interest however, is the change-over from bacteria to actinomycetes as the numerically dominant group (figure 9). It has been suggested that this indicates a fundamental difference in the ecological factors influencing the development of these soils. The dominance of bacteria and comparatively high numbers of yeasts in the reclaimed phase have been explained in terms of (i) relatively high grazing pressure stimulating root exudate production and generating a significant proportion of soil organic matter as animal excreta (ii) high earthworm activity and (iii) enhanced rates of decomposition releasing relatively simple organic substrates (Maltby, 1975). Conversely the physiological and metabolic capabilities of actinomycetes make them highly competitive in an environment where much of the supply of organic material is in the form of complex compounds such as hemicelluloses and lignin. This would be the case in the reverted phase where grazing is very limited, earthworm numbers generally low (Table II) and metabolic processes retarded by low pH, nutrient deficiencies and restricted aeration. Plant litter thus provides most of the organic matter input to the soil system. There is an excess of primary production over decomposition and an accumulation of organic matter as a discrete surface horizon. The effect is particularly clear from the representative plots of organic carbon distribution in figure 10.

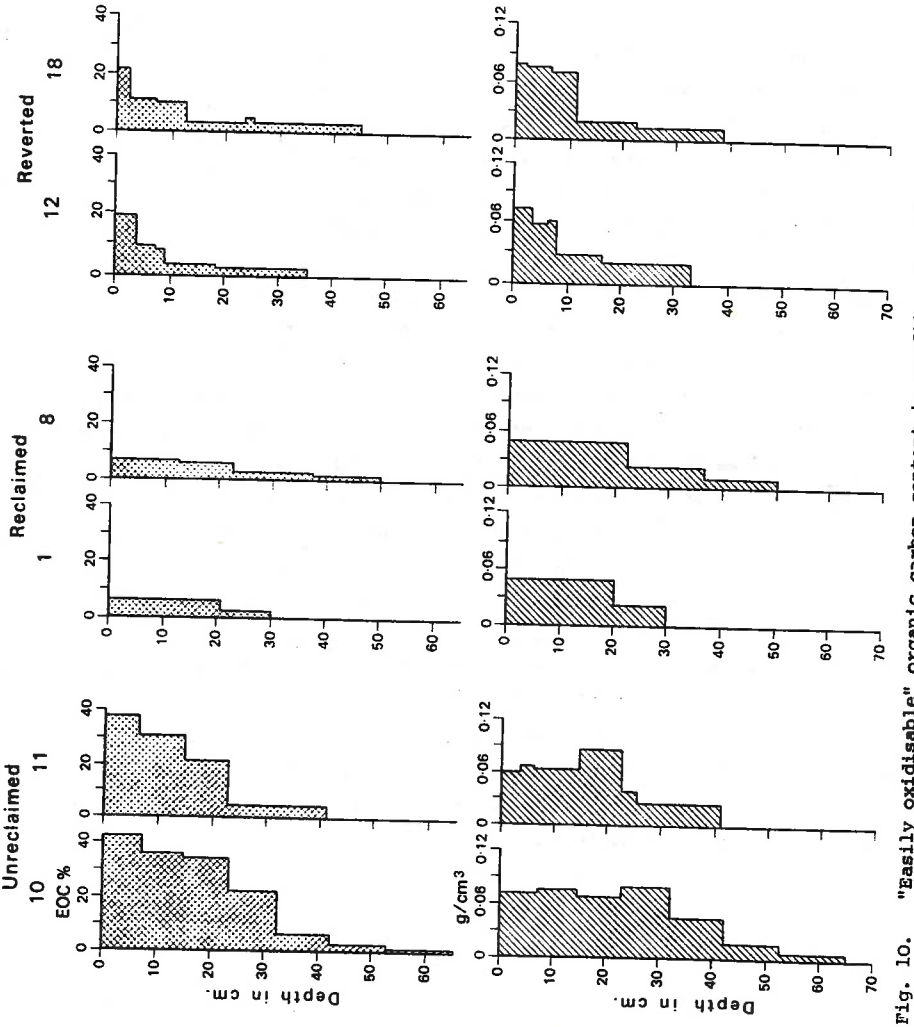


Fig. 10. "Easily oxidisable" organic carbon content in profiles from the Ashcombe series, Pinkery.

Table II. Numbers and (fresh wt. biomass)/0.25m^2 of earthworms in reclaimed and reverted phases of Ashcombe Series, Exmoor

Date	Reclaimed	Reverted	
		TL	FA
21.10.73	137 (24.02)		0 (0.0)
	167 (42.05)		1 (1.55)
	44 (8.40)		6 (2.70)
		21 (13.70)	4 (1.90)
24.11.73 (recl)	15 (4.40)*	0 (0.0)	7 (2.70)
		0 (0.0)	4 (3.20)
	147 (57.60)**	16 (3.90)	62 (28.20)
			14 (8.50)
8.4.74		0 (0.0)	10 (7.50)
		9 (9.25)	1 (0.25)
		13 (10.30)	23 (7.20)

* Fyldon ** Prayway All other samples Pinkery

Soil and ecological trends

Significant profile changes are detectable on a scale of days and the results of major pedogenic transformations are evident within years of reclamation. New A horizons in which component fractions from highly contrasted original horizons are totally indistinguishable have developed within 125 years in an upland environment and have probably required considerably less time to achieve their new condition. Figures 11 and 12 illustrate the trends towards new equilibrium conditions for

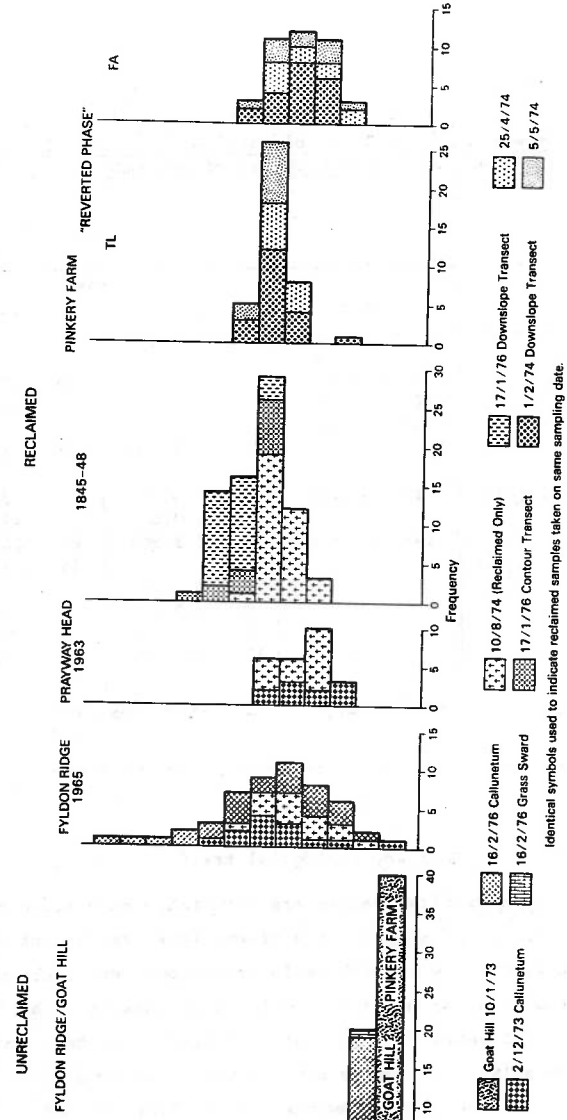


Fig. 11. Trend in bulk density with time since reclamation in the Ashcombe soil series.

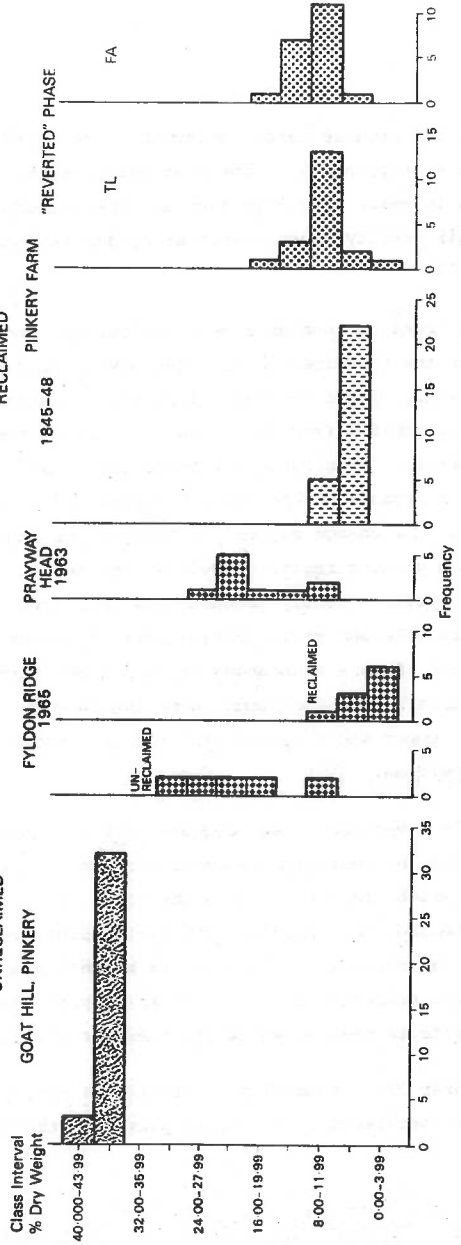


Fig. 12. Trend in 'easily oxidisable' organic carbon with time since reclamation in the Ashcombe soil series.

bulk density and organic carbon determinations in the surface 6.5cm. The original heterogeneity of the ploughed horizon is significantly reduced within 10 years of cultivation and the unimodal frequency distribution of bulk density measurements at Fyldon is good evidence of this (cf. figure 3).

The trend is towards a new equilibrium condition for soil properties in the reclaimed phase. Any new equilibrium is not, however, necessarily stable under the prevailing environmental conditions of upland Exmoor. Shifts from the reclaimed profile towards the original moorland condition (reversion) are indicated by soil microbial changes, an increase in organic carbon and C/N ratios and a decrease in surface bulk density. The change may not be homogeneous and the importance of vegetation and grazing regime is well emphasised in figures 10 and 11. Where the vegetation locally demonstrates less affinity with the originally reseeded sward (FA) and where grazing activity tends to be reduced there is a suggestion of more pronounced change in the surface soil properties towards the unreclaimed moorland. More intensively grazed areas locally dominated by clover and ryegrass (TL) retain greater affinity with the reclaimed condition.

While reversion is an adequate term to describe the changes taking place in the vegetation another term is required to describe the developments which are occurring in the soil. It is suggested that soil development towards the original (pre-reclamation) condition is adequately described as palingenesis (literally 're-birth') and is intended to convey the notion that processes are involved in complex developmental changes on the same site as that on which the previous profile was modified.

Figures 13-15 summarise in simplified ecological terms the salient relationships postulated in the three phases of the Ashcombe series.

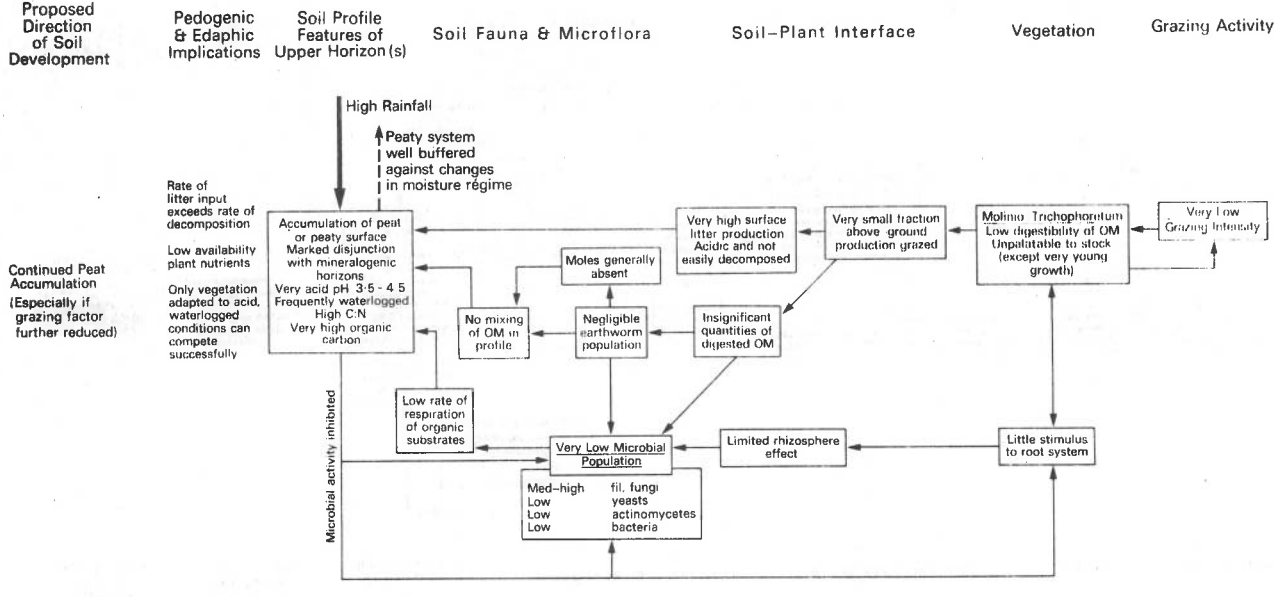


Fig. 13. Ecological relationships in the unreclaimed phase of the Ashcombe series.

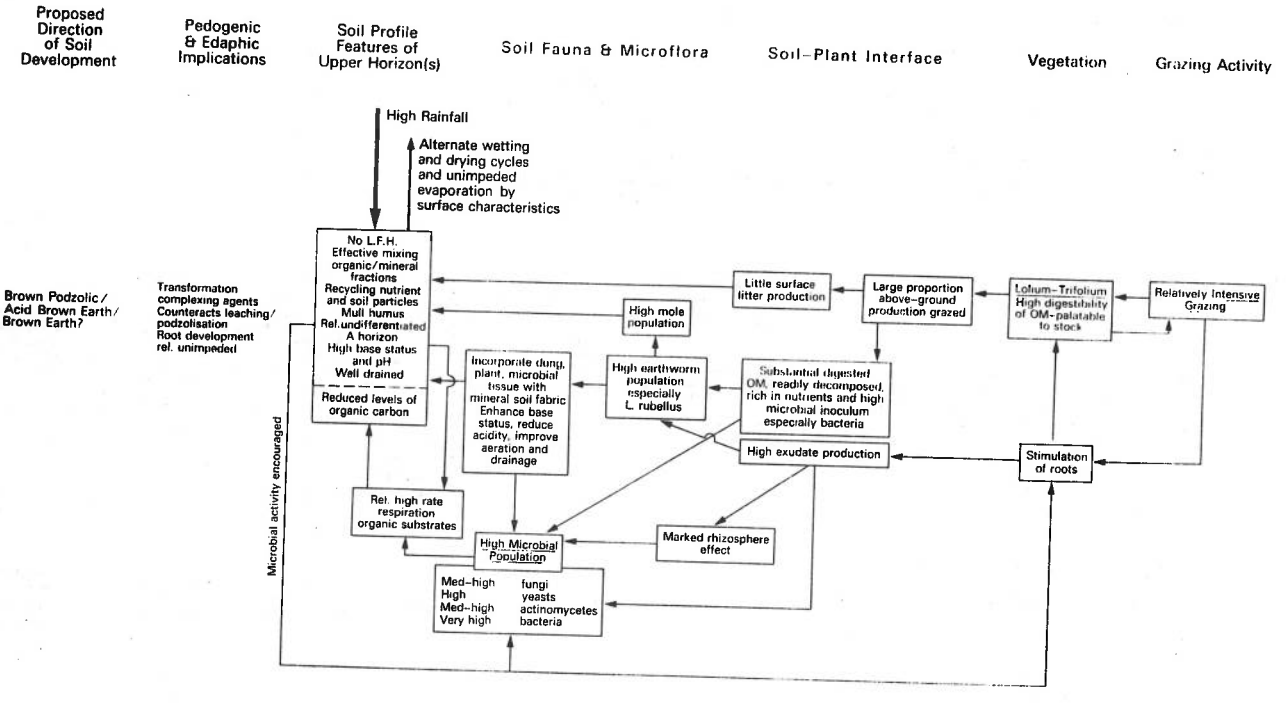


Fig. 14. Ecological relationships in the reclaimed phase of the Ashcombe series.

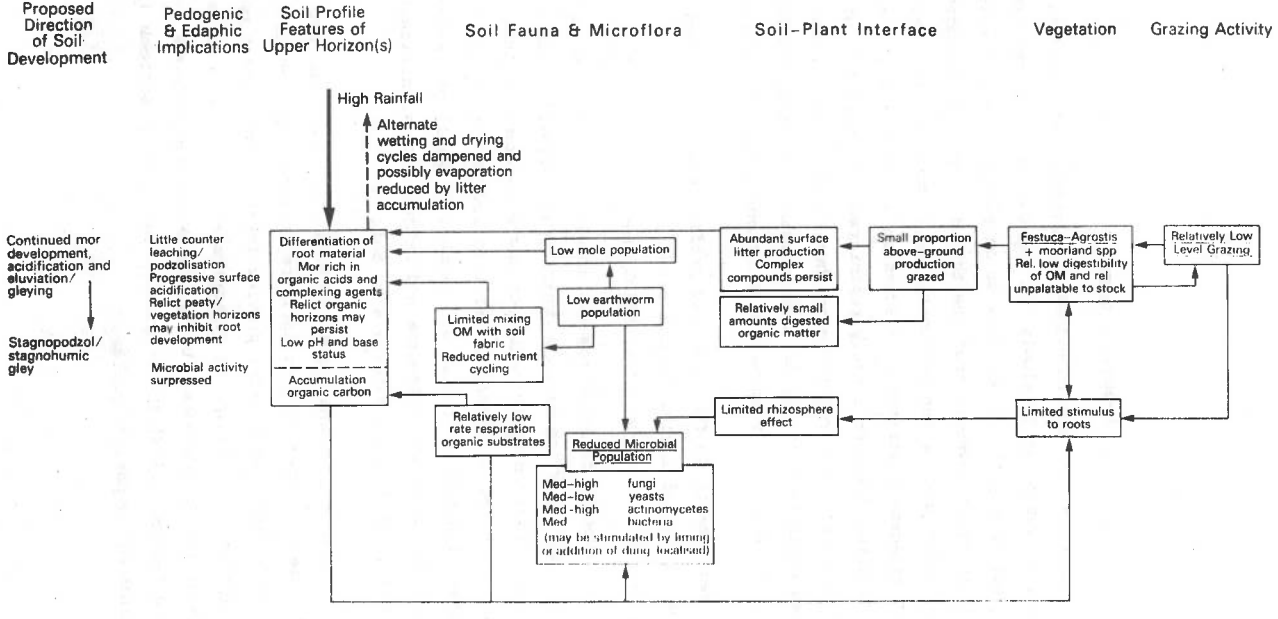


Fig. 15. Ecological relationships in the reverted phase of the Ashcombe series.

