HILL FARMING RESEARCH ORGANISATION

FIFTH REPORT
1967-1970

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RESEARCH STATIONS

THE three research farms continue to function under their respective Officers-in-Charge, Mr A. L. Fairlie (Glensaugh), Mr D. C. Currie (Lephinmore) and Dr R. H. Armstrong (Sourhope).

Glensaugh is situated at the eastern end of the Grampians. It consists of some 2200 acres of rough hill grazings dominated by heather and ranging from 450 to 1600 feet, with 250 acres of short and long term leys and 75 acres of forage crops. Average rainfall is 41 inches. The breeding stock consists of 880 Blackface ewes and 110 hill cows.

Lephinmore is situated on the east side of Loch Fyne in Argyll. It consists of some 2800 acres of hill grazings up to 1550 feet altitude, mostly over peat, and with a mixed herbage including heather, *Molinia*, *Scirpus* and hill grasses. There are 75 acres of short and long term leys. Average rainfall is 67 inches at sea level. The breeding stock comprises 750 Blackface ewes and 35 hill cows.

Sourhope lies 15 miles south of Kelso on the western slopes of the Cheviot. There are 2650 acres of hill grazings at 600 to 2000 feet, consisting largely of grasses such as the *Agrostis* and *Festuca* spp., with substantial areas dominated by *Nardus* and *Molinia*. There are 125 acres of short and long term leys. Average rainfall is 37 inches. The breeding stock comprises 820 South-country Cheviot, 350 North-country Cheviot and 430 Blackface ewes and 45 hill cows.

CURRENT RESEARCH PROGRAMMES

Animal Production

Influence of environmental and endogenous factors on nutrient requirements for maintenance and change of liveweight.
(J. M. D., A. J. F. R. and J. Z. F.)

Studies on the annual cycle of body composition of ewes in relation to nutrition and production.
(A. J. F. R., R. G. G., J. M. D. and J. Z. F.)

Nutrition in late pregnancy; survival and growth potential of lambs.
(A. J. F. R. and J. Z. F.)

Identification of pregnancy and foetal load at different stages of pregnancy. (J. Z. F., A. J. F. R. and J. M. D.)

Metabolic studies in under-nourished ewes. (A. J. F. R.)

Study of factors limiting food intake. (J. Z. F.)

The effect of supplementary concentrates on roughage intake.
(C. S. L.)

Lactation studies. (J. N. P.)

Influence of climatic, genetic and nutritional variation on ovulation rate, implantation and embryonic wastage.
(R. G. G. and J. M. D.)

Studies on lamb growth at pasture. (J. E.)

Regulation of wool growth rate and fibre shedding. (J. M. D.)

Plant-environment Interactions

Competition between sown grass species and indigenous grass species in hill pastures with reference to soil fertility and selective grazing. (J. K.)

Competition between seedling white clover and established grass awards (J. K.)

Grazing/burning interactions on heather moor. (S. A. G.)

Season and intensity of grazing and their effects on level of utilisation of pasture production, composition and stability of various moorland associations. (S. A. G. and J. E.)

Response of the heather plant to simulated grazing defoliation. (S. A. G.)

The relationship between plant growth and soil/moisture/and aeration. (J. A. R.)

The role of the animal in the circulation of plant nutrients. (M. J. S. F.)

Establishment of analytical techniques using X-ray spectrometry. (M. J. S. F.)

Response of a range of hill pastures and soils to grazing control, soil improvement, and plant introduction. (J. E. and M. J. S. F.)

The effect of soil acidity and related properties on the decomposition of organic materials. (M. J. S. F.)

Systems Synthesis

Systems of management based on year-round grazing with control. (J. E., J. K. and J. M. D.)

Systems of off-wintering with two systems of summer grazing. (J. E., J. K. and J. M. D.)

INTRODUCTION

THIS, the fifth Report of the Hill Farming Research Organisation differs from previous reports in that only selected parts of the research done over the past three years are described. These accounts are presented in some detail, and are intended primarily for scientists and specialist advisers who have an interest in the subjects discussed, and no attempt has been made to interpret the scientific findings in a practical context. However, we intend to summarise, in a *Bulletin* to be published later, the results of our research as they relate to the improvement of practical systems of animal production from hill land.

Due to an increasing volume of research it is our intention to publish reports more frequently—probably every two years, which will permit of a more continuous presentation of our work and results.

Since the Hill Farming Research Organisation is concerned with the application of applied research to the utilisation of a defined resource it is essential that the research effort is envisaged as culminating in economically viable systems of animal production. As these may differ substantially from existing systems it is important that they are rigorously tested under hill conditions. Consequently, a programme of development projects on a farm scale has been initiated and the context within which this programme is based is discussed in Section 5. We anticipate that this will be a continuing activity on our Research Stations and also on commercial farms in conjunction with the Advisory Services.

Progress in the continuing development of new systems of pasture management will only be possible if critical research is sustained. Such work will seek an improved understanding of the biological mechanisms and principles involved.

Research activities now cover a wide field and are being extended to include a more intensive study of heather (*Calluna vulgaris*) so that its role in pastoral systems, for sheep and other species, can be more precisely defined.

In the last Report (No. 4) it was suggested that the influence of the grazing animal on the soil-plant-animal nutrient cycle merited a greater understanding and required further study. The results from work initiated at that time are presented (Section 1).

Where more efficient herbage utilisation is feasible, the indications are that real benefits will be gained through increased return of excreta by grazing animals and from the stimulated organic cycle.

It is becoming increasingly clear that nutrition, particularly energy, is of primary importance in determining levels of animal production from hill pasture.

The effects of nutrition are of significance not only in the very obvious short and critical periods such as late pregnancy, but more importantly in the overall annual cycle of nutrition.

Since this Report does not present all the work done during the past three years, the other areas of research activity are listed in the summary of the current research programme.

Research topics not discussed in this Report will be reviewed in subsequent reports.

Much of the work of the Organisation would not be possible without the generous provision of facilities by the Animal Breeding Research Organisation and the Edinburgh School of Agriculture.

A programme of building has been initiated and the first phase, comprising an animal house, metabolism rooms, surgery, etc., and soil and plant facilities, is nearing completion. We anticipate that the building of a laboratory and administration block should commence in 1971.

As a result of the development of these facilities at Bush Estate the Organisation is now a member of the Centre of Rural Economy which has recently acquired additional land of which 600 acres of rough grazing, about 1 mile from the new buildings, has been allocated to the Organisation.

Staff

In addition to the staff listed, the following served for varying periods on the Scientific Staff during this triennial period:

R. L. REID, B.SC.(AGR.), PH.D., F.R.S.E., Director

Animal Studies

J. G. GRIFFITHS, B.A.

Botanical Studies

D. RATCLIFFE, B.SC., PH.D.

Dr R. L. Reid was appointed Director Designate on 1st January 1964, becoming Director from 1st October 1965, on the retirement of Mr A. R. Wannop. Dr Reid resigned from the Organisation on 31st January 1968, on his appointment to a Chair of Agricultural Science in La Trobe University, Melbourne.

An Australian by birth, Dr Reid brought with him a refreshing and stimulating approach to the evaluation of problems of hill farming in the U.K. and in the development of the research programme.

Basing his assessments on the basic information previously obtained, Dr Reid's wide scientific experience was effectively used in clarifying the future research objectives of the Organisation. Much of the work reported here was initiated during his term of office.

The plans for the new Headquarters of the Organisation were formulated by Dr Reid and these served as the basis of the current developments.

Dr Reid's enthusiasm, coupled with a warmth of personality and sense of humour, was a constant source of stimulation and encouragement to the staff.

On the constitution of a new Board of Management in March 1969, the Lord Stratheden and Campbell resigned after serving for a period of 11 years as Chairman of the Board.

His constant interest and wise guidance were of immeasurable benefit to the Directors of the Organisation.

Visits

Dr J. M. Doney visited Czechoslovakia under the aegis of the British Council, visiting research stations and teaching centres on an advisory and lecture tour.

Dr A. J. F. Russel is currently visiting laboratories in Australia and New Zealand.

In conjunction with the Animal Diseases Research Association a Course on 'Sheep Management and Diseases' was organised on behalf of the British Council, and 43 people attended from 17 countries.

The number of visitors including scientists, advisers and farmers, continues to increase.

Acknowledgments

We are especially grateful to the Animal Breeding Research Organisation, the Scottish Society for Research in Plant Breeding, the Edinburgh School of Agriculture and the Animal Diseases Research Association for facilities and collaborative support.

1. PLANT NUTRIENT CYCLING IN HILL LAND

M. J. S. FLOATE

Introduction

Sheep production systems in upland and hill areas depend upon herbage production, and the management system which is employed in the utilisation of that herbage. For a number of reasons, which include the amounts and availability of plant nutrients, herbage production is commonly low. All too frequently only a small proportion of the production (20-30 per cent.) is utilised by grazing sheep (Eadie, 1970). Some is consumed during the growing season, and

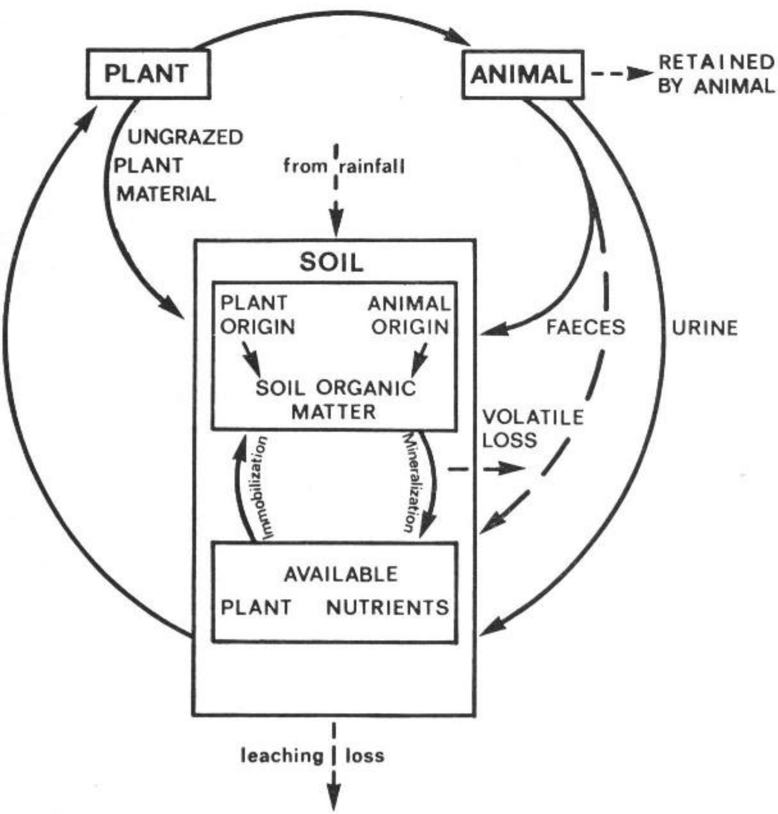

FIG. 1.—Nutrient cycle in grazed pasture soils.

some of the remainder is grazed during autumn and winter, but during this period its quantity and quality decline. The unconsumed plant material accumulates on the surface of hill soils as dead litter. This material decomposes very slowly and contributes to the reserves of soil organic matter. Such systems of herbage utilisation are inefficient but are traditionally employed to provide maintenance over winter on the hill.

It is the policy of H.F.R.O. to develop systems of sheep production which utilise herbage production more efficiently. The programme of research described here was undertaken to examine the consequences of system changes upon pasture utilisation and upon plant nutrient circulation.