Pedogenic trends

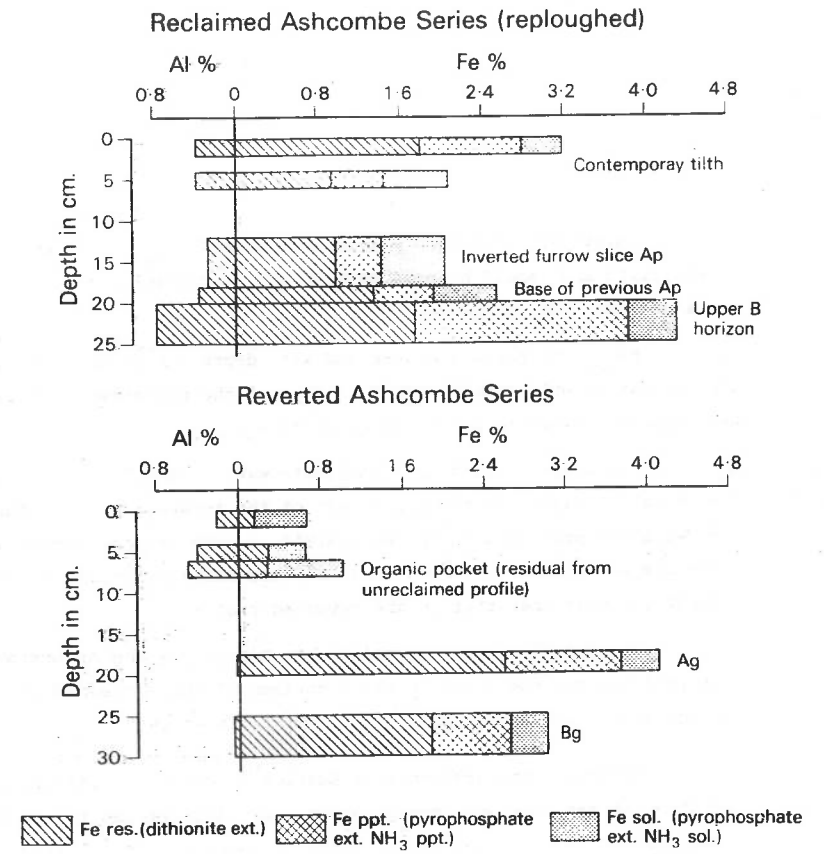
Ecological and pollen evidence suggests that peat will continue to accumulate (but possibly slowly) at the surface of unreclaimed Ashcombe and Burcombe profiles and more so on adjacent wetter soils and true peats. It is clear however, that the thin iron pan stagnopodzol and stagnohumic gley profile can be substantially modified by reclamation and subsequent management strategy. Discussion of the pedogenic aspects of such modification has been largely restricted to microbial and soil faunal involvement with organic matter humification and mineralisation and the redistribution of organic and inorganic material throughout the A horizon. At least two fundamental questions remain to be answered.

(1) Will pedogenesis in the reclaimed profile eventually lead to the development of a classifiable brown earth profile?

(2) Will reversion lead to differential pedogenesis?

Current work is being directed towards answering these important questions and the concluding section of this contribution presents some preliminary observations. Observed modification of the B horizons of these soil profiles appears limited to increased aeration and oxidation of previously gleyed pockets together with some entrainment of small particles at the upper horizon boundary by earthworms and rather more significant but localised mixing of A and B materials by mole activity.

Preliminary iron and aluminium data available from representative profiles of the reclaimed (and recently reploughed) and reverted phases of the Ashcombe series at Pinkery provide interesting comment on differential pedogenesis. Figure 16 demonstrates the clear contrast in iron levels between the Ap horizons. Using the extraction methods described in Avery and Bascomb (1974) and originally outlined by Bascomb (1968) several points of comparison emerge:



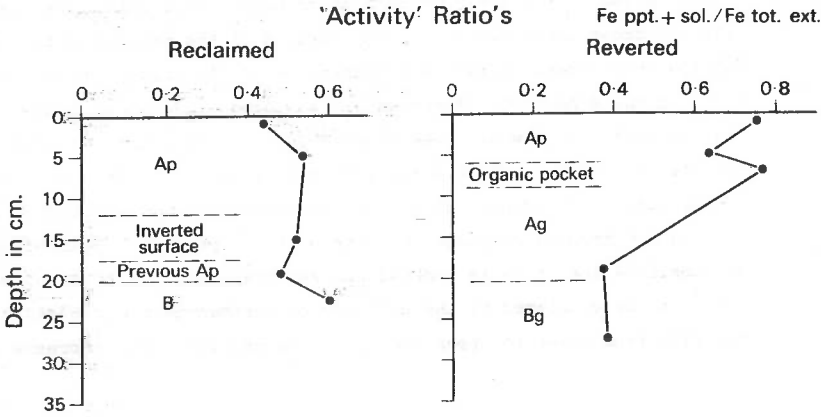


Fig. 16. Distribution of iron and aluminium in selected profiles of Ashcombe series.

(1) Values of dithionite extractable iron (Fe_{res} - including well crystallised and 'aged' hydrous oxides) are consistently higher in the reclaimed than the reverted phase.

(2) Fe_{res} comprises a higher and with depth a more constant proportion of extractable iron in the A horizon of the reclaimed profile compared with similar levels in the reverted profile.

(3) 'Activity' ratios (pyrophosphate ext. Fe/total ext. Fe) are significantly higher in the upper part of the reverted profile than in the reclaimed profile and decline sharply to very reduced levels in the lower gleyed horizons. The ratio in the reclaimed B horizon is considerably higher than that in the reverted profile.

(4) Extractable aluminium values are similar in the Ap horizons of both profiles but the level in the B horizon of the reclaimed profile is considerably higher than that in the reverted example.

Following the arguments of Bascomb (1968) a preliminary interpretation of the iron data can be attempted. High values for uncombined inorganic Fe (Fe_{res}) comprising a large proportion of total extractable Fe and having a relatively uniform distribution with depth are characteristic of brown earth soils. The Ap horizon of the reclaimed profile fulfils these characteristics and there is little change in the value of Fe_{res} in the B horizon. There is already good evidence of higher microbial numbers and it would seem reasonable to suppose that microbial and soil faunal activity is relatively high in this soil. This will encourage decomposition of organic matter and reactive compounds capable of dissolving and forming complexes with Fe will not persist. Remineralisation and mobilisation of Fe is reduced and any translocation that may occur is likely to be countered by the activity of earthworms recirculating material from lower to upper levels in the profile. The increase in the

'activity' ratio in the B horizon above that in the reverted profile does suggest a trend away from gleying at this level. The pattern in the reverted profile offers evidence of a fundamentally different pedogenic pathway. The high proportion of Fe_{ext} which comprises exclusively organically complexed Fe (Fe_{sol}) points to strong remineralisation and the formation of 'active' Fe compounds. In an environment of high acidity and reduced rates of microbial activity organic complexes persist and are available for mobilisation of crystalline iron. The relatively high levels of Fe in the Ag horizon may well be the result of translocation. With reduced numbers of earthworms there is less effective recirculation of translocated materials. Not only is there a progressive surface accumulation of fermenting organic material but relatively unhindered remineralisation of Fe in the Ap horizon. Under conditions of relatively free drainage this process may be expected to lead to progressive podzolisation. This pedogenic change might well be superimposed on a previously gleyed profile as a result of ploughing improving drainage.

Conclusions

Much more detailed and extensive investigations are clearly necessary before the possible long term pedogenic consequences of land use changes and management strategies can be fully evaluated. However, it is clear from these observations on Exmoor that not only are soil and vegetation properties fickle in the context of human activity but that reclamation and reversion may generate major changes of direction in the pathway of moorland soil development. The elucidation of alternative pedogenic pathways and the biological, chemical, physical and morphological changes associated with such developments are significant in the contemporary evaluation of the uplands from the agricultural standpoint. In

the wider context there are, moreover, far-reaching implications for our fuller understanding of the historical status of upland soils and peat accumulation particularly in view of the much-debated role of earlier human cultures on subsequent soil development.

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RENOVATION OF MOUNTAIN PASTURES IN CEREDIGION

Gwynn Jones
Agriculture Development and Advisory Service,
Aberystwyth

Introduction

Reclamation of rough pasture by ploughing and reseeding has long been a feature of farming in Ceredigion. The better land, colonised by bracken and gorse, was first ploughed, leading to a dramatic increase in the rate of stocking and to improved wintering of the flock. Nevertheless, in their enthusiasm for the plough, many farmers were, and a few still are, deceived by thin and peaty soils.

Early Work 1956-64

Earlier efforts to superimpose seeding on trial plots of varying phosphatic manures, with and without lime, on a Nardus/fescue sward had not proved successful. Harrowing had not proved drastic enough at seeding, while the land was unfenced and grazed only with sheep. When the land came to be ploughed some six years later, the growth of rape gave a clear indication of the basic slag plots.

My earliest attempts to adapt the Muirfad technique in the district were on the fringes of Cors Fochno, (Borth Bog), using limited dressings of lime but heavy applications of basic slag as the first stage of improvement. Heavy grazing, topping and spraying of rushes, prepared the way for harrowing and seeding of old meadows, while on moorland, burning or cutting with old forage harvesters was done to clear the ground for discing or harrowing. In 1959/60, some 40 out of the 120 schemes put forward under the Small Farmer Scheme, included renovation of either rough meadows or upland pastures.

During 1963/64 on Cors Fochno, a Landmaster knife-tined rotovator, disc harrow, zig-zag harrow and forage harvester were compared, with and without paraquat, on limed, slagged and burnt moorland. The take of seeds was in direct relationship to the degree of cultivation, with little benefit from spraying with paraquat but on a duplicate set of plots at Trefenter on a rough meadow, the chemical proved more effective in reducing the competition from the old sward. The success of the former set of plots, which were a green island in the brown of Cors Fochno in the autumn of 1964, must have made a marked impression on those who saw them, for the recently introduced Grassland Renovation Scheme was taken up with enthusiasm by local farmers. It was surprisingly simple to adminster and became the vehicle by which many farmers mastered the principles of grassland management.

Renovation is an act of faith, whereby a nucleus of sown species is introduced and fostered to replace gradually, but not entirely, the old sward. It should not be the aim to destroy the latter on land of low fertility, either by cultivation or chemical, for the resulting vacuum could well be partly filled by mosses and rushes. On the higher hills, shelter from the native vegetation must be of benefit in winter, to what are, with the exception of red fescue, grasses and clovers more suited to lowland conditions.

From 1964-68 several hill farmers started what has now grown to become an accepted practice on land beyond the mountain wall, as opposed to reseeding of the drier mineral soils of the ffridd. There are many good examples, including Glanrafon, Talybont, Rhosgoch, Capel Medog and Glanfred, Llandre but perhaps the best of all is Tyngraig, Talybont.

Tyngraig, Talybont

In the autumn of 1963, 600 acres and in 1969, 120 acres were bought to replace land lost to forestry and it is the development of this part of the whole farm of 1,120 acres that has been so impressive. There was already a long tradition of ploughing and reseeding on the farm, going back to reclaiming gorse and bracken-infested ffridd with horses before the Second World War. Some forty acres of dry ground was ploughed and reseeded but most of the bought land was of a peaty nature: ploughing could well have interfered with natural drainage by burying the surface mat and would certainly have led to a rapid invasion of the pasture by rushes. It was thus decided to renovate the native sward by surface improvement but to refrain from unduly breaking the surface crust overlying the peat.

Seeding :

In 1964, 2 tons of ground limestone and 1 ton of basic slag per acre were applied to 18 acres of a Molinia/Nardus dominant ffridd. In late winter of the following year, a slow burn against the wind, left the ideal bare surface, which facilitates both seeding and the subsequent grazing management, on which so much of the ultimate success depends. In early spring, the land was straight disced, the aim being only to make shallow grooves and not to expose clods. Seed falling into these would be in contact with soil moisture, whereas

any germinating on clods could well fail in dry weather and the native vegetation's contribution would have been lost to no purpose. Seeding followed on the first dry day, together with harrowing, rolling or treading by sheep and the application of 2/3 cwt of 20:10:10 fertiliser per acre. Seeding in late March/early April forestalls the growth of Molinia by at least a month, the ground has not dried out and becomes hard and grassy and last but not least, yearling sheep are available for treading in seeds. Heavy stocking with Welsh Black cows and calves followed throughout the summer to keep the native vegetation at bay and encourage the sown grasses and clovers to establish and develop.

Cattle :

The two stage method of renovation continued on the mountain, fencing and improving a block of 20/30 acres each year and was coupled with a high standard of grassland management. Ewes and wether lambs were grazed with the cattle during the summer as the swards improved and indeed became essential in controlling growth as more land was renovated each year. The role of the cattle during the first three years of establishment, however, cannot be over-emphasised. It became apparent, over the years, that the sown grasses and, in particular, the clover were gaining at the expense of the native vegetation.

Fertility :

Basic slag was applied every third year and a second dressing of ground limestone was given within eight years of the start. Soil samples taken in 1968 from the first block, which was limed and slagged in 1964 and given a second dressing of basic slag in 1967, showed at 0 - 2" a pH of 4.8; soluble P (ppm) 160 (7); soluble K (ppm) 390 (4)

and exch. Ca % of 0.54. The pH of the blocks limed in 1966 and 1967 was 5.8 and that in 1965, 5.3. Extra potash was applied as a plot in 1968 at seeding and to an established ley, because of apparent symptoms of potash deficiency having been observed in previous years but with little visual effect. The use of nitrogen in spring, after the year of seeding, is now the practice on a few blocks both to provide more keep but also to combat the spread of moss and rush.

Rushes :

The latter were beginning to establish a hold by 1968 of the block seeded in 1966 and for this reason, it was decided to forego discing on land to be seeded that year, after a slow burn had made the land very bare. Harrowing with a grass harrow was the only cultivation, while treading by yearling sheep followed seeding. The establishment of cover was as good as usual but the grasses were much less in evidence. The 1966 block has since been sprayed, which together with help from nitrogen and three dry summers, has retrieved the position greatly. An earlier attempt at sub-soiling had to be abandoned because of stones, which was unfortunate because the small area that was done, did benefit for some time.

Fronlas :

The 120 acres of land bought in 1969 is, by contrast, on a dry, south-facing slope, dominated by Nardus/fescue with heather. The vegetation was often sparse, which meant that cutting and burning would have to be done, where clear of stones, as opposed to burning in situ. No fencing into blocks was done, other than fencing off 20 acres for ploughing and reseeding, which, with the difficulty of topping stony ground, meant that the native herbage was much less under control. The

whole area has been limed and slagged but only some 40 acres of the 100 surface-seeded. It is a valuable addition, if only to carry the herd in wet weather and prevent poaching of the more tender peaty ground of the northerly slope.

Health :

Looping-Ill was experienced in the early days after ewes from the sheep-walk lost to the forestry were brought on to this land and the farmer had to fall back on upgrading the existing sheep stock, only half of which he had taken over on valuation. Bloat was troublesome later, one cow dying and another barely saved after grazing the improved swards. A snail survey was initiated in 1968 but no infected snails were found within the fenced blocks, only on the banks of the river Cletwr in the steep valley below the north facing slope. Symptoms of pine have appeared during recent years on lambs from Fronlas with a response to vitamin B12.

Benefits :

Land improvement has augmented the wintering ground of the ewes, enabling some of the fields to be kept back for lambing and avoiding severe punishment of the lower land, which would limit summer production. It is providing better keep for an increasing proportion of ewes and wether lambs, a number of which can now be sold fat off their mothers. The remainder are substantially bigger and reach heavier slaughter weights in a shorter time on aftermath and forage crops than those coming from the unimproved hill. Trials at HFRO have shown that high growth of lambs can be maintained after six weeks of age only if good pasture is freely available, which underlines the justification for effective methods of pasture improvement. Some of the ewes are in

that much better condition in autumn to face the winter, leading to more and better lambs and lower feed, if not forage, costs.

Of the total 720 acres, apart from the 70 acres of in-bye, 40 acres have been reseeded, 120 acres surface-seeded and 200 acres given lime and basic slag only: 5,000 yds of fencing was put up between 1964 and 1970. The lambing percentage has gone up by 20% and the stocking rate by 30%, leading to a doubling of the lambs for sale, while the wool clip, a sure indicator of good husbandry, has gone up by 60%. In the farmer's opinion, however, the greatest benefits are qualitative with better draft ewes and heavier fat lambs. Breeding has, however, played its part and not the least advantage is that he has now enough mating paddocks for progeny testing or selected matings of up to six rams. The cows have trebled in number from 20 to 60 and are of inestimable value to the sheep. The cost-benefit in 1972 was that for every £1 net spent on lime, slag, fertiliser, seeds, fencing posts and wire, the extra production realised £2.

GLANRAFON, TALYBONT

In 1965/67, a 15 acre Molinia/Nardus ffridd with dwarf gorse on the drier part was successfully renovated in two stages by burning and harrowing. In 1971/72, a 25 acre part of the mountain colonised by Molinia/Nardus/fescue with gorse and heather locally dominant was improved by burning and discing. In spite of being done late in a dry May, the use of a heavy, trailing disc, followed by wet weather after seeding, led to a sward that was good enough to demonstrate the following year. Less cattle on this farm made topping essential and justified the purchase of a heavy, robust flail mower: its use on the fridd, in particular, halted the reversion to the native herbage and has now

more than turned the tide. A farm where there has been no increase in flock numbers for the last 10/12 years but with Welsh Mountain ewes of around 90 lb live weight commanding the top price as draft ewes at Machynlleth and a lambing percentage of 120.

Rhosgoch, Capel Dewi

Some 120 acres of the 800 acre sheep walk, known as Wenffrwd, Blaenmelindwr has been surface seeded over the years. Much of the Molinia/Nardus could be burnt in situ but cutting, windrowing and burning preceded discing on the Nardus/fescue swards. A dressing of 2 cwt of 20:10:10 fertiliser per acre is applied every spring to the renovated swards, which are regularly topped. The homestead is six miles away but in 1975 and 1976, the herd of near 40 Welsh Black cows and calves spent the summer on the improved ffridd, together with some 300 ewes and wether lambs. More conservation and less punishment of the leys at home results from the earlier departure of the ewes to the hill and the absence of the beef herd.

Glanfred, Llandre

The sheep walk of Llechwedd Mawr, Blaenrheidol is ten miles from the homestead. In 1970, a 200 acre ffridd was fenced out of the mountain of 1,000 acres and during 1971/72, 100 acres of the enclosed land was limed and slagged. Surface seeding started in 1973 with a fenced block of 25 acres, after burning and cutting/burning of Molinia/Nardus. A spike rotovator, with every other spike removed, was used at first but on the third block of Nardus/fescue the farmer reverted to a disc because of stones. The use of dalapon had been considered but it was felt that at 1,500' on an exposed Hill, loss of

shelter from the native vegetation would be a severe handicap, beside the risk of moss colonising bare ground of low fertility. The cover on the first block was inoculated because of the altitude and isolation. The seeds-mixture which is now used consists of 1 lb of wild white clover (S184 or Kent), 2 lb of alsike clover, 3 lb of timothy (S48), 4 lb of red fescue (S59) and 8 lb of perennial ryegrass (S23) per acre.

Cattle from an upland farm have been agisted on the improved swards during dry summers but heavy stocking with ewes and lambs in the main way of controlling growth, together with topping several times a season. Lime lorries can only come within a mile of the land and from the river, which forms the boundary with Powys, spreaders have to cross boggy ground belonging to a neighbour before the final assault on the long ridge leading to the ffridd.

Analytical data from soils of Tyngraig, Talybont, Cardiganshire
(Sampled 14 May 1968)

S/304	0-2" sample)	from area seeded in 1968	
S/305	2-4" ")		
S/306	0-2" ")		
S/307	2-4" ")	" " "	1967 (Cae-r Arglwyddes 2)
S/308	0-2" ")		
S/309	2-4" ")	" " "	1966 (Cae'r Arglwyddes 1)
S/310	0-2" ")		
S/311	2-4" ")	" " "	1965 (Ffridd Fawr)

Sample No. / Analysis	S/304	S/305	S/306	S/307	S/308	S/309	S/310	S/311
pH	5.8	4.7	5.8	4.8	5.3	4.5	4.8	4.1
Sol.P (ppm)	80(6)	14(3)	32(4)	9.3(2)	28(4)	4.9(1)	160(7)	14(3)
Sol.K (ppm)	336(3)	216(3)	357(4)	300(3)	405(4)	209(3)	390(4)	296(3)
Exch. Ca(%)	1.34	0.42	1.00	0.37	0.73	0.20	0.34	0.19

Notes: Ground limestone at 2 tons/acre was applied about 12 months prior to seeding, and basic slag at 20 cwt/acre plus complete fertilizer at seeding time. The area seeded in 1965 received a further dressing of basic slag in 1967.

Analytical data from soils of Tyngraig, Talybont, Cardiganshire

(Autumn 1978)

(0-2" samples)

	pH	P_2O_5	K_2O	Mg	Copper Mg/l	Cobalt Mg/l	Mol. Mg/l	Sel. Total Mg/Kg
Ffridd Fawr Gwarcwm Uchaf	6.5	32(3)	120(1)	451(6)	3.0	0.07	0.09	1.3
Cae'r Arglwyddes								
1.	6.3	33(3)	70(1)	422(6)	2.5	0.10	0.09	1.9
2.	6.2	33(3)	85/1)	336(5)	2.4	0.21	0.08	1.3

Regional Soil Scientist commented that the soils were well supplied with lime, phosphorus and magnesium. Potassium was generally adequate. Copper levels were fairly satisfactory and molybdenum was not likely to cause trouble. Selenium levels were normal but cobalt was very low in the first two samples and could lead to pine in sheep.

PAST HISTORY

Ffridd Fâwr : lime and slag in 1964 and surface-seeded in 1965
Basic slag every third year and lime again in 1972

Cae'r Arglwyddes 1: lime and slag in 1965 and surface-seeded in 1966
Basic slag every third year and lime again in 1974

Cae'r Arglwyddes 2: lime and slag in 1966 and surface-seeded in 1967
Basic slag every third year and lime again in 1974

Botanic Analysis (Welsh Plant Breeding Station)
on 2.11.78

Ffridd

Tiller number (% of total)

	Gwarcwm Uchaf	Cae'r Arglwyddes (1)	Cae'r Arglwyddes (2)
Perennial ryegrass	83	76	58
Poa Annua	-	18	22
Red fescue	12	-	3
Bent	1	-	13
Yorkshire Fog	¼	-	½
Timothy	¼	-	-
White clover	3½	4	3½
Weeds	1	-	-
	100	100	100
Moss	2	4	3

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DISCUSSION

V. I. Stewart (UCW Aberstwyth) The management of land after reclamation is often inadequate. What was the management in earlier periods after the original reclamation?

T.C.B. Horne (ADAS) The nineteenth century reclamation process was well documented but there is little information on aftercare, because many areas remained improved, then by implication the management was good.

A. Charles (PBS) asked Gwynn Jones what seed mixture was used?

Gwynn Jones. The seed mixture now recommended is:

1 lb Wild white clover (S184 or Kent)
2 lb Alsike
3 lb Timothy (S48)
4 lb Red fescue (S59)
8 lb Perennial rye grass (S23)

G. A. Ramshaw (UCW Aberystwyth) asked Gwynn Jones about the value of paraquat used in conjunction with discs as an aid to improvement.

Gwynn Jones (ADAS) said that paraquat is not very effective on moorland grass species and did not want to see the existing sward completely killed out. The improvement process being a gradual change to better species, the existing species still had some use as a sheltering effect.

V. I. Stewart (UCW Aberystwyth) asked what the sward analysis was of reclaimed areas.

Glynn Jones (ADAS) It is easier to get seeds into an open Molinia Nardus sward, and a good ryegrass white clover sward results, at the other extreme Nardus, bent, fescue swards often have more indigenous species, so there can be a wide range developed depending on the existing sward and the subsequent management.

Arthur Troughton (PBS) asked if a gradual change was needed would not fertiliser and grazing control produce sufficient improvement.

Glynn Jones (ADAS) replied that it depends on what you have to start with; a nardus, fescue and bent sward on a south facing slope would be suitable, but not on a north slope, and it is essential to get clover into the sward. Most agrostis fescue swards have already been reclaimed.

E. Munro (PBS) asked Dr. Maltby about the effect on soil moisture of reclamation. Work at the PBS indicated that Ryegrass increases transpiration.

Dr. Maltby (Exeter) replied that he had only looked at moisture in soil horizons and in the profile, and confirmed that total soil moisture is reduced and this is greater in cases where the original peat surface is mineralised. He had not looked at the use of moisture by plants, but this would be an interesting line of enquiry.

B. Clayden (Soil Survey) observed that earlier speakers had related different problems to different soils. Mr. Horne by referring to Liscombe in general and relating this to the potential of Exmoor as a whole was misleading, in saying there was a 7-fold increase in stock carrying capacity and a potential £50/ha extra income.

Mr. Horne (ADAS) replied that 70% of land on Exmoor over 1,000 ft was similar to the high land at Liscombe and was improvable.

Dr. Bridges (Chairman) remarked that no one had mentioned bracken as being a problem?

Dr. Newbould mentioned a paper by Owen Davies to the B.G.S. which showed that chemical control of bracken can produce an extra 1,000 kg of DM from broadleaved grasses, which covers the cost of the chemical control.

J. A. Taylor (UCW Aberystwyth) said that vegetation survey of Wales and the Stapledon Survey in the 1930s indicate that bracken is increasing. For each 3 acres of land lost to urban use and forestry, 1 acre is lost to bracken. It is also possible to link bracken with sickness and cancer in cattle.

W. Adams (UCW Aberystwyth) asked what was the order of magnitude of changes in soil organic matter following reclamation.

Dr. Maltby (Exeter) said that from unreclaimed Ashcombe Series the decline in organic carbon in the profile is 11 kg/m^2 of which the initial loss is 4 kg/m^2 by burning and ploughing. The amount of organic carbon that has recovered by reversion is 1.6 kg/m^2 on a time scale of 130 years.

UPLAND SOIL SURVEY IN SOUTH-WEST ENGLAND

D. V. Hogan
Soil Survey of England and Wales

The Uplands of South-West England

The uplands of South-West England are inextensive compared with those of Northern England, Wales and Scotland. Essentially they are restricted to Dartmoor, Exmoor and Bodmin Moor. Table 1 illustrates the extent of high ground associated with these areas.

Table 1. Extent of Uplands in South-West England

	Km^2 above 180m O.D.	Km^2 above 300m O.D.	Maximum altitude (m O.D.)
Dartmoor	850	450	621
Exmoor (including Brendan Hills)	820	350	520
Bodmin Moor	350	20	419

The granite batholith of South-West England outcrops as a string of five major bosses and a number of minor ones between Dartmoor in the east and the Isles of Scilly in the west. The size of outcrop in terms of both areal extent and maximum altitude generally decreases westwards with the result that only the two most easterly large areas of Dartmoor and Bodmin Moor form true uplands with significant tracts of unenclosed wet moorland, of which small parts overlie metamorphosed sediments of the granite contact zones. Exmoor differs in being over Devonian slates and sandstones. In each area enclosed farmland occupies most of the ground below about 300m and, particularly on Exmoor, includes considerable land at higher altitude.

The uplands of South-West England have received considerable attention by workers with land use interests though until relatively recently little investigation of the soils has been carried out. Until about 20 years' ago the work of Vancouver (1808) provided the main sources of information on Devon soils; on Dartmoor he distinguished an eastern 'Granite Gravel District' of predominantly enclosed cultivated land from the 'Dartmoor Forest District' of high unenclosed wet moor land to the west. Peat deposits are described by Reid et al (1912) in the geological memoir describing the Dartmoor sheet. A general account of the soils of Dartmoor is given by Clayden and Manley (1964) who summarised information accumulated by the Soil Survey of England and Wales since its establishment in Devon in 1959. The first detailed soil map of an upland area in South-West England was of Exmoor Forest parish by Curtis (1971). In the extensive uplands of Northern England the Soil Survey has been engaged on a programme of small scale mapping. Considerable use has been made of aerial photography in the production of maps at a scale of 1:100,000. Because of the relatively small areas involved

in South-West England no special programme for mapping the uplands has been planned but rather areas are covered in the course of the current 1:25,000 mapping programme which was initiated by the Soil Survey in 1967. The areas chosen for survey were selected to be representative of wider major physiographic regions. The distribution of soil surveys impinging on upland areas is shown in Fig. 1. On Dartmoor, soils at the southern edge of the granite outcrop have been mapped at Ivybridge (Sheet SX65) (Harrod et al 1976) and small areas on slates, sandstones and one of the minor granite bosses are included in the Tavistock (SX47) survey (Hogan 1977). Granitic soils were also mapped in the 1:63,360 survey of the Exeter district (Clayden 1971) where the eastern part of the granite outcrop forms a plateau at about 300m O.D. A portion of the northern part of Bodmin Moor has been surveyed on the Camelford sheet (SX18) by Staines (1976). This also includes moorland soils on metamorphosed rocks of the granite aureole. A more complete picture of soil distribution is available for Exmoor. In addition to the Exmoor Forest Survey (Curtis 1971) soils at Brayford (Sheet SS63) (Hogan n.d.) and Lynton (Sheet SS74) (Hogan and Harrod n.d.) have been mapped together with a number of smaller areas which were surveyed to provide soil information for the Exmoor National Park Authority.

Upland Soil Classification

The Soil Survey of England and Wales is currently using the soil classification scheme of Avery (1973) in its 1:25,000 mapping programme. Soil profile classes are defined by four progressive levels of division into major groups, groups, subgroups and series, classes in the first three divisions being defined by composition of the parent material and presence or absence of diagnostic horizons within specified depth limits.

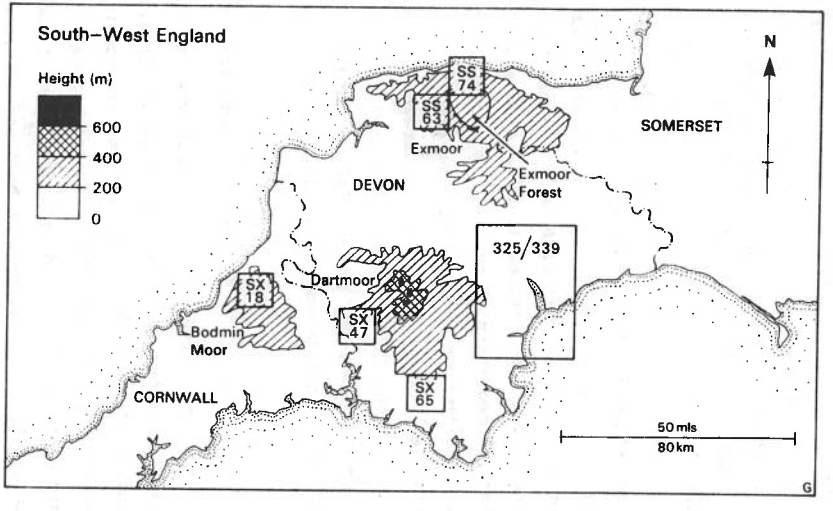

Fig. 1. Location of soil surveys in the uplands of S.W. England.

Within subgroups soil series are defined by one or more of the following chiefly lithological properties; dominant particle-size class including stones usually over the upper 80cm, presence of horizons of contrasting particle-size class, bedrock or compact horizons inpenetrable to roots, origin of the soil parent material such as drift from underlying rocks, soil mineralogy or related characteristics such as colour. Only soils within the podzolic, surface-water gley and peat soils major groups are considered here since the overwhelming majority of upland soils fall into these categories. The classes concerned are shown in Table 2. In the following sections features have been selected which are common in upland soils of South-west England. Horizon characteristics are given in the Soil Survey Field Handbook (Hodgson 1976).

Table 2. Soil classes predominating in the Uplands of South-West England

Major Group	Group	Subgroup
Podzolic soils	Brown podzolic soils	Typical brown podzolic soils Humic brown podzolic soils
	Podzols (*sensu stricto*)	Humo-ferric podzols Ferric podzols Ferri-humic podzols
	Stagnopodzols	Ironpan stagnopodzols Ferric stagnopodzols
Surface-water gley soils	Stagnohumic gley soils	Cambic stagnohumic gley soils
Peat soils	Raw peat soils	Raw oligo-fibrous peat soils Raw oligo-amorphous peat soils

Identification of podzolic soils

These are characterised by the presence of a podzolic B horizon (Bh, Bs or Bf) in which iron and/or aluminium has accumulated in amorphous forms often associated with organic matter. A Bh horizon is normally dark coloured containing translocated organic matter, associated with aluminium and variable amounts of iron, coating sand and silt particles or in sand or silt-size peds. A Bs horizon is brownish or ochreous and contains more than 0.3 per cent pyrophosphate-extractable iron and aluminium which amounts to at least 5 per cent of the measured clay content, and occurs as sand or silt-size peds or coating sand or silt grains. A sharply defined ironpan less than 0.5cm thick is designated Bf.

Brown podzolic soils have loamy or sandy weakly podzolised profiles with a subsurface Bs horizon. They lack an overlying bleached E horizon, thin ironpan or dark coloured Bh horizon. The most widespread are those of the typical brown podzolic subgroup, which are freely drained soils occupying much of the enclosed moorland fringe country below about 300m O.D. and extending to higher altitude on steep valley sides. In granitic parent material coarse loamy or loamy skeletal typical brown podzolic soils of the Moretonhampstead series are widespread. The Bs horizon can be brownish or ochreous with well developed fine granular structure. Microfabric is highly porous with pelletty material characteristic of a spodic horizon (Clayden 1970). In slaty parent material these soils can be difficult to distinguish morphologically from typical brown earths, which have B horizons with insufficient pyrophosphate extractable iron and aluminium to qualify as podzolic (Bs) and which are designated Bw (weathered). On the slate country of South Devon to the south and east of Dartmoor it was found that in general

Bw horizons were brownish and Bs horizons ochreous and field distinction between brown earths and brown podzolic soils was made on this basis (Clayden 1971, Harrod et al 1976). Fine loamy or fine silty typical brown podzolic soils of the Dartington series in this area most commonly occupy steep slopes often under deciduous woodland. The Bs horizons have well developed granular structure though can lack the porous pellety microfabric of the Moretonhampstead series (Clayden 1970). Fine loamy or fine silty typical brown earths of the Highweek series are extensive on the agricultural land occupying interfluves below about 300m O.D. However results obtained from subsequent work in slate country (Hogan 1977) have clouded the field distinction of Bw and Bs horizons; in places brownish B horizons qualify as podzolic on contents of pyrophosphate-extractable material though have morphological features more often associated with Bw horizons such as blocky rather than granular structure and lack of pellety microfabric. Similar brownish Bs horizons have been described in profiles from sandstone in the Exmoor area (Hogan n.d.). Most podzolic B horizons have high fluoride reactivity (Loveland and Bullock 1976) and react positively to a field test for allophane (Fieldes and Perrott 1966).

Humic brown podzolic soils, distinguished where a humose or peaty topsoil is developed, have been mapped as the Moor Gate series on the lower flanks of southern Dartmoor (Harrod et al 1976) and locally on Bodmin Moor (Staines 1976) under bent-fescue (*Agrostis-Festuca*) grassland commonly invaded by bracken (*Pteridium aquilinum*). However these profiles often also show characteristics of podzols (*sensu stricto*) and can be classed as ferri-humic podzols (see below), in which an accumulation of pyrophosphate-extractable carbon occurs in a dark coloured subsurface horizon which can be interpreted as Bh. A recent reconnaissance survey on eastern Dartmoor around Fernworthy has indicated similar soils to

occur commonly at 300-450m O.D. with annual average rainfall up to 2000mm. Profiles have a humose topsoil some 15cm thick overlying a brown or strong brown B horizon and lack a greyish E or obvious dark coloured Bh horizon. There is generally little indication of wetness in the profile or the vegetation, commonly of bent-fescue grassland or ling (*Calluna vulgaris*). However, positive identification of these kinds of profiles will have to await analyses particularly of pyrophosphate iron, aluminium and carbon contents. Less equivocal humic brown podzolic soils have been recognised in cultivated areas dominated by typical brown podzolic soils of the Moretonhampstead series, but where a humose topsoil at least 15cm thick is present. Further soil survey of the Dartmoor fringe country is needed to determine if these soils are sufficiently extensive to separate in mapping.

Podzols (*sensu stricto*) are soils with a continuous albic E and/or distinct Bh horizon with coated grains. The soils lack indications of wetness above or directly below the podzolic B horizon or within 50cm depth. Podzols with a well developed ungleyed E horizon have, to date, not been described on Dartmoor or Bodmin Moor, where masking of colours by organic matter commonly occurs. The separation of ferrihumic podzols from humic brown podzolic soils on granite depends on identifying a Bh horizon often only possible with certainty by using chemical analyses. Field identification of podzols has proved easier on Exmoor. Here soils of this group comprise usually a thin peaty topsoil over a variably stony bleached E horizon. Most profiles of this kind are formed in reddish head derived from sandstone, hard pieces of which are often abundant in the E horizon becoming fewer in an underlying ochreous Bs horizon. Most of these soils are defined as ferric podzols in which there is little or no development of a dark coloured Bh horizon underlying the albic Ea. They have been equated with the Larkbarrow series (Curtis 1971). Where

a Bh horizon is developed between an Ea and Bs horizon the soils qualify as humo-ferric podzols. In the Exmoor areas these are coarse loamy or loamy skeletal and are correlated with the Anglezarke series. The more extensive ferric podzols are often mixed with stagnopodzols and many intergrades between the two also occur. The differentiation of stagnopodzols from podzols involves the identification of hydromorphic profile features (see below). In unenclosed moorland areas identified as comprising a mixture of podzols and stagnopodzols there is usually little indication of wetness in the vegetation which is often dominated by *Calluna*. Soils have a peaty topsoil but it is often only a few centimetres thick due to presumed loss by oxidation following a long history of swaling to maintain a Callunetum. Since E horizons are generally very low in iron due to leaching little mottling occurs. The occurrence of soft, often ochreous stones has been used in conjunction with site and vegetation features to aid decisions on soil hydrology. Where management has changed the hydrology by cultivation, subsoiling or artificial drainage, as explained later, hydromorphic profile features may be fossil relics.