The circulation of plant nutrients in grazed hill pasture is illustrated in Figure 1. The system is essentially a three-component one in which nutrients pass between soil, plant and animal (Floate, 1970*d*). There are two alternative (or complimentary) pathways of nutrient circulation: (*a*) via the direct decomposition of plant litter which is derived from herbage neglected by the grazing animal and (*b*) via the consumption of herbage by the grazing animal and the return of excreta to the soil surface. More efficient pasture utilisation implies the increasing return of nutrients to the soil by pathway (*b*).

Although factors such as climate and the ability of indigenous species to respond may limit production, the major limitation to herbage production imposed by many upland and hill soils is the supply of available plant nutrients (Floate, 1967).

Nutrients in Hill Soils

These soils commonly contain quite large reserves of both nitrogen and phosphorus, but only very small amounts of these major plant nutrients are in a form available for plant nutrition (Table 1). These data show that a very large proportion of soil-N is organic and that less than 1 per cent. of the total is in a form available for plant nutrition. Available phosphorus in these soils is also low. The largest part of the total-P is organic in the upper horizons of the soil profile, but in the lower horizons increasing proportions of phosphorus are immobilised through fixation by iron and aluminium compounds. The conclusion is that large proportions of the soil pool of both nitrogen and phosphorus are held in organic form in the rooting zone of hill soils. This source of nutrients only slowly becomes available to plants through the decomposition of organic matter.

While the amount of available nutrients (which is a measure of the *intensity* of supply at any point in time) is small, the actual supply of nutrients during the growing season depends also on the total reserves (*capacity*) and upon the speed with which the available nutrients are replenished as they are withdrawn by growing plants

TABLE 1

Forms of nitrogen and phosphorus in hill soils

Nitrogen		Phosphorus	
Total-N	10,000 kg/ha	Total-P	2,000 kg/ha
Inorganic-N (NH_4^+, NO_3^-)	30 kg/ha	Available-P	40 kg/ha
NH_4^+-N	10-15 p.p.m.	Available-P	10-20 p.p.m.
NO_3^--N	0-1 p.p.m.		
Organic-N	99%	Organic-P	80-90%
		Fixed-P	10-20%

(*rate*). The data show that capacity is high but intensity is low, and it may be that in many hill pastures the critical factor limiting production may be the rate of nutrient supply in the soil. Since such large proportions of the reserves of nitrogen and phosphorus are held in organic form it is important to examine the rate at which inorganic plant nutrients are released through the mineralisation of organic materials.

Decomposition and Mineralisation

There is a wealth of published research concerning the mineralisation of plant nutrients from soil organic matter (see for example a review of mineralisation of organic nitrogen in soil (Harmsen and van Schreven, 1955)) but most of this work dealt with the organic matter present in mineral soils. In hill soils, organic matter accumulates on the surface of the mineral soil and freshly deposited organic materials, of both plant and animal origin, are isolated from the mineral soil by the surface organic (A_0) horizons. The presence of the A_0 horizons in these soils not only affects the conditions under which the organic materials decompose but also suggests that the rate of decomposition is slow. At the outset of this research programme little had been published regarding the decomposition of organic materials under these circumstances (Floate and Torrance, 1970).

Organic materials are returned to the surface of hill pasture soils as plant litter or as animal excreta (pathways (*a*) and (*b*) in Figure 1). In order to evaluate the effect of increased pasture utilisation it was necessary to compare the rate of mineralisation of plant nutrients from organic materials of plant and animal origin. The materials which were used in these experiments were plant materials from *Nardus* and *Festuca Agrostis* pastures on soils of the Sourhope Association (Muir, 1956) on the farm at Sourhope. Two cutting treatments were employed after the areas had been trimmed and fenced to exclude grazing sheep: (A) was cut once only in October and (B) was cut at monthly intervals between May and October. These plant materials, and faeces derived from sheep fed on the same materials, have been used in incubation experiments. The details of the incubation technique were described by Floate and Torrance (1970). Briefly, 2 g samples of each material were wetted with an aqueous A_0 soil inoculum and placed in incubation bottles together with tubes to absorb CO_2 and ammonia. These were incubated for 12 weeks and at the end of 1, 2, 3, 6, 9 and 12 weeks duplicate samples were analysed for evolved CO_2 and NH_3, and for extractable inorganic nitrogen and phosphorus. The production of mineral-P during incubation was measured by differences between the amount of inorganic-P extracted before and after a period of incubation. This amount is the net production of mineral-P or the balance between gross mineralisation and immobilisation which proceed concurrently during decomposition. Net mineral-N production was similarly measured, but total mineral-N production also included evolved ammonia.

The results have been reported in detail elsewhere (Floate, 1970*a*) but in general plant materials decomposed more readily than the faeces derived from the same source. After 12 weeks' incubation at 30°C up to 55 per cent. of the original carbon was evolved as CO_2 from plant materials while the maximum was 18 per cent. from faeces. The production of mineral-N depended upon the nature and composition of the material and the following averages summarise the results:

(i) materials from *Festuca Agrotis* pastures mineralised 13·9 per cent. original-N compared with 6·8 per cent. from *Nardus;*
(ii) materials from treatment (B) (monthly-cut) mineralised 13·9 per cent. compared with 3·9 per cent. from treatment (A) (annually accumulated);
(iii) plant materials mineralised 13·7 per cent. compared with 4·2 per cent. from faeces; and
(iv) the mineralised-N from plant materials increased from 1·6 to 25 per cent. as the N-content increased from 0·89 to 2·46 per cent.: from faeces the mineralised-N increased from 1·8 to 6·9 per cent. as the N-content increased from 1·07 to 2·05 per cent.

In general, faecal samples mineralised phosphorus during incubation while phosphorus was immobilised by plant materials throughout most of the incubation period. By the end of 12 weeks' incubation, an average of 14·2 per cent. of the original-P in faeces was mineralised compared with only 3·2 per cent. from plant materials.

Thus it may be concluded that plant materials decompose more readily than sheep faeces from the same plant source and also produce more mineral-N but less mineral-P. This result agrees with results obtained by Barrow (1960, 1961), who found that more nitrogen was mineralised from plant materials than from faeces mixed with mineral soil. These comparisons are, however, between plant material and sheep faeces from the same source, and are not applicable to the alternative pathways (*a*) and (*b*) in Figure 1. A more valid comparison in relation to these pathways is between the decomposition of annual plant material (A), and the faeces from frequently cut herbage (B) which is similar to that which might be consumed by grazing sheep. Such a comparison (Table 2)

TABLE 2

Production of mineral-N and -P during incubation of annually accumulated (A) plant material and faeces from sheep fed frequently cut (B) herbage

Material Incubated	Mineral-N as percentage of original-N	Mineral-P as percentage of original-P
Nardus (A)	1·6	5·5
Nardus (B) faeces	4·8	13·0
Festuca-Agrostis (A)	9·2	−5·2
Festuca-Agrostis (B) faeces	6·9	7·0

Twelve weeks' incubation at 100 per cent. MHC, at 30°C.

shows that not greatly different amounts of mineral-N were produced during incubation of organic materials from these two sources, and that more mineral-P was produced during incubation of the faeces. It thus appears that the increased participation of the animal in the nutrient cycle (increased pasture utilisation) may not significantly change the mineralisation rate of nitrogen but may result in an improvement in the mineralisation rate of phosphorus.

These conclusions were drawn from incubation experiments under optimised conditions at 30°C. In order that the results might be more realistically related to field conditions, the effects of variation in temperature and moisture content upon the mineralisation of nitrogen and phosphorus have also been investigated (Floate, 1970*b*, *c*). Experiments were conducted at 30°, 10° and 5°C, and at 25, 50 and 100 per cent. moisture-holding capacity (MHC).

Nutrient Cycles

Results for the maximum and minimum amounts of mineral-N and mineral-P production (from best and poorest combination of incubation conditions tested) have been used to calculate the amounts of 'potentially available' nutrients derived from unit areas of each pasture type (Floate, 1970*d*). These results are illustrated in diagramatic nutrient cycles for nitrogen and phosphorus in Figures 2 and 3. The first point of importance in these data is the increased production of plant-N under the frequent cutting treatment B. This resulted in an increase from 31·5 to 52·7 kg/ha plant-N on *Festuca Agrostis* and from 12·0 to 18·4 kg/ha plant-N on *Nardus* despite a depression of 6 per cent. and 24 per cent. in total dry-matter production under frequent cutting on each pasture respectively. During 12 weeks' incubation both the plant material from treatment (A) and the faeces from treatment (B) immobilised small amounts of nitrogen under the poorest conditions (5°C), but similar and small amounts of mineral nitrogen were produced under the best conditions. These amounts were, however, small in comparison with the large amount of nitrogen in urine. Since this is largely inorganic, or rapidly converted to inorganic forms (Doak, 1952), it has been included in the summation of 'potentially available'-N. It is clearly seen that via the vegetative pathway (A) only small amounts of potentially available nutrients are released and under the poorest conditions nitrogen may be immobilised. On the other hand, via the animal pathway (B), large increments of 'potentially available'-N may be derived from urine. The amounts were, as might be expected, considerably greater for the *Festuca Agrostis* pasture than for *Nardus*.

Very similar results have been demonstrated for phosphorus (Fig. 3). Larger amounts of plant-P were produced under frequent cutting than from the annually accumulated herbage. Phosphorus was immobilised by all materials, of plant or animal origin, under the poorest incubation conditions: under the best conditions the production of mineral-P was greater from faeces than from plant material. The largest component of 'potentially available'-P was the inorganic-P component of faeces. It will be noted that the sum of faecal organic-P and inorganic-P exceeds the total plant-P by an amount which appeared to be due to endogenous loss of phosphorus from the sheep during the feeding period. This aspect is currently under investigation.

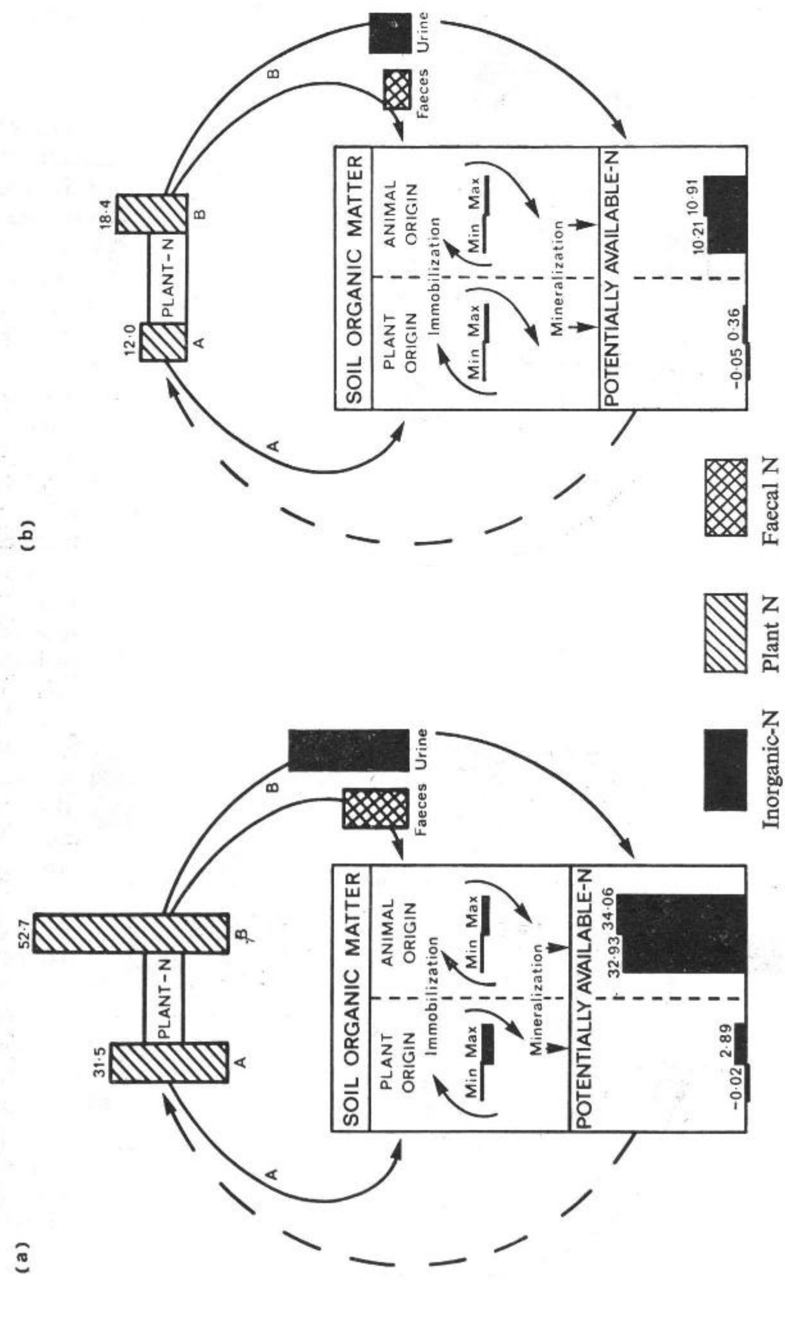

FIG. 2.—Simplified nitrogen cycle in (*a*) *Festuca-Agrostis* and (*b*) *Nardus* pasture soils. All units are kg/ha.