With increasing rainfall and altitude stagnopodzols predominate over podzols. Stagnopodzols are required to show indications of wetness such as a peaty topsoil or gleyed E horizon above a podzolic B horizon. On Exmoor this usually takes the form of a peaty topsoil up to about 30cm thick overlying a greyish Eag horizon with soft weathered stones and associated strong brown colours. At the base of the Eag a thin ironpan can be developed (ironpan stagnopodzols) though these soils are invariably mixed with profiles lacking an ironpan (ferric stagnopodzols). Below is a brightly coloured Bs horizon which grades downwards into drabber or redder stony head. On Exmoor ironpan and ferric stagnopodzols in

reddish head, which is developed over the outcrop of the Hangman Grits, have been distinguished as the Burcombe and Lydcott series respectively. The head derived from adjacent more slaty formations is greyish resulting in the separation of a separate suite of soils. Ironpan and ferric stagnopodzols in this material are correlated with the Hiraethog and Hafren series described widely on Lower Palaeozoic drift in Wales. The semi-natural vegetation on stagnopodzols on Exmoor is dominated by *Molinia* or *Calluna* with cross-leaved heath (*Erica tetralix*) commonly present. On the granite moors ironpan and ferric stagnopodzols (Hexworthy and Rough Tor series) are similarly mixed, though on contrast to Exmoor, the ferric stagnopodzols often intergrade to ferri-humic podzols with dark coloured horizons containing ochreous weathered stones occurring below the peaty topsoil and qualifying as Bh on pyrophosphate-extractable carbon content (Harrod et al 1976, Staines 1976).

Identification of surface-water gley soils

These are non-alluvial soils in which waterlogging results from slowly permeable horizons causing gleying within 40cm depth. In upland areas most of these soils are in the stagnohumic gley soils group and cambic subgroup. They comprise a peaty or humose topsoil at least 7.5 or 15cm thick respectively overlying a loamy gleyed subsoil. This passes down into less gleyed material which can be extremely compact. Fragipan features have been noted in these soils on Dartmoor and Bodmin Moor though in general not on Exmoor. Coarse loamy stagnohumic gley soils over granite are mapped as the Princetown series. Profiles can have podzolic characteristics with eluviation of iron and carbon revealed in pyrophosphate extract analyses. The gleyed B horizons often react positively to the field test for allophane. In slaty parent material both

coarse loamy (Wilsey series) and fine loamy (Ynys series) profiles have been distinguished though clay contents rarely exceed 25 per cent. On Exmoor similar soils have been described in reddish drift and separated at series level. Most cambic stagnohumic gley soils are under moorland dominated by *Molinia*. Wetness in these soils results from the interaction of high rainfall with poorly structured peaty topped soils occupying flattish sites.

Identification of peat soils

These soils comprise at least 40cm of organic material (12-18 per cent organic carbon depending on clay content) formed under waterlogged conditions and, if not artificially drained, saturated for long periods. At group level (Table 2) peats are classed according to the presence or absence of an earthy (ripened) topsoil usually characteristic of drained or cultivated peats. Most upland peat soils lack this feature and are classed raw peat soils. Subgroup divisions are based on pH and degree of decomposition. Since most upland peats qualify as oligotrophic with pH less than 4.5 between 20 and 60cm, field observation largely involves measurement of depth to mineral soil and estimation of fibre content by rubbing (Hodgson 1976). On soil maps hill and flush/basin pests have been separated as phases. Hill peat is relatively inextensive on Exmoor, much of it occurring on the surveyed Lynton sheet SS74 (Hogan and Harrod n.d.). Most is amorphous (Crowdy series) with semi-fibrous peat (Winter Hill series) occupying a few of the higher summits where maximum thickness is about 2.5 metres. Fibre content can be difficult to determine in upper parts of the profile because of the profusion of modern roots. On Dartmoor hill peat is more extensive particularly on the northern parts of the Moor. Though no systematic soil survey has been carried out information so far obtained (Staines pers. comm.) suggests

that both amorphous and semi-fibrous peats occur. Thickness is commonly 2-3 metres though with considerable variation resulting from hagging and peat cutting. Maximum thickness is developed on cols on the highest parts of the moor where 5 metres have been recorded. In many places more fibrous peat overlies amorphous material, a feature possibly linked with past climatic changes. On high plateaux the distinction between hill and basin peat is often blurred. Basin peat occupies many sites in valley heads and broad depressions though in valley bottoms the soils have been largely disrupted due to the past activities of stream tinners. On Bodmin Moor hill peat is restricted to one or two small patches on the highest ground where maximum thickness is only 1-2 metres. Both semi-fibrous and amorphous peats occur. Amorphous basin peats of the Crowdy series have been noted extensively in broad depressions.

Soil Patterns and Land Use

Dartmoor and Bodmin Moor

These two upland areas are considered together because of close affinities in soils, parent materials and physiography. Most of the enclosed farmland surrounding the moorland masses is dominated by typical brown podzolic soils of the Moretonhampstead series. These generally occur below 300m O.D. where the land around the moorland edge is mostly under permanent pasture with little evidence of rush except in discrete flushes and basins. The most extensive mapping of the Moretonhampstead series was carried out by Clayden (1971) on the eastern part of the Dartmoor Granite outcrop but at some distance from the main upland mass, where much of the land has a long history of cultivation; topsoils have insufficient organic carbon to qualify as humose. Closer to the moorland

margin humic brown podzolic soils of the Moor Gate series have been described though have not proved sufficiently extensive to map in such areas surveyed in the Ivybridge or Camelford areas. At the northern margin of Bodmin Moor outcrops of slate, sandstone and schistose aureole rocks carry stagnopodzols of the Hiraethog and Hafren series and stagnohumic gley soils of the Wilsey series. Some land is under *Molinia* moorland though in places the soils have been cultivated or used for forestry. Where long term cultivation of stagnopodzols has destroyed Eag and Bf horizons leaving a dark topsoil overlying an ochreous Bs horizon brown podzolic soils are recognised. Lower moorland slopes are mostly occupied by humic brown podzolic soils of the Moor Gate series, though as already explained, often having a Bh horizon suggesting many profiles qualify as ferri-humic podzols. The land, which is often steeply sloping and bouldery is usually under bentfescue grassland often with bracken. Topsoils are generally humose but, where locally peaty, profiles often intergrade to stagnopodzols with some thin ironpan development. On some steep slopes but more extensively on gently sloping higher ground ironpan and ferric stagnopodzols of the Hexworthy and Rough Tor series respectively have been mapped where bent-fescue grassland gives way to moorland dominated by *Calluna* and *Mollinia* with patches of whortleberry (*Vaccinium myrtillus*) and bracken. Peaty topsoils are generally about 15cm thick though often there is little indication of wetness in the vegetation. Many profiles have characteristics more akin to podzols than stagnopodzols; Rough Tor profiles can have a Bhs horizon with gleying poorly expressed. Stagnopodzols have been mapped on southern Dartmoor up to about 360m O.D. above which peaty topped cambic stagnohumic gley soils of the Princetown series predominate largely under *Molinia* moorland though also with occasional heathy patches. On Bodmin Moor the Princetown series has been mapped (Staines 1976) on enclosed land below 300m O.D.

though pastures are usually rush-infested and rough grazing predominates. Peat soils are mapped where the organic surface horizon thickens to at least 40cm. As explained above hill peats are most extensive in South-West England on the summits of Dartmoor with only a few small patches on Bodmin Moor. Much is occupied by *Molinia* with deer-grass (*Trichophorum caespitosum*) cotton grasses (*Eriphorum augustifolium* and *E. vaginetum*), bog moss (*Sphagnum spp*) and cross-leaved heath (*Erica tetralix*). Depressions in a variety of sites are occupied by basin peat with similar hydrophilous vegetation except deer-grass. The surveyed areas of southern Dartmoor (Sheet SX65) and northern Bodmin Moor (Sheet SX18) both reveal the pattern of soils and vegetation described above (except hill peats) under a similar range of altitude (up to 360m O.D.) and annual average rainfall (up to 1800mm). Reconnaissance work on moorland of north-eastern Dartmoor under 1600-1700mm rainfall has shown that soils with profile morphology similar to the Moor Gate series occupy extensive areas under grass and heather moorland at 360-430m O.D. These grade into stagnohumic gley soils under *Molinia* with relatively few stagnopodzols observed, these mostly on more strongly sloping ground which is under coniferous forestry at a number of sites.

Exmoor and the Brendon Hills

The range of soils is similar to that occurring on the granite moors apart from some important variations in the podzol group. However differing land use patterns testify to the more amenable nature of this area to agricultural improvement. The rugged terrain of the granite moors with their tors and clitter contrasts with the broad smooth outlines of Exmoor where rock and scree are confined to a few localities near the Bristol Channel coast. Whereas the granite moors comprise essentially

central upland cores with largely peripheral reclamation, on Exmoor much of the central portion has been reclaimed and farms established, notably the 8000 ha of Exmoor Forest, which was purchased and considerably reclaimed in the nineteenth century (Orwin and Sellick 1970). Below 300m O.D. on slaty rock formations most soils of the Exmoor fringe are typical brown earths of the Highweek series with some typical brown podzolic soils of the Dartington series largely confined to steep valley sides often under deciduous woodland formerly managed as coppice. Most except the steepest land has been farmed for hundreds of years though some nineteenth century enclosures occur with patches of cultivated stagnopodzols (Burcombe and Lydcott series) retaining gleyed Eag horizons and in places intact ironpans (Hogan n.d.). Above about 300m O.D. the Dartington series displaces the Highweek series from interfluves. Here most of the land is under permanent pasture with groundwater gley soils and peats in small areas of seepage. At the northern margin of Exmoor along the Bristol Channel coast a narrow belt of enclosed agricultural land some 2-3km wide running at 260-300m O.D. occupies rolling interfluves separated by deeply incised valleys. A variety of brown earths and brown podzolic soils, predominate on slates and sandstones with podzols and stagnopodzols under small patches of unenclosed heather common. The Exmoor upland extends eastwards as the Brendon Hills where land use is devoted to permanent pasture and forestry. Though land here rises to about 420m O.D. it lies in the rain shadow of Exmoor with annual average rainfall 1400-1500mm. Work carried out by the Soil Survey for the Exmoor National Park Authority indicates that brown earths predominate. The unenclosed parts of Exmoor comprise a central ridge of high wet ground dominated by grass moors of *Molinia* and *Trichophorum* flanked to the north and south by heather moors, the latter area of which has been greatly fragmented

by reclamation. Much of the heather moorland in the north has been surveyed either on Sheet SS74 (Lynton) or on an additional 30km^2 mapped on Sheet SS84. A mixture of podzols and stagnopodzols occupy much of this land, the proportion of stagnopodzols increasing southwards with higher altitude and rainfall. Eastwards under heather moorland including Dunkery Beacon, at 520m (1705 ft) O.D. the highest land on Exmoor, podzols become dominant. Cultivation of podzols and stagnopodzols along the northern edge of Exmoor has been extensive up to about 395m O.D. On higher ground where rainfall exceeds about 1500mm stagnopodzols occupy most interfluves with stagnohumic gley soils and hill peats mantling high level summits. *Molinia* becomes dominant over *Calluna* and this change is particularly noticeable across the boundary into Exmoor Forest where a long history of heavy summer grazing is thought to have played a part in the development of the vegetation (Curtis 1971). Most of the hill peat of Exmoor occurs in Exmoor Forest parish blanketing interfluves above about 400m O.D. Most are classed as raw oligo-amorphous peat soils of the Crowdy series often between a half and one metre thick. A few patches of raw oligo-fibrous peat soils of the Winter Hill series occupy highest summits where annual average rainfall is about 2000mm. Maximum peat thickness here is about 2.5 metres. Within Exmoor Forest considerable reclamation of stagnopodzols has taken place at 300-450m O.D. with establishment of good quality grassland.

INTERPRETATIONS FOR AGRICULTURE

(i) Land Capability Classification

Each 1:25,000 soil map produced for South-West England is accompanied by a land capability map indicating land separated into classes of agriculture capability using the scheme of Bibby and Mackney (1969). Upland soils fall in classes 4-7.

Class 4: Land with moderately severe limitations that restrict the choice of crops and/or very careful management. This is the lowest class in which arable cropping can be considered.

Class 5: Land with severe limitations that restricts use to pasture, forestry and recreation.

Class 6: Land with very severe limitations that restricts use to rough grazing, forestry and recreation.

Class 7: Land with severe limitations that cannot be rectified.

Subclasses that defined the kind of limitations operating within a particular class are assigned a lower case letter. The following have been used for upland soils on maps so far produced: w (wetness), s (soil), g (gradient) and c (climate). The various classes and sub-classes to which soils have been assigned is shown in Table 3.

Table 3. Capability classification of Upland soils in South-West England

	Sheet SX18 (Camemford)	Sheet SX65 (Ivybridge)	Sheet SS63 (Brayford)	Sheet SS74 (Lynton)
Brown podzolic soils	4c, 5cs	4c, 5cs 5g/6g steep	4c 5g steep	4c 5g/6g steep 6gs steep rocky
Podzols	-	-	6g steep	5s 6g steep
Podzols/ stagnopodzols	-	-	-	4cs, 5cs
Stagnopodzols	4c(cultivate) 5cw	5cw 6g steep	4cw(cultivate) 5cw	5c (cultivate 5cw
Stagnohumic gley soils	6cw	6cw		6cw
All peat soils	6w	6w	6w	6w
Bouldery/rock land	7s	-	-	7s

Brown podzolic soils

These soils particularly of the typical subgroup form the permeable land which occupies much of the in-bye country surrounding the main moorland areas. Good natural drainage allows stocking and trafficking soon after wet periods without risk of compaction and poaching. Severe climate with high rainfall often coupled with extreme exposure limits arable use to forage crops and occasional cereal breaks. However the soils are well suited to grassland (see below) and the high resistance of grainte soils in particular to structural damage permits intensive use. Bibby and Mackney (1969) suggest that land above 180m O.D. with more than 1270mm annual rainfall is not better than class 5. In the uplands of South-West England these limits have been somewhat extended; on Bodmin Moor (Sheet SX18) these soils classed 4c extend to almost 270m O.D. with annual rainfall of 1600mm, and on Exmoor (Sheet SS74) to 300m O.D. under similar rainfall. Though most typical brown podzolic soils in the uplands have been classed 4c, they are downgraded to 5g on steep slopes often in excess of 15° which hamper mechanised improvement. Here pasture has often deteriorated to rough grazing with bracken, gorse and scrub. Many steep valley sides are under woodland including old oak coppice, the valleys providing shelter from prevailing winds. In the Lynton area of North Devon many valley sides and coastal slopes are steeper than 25°. These are classed 6g or, where locally rocky, 6gs. Humic brown podzolic soils have been mapped only on granite moorland margins and have been classed 5cs or on steep slopes 6g. Most occur around 300m O.D. with annual rainfall of about 1600mm. The soil limitation (s) is due to the variable occurrence of surface boulders locally known as 'clitter', which preclude cultivation. Improvement of grassland by surface treatment with fertilizers is possible though mostly inappropriate on account of the high amenity value of these and other moorland areas.

Podzols

Areas dominated by podzols are largely confined to steep valley sides and are classed 6g. On flatter sites 5s is appropriate since the soils are too stony to cultivate without excessive implement wear and problems of seedbed establishment.

Podzols/stagnopodzols

Compound map units are extensive on the northern parts of Exmoor and most areas are classed 5cs. High rainfall and exposure preclude arable cropping and restrict timing of stocking on reclaimed soils. Variable stoniness hampers cultivation. Wetness of moorland soils due to sporadic ironpans and slowly permeable subsoils can be alleviated by subsoiling and drainage measures. In a few places where rainfall is lower (i.e. below about 1300mm) the soils are classed 4cs.

Stagnopodzols

Most soils of this kind are under *Calluna* or *Molinia* moorland and are classed 5cw. They have been mapped at 220-450m O.D. under annual rainfall varying from 1400 to 1800mm. Wetness is due to horizons of low permeability within the profile interacting with high rainfall. Subsoiling has been shown to alleviate wetness allowing some reclaimed soils to be classed 4c or 5c depending on local climate (Staines 1976). However dip-well information has revealed that in certain situations slow permeability at depth causes waterlogging within the subsoil of cultivated profiles (Hogan n.d.). These areas have been classed 4cw. Very steeply sloping areas are classed 6g.

Stagnohumic gley soils

These mostly occupy flattish sites on high moorland generally above 300m O.D. They have been classed 6cw, though subsoiling of these soils on Bodmin Moor (Staines and Hughes n.d.) has been shown to improve subsurface permeability and reduced surface wetness; however such improvement is economically feasible only in accessible areas. Many are remote and amenity considerations are of overriding importance.

Peat soils

Both hill peats and those in flush and basin sites are generally not suitable for economic improvement and are classed 6w. Drainage of small areas at lower altitude can be feasible.

Bouldery and rocky land

Tors and clitter fields on the granite moors and areas of scree and rock outcrops on the North Devon coast are classed 7s. Though of no agricultural significance their amenity value is considerable.

(ii) Soil suitability for grassland

In upland areas agricultural limitations, particularly of severe climate, can be considerable in reducing the choice of suitable crops though these conditions often encourage the growth of grass. A scheme to assess the suitability of soil specifically for grass has been devised by Harrod (1979), in which potential grass yield is balanced against factors affecting the ease of utilization and management

of the crop in terms of traffickability and poaching risk. Yield categories are derived from a calculation of potential droughtiness resulting from the interaction of between soil properties and climate. Traffickability and poaching risk depend on soil bearing strength which in turn relates to various properties observed in systematic soil survey. Retained water capacity is set against soil wetness class modified by the depth to impermeable layers to give risk categories. Four suitability classes are devised as follows:

(A) well suited to pasture, (B) moderately suited to pasture, (C) suited to seasonal pasture but subdivided according to the nature of the imbalances between yield and trafficability, (D) ill-suited to pasture. The scheme applied to mapped areas of upland in South-West England indicates suitability for grassland as follows:

Class A. Well suited to pasture

Potential yields are high and growth is ample throughout the season. The land is readily trafficked and poaching risk is slight. Reasonable amounts of winter stocking can be tolerated. Soils included are typical brown podzolic soils and podzols. Mixed map units of podzols and stagnopodzols are also included where they occur on low ground with a long growing season and not on steep slopes.

Class B. Soils moderately suited to pasture

Typical and humic brown podzolic soils, reclaimed podzols and stagnopodzols on high ground are included, where climatic limitations reduce the length of the growing season.

Class C. Soils suited to seasonal pasture

These soils have various limitations of yield or traffickability which make them unsuitable for intensive grassland use. Unreclaimed peaty topped stagnopodzols and stagnohumic gley soils generally have good potential yield in a shortened growing season but suffer from high poaching risk and difficult traffickability. Brown podzolic soils, podzols and stagnopodzols on stagnopodzols on steep slopes (>11°) similarly can have high potential yield but restricted traffickability.

Class D. Soils ill-suited to pasture

These include peat soils with severe wetness limitations, soils on precipitous slopes (> 25°) and those in which boulders or rock outcrops predominate.

Other Interpretations of Upland Soil Maps

Though upland areas often have considerable agricultural limitations they are extremely important for amenity and recreation. The recently completed survey of the Lynton sheet (Hogan and Harrod n.d.) within the Exmoor National Park covers such as area. The seasonal holiday trade draws large numbers of visitors, many of whom seek low budget self-catering holidays on camp or caravan sites. An understanding of soil properties can aid the choice of suitable land. Erosion on pathways and around car parks has become serious in a number of places on Exmoor. Soil and vegetation has been removed by large numbers of walkers, sightseers and parties of pony trekkers. Guidelines for the siting of footpaths, camping, caravan and picnic areas have been outlined by George and Jarvis (1979) based on soil profile properties and environmental limitations. Classes are as follows:

Well suited (w). Land or routes with at most only minor limitations.

Moderately well suited (MW). Land or routes with limitations that require some modification or improvement (or preventative measures in the case of footpaths).

Poorly suited (P). Land or routes with severe limitations requiring substantial improvement before use.

Unsuited (U). Land or routes with such severe limitations that improvements are unfeasible or uneconomic.

Soil properties concerned are profile wetness class, permeability and dryness subclass (Hodgson 1976), topsoil particle-size class, retained water capacity and stoniness. Other influencing factors are site flood hazard, slope, rockiness and exposure, the last not applying to footpaths. Application of the scheme in the Lynton area indicated exposure to exclude many otherwise suitable areas from well or moderately suited classes. Therefore the classification shown in Table 4 assumes that shelter is provided by buildings or windbreaks if the site is not naturally well sheltered by topography.

The poor suitability of podzols and stagnopodzols results from the presence of a peaty or humose topsoil, which thickens in stagnohumic gley soils and peats to render them unsuitable. Elsewhere in the district steep slopes are the main cause of unsuitability.

Table 4. Suitability of soils in the Lynton Area for camp, caravan and picnic sites and footpaths

Soils	Suitability for camp and caravan sites		Suitability for picnic sites		Suitability for footpaths	
	Class	Limitations	Class	Limitations	Class	Limitations
Brown podzolic	MW	(PSC), (RWC) (SL)	W	-	MW	RWC, PSC, (SL)
Podzols	P	PSC	P	PSC	P	PSC
Stagnopodzols	P	PSC	P	PSC	P	PSC
Stagnohumic gley soils and peats	U	PSC, W	U	PWC, W	U	PSC, W
All soils on steep land	U	SL	U	SL	U	SL

Abbreviations for limitations:

PSC particle-size class; RWC retained water capacity; SL slope, W wetness class. Brackets indicate limitations which are not always present.

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WINDTHROW AND MANAGEMENT IN UPLAND FORESTS OF SOUTH WALES

J. E. Everard
Forestry Commission, Cardiff

The Problem

Wind damage has been recognised as one of, if not the most, important factors in the management of upland forests in Britain. Not only is Britain one of the most windy countries of the world but we often practise forestry on the wettest soil types.

In South Wales Conservancy in the past five years, harvesting after windthrow has accounted for about 200,000 cubic metres, slightly more than 20 per cent of the total production. This represents a considerable loss in revenue because:

1. Rotations are shortened below the financial optimum
2. A proportion of trees are damaged
3. Harvesting costs are increased
4. Work programmes are disrupted and local market prices are depressed.

It seems probably that this is not a transient stage because each year the area at risk, i.e. crops about 15m in height on wet soils, increases.

Research

The Research Division of the Forestry Commission has been working on the problem for some 20 years and has made substantial advances. Work has been generally on two aspects:

1. Reduction of windthrow by changes in forestry practice, e.g. culvitation and thinning.
2. Predicting the occurrence of windthrow; relating the height at which windthrow starts and extends on various sites.

It is fair to say that to date success is more marked in the second rather than in the first aspect. Anyone involved in the field of soil drainage will appreciate the difficulties in improving the physical structure of upland soils. Also cultural advances made over the last 10 years will bear fruit, in relation to windthrow, from 1990 onwards.

Forest management in relation to research

Managers have closely followed the lead of research and, in many cases, research has developed techniques and practices started by field managers themselves. In Wales the observation and analysis done by Stumbles at Kerry Forest and Francis at Clocaenog Forest, and by the Commission's Site Survey teams have generally been closely followed by practising foresters.

As a result of research the following practices are now follows:

1. Avoid sites where rooting less than 30cm is likely
2. Concentrating effort on local drainage by ploughing rather than relying on spaced open ditches
3. Using double furrow ploughs to give a wide rooting platform
4. Recognition that it is the soil and not the tree species that determines the depth of rooting and ultimately the occurrence of windthrow.

Thinning, particularly if delayed, can significantly advance the onset of windthrow on sites where downward rooting is restricted.

Predicting windthrow on an objective basis

In a long term business such as forestry it is important to have reliable forecasts. Windthrow, if totally unexpected, can create havoc with such forecasts and considerable effort is going into predicting the likely occurrence of wind damage.

Windthrow Hazard Classification

This system has been developed by T. G. Booth (1977) of our Northern Research Station and is a summation of 15 years' work by numerous researchers including Fraser (1967), Neustein (1971) and Mayhead (1973). It is based on the four factors which seem most involved in the determination of windthrow, and by scoring each of these it is possible to arrive at the windthrow hazard.

1. Windiness. Based on tatter flag data and meteorological office records.
2. Elevation.
3. Topographic position. Topex scale, described by Pyatt (1977).
4. Soil type. In terms of the depth of rootable soil.

Cultural practice can influence windthrow and the hazard rating can be modified accordingly. For example, in South Wales it is proposed to weight the rating to take account of delay in thinning.

The main use of the hazard classification will be to grade sites in their susceptibility to early windthrow. Having done this we are deciding whether or not to thin. Thinning basically is a profitable proposition because it advances revenues and stimulates diameter increment. There are however costs involved in thinning - road building and a first thinning of marginal profitability. There is no point in incurring such expenditure if windthrow is likely between 1st and 2nd thinning or soon after. We now have quite large blocks of forests under a no-thin regime.

In addition the hazard classification will give an indication when crops will blow down and this can be used in forecasting timber yields. In theory we should fell a crop the year before it is due to blow down. In practice we allow the wind to confirm our prediction and fell when about 25 per cent of the trees have been blown down.

Rheola Forest

This is one of the older forests in South Wales and is used here to provide a practical example of the use of the Windthrow Hazard Classification.

The forest lies at the lower end of Glynneath and extends to about 4200 hectares. Soils are mainly gleys and peats, which are regarded as "susceptible" to windthrow. Elevation ranges up to 500 metres, with much of the higher ground classed as severely exposed. As can be expected, the high scores on the three local factors - elevation, exposure and soil - coincide on much of the high ground and so 625 hectares have been placed in a no-thinning regime. Already windthrow has occurred and premature felling carried out.

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NUTRIENT CYCLING IN RELATION TO TREE GROWTH AND SOIL DEVELOPMENT

Hugh G. Miller

The Macaulay Institute for Soil Research,
Craigiebuckler, Aberdeen, AB9 2QJ

Introduction

Many processes transfer or transform nutrients in a forest ecosystem. Although these will interact uniquely at every site, there are common to all sites a limited number of possible critical pathways, movement along any of which may control tree growth. If, in any situation, the rate-limiting pathway can be identified, then remedial action can be aimed directly at the immediate cause of the disturbance. The aim of ecosystem analysis in nutrition research, therefore, is to obtain the understanding that will enable diagnosis of pathways that are, or will become, critical. There are, however, still many practical and conceptual problems in such an experimental approach. While certain transfers, such as that in litter fall, can be readily monitored, others, such as nutrient uptake, can only be assessed from mass balance studies involving repeated determinations of the accumulation in vegetation or soil; and yet others, such as transfers through crown leaching, or the input in aerosols and dust, are particularly difficult to measure and present present problems of interpretation.

Welsh Soils Discussion Group Report No. 20

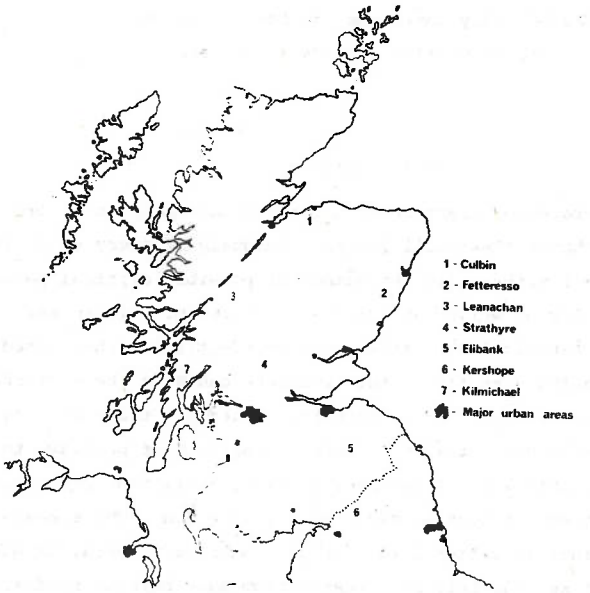

Fig. 1. Locations of experimental sites.

It is convenient to consider nutrient cycles within a forest at three interrelated levels: (a) the cycle that introduces nutrients to, and removes them from, a forest site; (b) the cycle that transfers nutrients within the ecosystem from one zone of accumulation to another- (c) the cycle of nutrients within the tree.

Cycle External to the Ecosystem

Most nutrients are transferred from the atmosphere to a forest both in rain-water and via a further pathway that has been variously described as dry deposition, aerosol input or the filtering, or trapping, effect. It has become conventional to divide atmospheric input into wet and dry deposition. However, Miller, Unsworth and Fowler (1979) have suggested a more logical division would be into the portion of the input independent of the receiving surface - i.e. that in precipitation and sedimentation - and the portion dependent on the size and nature of the surface of the vegetation exposed to the wind - the "filtering action" of Mayer and Ulrich (1974). Certainly, placing an inert wind filter over a rain gauge can markedly increase the concentration of many elements in water collected in the gauge (Table 1), an effect most marked in coastal regions (Fig. 1).

It is difficult to assess the amount of any nutrient reaching a forest through what may loosely be termed trapped aerosols. The results of three recent attempts are shown in Table 2. Clearly aerosol capture is an important process leading to enhanced input of soluble salts, notably potassium, and it undoubtedly increases the amount of insoluble dust collected, from which nutrients can be subsequently mobilized by weathering. As yet no estimate of input has included the proportion taken up directly by the trees through foliar absorption, either as soluble

Table 1

Concentrations of nutrients in rainwater collected beneath inert wind-filters of polyethylene-coated wire mesh expressed as a percentage of the concentration in rainwater collected in a standard rain gauge for the six forests shown in Fig. 1.

Year	Forest	N	P	K	Ca	Mg
1976/77	Fetteresso	170	130	500	230	410
	Leanachan	120	100	310	210	400
	Strathyre	180	230	110	115	200
	Elibank	180	210	190	150	300
	Kershope	240	160	460	250	500
	Kilmichael	224	250	470	190	470

salts through the leaf surfaces or as gases, such as ammonia and sulphur dioxide, through the stomata. Further, microbial fixation of nitrogen has been variously estimated to make an annual contribution of from 0.4 kg ha^{-1} (Granhall and Lindberg, 1978) to 100 kg ha^{-1} (D'Sylva, cited in Frissel, 1977). Although most studies would suggest values at the bottom end of this range, such fixation is undoubtedly an important process for the health growth of forests.

Input in rain, like that in aerosols (Table 1), varies with locality (Table 3) and may also show considerable variation from year to year at the same site (Table 4). This varying input is not necessarily related to, and may show a greater spread than, the variation in the amount of rainfall. As a result, in the absence of long-term measurements it is difficult to estimate the nutrient input at any one site.

Table 2. Inputs in rainwater and through the trapping of aerosols at three sites

		kg ha^{-1} yr^{-1}			
		Na	Ca	K	Mg
Beach[1]	Rainwater	7	13	4	3
	Aerosol	3	6	5	1
Pine[2]	Rainwater	25	3	3	3
	Aerosol	15	4	7	2
Spruce[3]	Rainwater	42	nd	3	nd
	Aerosol	22	nd	7	nd

nd not determined

[1]Solling, Central Germany -- Mayer and Ulrich, 1974.
[2]Culbin, Scotland -- Miller, Cooper and Miller, 1976.
[3]Fetteresso, Scotland -- Lakhani and Miller (in press).

What can be said is that the amount could be large and, for an established forest, would be much underestimated from measurements on rainfall alone. For potassium, the rate of input is likely to compensate for the envisaged rate of removal in harvesting (Table 5) and under certain circumstances the same may hold for nitrogen; the phosphorus input, however, is unlikely to make an important contribution.

Table 3. Input of nutrients in rainwater over one year

Year	Forest	mm rain	kg ha^{-1}				
			N	P	K	Ca	Mg
1967/77	Fetteresso	1120	19	0.09	2.0	10	6.0
	Leanachan	1080	12	0.07	1.3	11	2.8
	Strathyre	1620	13	0.09	3.8	8	2.6
	Elibank	1020	10	0.06	2.3	9	2.4
	Kershope	1130	11	0.10	1.1	9	2.5
	Kilmichael	1530	10	0.12	1.4	10	4.3
1966/67	Culbin	700	5	0.04	2.8	3	2.7

Table 4. Annual variation in nutrient content of rainwater at two sites

		1973-74	1974-75	1975-76	1976-77	1977-78
FETTERESSO						
mm rain		750	860	740	1120	1010
kg ha^{-1}	N	10	9	5	19	22
	P	0.04	0.02	0.04	0.09	0.13
	K	2.7	4.3	1.5	2.0	0.7
LEANACHAN						
mm rain		2000	1910	1410	1080	1160
kg ha^{-1}	N	7	5	6	12	14
	P	0.07	0.12	0.06	0.07	0.08
	K	11.8	4.5	2.9	1.3	1.4

Table 5. Nutrient input in comparison with estimated removal through harvesting of pine

		kg per ha per 100 years		
		N	P	K
Possible range of input:				
rain[1]		500-1900	6-12	110-380
aerosol[2]		0-360	--	480-700
microbial fixation[3]		35-320	--	--
Removal in trees[4]:				
Traditional harvest	YC6	164	17	100
	YC10	318	32	170
	YC14	524	46	264
Whole-tree harvest	YC6	416	53	280
	YC10	801	94	502
	YC14	1358	138	760

[1] Values from Table 3

[2] From Miller, Cooper and Miller, 1976, and Mayer and Ulrich, 1974.

[3] From Granhall and Lindberg, 1978

[4] From Miller, Miller and Cooper, unpublished. YC - Yield Class (Hamilton and Christie, 1971). Values include thinnings over rotations of 70, 65 and 60 years for YC's 6, 10 and 14, respectively, and assumes for traditional harvest removal of trunks alone and for whole-tree harvest removal of all above-ground components plus, at clear felling only, removal of stumps.

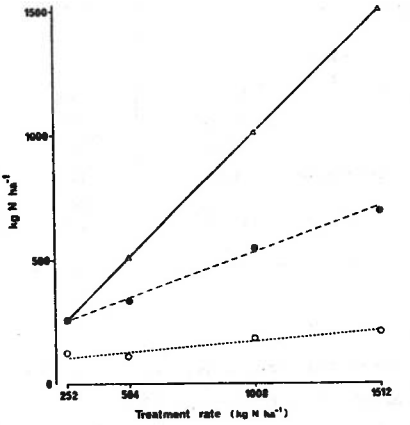

Fig. 2. Retention of nitrogen in the total ecosystem (Δ) and in the soil organic layers (o) in comparison to the four rates of fertilizer applied (•) at Culbin forest (from Miller, Miller and Pauline, 1976).

If these inputs are to have a significant effect they must be largely retained within the ecosystem. It does seem to be generally true that forests are very effective at retaining atmospheric inputs, for numerous studies have produced results similar to those shown in Table 6. For spruce in Central Germany, Mayer and Ulrich (1977) have calculated that sodium is the only element of those listed in Table 6 that decreases in the ecosystem. In more maritime regions, however, there is reason to suppose that sodium may actually be accumlating (Williams et al., 1978). Indeed, forests appear to be more effective at retaining nutrients than are other forms of vegetation cover (Dillon and Kirchner, 1975) and are even able to retain large amounts applied as fertilizer (Fig. 2). Cole and Gessel (1965) have shown that nutrient retention is reduced when the crop is clear felled, an effect that is most marked if reinvasion by vegetation is prevented by application of herbicides (Likens et al., 1978), and recently Stark and Jordan (1978) have suggested that the pronounced retention they found in the root mat of Amazonian forests was due to uptake by roots and mycorrhizal fungi. The latter suggestion accords well with the observations at Fetteresso forest, where retention of nitrogen in undisturbed humus, with its characteristic large concentration of feeding roots (Table 6) greatly exceeded that in humus placed in plant pots beneath the forest canopy (Williams, pers. comm.).

Cycle within the Ecosystem

Within the forest, nutrients cycle between the three zones of accumulation represented by the vegetation, the soil organic layers and the mineral soil horizons. The calculated fluxes of potassium, phosphorus and nitrogen between these zones of accumulation necessary to maintain

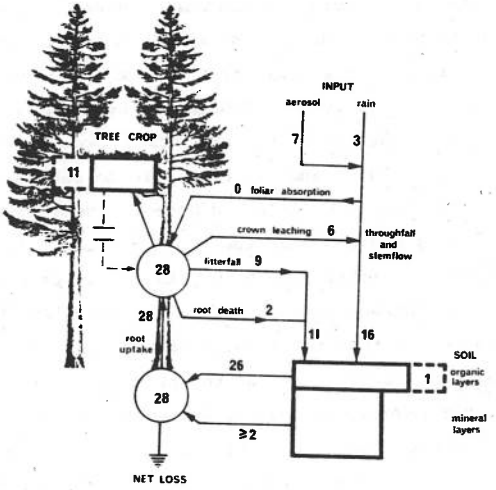

Fig. 3. Calculated annual fluxes and rates of accumulation of potassium (kg Ha^{-1}) at maximum growth rate (19.7m^3 ha^{-1} yr^{-1}) of Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melv.) at Culbin forest, together with measured rates of input. Zones of accumulation are shown by rectangles, the annual rate of new accumulation being represented by the dashed portions, mobile pools are depicted by circles (from Miller, Cooper, Miller and Pauline, 1979).

optimum growth of pine at Culbin forest (Miller, Cooper, Miller and Pauline, 1979), together with the measured inputs at this forest, are shown in Figures 3, 4 and 5.