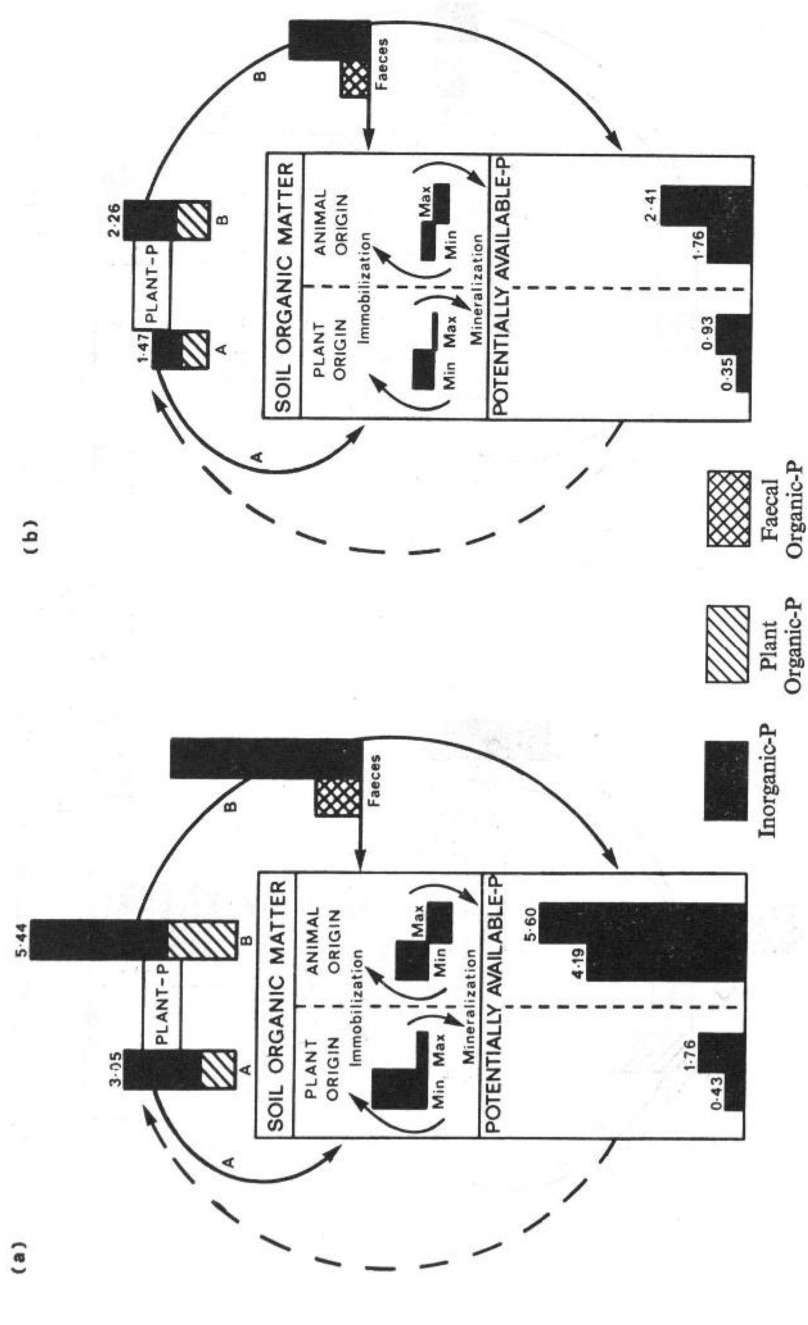

FIG. 3.—Simplified phosphorus cycle in (*a*) *Festuca-Agrostis* and (*b*) *Nardus* pasture soils. All units are kg/ha.

'Potentially available'-P was obtained from inorganic-P (of plant or animal origin) plus or minus the net mineralised-P. The results show that much larger amounts were derived from the animal pathway (B) than from the direct decomposition of annual (A) plant material.

These results suggest that when the grazing animal is involved in the nutrient cycle larger amounts of 'potentially available' nutrients should be released and that this may result in improved nutrient re-circulation under systems of increased pasture utilisation. However, the term 'potentially available' has been used because the amounts of plant nutrients which actually become available for plant growth are affected by a number of other considerations.

Factors affecting Utilisation by Plants of 'Potentially Available' Nutrients

These considerations include the degree of utilisation of a grazed pasture, the manner in which excreta are deposited by grazing animals, the losses of plant nutrients which may occur, and the availability and accessibility of the mineral nutrients. In calculating the amounts of nutrients derived from the conversion of feed to faeces it was assumed that all the herbage from the frequently cut treatments was consumed by sheep. In metabolism crates the consumption was almost 100 per cent. but in the grazing situation, incomplete consumption would result from grazing selectivity. For range pasture situations, Peterson, Woodhouse and Lucas (1956) have shown that the greatest benefits from excretal return appear under conditions of high stocking rate and over long periods of time. It may be concluded that to obtain maximum benefit from the increased amounts of 'potentially available' nutrients from sheep excreta, management should be so arranged as to result in a high degree of utilisation of available herbage.

Losses of 'potentially available' nutrients may occur through volatilisation or leaching. Loss of ammonia is known to occur when urine is deposited on soil (Doak, 1952; Watson and Lapins, 1969). The losses are greatest when the soil is calcareous, or has a high pH, and when the moisture content is low. Losses of ammonia from urine may be minimised in grazed upland soils which are frequently acid or moderately acid and where the moisture content is high for prolonged periods of the year (Floate, 1970*c*). Volatile losses are also known to occur during the making of manure (Hall, 1955), but it is believed that these also arise from urine-N rather than faecal-N. Evolution of ammonia during the decomposition of plant materials has been reported (Floate, 1970*a*, *b*, *c*) but the losses from plant materials under hill soil conditions are probably negligible. It was suggested, however, that significant losses in this form could occur during the decomposition of sheep faeces in a moist state near or above 10°C (Floate, 1970*b*). Denitrification is a further possible source of nitrogen loss (Bremner and Shaw, 1958), but they showed that the prerequisites for maximal loss included abundant organic matter, high moisture content, restricted supply of oxygen for soil micro-organisms, and a moderate supply of nitrate. Denitrification was enhanced by increasing temperature and soil pH. Since these conditions of temperature and pH, and even a moderate supply of nitrate are rarely encountered under hill conditions, the losses by this means are probably small.

Losses of nutrients in solution may occur through leaching and this is enhanced by the higher rainfall in hill areas compared with lowlands. Walker (1962) observed that most of the N, S, K, Na and Cl are excreted in soluble form in urine while P, Ca and Mg are mainly in faeces. He pointed out the non-uniform distribution of these nutrients by the grazing animal, and concluded that the dangers of leaching losses were greater when these were deposited in concentrated patches than if the same quantities could be more uniformly distributed over the pasture.

The actual availability to plants of the nutrients in sheep excreta also depends on their chemical form and accessibility to plant roots. Nitrogen in urine is either inorganic or is rapidly converted to inorganic forms so that this, together with the mineral-N produced during the decomposition of organic residues, may reasonably be expected to be readily available for plant growth. The lush growth of grass in urine patches provides evidence that this is so.

Some workers have doubted the value of faecal phosphorus in plant nutrition (Wolton, 1955; Watkin, 1957), but the availability of the inorganic fraction to plants in pot experiments has been demonstrated by McAuliffe, Peech and Bradfield (1949), Bromfield (1961) and Gunary (1968). Gunary also tested the availability of phosphorus in faeces applied to the surface of the soil and showed that uptake depended on the extent of root-dung contact. In hill pasture soils faeces are deposited on the surface and only after comminution by soil organisms are these accessible to plant roots. It is possible that under hill soil conditions faecal inorganic-P may be leached into the root zone. This possibility was tested in laboratory experiments in which faeces containing a range of phosphorus concentrations were subjected to a sequence of five successive water extractions. The results, some of which are presented in Table 3, show that most of the inorganic-P was removed in the first extraction

—declining amounts were removed in successive extractions and after five repetitions all the inorganic-P (soluble in 0·2$\overline{N}$ HCl) was

TABLE 3

Water-solubility of faecal inorganic phosphorus

Inorganic-P soluble in 0·2N HCl (mg/100 g)	Water-soluble-P removed in successive water extractions (mg/100 g) 1st	2nd	3rd	4th	5th	Total	Total water-soluble-P as percentage of HCl-Soluble Inorganic-P
256	217	29	8	6	0	260	101
481	353	83	27	13	6	482	100
843	621	130	48	26	12	837	99
1160	515	144	65	45	22	791	67

extracted except from the sample containing the highest concentration of phosphorus. These results show that faecal inorganic phosphorus is water-soluble and it seems likely that some faecal-P may become accessible to plant roots through leaching.

Improvement of Hill Soils

The data presented in Figures 2 and 3 show that under increased utilisation of a grazed pasture, the re-circulation of nutrients may be increased. It is well known that the temporary conversion of arable land to grazed pasture results in an accumulation of fertility in the pasture soil (Richardson, 1938; Russell, 1961; Jackman, 1964). It has also been demonstrated by Sears and his co-workers in New Zealand (Sears, 1953) and by research at Wye College in the U.K. (Watkin, 1954, 1957; Wolton, 1955; and Wheeler, 1958*a*, *b*) that the return of dung and urine by grazing sheep has a substantial effect on the productivity of grazed lowland swards. Rawes and Welch (1969) showed that the removal of nutrients by grazing sheep on hill pasture in the Pennines was low. They also referred to the importance of nutrient return in excreta. But apart from this work little attention has been paid to the influence of the grazing animal upon the productivity of hill or upland pastures, or upon the maintenance or build-up fertility in grazed hill pasture soils.