Table 6. Concentrations of elements in rainwater reaching the forest soil and in soil leachate collected below the humus and below the root zone of Sitka spruce at Fetteresso (Miller, 1979).

	mg per litre					
	N	P	K	Ca	Mg	Na
Thoroughfall and stemflow	8.0	0.235	5.7	7.4	2.2	9.6
Leachate-below humus	3.1	0.044	2.3	5.3	0.8	7.0
-below root zone	1.1	0.004	1.3	3.7	1.2	44.7

Although rather more than one third of the potassium uptake is retained to be incorporated in new tree tissues (Fig. 3), the rate of accumulation in the soil organic layers is very low. Thus, net retention in the trees and soil organic layers amount to only 12 kg $ha^{-1}yr^{-1}$, roughly comparable with the 10 kg received in rainfall and aerosols. The remaining 2 kg plus any unmeasured leaching loss, would have to be supplied by the mineral horizons. Potassium input in rain at other sites (Tables 3 and 4) has ranged from 1 to 12 kg $ha^{-1}yr^{-1}$ and the two estimates of aerosol input presently available for Scotland are both of 7 kg (Table 2). It would seem, therefore, that once an established forest has sufficient potassium in circulation, the system can be very nearly maintained on atmospheric input. The same holds true for magnesium, for which input is frequently likely to exceed the net rate of immobilization.

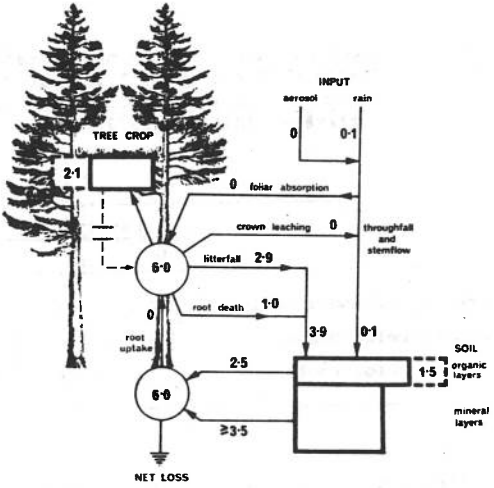

Fig. 4. Calculated annual fluxes and rates of accumulation of phosphorus (kg ha^{-1}) at maximum growth rate of Corsican pine at Culbin forest. For explanation of symbols see Fig. 3 (from Miller, Cooper, Miller and Pauline, 1979).

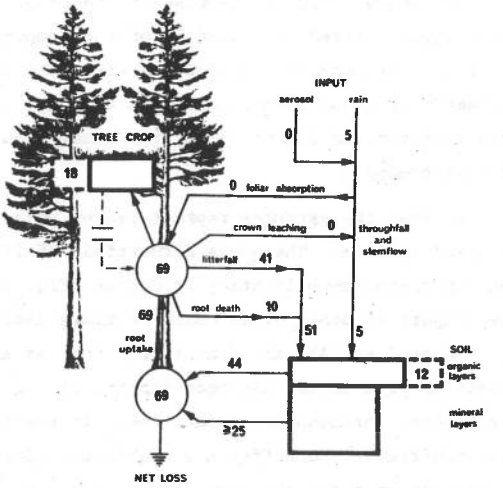

Fig. 5. Calculated annual fluxes and rates of accumulation of nitrogen (kg ha^{-1}) at maximum growth rate of Corsican pine at Culbin forest. For explanation of symbols see Fig. 3 (from Miller, Cooper, Miller and Pauline, 1979).

Phosphorus (Fig. 4) represents the other extreme - in the forest examined, input covered less than 3% of the temporary loss through immobilization. At none of the Scottish sites has phosphorus input come near to matching requirements, and even the high value of 0.7 kg ha^{-1} measured by Mayer and Ulrich (1974) in Germany would contribute less than 20% of that needed.

Between the extremes represented by potassium and phosphorus lie nitrogen and calcium. There was a shortfall of 25 kg nitrogen $ha^{-1}yr^{-1}$ between input and immobilization at Culbin (Fig. 5). Although the measured inputs at other sites could at times almost compensate for this amount (Tables 3 and 4), it seems likely that at all sites the trees would have to call on the nitrogen capital of the soil, or on microbially fixed nitrogen, throughout the rotation. If the nitrogen capital of the site is insufficient to buffer the temporary reduction resulting from immobilization in trees and humus, then the crop became progressively more nitrogen deficient. Indeed, measurements of past growth suggest that this is precisely what occurred in the experimental crop at Culbin (Fig. 6), and similar examples of progressive site degradation have been reported from many northern regions of the world (e.g. Tamm, Carbonnier and Hagberg, 1960; Zöttl, 1960; Weetman, 1962; Heilman and Gessel, 1963; Turner, 1977; Miller, Miller and Binns, 1977).

Cycle within the Trees

Trees can readily move nutrients from one organ to another, the best known example probably being the withdrawal of nutrients from old foliage prior to abscission. There is also considerable movement associated with the accumulation of nutrients during dormancy and their

subsequent mobilization for use, often in a different part of the tree, during periods of active growth (e.g. Durzan, 1967; Tromp and Ovaa, 1971). The seasonal appearance and disappearance of mobile nitrogen is even reflected in the amounts of mineral nitroven lost from the tree through crown leaching (Miller, Cooper and Miller, 1976).

Thus, there is a storage of nutrients during the dormant season that, together with uptake during the growing period, would normally contribute all the nutrients required for growth. However, miller, Cooper, Miller and Pauline (1979) have pointed out that, should these supplies from "first level sources" be insufficient, then the tree has the option to mobilize nutrients taken up during the previous growing seasons. Mobilization from these "second level sources", represented by the dotted loops in Figures 3, 4 and 5, is usually at the expense of the proper functioning, or even continued existence, of older tissues, as illustrated by the early age at which needles senesce on nutrient deficient trees. Occasionally mobilization from second level sources can be of nutrients taken up and stored during a period of excess supply, such as when fertilizers are applied. Certainly all living components of the tree accumulate fertilizer nutrient over the short period following application (Table 7). During subsequent years, these fertilizer-enhanced concentrations drop progressively to pre-application levels. Indeed, calculation on this basis for the fertilised pins shown in Table 7 showed that mobilization from second level sources alone was sufficient to explain the continued growth response in the years after fertilizer was last applied (Miller, Miller and Pauline, 1976).

Table 7. Changes in amount of accumulated nitrogen following application of nitrogen (504 kg $ha^{-1}yr^{-1}$ for three years) to 40-year-old Corsican pine at Culbin (Miller, 1979).

Tree component	% increase in N concentration	Increased Weight of N, kg ha^{-1}
Foliage	280	250
Branches	210	45
Stem Bark	255	55
Stem Wood	185	45
Stump	190	10
Lateral Roots	295	90

Discussion

Recently Miller, Cooper, Miller and Pauline (1979), discussing the models derived for nutrient cycling in Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melv.) (see Figs. 3, 4 and 5) on the sand dunes of Culbin forest, in north-east Scotland, concluded that tight cycling (i.e. minimum loss from the ecosystem) and low rates of immobilization in trees and humus, coupled with effective retention of relatively high atmospheric inputs, probably represents an adaptive mechanism that enable trees to thrive on soils low in potassium and magnesium. However, high rates of immobilization and low rates of atmospheric input relative to tree uptake, mean that, despite the maintenance of

tight cycles, the trees continue to make significant demands on soil reserves of nitrogen, phosphorus and calcium throughout their life-cycle. This emphasizes the importance of the evolution of the mycorrhizal relationship in ensuring adequate supplies of nitrogen and, in particular, phosphorus from poor soils. More recent information suggests that perhaps there is a need to qualify these conclusions in terms of the geographical and temporal variability in atmospheric input, the development stage of the crop, and the interaction of these factors. Clearly the nitrogen input in rainwater (Table 3) can be much greater than that measured at Culbin. It may be that, at some sites, the input in rainfall and the unknown inputs through aerosol capture and microbial fixation would together be sufficient to compensate for the temporary loss through immobilization. Similarly, the shortfall in calcium may often be less than found in Culbin. For potassium and magnesium, the limited evidence available suggests that at all sites in Scotland a closed-canopy forest should receive, over any extended period, sufficient atmospheric input to maintain at least the growth rate measured as optimum at Culbin (Yield Class 16). However, in the very short-term, the puzzling appearance and disappearance, in crops that do not respond to potassium fertilizers, of the foliage yellowing typical of potassium deficiency suggests that potassium uptake may follow very closely variations in atmospheric input. Variations in nitrogen supply, on the other hand, are unlikely to produce such immediate responses because the tree has considerable ability to store and husband this nutrient.

Thus, once canopy has closed and a nutrient cycle is established, trees can become largely independent of the deeper soil horizons for their supply of certain major nutrients, while for others the soil supply can be supplemented sufficiently from atmospheric sources to prevent the development of deficiencies. However, trees will always be

mainly dependent on soil sources for phosphorus, as indeed they are for all nutrients up to the time of canopy closure. Prior to canopy closure there is likely to be very limited aerosol capture, which severely reduces the atmospheric input of some elements, notably potassium (Table 2), and the crucial factor is likely to be rate of root extension into new volumes of soil.

This division into an initial soil-dependent stage, and a subsequent stage when the dependence on soil supplies is much reduced, may go some way towards explaining the observed pattern of fertilizer responses. For, whereas responses to nitrogen, phosphorus or potassium are frequently obtained at the establishment phase, fertilizer trials on similar soils in crops that have recently closed canopy have produced disappointing results, with the exception of a few marked responses to phosphorus. There then remains a third stage during later years when deficiency may result from tree-induced changes in the ability of the soil to supply nitrogen. In forests of very low nitrogen capital, immobilization in the humus may lead to nitrogen deficiency fairly early in the rotation, as was found in Culbin (Fig. 6). More usually, however, this is a problem that develops in late middle-age and old-age.

Thus, in the search for critical pathways that may limit tree nutrition it is clearly necessary to consider separately a stage when soil supplies are of first importance, then a stage when atmospheric input plays an important role and finally a stage at which immobilization in the humus seriously reduces nitrogen supply.

For much of their life trees interact with the atmosphere to increase nutrient supply through aerosol capture in a way that is likely to have pronounced effects on the development of soil fertility. The

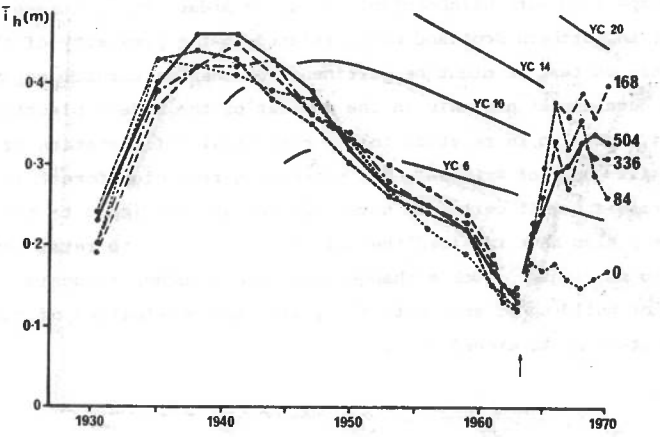

Fig. 6. Progression of mean annual height increment ($\bar{i}_h$) for the Corsican pine experiments at Culbin. Arrow marks year of first fertilizer application which was given at rates of 0, 84, 168, 336 and 504 kg N $ha^{-1}yr^{-1}$ over the three years 1964-1966. In comparison to the normal pattern of height growth, shown for different Yield Classes (YC) using values from Hamilton and Christie (1971), these trees show signs of progressive site degradation resulting from increasingly severe nitrogen deficiency (from Miller and Cooper, 1973).

results from Solling and Culbin given in Table 2 show that the "aerosol" component increase the cation input to the soil by as much as a half to three quarters of that in rainfall. Although there would still be some aerosol input to less tall vegetation, such as heather moorland, there can be little doubt that this form of input is greatest under trees. Indeed Williams et al., (1978) have noted a highly significant increase in the amount of exchangeable sodium in peat beneath trees in comparison with neighbouring unplanted areas, the increase over six sites in northern Scotland being related to the proximity of the sea. In this context it might be pertinent to consider aerosol capture and soil development not only in the context of the recent planting of trees, but also in relation to the historical deforestation of much of the hill lands of Britain. The conversion from high forest to shrub or grassland will certainly have reduced nutrient input to the site, and may also have impaired the ability of the site to retain atmospheric nutrients. Such a change must mark a sudden reduction in the rate of build-up of soil nutrients, with the possibility of nutrient loss starting to exceed input.

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DISCUSSION

E. Clayden (Chairman) asked Dr. Miller (Macauley Inst.) if sewage sludge had been used as a fertiliser for trees on the Culbin Sands.

Dr. Miller (Macaulay Inst.) answered that this treatment had been used upon Douglas fir in Washington State U.S.A.

Dr. B. E. Davies (UCW) pursued the problems of using sewage sludge, because although it was a source of nitrogen, it also contained lead cadmium and mercury. Dr. Miller had shown forest trees were effective at accumulating elements - what was the position regarding toxic heavy metals? If sewage sludge is used and the trees do not take these elements up they have been spread over a wide area. If the trees do take them up, then when they are used for paper, packaging or burnt the heavy metals are again spread in the environment and this was unsatisfactory. Could Dr. Miller tell us more about it.

Dr. Miller replied that work had been done on sewage sludge and composted town waste which contained cadmium nickel and lead. Care had to be taken not to use waste which contained high levels of heavy metals.

T. Boyle (Forestry Commission) commented on the application of nitrogen in sewage sludge to opencast areas. Subsequent growth of trees suggests that if the sewage sludge is chosen carefully on the basis of low heavy metal concentrations the trees do not accumulate heavy metals to any extent and that toxicity does not result.

Dr. E. M. Bridges added that analysis of trees planted for amenity purposes in the Lower Swansea Valley were showing an interesting cycling of elements in the ecosystem with lead being held in the litter

layers, and other elements, for example zinc and magnesium, being held in the soil above a fragipan.

Dr. W. O. Binns (Forestry Commission) took up a point raised by Dr. Miller about rainfall variation and the input of Chloride. He commented that Chloride was the dominant anion in Scotland; was this in terms of proportion or total amount?

Dr. Miller replied that he was speaking in terms of proportion, but added that it was also in terms of absolute amounts. The Chloride came in the form of sodium chloride.

Dr. C. C. Rudeforth (Soil Survey) was interested to see the relationship of yield against elevation shown by Dr. Binns for a particular North Wales forest; a less strong relationship for N. Wales as a whole and only a slight correlation of yield with elevation in South Wales. Did Dr. Binns consider that yields would correlate well with elevation when continentality (in particular summer temperatures) was taken into account.

Dr. Binns agreed it could well be so, but broad generalisations are always suspect.

Mr. J. Everard (Forestry Commission) added that he had done a regression with distance to the sea and that after elevation this was the second most important factor. After eliminating 'carboniferous' soil data from the calculation, better growth was observed at the same elevations on the soils of the Old Red Sandstone on the Brecon Beacons so it was not a soil effect.

Mr. Clayden (Chairman) chided members for referring to soils by the names of their geological parent materials in their discussions.

Dr. Gareth Roberts (Institute of Hydrology) enquired from Dr. Miller how important crown leaching was in the nutrient cycle.

Dr. Miller replied that crown leaching was very important indeed, especially for potassium as more moves in crown leaching than in litter-fall. A large amount of calcium and magnesium moves. In work with pine, it is not important, but in spruce it is significant but less so than litter fall.

Dr. G. Roberts described how they were monitoring two streams on Plymlimon, one from forest and one from a grassland catchment, and that they were finding consistently higher nitrate nitrogen from the forested catchment. Could this be due to crown leaching?

Dr. Miller thought that it should be the other way round. Crown leaching comes out in all forms, not just as nitrate but other organic forms and ammonium. In the soil nitrification was irregular in occurrence and was encouraged by fertilizer treatments.

Dr. W. O. Binns commented that nitrates appear in run-off water in forest streams following harvesting and thinning but concentrations are very low and give no cause for alarm.

Dr. Miller reported that he had observed nitrates coming out in drainage water in concentrations up to 7 ppm.

Dr. G. Roberts added he had always found less than that.

Mr. C. Evans (ADAS Aberystwyth) argued that grass was a better utiliser of nitrogen and added there were fewer organisms in forests capable of utilising the nitrogen.

Dr. Miller said they had been interested in the riparian zone where nutrients in waters had seeped away from streams to benefit the vegetation along the banks.

Mr. Finch (ADAS Aberystwyth) asked Dr. Binns about the economics of aerial fertilizer application in forests.

Dr. Binns said it only becomes economic if the trees grow faster after treatment. Most work had been done in cases where crop failure was imminent and there had been few opportunities to try it on other crops. The costs are between £16 to £20 for 1/3 tonne per hectare for fertilizer to which must be added the cost of the aircraft and other overheads. On poorly growing crops it is economic but on older and better crops it is more difficult to guarantee improvements in growth which is why tree crops are not being treated on an extensive scale. It only has to be done at intervals of ten or twelve years.

It being lunch time, the acting Chairman, Mr. Clayden, drew the discussion to a close by thanking the speakers who had provided such an interesting series of papers during the morning.

OPERATIONAL RIVER FLOW FORECASTING IN NORTH WALES USING GENERALIZED SOIL MOISTURE STORAGE/OUTFLOW RELATIONSHIPS

A. O. Lambert
Welsh Water Authority, Mold

The ISO - function method

The ISO - function method is used for sub-catchment modelling on the River Dee regulation system (Type I logarithmic functions) and for river channel routing calculations in the Lower Dee (Type II linear functions in series). Flood routing calculations in the Upper and Middle Dee are based on the Variable Parameter Diffusion Model developed by R. K. Price of Hydraulics Research Station. The computer based telemetry system on the Dee incorporates hydrologic/hydraulic models which provide real-time flow forecasting in all river conditions.

A simpler, but still effective, adaptation of ISO - functions is used on the River Elwy in North Wales, for flood prediction only. The flows from an interrogable river gauging station (Pont y Gwyddel) are expressed not only in m^3/sec but also in mm/hr over the 194 km^2 catchment area; average rainfall rate at two interrogable rain gauges is continuously compared with run-off rate, knowing that the catchment area has a ½ hour 'lag', and regular forecasts are made if the river will rise, fall or remain steady (see paragraph 6 of following notes). There is a 2½ hour time of travel from the gauging station to St. Asaph, the town with flooding risk, and various Pont-y-Gwyddel flood flows have been correlated to specific flood levels in and around St. Asaph. This

unsophisticated method has been proved to work excellently in practice, and is quite adequate for such a situation.

Research is proceeding into the derivation of ISO - function equations for a more general Type III ISO - function, of the form

$$S = k \log_e (q + a) + c$$

The following notes summarise the principles used in the ISO - function method of catchment modelling and flood routing.

The ISO-function method of Hydrological Modelling

1. The method assumes that a natural catchment area may be represented by a single unified natural storage (S) which controls the rate of river flow (q), and which is intermittently replenished by inputs of rainfall (r)*. No subdivision of river flow into components (surface runoff, interflow, baseflow, etc.) is assumed.

The water balance equation may be written as -

$$\frac{ds}{dt} = r - q \qquad \ldots \ldots \ldots (1)$$

where r and q are rates of rainfall and river flow.

Assuming that q is uniquely related to S,

$$S = f(q) \qquad \ldots \ldots \ldots (2)$$

then, differentiating with respect to q

$$\frac{dS}{dq} = f'(q) \qquad \ldots \ldots \ldots (3)$$

* Evaporation may be considered mathematically as negative rainfall.

2. Dividing equation (1) by equation (3)

$$\frac{dS}{dt} \times \frac{dq}{dS} = \frac{dq}{dt} = \frac{(r - q)}{f'(q)}$$

$$\text{or} \quad \frac{dq}{dt} = (r - q) \div f'(q) \qquad \ldots\ \ldots\ (4)$$

It is therefore apparent that $\frac{ds}{dq}$, or $f'(q)$, the slope of the storage/outflow relationship, is an extremely important factor; if it can be defined mathematically, equation (4) becomes a differential equation relating q (river flow rate) to time (t) for different rainfall rates (r).

3. In order to integrate equation (3) it is advantageous to use storage/outflow functions for which the derivative f'(q) is mathematically simple. Two such functions are logarithmic (Type I) and linear (Type II).

4. ISO-function Type I (logarithmic)

$S = k \log_e q + a$

where a is a constant

$\frac{dS}{dq} = f'(q) = \frac{k}{q}$

plots as straight line on semi-log graph paper; k in same units as S, e.g. mm over catchment area.

5. ISO-function Type II (linear)

$S = Kq \div b$

where b is a constant

$\frac{dS}{dq} = f'(q) = K$

plots as straight line on arithmetic graph paper; K in units of time, e.g. hours or days

6. The next step is to substitute these derivatives (f'(q)) in equation 4, i.e.

Type I $\frac{dq}{dt} = (r - q) \cdot \frac{q}{k}$ i.e. if $(r-q)$ + ve, $\frac{dq}{dt}$ is +ve, rising hydrograph

or if $(r-q) = 0$, $\frac{dq}{dt} = 0$, steady river flow

Type II $\frac{dq}{dt} = (r - q) \cdot \frac{q}{k}$ if $(r-q)$ - ve, $\frac{dq}{dt}$ - ve, falling hydrograph

and to integrate over a time period T, assuming that over this period r is effectively constant. This gives

Type I
$$\int_{q_n}^{q_{n+T}} \frac{dq}{-q(q-r)} = \int_{n}^{n+T} \frac{dt}{k}$$

Type II
$$\int_{q_n}^{q_{n+T}} \frac{dq}{-(q-r)} = \int_{n}^{n+T} \frac{dt}{k}$$

7. Different integrals are obtained for the two conditions $r = 0$ and $r \neq 0$

Type I, r=0 $\quad q_{n+T} = q_n \left(\frac{1}{1+q_n T/k}\right)$

$$\underline{\text{Type I, } r\neq 0} \qquad q_{n+T} = q_n \frac{1}{e^{-rT/k} + \frac{qn}{r}(1-e^{-rT/k})}$$

$$\underline{\text{Type II, } r=0} \qquad q_{n+T} = q_n \, e^{-T/K}$$

$$\underline{\text{Type II, } r\neq 0} \qquad q_{n+T} = q_n \left\{ e^{-T/K} \left(1 - \frac{r}{q_n}\right) + \frac{r}{qn} \right\}$$

From these equations, the river flow rate at time (n+T) can be calculated if the initial river flow rate (q_n) is known and values of r, T, k or K are substituted. This type of hydrological model has obvious advantages for a river management system, because once the catchment parameters (k or K) have been quantified by hydrograph analysis, the only measured catchment information needed for a hydrograph forecast is the present rate of river flow. The previous equations may be used to calculate successive points on a flow hydrograph at time interval T, given the initial river flow rate (q_n) and the sequence of rainfall rate inputs (r_1, r_2, r_3 etc).

8. It is also possible to calculate the volume of river flow in the sequence of time intervals (Q_1, Q_2, Q_3 etc.); this is useful for predicting volume of inflow into reservoirs. The water-balance equation (in volumetric form) is

$$S_{n+T} - S_n = rT - Q = R - Q$$

or $$Q = R - (S_{n+T} - S_n) \qquad \ldots\ldots \quad (5)$$

Type I ISO-function

$S = k \log_e q + a$

$S_{n+T} = k \log_e q_{n+T} + a$

$S_n = k \log_e q_n + a$

$(S_{n+T} - S_n) = k \log_e \frac{q_{n+T}}{q_n}$

Therefore Volume of Runoff $Q = R - (S_{n+T} - S_n)$ (equation 5)

$= R - k \log_e \frac{q_{n+T}}{q_n}$

Type II ISO-function

$S = K_q + b$

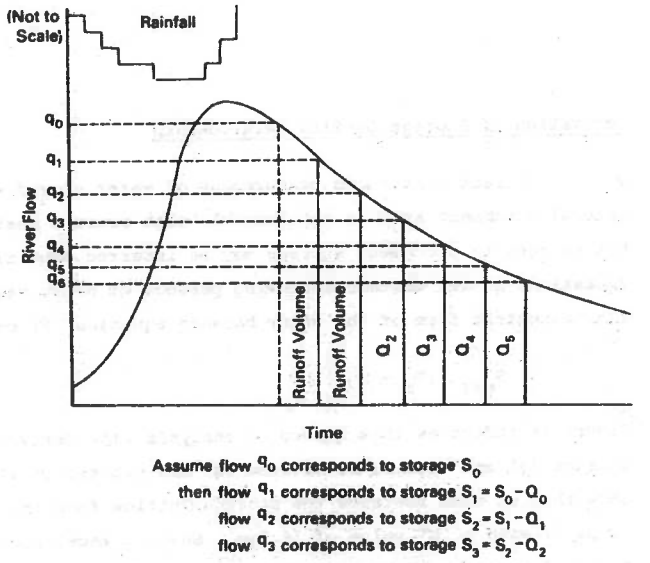
$S_{n+T} = K_{q_{n+T}} + b$

$S_n = Kq_n + b$

$(S_{n+T} - S_n) = K(q_{n+T} - q_n)$

Therefore Volume of Runoff $Q = R - (S_{n+T} - S_n)$ (equation 5)

$= R - K (q_{n+T} - q_n)$



Assume flow q_0 corresponds to storage S_0

then flow q_1 corresponds to storage $S_1 = S_0 - Q_0$

flow q_2 corresponds to storage $S_2 = S_1 - Q_1$

flow q_3 corresponds to storage $S_3 = S_2 - Q_2$

Fig. 1a. Hydrograph analysis

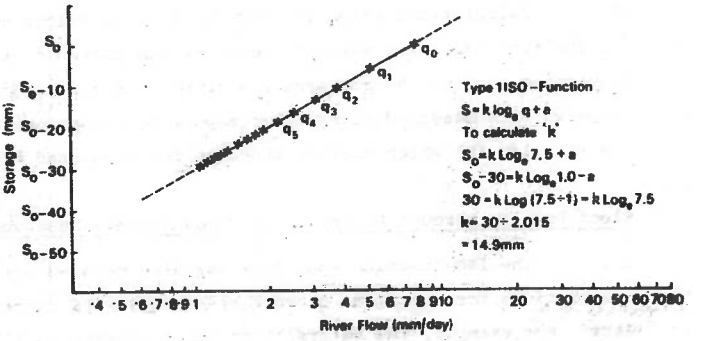


Fig. 1b. Storage/outflow relationship of Afan Coiriog at Brynkinalt

Derivation of Storage Outflow Relationship

9. Direct continuous measurement of water stored within a large natural catchment area is not feasible with present instrumentation, but charges in catchment storage may be inferred from river flow recessions in dry weather following periods of heavy rainfall, when the volumetric form of the water balance equation (5) becomes

$$S_{n+T} = S_n - Q$$

Figure 1a indicates this method of analysis; the derived values of storage (S) and rate of river flow (q) are plotted in figure 1b and show that in this instance the storage/outflow function is logarithmic (Type 1) with a 'k' value of 14.9mm. Several recessions at different times of year should be analysed, over a wide range of river flows, and the results combined to produce a master curve for the storage/outflow relationship.

Derivation of Catchment 'Lag'

10. Calculations using the ISO-function equations make no allowance for the time taken for water to move through the soil and along streams. Comparison of river hydrographs predicted from measured rainfalls, and compared with measured river hydrographs, gives appropriate values of the time-lag (L) which must be added to the predicted hydrograph.

Flood Routing through Uncontrolled Flood Storage Reservoirs

11. The ISO-function equations may also be used for flood routing calculations through flood storage reservoirs with uncontrolled outlets. For example, the natural Llyn Tegid storage/outflow relationship is shown in Figure 2; this was derived from simultaneous readings of

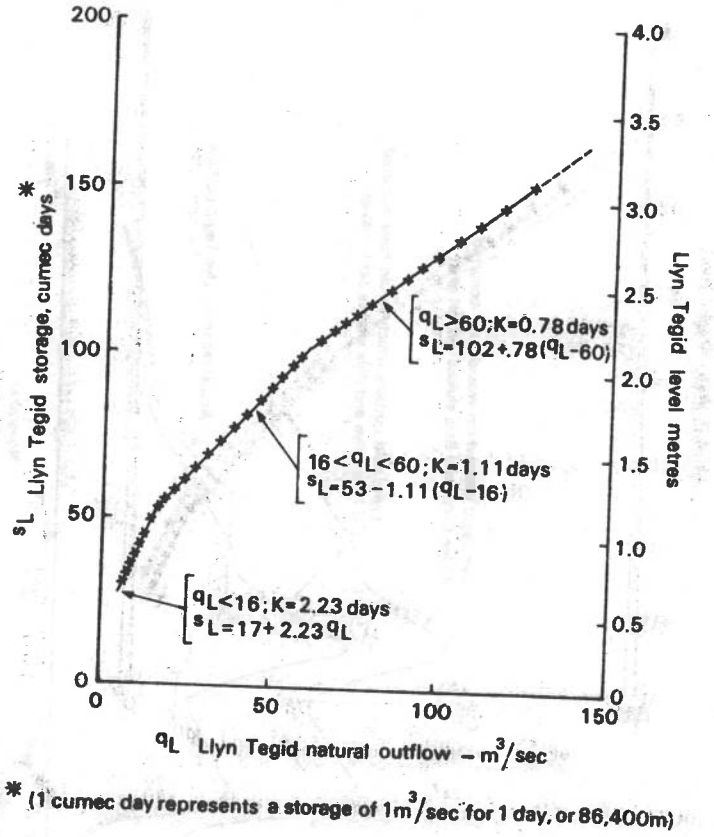


Fig. 2. Llyn Tegid storage/outflow relationship when Bala sluices are not restricting outflows.

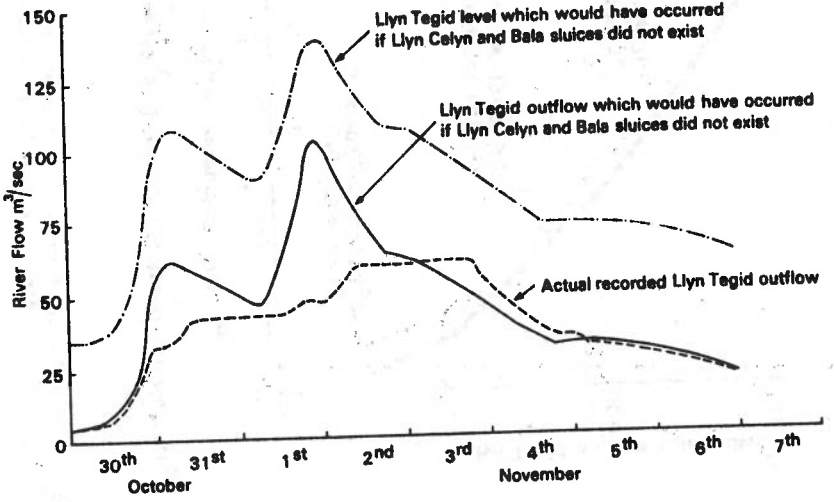


Fig. 3. River Dee flood of 30th October - 7th November 1977.

lake level and outflow during the recession of a large flood in October 1971, during times when the Bala sluice gates had been raised clear of the water. For calculation purposes, the Llyn Tegid storage/outflow relationship may be considered as a Type II ISO-function, with three linear segments. This is particularly useful for calculations (such as Figure 3) of the Llyn Tegid levels and outflows which would have occurred in a particular flood event if Llyn Celyn and Bala Sluices did not exist, and the only flood routing effect on Llyn Tegid inflows was that caused by the restricted lake outlet.

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GREEN LANES OR WHAT?
PRACTICAL CONSERVATION ISSUES IN THE FACE OF SOIL EROSION
(Synopsis)

J. D. Bryant
Project Officer, Brecon Beacons National Park

The expression "Green lanes" is used to refer to old unmetalled transport routes which have become grassy from very light use or total disuse. There is no statutory definition of the term and their legal status varies. Rights of way on them (if any) and responsibility for maintenance (if any) can be complicated matters.

Modern recreational pressures, especially from commercial riding, are having a seriously detrimental effect on them and in places where no track formerly existed in open country. Even those used by large numbers of walkers in very popular places - especially well known mountains and hills are being affected. More intensive farming methods and greater use of cross country vehicles is adding to the problems. Physical damage to vegetation and ground surfaces starts a chain of events which leads to scouring away by water or wind of soft material creating visible scars and difficulty in traversing many places. Trespass, conflict and subsequent repetition of the sequence nearby are the usual results.

The authorities concerned, and statutorily responsible, particularly for conservation recreation and wellbeing of local inhabitants are backed by the Countryside Commission in tackling the new serious issues involved in many places, particularly national parks, urban fringes and areas of outstanding natural beauty.

The methods adopted fall into two general categories (1) field engineering work which is aimed at rectifying damage and providing means to withstand the wear and tear which does occur (2) Management methods to prevent or reduce the causes while continuing to allow the activities involved to take place. Various examples of types of work carried out under these headings were illustrated. The important ones, still not proven to be practical answers, are these:

Field Engineering

1. The construction or reconstruction with suitable materials of routes designed to carry the loads while remaining aesthetically acceptable. (The creation of proper surface drainage is important and the regular maintenance of it critical).

2. Surfacing techniques which can be viable in remote places often with difficult terrain and sometimes no vehicular access and which can be reasonably lasting and simply maintained.

Management

(which entails some engineering type work)

1. Voluntary acceptance by commercial operators and members of the public of a certain degree of direction as to where they may go.

2. Warden patrols to advise and monitor use and behaviour.

3. Sign posting and way marking to foster use of certain routes.

4. Replacement of old gates and installation of fences to influence use in a helpful way.

5. Selection of sites and provision of hitching rails for parties of riders to stop for lunch and thus encourage use of certain areas to the advantage of others.

6. Rationalisation of the rights of way network to achieve practicable routes which are acceptable to landowners and users, and which can be formally maintained in contrast to many a present situation.

7. Agreements with landowners for use of alternative routes will often help to avoid trouble spots.

8. Alternative attractions ("honeypots"), subtle publicity and planned outdoor education and information of the public are used in many ways aimed at alleviating the pressures.

In the end increased expenditure on care, maintenance and development of facilities is likely to be the right course and must be carried out sympathetically. At best a compromise result will probably be the solution.

DISCUSSION

Dr. M. Hornung (I.T.E. Bangor). Where trekking routes have been rested you had some recolonisation by plants. Have you tried covering the area with a seed mulch to try to get a rapid recolonisation?

Mr. Bryant replied that they have used fertilizers, and they had considerable success on banks where treading no longer took place, but when continually used paths were seeded their success was not so great.

Dr. Hornung stated that considerable success with straw and fibre seed mulches had been obtained in the Lake District on heavily used areas.

Dr. W. O. Binns (Forestry Commission) commented that the Commission's experience had been the same, that constant treading by ponies is very damaging. Was there any means of reclaiming costs of repair from pony trekking establishments?

Mr. Bryant said a report had been submitted suggesting some payment, but thousands of pounds were needed and not just a token payment.

Mr. C. Evans (ADAS Aberystwyth) asked if anyone had investigated the possibility of a different type of horse-shoe - one that did not cut into the soil?

Mr. Bryant thought this was a novel idea, and in reply to Dr. Hornung who asked if anyone can set up a riding establishment, stated that the Riding Establishment Act only required licensing of the stable and which had no control over numbers, only vetinary standards. Previous Planning Authorities had not exercised much control but present planning laws can now help to regulate the last 10-15 years of uncontrolled growth in numbers.

Mr. C. Evans (ADAS Aberystwyth) The flood hazard in winter period occurs when evapotranspiration is at its lowest. What differences in time-lag occur in winter compared with summer?

Mr. Lambert replied that during the winter it was impossible to stop the Lower Dee Valley from flooding but because of control of water in the storage reservoirs flooding had been eliminated in summer. The time-lag of flooding in winter and summer appeared to be the same, but in the summer the catchment does respond more slowly than the model assumes. Mr. Lambert was then asked if any investigations had been done into control of sluice-gates by computer. In reply he stated that this was best done through the experience of the man on the spot as they were dealing with a 3-reservoir system, not just Bala Lake. Rainfall forecasts are not sufficiently accurate at present.

Dr. C. C. Rudeforth asked if this was an overall rainfall forecast or whether it was a composite one for the catchment area.

Mr. Lambert replied that the Meteorological Office maintained a dense network of automatic rain gauges in the area for a period and that they use a forecast based upon Bala together with an index for any particular synoptic situation.

Miss L. Roberts said that they used the vegetation instead to indicate the soils present and they had to continue their survey now, not in two or more years when the Soil Survey's material became available. However, it will be possible to revise maps of the uplands when fresh information is provided.

Dr. C. C. Rudeforth (Soil Survey, Aberystwyth) drew attention to Mr. Lambert's statement that previously complex models were used to predict river flow, but that these have now been superseded by simpler models excluding the need to assess soil water storage. Could he say if soil information, such as was collected in the soil survey of the Dee catchment in 1969, is of any value in long term low flow forecasting?

Mr. A. O. Lambert replied that hydrologists would generally use the analysis of river flow records to determine long term flow patterns. The river flow records would summarise all the existing soil moisture behaviour of the catchment as it exists. However, if one were seeking to estimate the response of ungauged catchments, one might need to correlate the storage/outflow relationships on measured rivers with soil types within the catchments. Mr. Lambert was next asked if his model for forecasting river flows worked when there was heavy snowfall. In reply he said the model did not work with snow, it assumes water is free to move in the soil. Increased runoff from snow can be retained in the reservoirs in the same way as flood waters can be retained.

Mr. J. Blackie (Institute of Hydrology) If you have allowed for snow melt in the upper catchment in your model what happens to snow melting in the lower catchment?

Mr. Lambert replied that most snow occurs on the hills and although snow on lowlands is a weakness in the model it doesn't cause any large problems.

GENERAL DISCUSSION

Dr. W. O. Binns (Forestry Commission) commented that the earlier meeting had touched upon the conflict of land use in the uplands. Was there any sign of a more rational approach emerging, he asked?