It was shown from the data in Table 1 that a very large proportion of the reserves of nutrients in hill soils are in organic form. An important source of the accumulated organic matter is the annually accumulated plant litter from herbage neglected by grazing animals. Many factors are operative in controlling decomposition rate, but when this is slow, and when pasture utilisation is at a low level, the

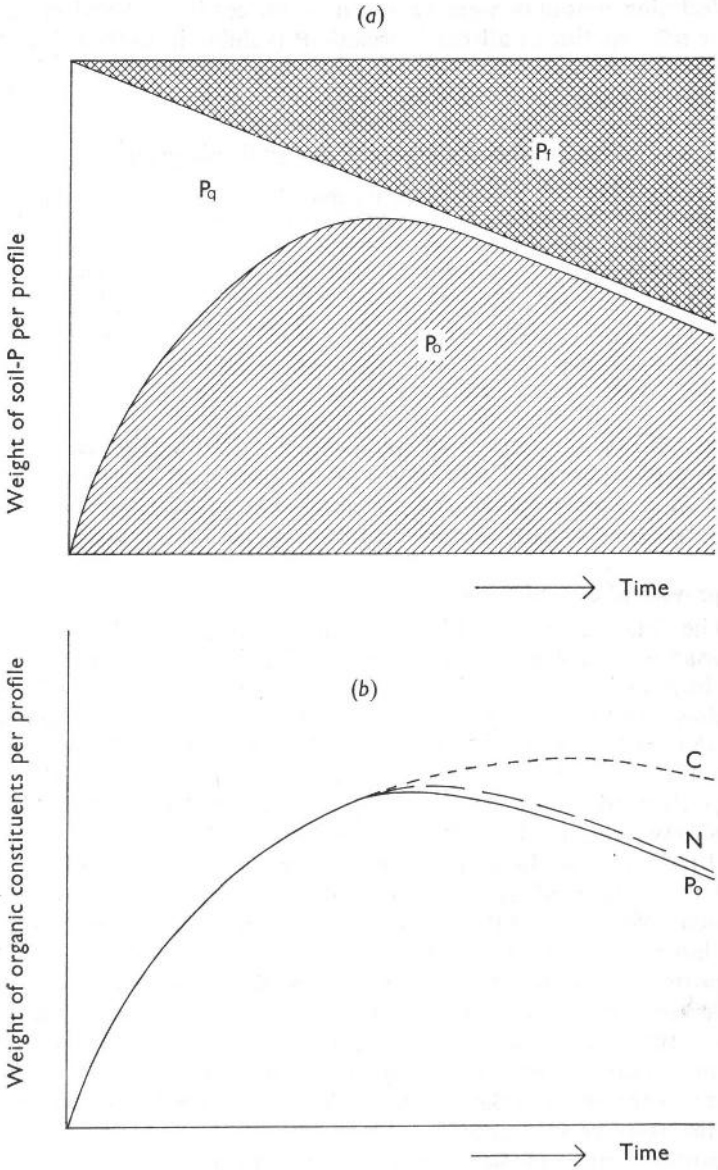

FIG. 4.—Changes in the forms of (*a*) soil phosphorus and (*b*) constituents of soil organic matter during soil development (after Floate, 1962; and Walker, 1965).

net effect is towards increased organic matter accumulation and a diminution in the supply of available nutrients. What is required in the improvement of hill pasture soils is a reversal of this process and a mobilisation of some of the nutrients held in the organic matter reserves.

Walker (1965) explained the accumulation of organic matter in soils in pedological terms and showed that many soils in humid and temperate regions had reached or passed a peak of soil organic nitrogen and phosphorus (P_0) accumulation (Fig. 4*a* and *b*). In many cases he related this to the diminution in the supply of available-P and the consequent decline in N-fixation by legumes. In extreme cases the accumulation of organic matter continued on the surface of the mineral soil and was characterised by widening C/N and C/P_0 ratios (Fig. 4*b*). This situation is exemplified in many hill soils where there is considerable accumulation of organic matter in the A_0 horizons and where C/N and C/P_0 ratios are very wide (Floate, 1962). Walker (1962), in a discussion of the fertility of soils in a grass-animal regime, suggested that the aim in reclamation should be to re-create soil conditions similar to those characteristic of an early stage in soil formation. These would include adequate supplies of plant nutrients including available-P, high base status and pH, and low C/N and C/P_0 ratios in soil organic matter intimately mixed with, rather than deposited on, the mineral soil.

The experimental evidence presented earlier suggested that the grazing animal might be effective in promoting a more efficient re-circulation of plant nutrients. If this is the case, then under the increasing influence of the grazing animal, some improvement in soil fertility may result. A study of pairs of soils on opposite sides of dividing fence-lines has shown that over long periods of time, minor differences in animal influence can alter soil properties some way in this direction. The results showed that under the influence of increased utilisation by grazing sheep the vegetation showed a decline in heather and an increase in graminaceous species including *Agrostis*, *Festuca*, *Deschampsia* and *Poa*. The thickness of the surface A_0 horizons, and the amounts of surface organic matter were reduced, and there was a marked reduction in C/N and C/P_0 ratios at all five sites examined. Average results are presented in Figure 5 and these also show that both total and organic phosphorus increased but that available-P was low and did not change significantly. Soil pH increased especially in the surface horizons but base saturation showed no significant alteration and remained low.

Thus it was demonstrated at five upland sites in Southern Scotland that increased pasture utilisation by the grazing sheep has been

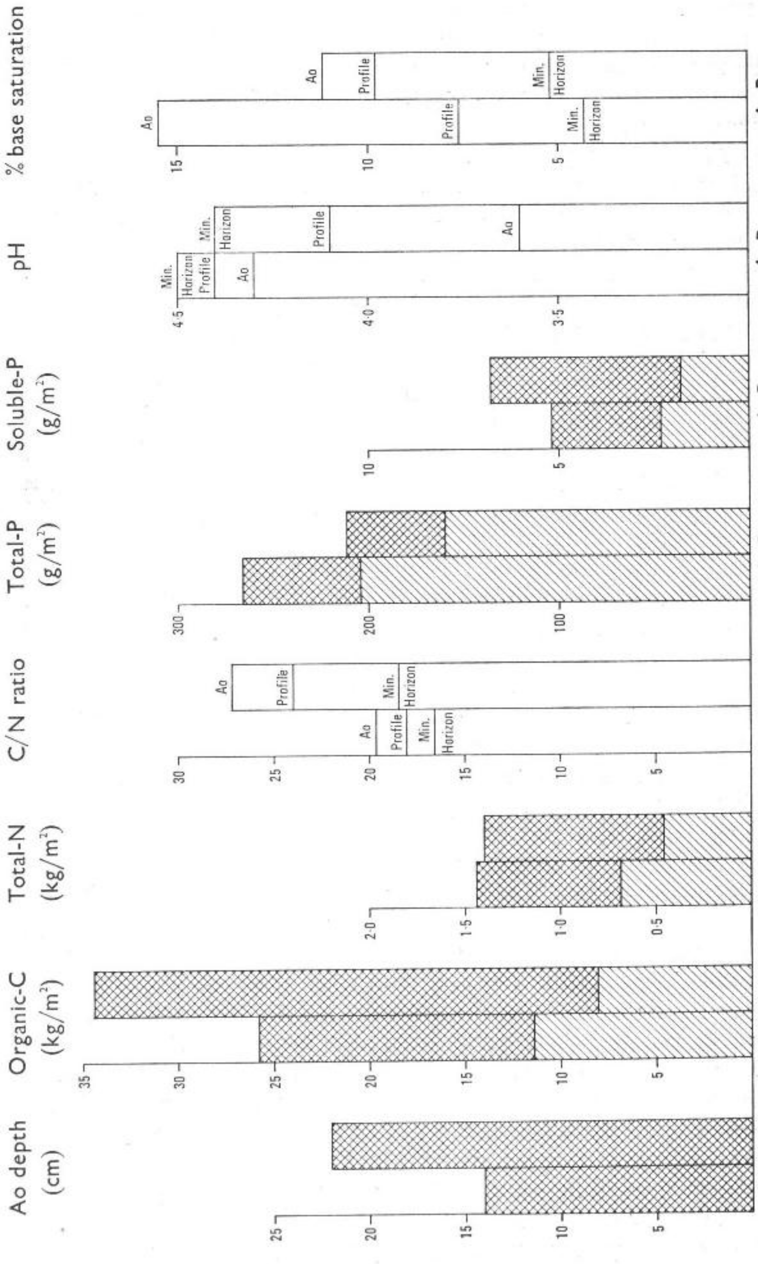

FIG. 5.—Comparison of soil properties at adjacent sites under (A) more intensive and (B) less intensive influence of grazing sheep. (Averages of 5 sites.)

instrumental in effecting changes in the amount and composition of surface organic matter, and in pH, in the direction suggested by Walker (1962) as necessary for improvement of these soils. There was, however, little change in either base saturation or available-P. It may well be that little further improvement can be expected under the influence of the grazing animal alone. Certainly improvements in both base status and phosphorus availability would be required for clover establishment and the fixation of atmospheric-N.

Data from a moorland: improved pasture comparison in Northumberland (Floate, 1962) and results from Australia (Donald and Williams, 1954), New Zealand (Sears, 1953; Walker, Thapa and Adams, 1959) and the U.K. (Wolton, 1955) have shown that increased pasture utilisation by grazing animals coupled with fertiliser treatments has led to dramatic increases in pasture production and improvements in soil fertility.

The evidence suggests that the grazing animal, as well as being the product of the system, is a potent influence within it. Furthermore, it suggests that when properly used this influence may lead to improved soil fertility and pasture production.

In 1968 experiments were started at Sourhope to assess the effects of faeces and urine return upon herbage production and nitrogen and phosphorus uptake by a natural *Festuca-Agrostis* pasture. An adjacent supply area was cut to provide herbage fed to sheep in metabolism crates for the collection of faeces and urine. These were applied in proportion to the dry-matter yields of small plots. Applications were at the rates of $x\frac{1}{2}$, $x1$ and $x4$ production and were made three times per season. In addition, parallel experiments were carried out in which N (as NH_4NO_3) and P (as superphosphate) were applied in amounts such that N = N content of urine, and P = inorganic-P content of faeces. The total amount of N and P applied to plots receiving faeces and urine therefore exceeded the amounts applied to NP plots by amounts equal to the organic-N and -P content of the faeces. The results for dry-matter production are illustrated in Figure 6 (unpublished data of Floate and Black). These show that herbage dry-matter production ranged from 3100 (P_1) to 4000 (N_4 P_4) kg/ha in 1968. In 1969 the yield ranged from 2400 ($F\frac{1}{2}$) to 6000 (U_4F_4) kg/ha. In both seasons there was a progressive increase in dry matter production through each sequence of return levels ($x\frac{1}{2} < x1 < x4$). In 1968 the highest yields were obtained under N_4P_4 treatment but in 1969, U_4F_4 gave the highest production. Since UF treatments exceeded NP treatments by amounts equal to the organic-N and -P content of faeces, the results suggest that in 1969 some benefit has been derived from organic sources. It is

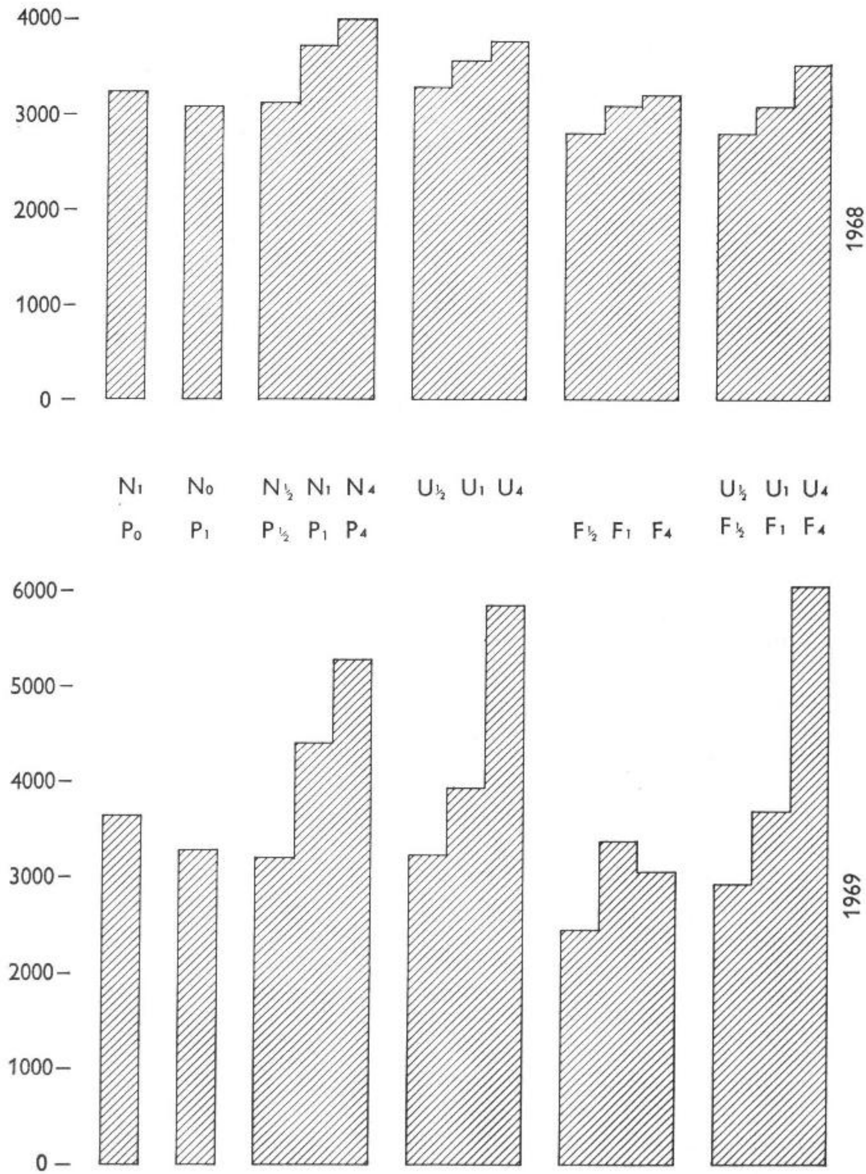

FIG. 6.—Effect of faeces and urine upon dry matter production from natural *Festuca-Agrostis* pasture.

Treatments—Faeces and urine applied three times per season in amounts proportional to dry matter production $x\frac{1}{2}$, $x1$ and $x4$.

N applied as NH_4NO_3 solution } in amounts
P applied as superphosphate }

such that: N = N content of urine
P = Inorganic-P content of faeces.

possible that this could be due to mineralisation of N and/or P from faeces applied during the same season, or to a carry-over effect from the previous season's application.

There was a progressive increase in N-uptake through each return sequence in both 1968 and 1969. The range was from 67 to 96 kg/ha N in 1968 and from 45 to 164 kg/ha in 1969. Highest values were for the same treatments as yields. Uptake was greater than the amounts applied at $x\frac{1}{2}$ and $x1$ return levels, but at $x4$ application was greater than uptake so that a carry-over of the surplus from 1968 to 1969 was possible. The increased uptake above the level of N_0 indicated the re-circulation of N from inorganic and urine sources but there has so far been little evidence for the uptake of N from faeces.

Phosphorus uptake also increased in all sequences in both seasons. The amounts were 8·5-11 kg/ha in 1968, and 6·5-15 kg/ha in 1969. Highest uptake values corresponded with highest yields and there was evidence of re-circulation of P from inorganic sources both as superphosphate and in faeces.

These experiments are still in progress, but the preliminary results indicate that yield benefits are derived from the return of faeces and urine to natural pastures under hill conditions. That the results for N- and P-uptake increase with increasing application of excreta provides evidence for nutrient re-circulation via sheep excreta.

Reclamation methods which involve ploughing, re-seeding, liming and fertilising are very costly and really seek to convert upland moor into lowland pasture. This operation is not only expensive in capital outlay but also in maintenance. Management systems which really make full use of the improved production have rarely been coupled with such measures. It could be argued that such techniques are needlessly expensive for they pay little attention to the existing reserves of plant nutrients held in the organic matter.

The application of basic slag and lime to hill pastures has traditionally been employed in reclamation. Shaw (1958) concluded that low pH was an important factor in limiting the decomposition rate of upland grassland mats. The success which has sometimes been achieved through lime and slag may therefore be due, at least in part, to accelerated decomposition of the accumulated organic matter.

In the farming context, these treatments have usually been applied with a direct production benefit in mind. It is in a sense indirectly that increased return of plant nutrients in the form of dung and urine results from increased herbage production and utilisation. The consequences which follow from these improvement treatments are not always fully realised. Hitherto, little was known of the consequences of applying an increasing proportion of organic residues to hill pasture soils in the form of sheep excreta.

General Conclusions

As a result of increased pasture utilisation, or the greater return of organic materials as sheep excreta (pathway *b*, Fig. 1) several benefits have been demonstrated:

(i) increased frequency of defoliation resulted in increased plant uptake and yield of nitrogen and phosphorus (but somewhat lower total herbage production);

(ii) decomposition of faeces derived from frequently cut herbage produced about the same amount of mineral-N, but more mineral-P, than the decomposition of annual-cut herbage from the same pasture;

(iii) greatly increased amounts of 'potentially available' nitrogen and phosphorus were released (mainly as urine-N, and inorganic-P in faeces) when the animal was introduced into the nutrient cycle;

(iv) despite some losses, and the inefficient utilisation of this 'potentially available' supply, the application of urine and faeces have been shown to give increases in herbage production and nitrogen and phosphorus uptake by native hill pasture;

(v) under increased intensity of utilisation by grazing sheep, the vegetation and properties of hill soils have been shown to change in the direction of improvement.

It is probable that little further improvement in soil properties or nutrient circulation can be expected until other improvements are made. A series of grazing experiments on a range of soil and vegetation types are currently being studied. The aim in these experiments is to assess the effects of grazing control, lime, slag, introduced clover and grass species on the circulation of nutrients, on herbage production, and on live-weight gain by grazing sheep. The results of these long-term experiments are eagerly awaited for it is only from experiments of this kind that the true value of the treatments, and of the value of nutrient re-circulation via the grazing animal can be assessed not only by their effects on soil properties but also by their effects in sheep production.

From the benefits of increased participation of the grazing animal in the nutrient cycle which were listed above, we may conclude that increased pasture utilisation should lead to more efficient utilisation of the nutrients held in the organic matter of hill soils. To benefit from these effects, systems of sheep production must be developed in which the herbage produced by hill pasture soils is much more fully utilised during the growing season. Two such systems are currently being tested in the systems development programme of the Hill Farming Research Organisation.

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2. PRODUCTION AND THE HEATHER MOOR

SHEILA A. GRANT AND JOHN KING

Introduction

The agronomy of heather is a subject which has long been of interest to those who manage sheep grazing and grouse moors. The main principle on which current heather management practice is based is undoubtedly sound. This is to maintain a proportion of the heather area in an immature stage of growth at which the production of edible green shoots is high and utilisation at a maximum. It is known that this practice which calls for periodic burning, when combined with uncontrolled grazing, even at very low stocking rates, may lead to deleterious changes in the vegetation and sometimes to the disappearance of the heather itself. But so long as hill sheep farming is based on low stocking rates and uncontrolled grazing there is little chance that management practice can be greatly improved.

However, the increasingly unprofitable results of traditional sheep farming is now making it necessary to intensify management practices and to increase both stocking rates and individual animal performance. The resultant increased demands of the grazing animal on heather communities raises in acute form a number of questions as to how far these demands can be met without causing degenerative changes to occur among the plant communities involved.

The present programme of research on heather at H.F.R.O. is intended to answer some of these questions. It is of course necessary to set the work in the framework of the range of heather communities commonly found on hill grazings. Gimingham (1964) has listed nine heather vegetation types, but of these there are only four which are of significance in the present context. These are:

(1) *Calluna-Erica cinerea* heaths.
(2) *Calluna-Vaccinium* heaths.
(3) *Calluna-Erica tetralix* wet heaths, including the common *Trichophorum*-rich and *Molinia*-rich types.
(4) *Calluna-Eriophorum vaginatum* wet heaths.

The first two are the principal heather moorland types found on podsolised soils in eastern districts. The others are associated with deeper peat and are widespread in the west.

So far work has been carried out mainly on the first type, at Glensaugh, but is now being extended to include all four.

In addition to the phyto-sociological framework, it is also desirable to take into account the grazing management objectives set by a high individual sheep performance, the associated annual cycle of nutritional requirements and the necessity of providing for this as far as possible by grazing. This has not so far been done to any extent, since until recently the only management context was that of the traditional year-round uncontrolled grazing in which overall stocking rate and animal grazing behaviour patterns largely determined both the level and the seasonal pattern of grazing pressure.

With these considerations in mind, therefore, the questions to be answered can be listed as follows: firstly, what is the maximum level of sustained productivity, in terms of digestible organic matter, which can be obtained from heather and how does this compare with the productivity of other vegetation types? Secondly, what management is required to bring about a high level of plant productivity and to what extent is this compatible with the management pattern designed to fulfil animal nutritional requirements? Thirdly, what is the effect of these practices on the composition and stability of different heather community types?

Management Effects on the Heather Plant

The components of management that have been so far considered are defoliation and burning. The effects of these on the heather plant have been investigated in two related experiments. The first of these examined the effects of frequency and season of defoliation by cutting on morphology, productivity and chemical composition of the heather plant (Grant and Hunter, 1966). The second experiment investigated the effects of burning and defoliation by grazing on *Calluna-Erica cinerea* moorland. The experiment was conducted in three phases. The first phase examined the interaction between burning and grazing on the development of the heather stand. The height of the stand and general growth form of the plant were markedly affected by management; so also were the earliness and amount of current season's growth and the chemical composition of the current season's leaves. Grazing sheep exhibited marked preference for certain stand types, those which may be designated as physiologically young. This phase of the study was completed in autumn 1967 and has been reported on (Grant and Hunter, 1968).

The second phase was commenced in late 1967 and lasted for two years. During this phase, data were collected on the production characteristics of the heather as affected by management, account being taken of both quantity and quality of edible material. Attempts were also made to measure the degree of utilisation or grazing pressure associated with the different grazing treatments.

The third phase is newly begun and the effects of past management, which has produced a wide range of stand types adjacent to one another, on the fire characteristics when burned and on subsequent regeneration will be studied.

In both these experiments defoliation by cutting or grazing was carried out in summer (late June-August) and/or winter (December-March). Sensitivity differed as between seasons, the response to defoliation in summer, in the middle of the growing season, being greater than that to a similar level of defoliation in winter, the dormant season. The growing season stretches from late April until October (approximately) and it cannot be assumed that the sensitivity or response to cutting or grazing will be uniform within this period. It is important to know the extent of these variations and the limits to utilisation set by plant responses before one can suggest a rational management for heather moorland. Thus future work is planned to examine the effects of grazing and cutting at different times within the growing season in greater detail.

The main findings of the above two experiments and their implications will now be briefly summarised and discussed.

Production Characteristics: Quantity

Production characteristics of the heather plant are directly related to the growth-form of the plant. This is influenced both by age and grazing (or cutting). The factor of importance is the ratio (by weight) of green assimilating shoots to woody supporting tissue. This ratio is highest in young plants and falls as the plant ages. As the ratio falls the relative productivity of the plant in terms of dry matter produced expressed as per unit of the total plant weight also falls. In terms of weight per unit area of ground, the fall in relative productivity is offset to some extent by the increase which occurs in both the percentage cover and in the weight of standing crop so that the annual dry-matter yield from a short juvenile stand may be similar to that of a taller more aged stand.