Mr. B. Clayden gave his personal view, and it was that of Dr. Newbound in the earlier Trawscoed meeting that there was no clear policy. The Government simply wanted more of everything. He drew attention to the correspondence in the Farmer's Weekly following an address by Professor Bowman at the Bath British Association's meeting where it was suggested that support for hill farmers should be removed and more trees planted! If we knew more about the resources of the uplands we could begin to develop a more rational approach to their use. This is particularly true for the soils of the uplands which are particularly variable. Dr. Hamish Monroe had drawn attention to differences in nitrogen in a peaty-gley soil (1-2 kg/ha) and an iron pan podzol (20-30 kg/ha). Soil maps would show these differences.

Dr. W. O. Binns commented that aspect was important and suggested that farmers could have the warmer, sunny slopes and the foresters could use the north-facing slopes.

Dr. M. Hornung (I.T.E. Bangor) described some progress with integrating forestry with sheep grazing. Specific areas in forests could be improved for grazing and other areas afforested. However, this did require a detailed knowledge of the soils.

Miss L. Roberts (ADAS Aberystwyth) commented that before we have a policy it is necessary to do the survey work and the Land Service Hills and Uplands survey is an attempt to assess the grazing potential and improvement potential of the uplands. As a result of the Exmoor Enquiry chaired by Lord Porchester the national survey had been used and other National Parks should find it helpful, especially when conservation orders are introduced.

Mr. B. Clayden stated that the Land Service Survey had no soil information to call upon in upland areas at present, but the Soil Survey was embarking upon a national map at 1:250,000 which should help in future.

Mr. B. Clayden, as Chairman, closed the meeting by thanking the speakers for making a success of the day. He also asked that the thanks of the Group be passed on to the Geography Department of the University College of Swansea for providing facilities for the meeting.

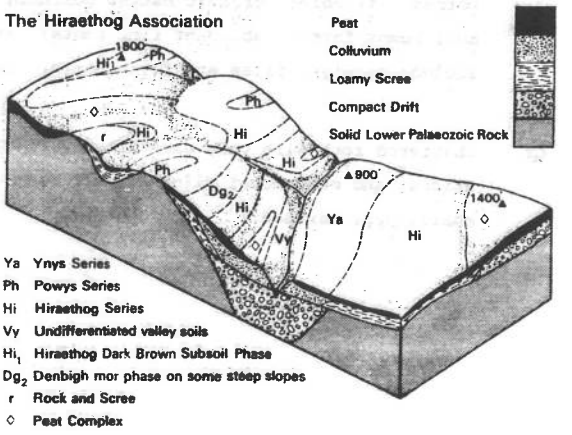
Finally, Dr. Bridges thanked Mr. Clayden for chairing the meeting at the last moment owing to the indisposition of Mr. H. T. Davies. It was the last meeting of the Group which Mr. Clayden would attend as a resident of Wales, but it was hoped he would maintain contact with our affairs after his move to Rothamsted.

WELSH SOILS DISCUSSION GROUP

FIELD MEETING - 31 May 1979

Soils of Pwllpeiran

At altitudes above about 1,100m grey eluvial horizons characteristic of podzolized soils are widespread on all but the steepest slopes, in the shallowest materials over rock, and where recent erosion or deposition has inhibited profile development. Except for very small areas of alluvium, the soils belong to the Hiraethog Association which includes rankers (Powys series), stagnopodzols (Hiraethog and Hafren series), stagnohumic gley soils (Ynys series), and peat. Hiraethog series and the complex of undifferentiated peat soils occupy most land, with rocky complexes forming up to 10 per cent; Powys and Ynys soils are very limited.



Profile No. 1 Powys humic ranker variant

Location: Llechwedd Hirgoed (grid ref. SN 813836)

Relief: Mountain ridge; convex site just above rocky cliff

Slope: 15° Aspect: W Altitude: 1,700 ft. OD.

Parent material: Silurian shale

Drainage class : good

Land use: rough sheep grazing; sward, up-graded by sheep droppings, includes matgrass, sheep's fescue and common bent-grass.

Horizons:

cm		
0.25	H	Root mat and litter with signs of much faunal activity; strong fine crumb structure; merging boundary.
25-10	HA	Very dark brown (7.5 YR 2/2) loamy peat with a few angular shales; strong fine crumb structure; highly porous; friable; organic matter dominant (mor-like mull humus form); abundant fine roots; small fauna include earwigs, flies and flying ants; narrow boundary.
10-20 Bsh	Cr	Shattered rock with very dark brown (7.5 YR 2/2) interstices, and occasional slightly yellowish weathering shales near surface.

Profile No. 2 Hiraethog series

Location: Nant-y-Moch (grid ref. SN 761859)

Relief: uneven mountain side with occasional rock outcrops

Slope: 5°. Aspect: W Altitude: 1,3000ft OD.

Parent material: Ordovician and Silurian shales with sandstone colluvium

Drainage class : very poor

Land use: rough sheep grazing, with fescues, deer-grass and rushes

Horizons:

cm		
0-8	Oh1	Very dark brown (7.5 YR 2/1) peat, with a few subangular stones (mainly bleached sandstone); fibrous structure merging to strong medium crumb below; abundant fine pores and very fine fissures; friable; njmerous roots; merging boundary.
8-18	Oh2	Black (N2/0) peat with stones as above; amorphous with only a few very fine fissures (mainly closed when saturated); soft, spongy; frequent medium and fine roots; narrow boundary.
18-25 35AE/g)		Dark greyish brown (10 YR 4/2) very fine sandy clay loam; numerous bleached subangular sandstones and occasional angular shales; very weak medium prismatic structure; slightly sticky, moderately soft; horizon strongly humus stained; roots common; occasional ferruginous traces towards base; sharp irregular boundary.
25,35	Bf	Dark reddish brown (5 YR 2/2) becoming paler with depth (5 YR 3/4); thin iron pan (⅛ in), with organic matter staining; narrow boundary.

25, 35-40 50	IIB_S	Yellowish red (5 YR 4/8) sandy loam with abundant angular pieces of shale increasing in numbers with depth; moderate medium and fine crumb structure between stones; abundant pores; friable, slightly sticky in places; organic matter moderate, a few roots; merging boundary.
40, 50-125	IIBsCr	Weathering shattered rock with material from above and humose loam filling cracks.

Profile No. 3 Hiraethog series, dark brown subsoil phase

Location: Llechwedd Hirgoed (grid ref. SN 813837)

Relief: convex mountain ridge

Slope: 8^{o}. Aspect: W Altitude: 1,725ft OD.

Parent material: drift from Lower Palaeozoic sediments over shale rock

Drainage class: very poor (but well drained B horizon)

Land use: rough mountain grazing, with mat-grass, sheep's fescue, bilberry and mosses common.

Horizons:

cm		
0-2.5	F	Very dark reddish brown (5 YR 2/1.5) root mat and litter; narrow boundary.
2.5-8	1-3 OM	Black (7.5 YR 2/1) stoneless peat with dark reddish brown (5 YR 2/2) fibrous laminae; porous; non-sticky where black (F1, K2, P1, C3), labile, slightly plastic where brown (F1, K1.5, P1, C3); moderately humified; abundant medium and fine roots, living and dead; enchytraeids common; narrow boundary.

8-15	Oh	Black (10 YR 2/1) peat merging to silty peat at base, slightly stratified; stoneless; structureless; few pores; labile, slightly plastic (F1, K1.5, P1, C3); fibrous, abundant dead roots and stems; occasional live roots; enchytraeids common; merging boundary.
15-25	AE	Dark greyish brown (10 YR 4/2) with dark reddish brown (5 YR 2/2) humus in fissures and pale brown (10 YR 6/3) weathered shales; silty clay with highly weathered soft shales; almost structureless but with incipient vertical fissures about 8" apart; fine root channels common; firm plastic (F3, K1, P1, C4.5); moderate organic matter; sharp boundary.
C25	Bf	Dark reddish brown (5 YR 2/2) strong iron pan, both through and around shales; fine laminar structure; compact and brittle, high organic matter content immediately above where there is a concentration of roots unable to penetrate; narrow irregular boundary.
25-46	Bsh (Cu)	Dark reddish brown (5 YR 3/2) with traces of light olive-brown (2.5 Y 5/4) close to the iron pan and dark greenish grey (5 GY 4/1) shales; humose friable loam between angular shales of coarse scree; very porous; moderate fine roots.

Profile No. 4 Ynys series

Location: Pwllpeiran (grid ref. SN 785754)

Relief: Gentle spur in large basin among mountains

Slope: 2°. Aspect: SW. Altitude: 1,200 ft. OD.

Parent material: Silurian shales

Drainage class: very poor

Land use: rough grazing, with Juncus conglomeratus, purple moor-grass and Sphagnum spp.

Horizons:

cm		
0-33	O	Peat with alternating light and dark layers; roots and shales (some very large) throughout; merging boundary.
33-46	AEg	Mottled pinkish grey (7.5 YR 6/2) with yellowish red (5 YR 4/8) in root channels, and ochreous pockets; silty loam to silty clay loam; labile; earthworms present; merging boundary.
46-54	Bg	Pinkish grey (7.5 YR 7/2) silty clay loam with reddish yellow (7.5 YR 6/8) in root channels; weakly prismatic; labile; some humus staining; merging boundary.
54-60+	Bg/G	Light greenish grey (5 GY 7/1) silty clay loam; with yellow (10 YR 7/8) in root channels; weakly prismatic; labile; merging into shattered rock.

Profile No. 5 Undifferentiated peat soil complex

Location: Pwllpeiran (grid ref. SN 804783)

Relief: convex mountain slope

Slope: 7^{o}. Aspect: NNW. Altitude: 1,570 ft OD.

Parent material: acid hill peat over Silurian shales.

Drainage class: very poor (B horizon moderately well drained)

Land use: poor mountain grazing, with purple moor-grass, cotton grass and mosses.

Horizons:

cm		
0-70	O	Very wet peat with roots and a few shale fragments; merging boundary.

70-90	AE(g)	White (10 YR 8/1) clay loam with brownish yellow (10 YR 6/8) mottles; shale fragments; weakly prismatic structure; labile to plastic; humus staining in root channels; sharp boundary.
C100	c.39 Bf	Red and dark red (2.5 YR 4/8-3/6) hard iron pan through which no roots penetrate; narrow boundary.
100-115	Bs	Yellowish red (5 YR 5/8) silty loam with abundant shale fragments at base; merging boundary.
115-200+	BCr	Shale fragments abundant, stained light yellowish brown (10 YR 6/4); merging into shattered rock.

Profile No. 6 Undifferentiated peat soil complex

Location: Nant-y-Moch (grid ref. SN 762860)

Relief: uneven mountain slope with occasional rock outcrops and peaty hollows; site concave.

Slope: 5°. Aspect: NW. Altitude: 1,325ft OD.

Parent material: peat over drift from Lower Palaeozoic sedimentary rocks

Drainage class: very poor

Land use: very poor mountain grazing; mosses dominant, mainly Polytrichum and Hypnum spp., with deer-grass; peat has been cut nearby.

Horizons:

cm		
0.8	F	Tough brown fibrous root mat; stone less; narrow boundary.
8-28	Oh1	Dark reddish brown (5 YR 2/2) stoneless peat; almost amorphous, but with weak horizontal fibrous alignment; numerous roots; enchytraeids present, narrow boundary.

28-56 Oh2 Black (5 YR 2/1) peat with many medium and fine roots, as above; merging boundary.

56-72 AE Olive-grey (5 Y 5/2) gravelly loam with dark reddish brown (5 YR 3/3) humus staining, becoming paler grey with depth; many subangular and rounded stones, occasional boulders; weak platy structure; a few weak irregular fissures emphasized by humus staining; slightly sticky; a few roots penetrate; sharp boundary.

72-100+ Cg Greenish grey (5 GY 5/1) gravelly clay loam with many small subangular and angular shales; laminated; compact; sticky to plastic/fluid; low organic matter; a few dead dark greyish brown (10 YR 4/2) fibrous roots; occasional very fine ochreous traces.

Profile No. 7 Manod Series

Location: Cwm Rheidol (grid ref. SN 756797)

Relief: steep plane scree slope with small solifluction terraces emphasized by sheep walks

Slope: 25°. Aspect: W. Altitude: 900ft OD.

Parent material: loamy scree from Lower Palaeozoic sedimentary rocks

Drainage class: good or moderate

Land use: hill pasture with bracken and gorse.

Horizons:

cm

0-1 F Dark brown (10 YR 3/3) tough fibrous organic mat bound by abundant grass roots; narrow boundary.

1-8	Ah	Dark brown (10 YR 3/3) (gritty) silt loam with dark reddish brown (5 YR 3/4) traces; many medium and small, mainly angular, shales and sandstones; strong medium and fine crumb structure; porous; friable; high organic matter; abundant medium and fine grass roots with occasional large bracken root; occasional bleached pockets surrounded by weak thin iron pan; a few small insect larvae; merging boundary.
8-15	AB	Dark yellowish brown (9 YR 4/4) (gritty) silt loam with mainly medium and fine subangular blocky structure; fine fissures common; friable; high organic matter; abundant roots; occasional weak ferruginous concentrations; a few small insect larvae; merging boundary.
15-28	BS1	Strong brown (7.5 YR 5/6) (gritty) silty clay loam with stones as above; moderate medium subangular blocky structure; fine fissures common, some with slight traces of illuviation cutans; friable; moderate organic matter; roots common; occasional charcoal fragments, associated in places with slight pinkish stain; merging boundary.
28-45	BS2	Yellowish red (6 YR 5/9) (gritty) loam becoming duller with depth, and occasional darker brown stains; numerous shales and sandstones, mainly angular, of various sizes; weak medium and fine angular blocky structure between stones; abundant fine pores; friable; roots common; narrow boundary.

46-66 Cu Yellowish brown to light olive-brown (10 YR to 2.5 Y 5/4) (gritty) silty clay loam, dominated by angular shale fragments imparting a weak platy structure; finely porous, though with more interstices filled with fine material towards base; loose-friable to slightly sticky, soft at base; low organic matter; occasional roots; a few weak ferruginous traces.

Table 1. Soil Series in map units (%)

	Powys	Hiraethog	Hafren	Ynys Frenii	Caron	
	Humic Rankers	Ironpan Stagnopodzols	Ferric Stagnopodzols	Stagnohumic and humic gley soils	Raw peat soils peat >90cm	peat >90cm
Improved grassland	30	40	15	0	10	0
Dry bank	16	20	35	2	15	2
Dry heath	3	13	27	7	18	32
Juncus	0	15	0	25	50	10
Wet heath	3	3	3	18	18	55
Eriophorum bog	3	3	7	5	34	48
Peat hag	8	5	0	0	14	73
Forestry commission*	0	5	0	0	19	76

* 160 ha (400 acres) of deep peat bog of low agricultural value were sold to the Forestry Commission for planting and the money realised used for access roads and fencing.

Table 2. Thickness of peat in relation to map units

Per cent

	<10 cm	>10 cm	>20 cm	>30 cm	>40 cm	>50 cm	>60 cm	>70 cm	>80 cm	>90 cm
Improved grassland	20	80	30	10	10	5	5	0	0	0
Dry bank	10	90	57	30	17	15	10	2	2	2
Dry heath	5	95	82	68	50	46	46	42	42	32
Juncus	0	100	90	80	60	45	25	20	15	10
Wet heath	0	100	95	79	76	74	71	66	61	55
Eriophorum bog	2	98	93	90	83	78	65	60	48	48
Peat bag	4	96	91	86	86	77	73	73	73	73
Forestry Commission	0	100	100	100	95	90	86	76	76	76

Table 3. Slope and vegetation

Per cent

	> 2°	> 4°	> 6°	> 8°	> 10°	> 12°	> 14°	> 16°	> 18°
Improved grassland	95	80	75	70	55	40	25	20	10
Dry bank	97	87	75	62	55	40	37	30	22
Dry heath	86	86	73	45	27	18	9	9	5
Juncus	90	70	60	50	25	10	5	0	0
Wet heath	84	58	42	24	16	11	3	0	0
Eriophorum bog	85	45	22	12	0	0	0	0	0
Peat hag	73	45	32	23	18	9	5	5	5
Forestry Commission	95	48	19	10	5	5	0	0	0

WELSH SOILS DISCUSSION GROUP

ANNUAL REPORT OF THE GENERAL SECRETARY

20th Session, 1978-9

Secretarial Report

Meetings took place last year at Trawscoed, Swansea and Pwllpeiran and were well supported. The Group is grateful to the authorities for permission to use their facilities and to the individuals at each place for making the domestic arrangements for the meetings. Membership of the Group stands at 70 but attendance at meetings is increased by student day-members. The Group is grateful to Mr. P. Stevens for arranging the programme for the autumn and spring meetings on the theme of 'Soils and Upland Management', and to Mr. R.J.W. Dight for arranging the field meeting.

The officers and committee for the session 1978-9 were:

Chairman	Mr. H. T. Davies		
Conference Secretary	Mr. P. Stevens	Assistant Secretary	Mr. R.C. Hartnup
Editor	Mr. R.J.W. Dight	Assistant Editor	Mr. P. James
Publications Manager	Mr. P. S. Wright	General Secretary	Dr. E.M. Bridges
Committee Members	Mr. I. Carolan and Mr. R. Kingman		

The annual general meeting took place on Wednesday, 14th March at Swansea when officers for the 21st Session were elected, including Dr. B. E. Davies as Chairman.

Financial Report

The session 1978-79 has been a quiet year financially as no Reports of the Group have reached the stage of being printed and so no large sums of money have changed hands. The balance sheet shows a slight increase in the surplus left after the payment of routine expenses on the secretarial account. Our publications have continued to sell, but we have a cash-flow problem ahead as two reports will be ready simultaneously and we have only sufficient funds to pay for one of them, and another is following closely behind.

A second problem begins to make itself evident during this financial year. In the past the Group has relied upon speakers' institutions to meet their travelling and maintenance expenses. A.D.A.S., the Scientific Civil Service and Universities are no longer willing or able to do this.

As there were only three items of expenditure and the same number of income, it seemed that the sum charged by the auditors in the previous year was becoming out of proportion to the sums of money involved. (It amounts to one quarter of our subscriptions going to pay the accountants!). Accordingly, I have prepared the books myself and have asked an independent check upon them privately. The books are available together with supporting documents, and I hope the Group will accept this change in procedure.

E. M. Bridges

WELSH SOILS DISCUSSION GROUP

FINANCIAL STATEMENT FOR YEAR ENDING 30th SEPTEMBER, 1979

Balance brought forward 30.9.1978			
current account	554.07		
deposit account	368.10		
publications account	196.35		1118.52
* * * * * *			
Income			
Members subscriptions	110.40		
Sundry income	20.50		
Deposit account interest	14.43		
	19.41		
Sales of reports	139.55	304.29	
Expenditure			
Secretarial expenses	44.00		
Publications expenses	16.00	60.00	
Surplus of income over expenditure			244.29
			£ 1362.81
* * * * * *			
Balance carried forward 30.9.1979			
current account	640.97		
deposit account	401.94		
publications account	319.90		
			£ 1362.81

E. M. Bridges
General Secretary