The influence of defoliation on the ratio of green shoots to wood and on growth form have also further implications. A heavily grazed heather plant, of say 10 years, will have a very different growth form and physiological age to a more lightly grazed plant of the same chronological age. The former will have over 40 per cent. of its dry matter accounted for by current season's growth, the latter a mere 16 per cent. Grazing suppresses the build up of the woody framework of the plant and stimulates the growth, both number and length, of current season's shoots. The arrangement of the shoots too is such that on the short, more bushy grazed plant a grazing animal is likely to ingest current season's shoots only, while on the much more diffuse and leggy undergrazed plant it will necessarily also ingest some older green material. The latter is of poorer nutritional value and will therefore dilute diet quality. Litter production by more heavily grazed plants is also greatly reduced. Accumulation of mor humus leads to increased soil podsolisation and thus management which reduces litter production is desirable if one wishes to conserve soil fertility.

One aim of management of heather moors is to achieve the maximum possible area of heather in the most productive growth phase. A dry-matter production of 2000-2500 lb/acre/annum should be possible on a suitably managed eastern heather moor (e.g. *Calluna-E. cinerea/Vaccinium* heath) where heather itself usually accounts for over 80 per cent. ground cover. This estimate is based on yield measurements at Glensaugh and agrees closely with figures quoted by Miller (1969). Grazing management can be used to influence the ageing process and to maintain production levels by creating heather stands of the optimum growth form and low physiological age. Grazing control is therefore essential if this is to be achieved and if, at the same time, any undesirable vegetation changes which may accompany increased grazing pressure are to be avoided. Such undesirable vegetation changes are often the result of allowing the heather to become too aged before burning. Though the yield per unit weight of plant falls as the heather ages, because of increasing standing crop, the yield per unit area remains fairly constant over a wide age-range; grazing animals avoid older heather; it is more susceptible to disease; its ability to withstand any degree of grazing is reduced and regeneration following burning is more hazardous. If there is too great a proportion of aged heather on a moor, the grazing pressure on the relatively small areas of younger heather will be severe and even at overall stocking rates as low as 10 acres per sheep, it is possible for the grazing pressure to be so severe as to weaken the plant and even eliminate it.

Because of the variation in age mosaic of heather stands on the open hill it is almost impossible to relate overall stocking rate figures to grazing pressure. In consequence it is not very meaningful to speak of overall stocking rates on heather moorland of mixed age-classes.

A more useful measure of grazing pressure is the percentage utilisation or percentage eaten in relation to that available. The measurement of utilisation involves the use of cages, serial sampling techniques and estimates of the edible and supporting tissue fractions. Both the cutting and the small-scale grazing experiment referred to above indicate that heather of suitable growth form and of relatively low physiological age can certainly withstand 60 per cent. utilisation. However, there were indications of an increase in cover of competing grasses in the grazing experiment on plots where utilisation reached 90 per cent.

Production Characteristics: Quality

Having dealt with the production capacity of the plant and its ability to withstand a certain grazing pressure, the next and obvious question is in regard to its ability to support the grazing animal. What is the nutritional value of heather? Does management affect its value? These are difficult questions to answer. Management certainly affects the chemical composition of the current season's material. Thomas (1935, 1956) quoted figures to show that nitrogen and various ash components varied with age and season, and Grant and Hunter (1966 and 1968) showed that cutting and grazing, presumably by influencing physiological age, also had an effect. Current season's material of hard-grazed plants had higher levels of nitrogen and some ash components than had more lightly grazed plants. However, nutritional value to the grazing animal is not indicated by such data. The parameters of relevance here are digestibility and voluntary intake.

Several attempts have been made to measure digestibility, but none of them has been very satisfactory. Thomas and his co-workers (1952, 1953, 1954), using dried cut heather in admixture with hay, conducted several *in vivo* trials. Digestible organic matter ranged between 40 and 54 per cent.; young heather (4 years) had a higher digestibility than old heather (10 years), and in one trial the two sheep used showed marked differences in their digestive capacity for heather. In all the trials food intake of the sheep fell when the heather content of the feed reached a high level. *In vitro* digestibility measurements made on dried and ground samples collected from the Glensaugh experiments already mentioned had a similar range of dry-matter digestibilities, i.e. varying from 40 per cent. to about 55 per cent. There was a significant trend for the digestibility of the current season's material to decline as the season advanced and older green material was inferior in digestibility to current season's growth. Thomas and Smith (1954) concluded that heather was as good a source of energy as much of the hay which is hand fed to sheep in winter but was poor as a source of protein. They considered that since the main requirement for the hill ewe in winter is for energy, heather should prove an adequate substitute for hay, and also drew attention to the undoubted value of heather as a source for certain minerals.

For various reasons it was felt that the estimates of digestibility obtained on dried heather were not indicative of its true fresh *in vivo* value. Performances of sheep on heather-dominant pastures, lamb growth rates on the Lammermuirs for example, are much better than figures of 40-55 per cent. dry-matter digestibility would lead one to expect. There are several possible sources of error in estimating heather digestibility. Drying could be associated with changes in the chemical structure of certain cell constituents with possible changes in digestibility or drying may affect voluntary intake. Handley (1961) discusses the effects of drying heather in some detail. He reviews a number of digestibility studies and considers the results in relation to the effects of tannin-like protein-precipitating materials in leaves. If dried, these protein complexes are highly indigestible. Low nitrogen availability would inhibit the activities of the rumen flora and their ability to digest carbohydrate. In addition to the possible effects of tannins on digestibility there may also be other effects on such factors as intake or the assimilation of nutrients, but whether this is so is unknown. In other ways also heather has a rather unusual composition compared with other feeds, it is relatively high in lignin but low in fibre. Figures for samples collected in July 1969 showed lignin contents ranging from 13 to 17·5 per cent. and fibre contents ranging from 23·5 to 29 per cent. It is well known that animals require a period to adapt to changes in diet and the rumen liquor used for *in vitro* tests may give false estimates of digestibility if the feed of the sheep supplying the liquor is different from the test sample. The only really satisfactory measure of heather digestibility would be given by *in vivo* trials conducted with fresh heather. However, there are still technical difficulties to be overcome before such trials can be run.

In the meantime, in collaboration with colleagues on the Agronomy staff (S. Lamb and R. Campbell), comparisons of the *in vitro* digestibility of fresh versus dry heather and the efficiency of rumen liquors from sheep on varying diets are being made. Preliminary results of this work indicate that the variation in the rumen flora associated with different diets is a very important source of error. The same heather sample gave digestibilities ranging from 42 to

58 per cent. dry-matter digestibility depending on the rumen liquor used. Low estimates resulted using liquor from sheep fed medium quality hay (67 per cent dry matter digestibility) and higher estimates with liquor from sheep fed a mixed ration of a similar hay plus maize (70 per cent. dry matter digestibility). Fresh heather gave inconsistent results and no clear differences between fresh and dried heather have emerged as yet.

The fall in digestibility of heather with season as indicated by the earlier *in vitro* work, though significant, is rather small. If the estimates of digestibility in this earlier work prove to be underestimates by even 10 to 15 per cent. (they were made using rumen liquor from sheep fed on medium-quality hay) this would still leave the quality of summer heather below the best grass. The winter quality, however, may well reach levels which are very favourable when compared with other sources of winter feed. Future work will certainly include investigation of samples of heather of varying maturity both within and between seasons.

The current studies indicate the need to develop techniques specifically for the evaluation of heather and therefore the digestibility figures quoted here may be no more accurate than those quoted elsewhere.

Voluntary Intake

Little is known in quantitative terms about the voluntary intake of heather. Most work done on this aspect has been of a descriptive nature. Both Thomson and Robertson (1959) and Grant and Hunter (1968) noted a distinct preference of sheep to graze very young heather at all seasons. MacLeod (1955) examined the herbage in the rumen of sheep after slaughter, the sheep having come from Lephinmore where the vegetation belongs predominantly to the *Calluna-Erica tetralix* type with abundant *Trichophorum*, *Molinia* and *Eriophorum*. This investigation showed that heather was a constant source of feed throughout the year. There was an indication that extreme tips of shoots were selectively grazed in the period July-September, while at other times of year longer shoots up to 1 and even 2 inches were taken. Samples containing longer shoots were most frequent in the period December-February. MacLeod, while not attempting to evaluate the quantity of heather in any sample, from observation estimated that heather accounted for about 20 per cent. of the diet in summer and 40 per cent. in winter.

Clearly, more needs to be known quantitatively about the voluntary intake of heather, its rate of passage through the gut, etc. Until this information is available meaningful statements cannot be made about the value of heather as a food source.

Grazing Management

Decisions about when and at what intensity to graze a heather moor will be based on an assessment of several factors, some of which have been mentioned already. To meet the nutritional requirements of the grazing animal is a basic necessity and for higher levels of individual animal performance high-quality feed is required at tupping, at lambing and during lactation.

The nutritive value of the heather plant, its digestibility and voluntary intake and factors affecting these will dictate the kind of grazing system which can be used. If heather itself cannot supply the necessary quality at a particular time, then a system integrating the use of grassland, either natural, or reseeded, with heather may have to be used. Certainly in the case of the *Calluna-Erica tetralix* vegetation of the west where heather is not always the most abundant species and the associated species are likely to be nutritionally inferior, this seems more likely to be the case than in the east where the dominance of heather in the moorland is often very high indeed. Considering the eastern type of heather moorland and assuming that the heather is to be utilised as such and not converted to grassland, the productivity of heather and the grazing pressure (i.e. the percentage utilisation) which the plant can tolerate, will influence the overall stocking rate which can be used. If high utilisation and production levels are desired, then high grazing pressures must be imposed after burning from the seedling stage onwards. This will produce stands of prostrate growth form, and low physiological age while percentage utilisation will be high (i.e.$>$60 per cent.). It would seem to be logical to try to restrict as much as possible the physiological age-range of the stands within one enclosure. This will minimise the risk of one stand being subject to overgrazing and increase the degree of grazing control which is possible. This is most practicable, possibly even essential, when paddock grazing is used. The greater the physiological age-range of the stands and the smaller the proportion of young stands, the lower must be the overall stocking rate and overall percentage utilisation if individual stands are not to suffer from overgrazing. The season of grazing must also be taken into account as there is evidence that heather is more susceptible to damage by hard grazing in summer than in winter.

In the west, where heather dominance is less and community composition is more variable, the situation is more complex though on present information the same principles that apply to eastern moorland apply here also. Grazing preferences will be affected by grazing pressure and the spatial relationships of the different vegetation types, thus the consequences of increased grazing pressure are difficult to predict without more information.

It is important that any system of grazing should not be one of short-term exploitation leading to long-term deterioration. It is necessary to know in advance what possible harmful trends may be associated with increased grazing pressures.

As grazing affects the ageing process in heather, the frequency of burning should vary with different grazing managements. The main beneficial effect of burning is in rejuvenating the stand where grazing pressures are insufficient to prevent a build-up of woody tissue. Where heather is allowed to become too aged, apart from the diminishing returns obtained in terms of production and utilisation, delay in burning allows the quantity of fuel to build up to levels where high fire temperatures are likely with increased risk of nutrient losses (Evans and Allen, 1970). Regeneration is slower and thus the period when bare ground is exposed to erosion risk greater. Species other than heather have time to become better established before the heather is able to compete. Too frequent burning can also have harmful effects, especially when in combination with heavy grazing pressures. Heavy grazing tends to prolong the early successional phases of the ageing cycle of heather moors, and on freely drained sites grasses are often relatively abundant at these stages. The early results of the third phase of the Glensaugh experiment already referred to included heavily grazed plots which were burned while still in the early building phase. On these plots, though the frequency of regenerating heather shoots was higher than with other treatments, so also was the frequency and cover of grasses. Burning frequency should be adjusted to physiological age rather than actual age and good management should aim at achieving the best balance between improved production and utilisation and community stability.

The vegetation recording which is at present carried out as part of the monitoring of large-scale grazing system trials at Lephinmore and elsewhere should provide data on what changes may be expected to occur under practical conditions. In addition, experiments are being set up in both the eastern and western situation to investigate the response of the vegetation to varying intensities and seasonal distribution of utilisation. The sensitivity of the plant to grazing at different times in the season, effects on stand development and on vegetation change will be examined.

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3. SOME FACTORS AFFECTING REPRODUCTIVE RATE IN HILL SHEEP

R. G. GUNN AND J. M. DONEY

REPRODUCTIVE rate in hill sheep, when expressed in terms of lamb production, is generally low. Lamb production in itself gives no indication of maximum potential fecundity in the ewe, which is the maximum number of ova shed in any one oestrus cycle within the peak of the normal breeding season by a ewe in natural physiological state uninfluenced by treatment with exogenous hormones. Lamb production is the net result of two main complementary factors, the one being ovulation rate or the number of ova shed in the oestrus cycle at which mating occurs, and the other being embryo mortality or wastage, which is the total loss of potential lambs (determined by ovulation rate) to time of parturition.

It must be emphasised that unless sufficient ova are shed at the time of mating nothing that may be done subsequently can improve the level of fecundity in that breeding year. Therefore, knowledge of the conditions necessary to achieve the optimum number of ova for any one breed or enterprise is of primary importance. Equally important is knowledge of the conditions necessary to bring as high a proportion as possible of these ova to term as viable lambs, since wastage may occur at any one of a series of arbitrary stages throughout pregnancy.

The final reproductive rate in terms of viable lambs born therefore depends on a variety of factors within all stages, with ovulation rate determining the maximum potential fecundity and wastage reducing the subsequent response to below the potential. Determination of the various factors is obviously complex as it is difficult to consider the influence of any one factor alone in a series of interactions in time.

The factors involved can, for convenience, be grouped under the following headings: nutrition, climate and management. The pathways by which these factors impose their effects are imperfectly understood, although it is generally considered that they act through the endocrine system and may be modified by genotype. Much of the field scale work on the relationships between the above factors and reproductive function has been, and still is, observational, and differences in detail of both method and results can lead to variable interpretation. It is therefore possible to only speculate on the cause of reduced fecundity resulting from the factors described. In this paper, then, it is intended to concentrate on the consequences rather than on the pathways of these factors and to attempt define the underlying principles with a view to simplifying interpretation.

Nutritional factors can be considered under two broad headings, firstly that of energy and protein intake, and secondly that of the requirements for specific nutrients. So far, the work of the Organisation has concentrated on the effects of variation in energy and protein intake, particularly the former. This does not imply that specific nutrients do not play a part in the control of reproductive function as indeed they have been shown to do in many parts of the world where, in particular, mineral deficiencies or imbalances exist but rather that, in general, they play a lesser part in most situations where energy deficit is the main limiting factor.

Climatic factors, particularly those associated with low temperatures, wind and wetness, have so far received little attention in relation to fecundity. There is, however, plenty of evidence on the effects of high-temperature stress on various aspects of fertility and it seems likely that cold stress could also have some influence. Work has been initiated by the Organisation to examine the effects of various climatic factors on fecundity in the ewe.

Management is closely interrelated with the other two factors, being concerned in the control of nutritional effects and in the modification of climatic influences. It includes not just the management of the ewe but also of the pastures on which she grazes, and it must take into consideration psychological as well as physiological functions.

It is now proposed to consider the influence of the above three main factors on the main components of reproductive function, ovulation rate and embryo mortality, and to describe some of the work being carried out by the Organisation.

Nutrition and Ovulation Rate

Within normal physiological limits there is a genetic maximum number of ova produced in any one oestrus cycle and this varies between breeds. Where the maximum is very low (1·0-1·2),variation due to nutritional effects is likely to be slight, unless low nutrition results in an increase in the number of ewes failing to ovulate. Conversely, where the maximum is very high (3·0-4·0), it is probable that nutritionally created variation also could be high, although it is possible that in some breeds ovulation rate might be largely independent of nutrition. However, in general terms, it has long been accepted that ovulation rate can be influenced by nutrition. Around this has arisen the concept of 'flushing', a term and technique loosely discussed since the early nineteenth century. Definitions of flushing vary and are mostly unclear. Some very early concepts were fairly general and took into account body condition, live weight, previous and current levels of nutrient intake and so on. In practice, the emphasis has changed to consider flushing as involving a rapid increase in food supply and hence in body condition a few weeks prior to mating. It has also frequently involved a deliberate reduction in condition *before* flushing, although the evidence to support this practice is very uncertain. The implication is that a period of rapid change in metabolism and/or body condition can stimulate both the onset of oestrus and the number of follicles which produce ova. Many observations and experiments suffer the disadvantage of using lambing percentage as the criterion rather than ovulation rate, and most have not had the situation sufficiently clearly defined, so that contradictory results cannot be explained and some explanations are capable of alternatives.

To define the importance of nutrition in determining ovulation rate, it is therefore vital to define such factors as breed, body condition, live weight, and level of intake at mating, together with the rate of change of these latter components (either up or down) immediately prior to ovulation. Observations, on which recommendations have been based in the past, range widely over most permutations of comparisons between fat and/or thin ewes losing and/or gaining weight, as well as with variable rates of gain or loss, and even with no knowledge at all of gain or loss in weight. Where the contributory factors have been only loosely controlled it is possible that the potential interactions may involve other forms of stress perhaps imposed by the experimental provisions themselves.

One difficulty is that with greater experimental control and restrictions, extrapolation or wider application is also restricted. Nevertheless, we have carried out a series of experiments with Scottish Blackface ewes where we have attempted to exercise control over certain of these variables and where some of the interactions have been eliminated. The principal feature of one experimental design was to produce, at mating, homogeneous groups of Blackface ewes in widely differing body conditions assessed by means of a subjective, condition-scoring system based on loin palpation; a system which has been shown to give acceptable estimates of the quantity of total chemical fat in the body. Two levels of body condition were arbitrarily selected, grades 3 and 1·5, levels at which the body contains approximately 30 and 15 per cent. total fat respectively. The second feature of this design was that both groups should consist of ewes which had achieved these desired body conditions at mating in three different ways, by losing, by maintaining, or by gaining body condition through different levels of food intake during the previous 5-6 weeks. The experimental design is shown schematically in Figure 1. Ovulation rate was estimated by

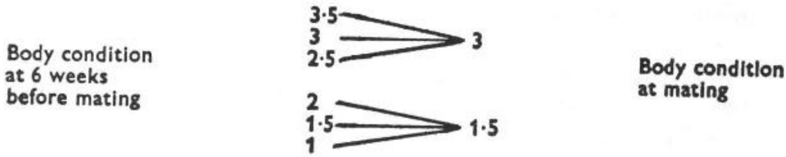

FIG. 1.—Schematic design of body condition changes during the 6 weeks prior to mating.

counting active *corpora lutea* in a predetermined random sample of ewes from each of the six pre-mating groups killed 2-3 days after mating.

The results in terms of ovulation rate are shown in Table 1. These indicate that when ewes were in poor condition (grade 1·5), ovulation

TABLE 1

Number of ewes with 0-3 *ovulations in the predetermined sample killed* 2-3 *days post-mating*

No. of ovulations	Body condition at 6 weeks before mating						Body condition at mating	
	3·5	3	2·5	2	1·5	1	3	1·5
0	0	0	0	0	0	0	0	0
1	0	0	1	9	8	5	1	22
2	8	8	7	0	1	3	23	4
3	1	1	1	0	0	0	3	0
Percentage ovulations	211	211	200	100	111	138	207	115

rate was low (1·0-1·4) but was marginally increased by current high food intake. Conversely, when ewes were in good condition (grade 3), ovulation rate was high (2·0-2·1) but was not depressed by current low intake. Therefore body condition *per se* seems to be important in the determination of ovulation rate. Subsequent work on several different populations of ewes of the same breed has confirmed this conclusion.

Further conclusions were, that at the high level of condition, current nutrition was unimportant in relation to ovulation rate and that at the low level of condition, high current nutrition was no substitute for body condition, but apparently did have some influence on ovulation rate.

There are still many unanswered questions. It is possible to ask, what happens when ewes are in conditions between grades 3 and 1·5? Is there a linear relationship between ovulation rate and condition, and could the level of current food intake interact with ovulation rate only below some intermediate threshold of condition, if it interacts at all? Then what happens when ewes are above grade 3 in condition, does the high ovulation rate represent the genetic limit? If it does, then there is no immediate point in attempting to raise the level of condition any higher, and presumably all individual ewes in the population must have reached their individual genetic maximum. It is also possible that individual variation is such that some ewes reach their maximum ovulation rate at lower levels of condition than others, and raising their condition higher could have no effect and may possibly even have an adverse effect. It is frequently suggested that overfatness or excessive feeding may depress ovulation rate but these terms are badly defined and the evidence is not very strong or conclusive. This aspect has not been studied as yet.

Then there is the question of differences in the genetic maximum between different populations of the same breed and whether phenotypic factors such as nutrient history can influence this. For example, in another experiment, Blackface ewes purchased from a farm sustaining a lower nutritional cycle than our own farm source were transferred there and brought into similar levels of body condition (grades 3 and 1·5) at mating as our own home-bred ewes. Although the purchased ewes were, within grades, from 8 to 11 kg lighter at mating than the home-bred ewes, there was no difference in the proportion of fat present. However, the purchased ewes consistently produced fewer ova than the home-bred ewes, only 1·5 compared with 2·2 at grade 3 and only 0·9 compared with 1·3 at grade 1·5.

From our evidence, the incidence of ewes which do not ovulate is low, but it may increase when ewes are in poor body condition. In the two experiments so far described, all home-bred ewes ovulated, while in the second experiment, 17 per cent. of grade 1·5 purchased ewes were not mated and of these two-thirds or 11 per cent. of the total had not ovulated. This may be related to their poorer long-term nutritional history which suggests that there may be another threshold of body condition below which ovulation failure increases, a threshold which is raised by such long-term restriction. Some of the

Australian and New Zealand work also suggests the existence of such a threshold, but there is general doubt as to its physiological basis. Earlier studies on reproductive failure in inbred Blackface ewes showed that ovulation failure was common but even in these sheep it appeared that this incidence could be modified by both long and short-term factors associated with nutritional state.

Climate and Ovulation Rate

It is frequently suggested by flockmasters that cold weather conditions during mating result in fewer lambs born. This, if so, could be due either to a reduction in the number of ova shed or an increase in some aspect of early wastage. Experiments were carried out to examine and separate these two possible effects. As wetting has been shown to simulate cold stress, Blackface ewes, shorn in late August, were brought into and maintained in the condition range of 2·5-3, and after being chemically synchronised for oestrus, half were exposed to a 6-hour daily wetting by sprinkler in an open outdoor pen for an average of 18 days prior to mating at the second oestrus after synchronisation. The control groups were housed indoors. After mating, half from each group were interchanged between the two environments and all were killed 26 days later.

There was no difference between the groups at mating in either live weight or body condition, while the outdoor stressed group were fed marginally more to compensate for any possible energy cost of the climatic stress. Ovulation rate in the outdoor stressed group was significantly lower than in the indoor group (1·52 *vs.* 1·86). Climatic stress of the kind imposed therefore had some influence on ovulation rate and while it is not possible to define the stress more critically, it seems fairly safe to say that exposure to cold and wet at some period or stage during the oestrus cycle prior to mating can reduce fecundity. This aspect is currently being examined in relation to stress in different periods of the premating oestrus cycle and the preliminary results suggest that the period within a few days prior to oestrus is the most critical. Although there was very little range in body condition in the first experiment, there was a suggestion that the effect of cold stress was greater in those ewes with the least reserves of fat, there being no difference in ovulation rate between the fattest ewes in the two groups. The fact that the main effect was on incidence of multiple ovulations rather than ovulatory failure will make interpretation complex, since as condition declines so also does the number of twin ovulations, making only a limited range of condition in which sufficient twin ova are shed for response to be significantly tested.

Management and Ovulation Rate

There is very little evidence of a direct effect of management changes during the period prior to ovulation although the observed lower ovulation rates in transferred sheep may be a direct effect of the transfer to a new and unfamiliar environment. It is also possible that physical disturbance, such as chasing by dogs, might create similar stress conditions as were caused by cold and wetness, and could therefore depress ovulation rate in the same way. There are, of course, many indirect ways in which management may influence ovulation rate. These are mostly concerned with the control of grazing and access to pasture necessary to achieve the required levels of body condition for specific reproductive objectives. Where the aim is to maximise ovulation rate, a high level of body condition has been shown to be necessary. Having once achieved this, the evidence suggests that not only is climatic stress less likely to reduce fecundity but also that the ewes come earlier to the ram and are more likely to hold to first service, which is partly an expression of reduced wastage.

Egg Wastage

As has been said, wastage can reduce fecundity below its potential maximum at any one or several of a series of stages between ovulation and parturition. Estimates of normal wastage from widespread reports range from 10 to 40 per cent. Taking nutrition first, there is no evidence of any direct nutritional effect on fertilisation. In general, fertilisation failure may be partly a function of the ewe, partly a function of the ram and partly due to specific genetic fault of the ova. Difficulty in separating fertilisation failure from early embryo mortality in many experiments makes it impossible to define accurately the influence of specific factors. Climatic and management factors may therefore have some influence on fertilisation but may act through the ram rather than the ewe.

In the pre- and post-implantation stages most wastage appears to be accounted for by the thirtieth day after fertilisation (day 30). Within this period there may be differences in sensitivity and in cause of failure, but in most experimental work involving variable restrictions they are difficult to separate. Many workers have studied the effect of short-term nutritional stress (such as 2-3 days starvation); of longer periods of undernourishment (such as 7 or more days at variable levels below maintenance); and of overnourishment; but the results have been extremely variable. Overfatness or being too well fed may cause some losses; severe undernourishment depends on timing and on previous factors but may increase wastage by up to 5 per cent. Sustained, moderate undernourishment appears to have little effect: we have compared wastage in ewes which were undernourished from mating to day 25 and lost 8 per cent. of their live weight, with that from similar ewes which were moderately well fed and gained 5 per cent. over the same period, and could show no difference.

More work is obviously required to define the nature and magnitude of the effects of high and low planes of nutrition on embryo mortality. As there is evidence which indicates that wastage can be influenced by the level of body condition at mating, there could therefore be an interaction between condition at mating and post-mating nutrition which may partly account for the year-to-year variation in wastage response which has been reported.

As has been suggested earlier, climatic stress after mating might influence wastage. In the experiment previously described, the effect of a wetting stress during the first 26 days post-mating was examined on returns to service and on the number of active *corpora lutea* not represented by embryos. There was no effect on the incidence of returns to service and although there was a suggestion that actual wastage might have been increased by the treatment this was small compared to the effect on ovulation rate. Other workers have shown that heat stress can result in embryo mortality during these early stages and cold stress may well act along similar physiological pathways. However, since we obtained little response in our experiment it is suggested that the animal may be able to compensate for or acclimatise to moderate continuous cold stress although it might show greater response to extreme, short-term cold stress. This obviously demands more critical examination.

Embryo mortality or wastage may also be influenced by management. There is little experimental evidence of a direct effect of management on wastage in the ewe, but from evidence on other species, including man, it is possible to speculate that disturbance factors may create stress conditions which result in increased loss of embryos. There is evidence that the embryo may be most sensitive at or about day 14-15. This also requires more critical examination.

Wastage during the mid-pregnancy period (from 45 to 100 days) is generally accepted as being low in normal situations. Much of the available evidence, both direct and indirect, suggests that foetuses surviving to this stage are likely to be present at term. Such wastage as does occur during this time, and we have found up to 5 per cent. of implants may be lost, may be due to a specific genetic fault of the foetus and not to nutritional, climatic or management influences. There are, however, a few limited reports of unaccounted wastage occurring during this mid-pregnancy period which need investigation.

Wastage during the late pregnancy and neo-natal periods is probably dependent on genetic factors influencing the partition of intake, which in turn will depend on nutrient availability. As late pregnancy nutrition and the response of the ewe and her uterine contents are subjects of considerable complexity and much research effort, it is not proposed in this paper to discuss them further, particularly as variation in intake appears to have more influence on foetal weight than on foetal number.

Practical Implications

The most important one as far as hill sheep, and the Blackface breed in particular, are concerned, is the considerable potential fecundity which is available and can be achieved when certain restrictions are removed. It is clear that ovulation rate at mating is closely related to the level of body condition at that time, although current nutrition may play a part and external environmental factors such as climatic stress at the time of follicle formation or ovulation may have an overriding influence. In situations such as we have in this country, where ewe live weights follow a cyclic pattern with a post-lambing minimum, the period from lambing to mating can be called the recovery period during which the ewe has to replace reserves of energy, protein, minerals, etc., depleted during the previous reproductive cycle. Although some recovery during lactation is possible, it is between weaning and mating that most occurs, and while the absolute level of condition which is established before ovulation is important, it is still not certain whether or not the rate of recovery is just as important. As the requirements of both body condition and level of nutrition differ with the breed or strain of ewe and with the number of viable and surviving ova which are expected, so also will ewe management during this time depend on the reproductive objectives.

It is by no means certain whether maximum efficiency in terms of animal recovery is the same as maximum efficiency of pasture utilisation in our temperate zone climate. For example, we do not know whether the resting of good quality pastures after weaning, followed by their utilisation during the immediate pre-mating period is a more efficient animal treatment than is a rapid improvement in body condition immediately post-weaning, followed by maintenance nutrition. However, as our results do suggest that high body condition is the important requirement for high ovulation rate, irrespective of how it has been achieved, it can be argued that this may be more easily achieved on good-quality pasture in mid-summer than on the same pasture in the autumn when it will be of lower quality and when weather conditions may impose additional limitations.

Having once achieved an adequate level of condition at mating for optimal incidence of multiple ovulations, there are further advantages to be derived. Our evidence suggests that barrenness is more likely to result from single ovulations, so with higher condition there is less barrenness. Our evidence also suggests that wastage is influenced by pre-mating body condition to a similar extent in both single and twin ovulating ewes, which means that higher condition results not only in more twins but also in less wastage, although work in other centres suggests that there are circumstances in which wastage of twin ovulations is greater.

Finally, if a large majority of ewes do carry twins, and not too many carry singles or triplets, late pregnancy nutritional requirements can be more efficiently standardised. Therefore a ewe population which has a genetic maximum fecundity of two ova per ewe and little variability round this, is extremely suitable for any hill farming enterprise which aims at a system of intensifying lamb production.

Most of the critical work of the Organisation in the study of reproductive rate has been carried out on the Scottish Blackface breed. While it is assumed that the principles established with this breed will apply in relation to other breeds, although perhaps differing in degree or extent, this has yet to be tested. Nevertheless, field observations do suggest that in general the higher the body condition of ewes at mating the more lambs the farmer is likely to get, irrespective of breed.

4. FACTORS INFLUENCING LACTATION OF HILL EWES

J. N. PEART

CHANGES in the relative values of sheep products from the hill pastures of Britain attach increasing economic importance to lamb production and lamb growth. Though considerable variation occurred between years, mean values taken from the Organisation's farms

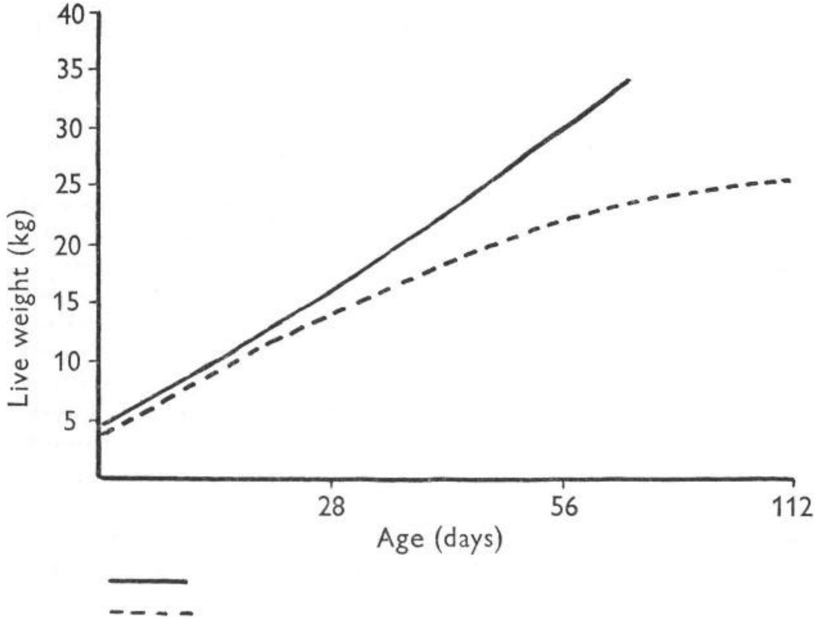

FIG. 1.—Growth rate of single-suckled hill lambs.
——— Reared *ad lib* feeding (concentrate) - - - - - - Reared on hill pasture.

show that the growth rate of single born lambs reared on hill pasture is 230 g/day from birth to about 6 weeks of age, declining to 110 g/day at about 14 weeks. In contrast, intensively reared hill Blackface and Cheviot lambs have gained 325 g/day from 0 to 4 weeks of age and 400 g/day from 4 to 12 weeks. These growth curves are compared in Figure 1, from which it is apparent that the rate of live-weight gain of the intensively reared lambs was almost double that of comparable hill-reared lambs. It is clear that lambs from our hill flocks have a growth potential which is rarely, if ever, attained in normal practice.

Supplementary feeding of hill ewes in late pregnancy had previously shown responses, if they occurred, in terms of increased number of lambs reared rather than in increased lamb growth (Robinson *et al.*, 1961). Other work suggested that nutrition of the ewe in early lactation was of greater importance to lamb growth (Munro, 1962). Further evidence on this point was obtained from a feeding trial of hill ewes in late pregnancy and early lactation. The results suggested that a substantial improvement in nutrition, sufficient to increase live weight by 13 kg in the last 6 weeks of pregnancy, had no effect on the milk production of ewes with single lambs when returned to hill pasture after lambing (Peart, 1967*a*).

A field study involving controlled grazing and increased sheep stocking rate of hill pastures has demonstrated a linear relationship between increased sheep numbers and sheep production per acre, but the effect on lamb growth rates was insignificant (Peart, 1970*a*). The importance of milk to lamb growth in early life is well recognised and it is clear that severe limitations to lamb growth on hill pastures are imposed through inadequate milk production by their dams. Despite this, there has been a lack of scientific investigation into factors influencing milk production of hill ewes which is necessary for an understanding of the conditions which encourage or retard lamb growth. However, the disadvantage of experimentation of this sort under hill conditions is the forced acceptance of uncontrollable conditions which may prevail or change during an experiment. This may lead to difficulties of data interpretation resulting in wrong conclusions. Therefore, more precise answers have been sought from experiments carried out under controlled nutritional conditions in which the level of nutrition of ewes can be described in terms of the response of the ewe herself and also in terms of food intake. Data from such experiments can be more easily related to field conditions. Such reasoning has given rise to a series of experiments specifically designed to study factors which influence milk production of hill ewes and to measure responses or limitations resulting from experimental treatments. All ewes used in each of these experiments were selected from the same parent flock of Blackface ewes and were either 4½ or 5½ years old (fourth or fifth lamb crop). Approximately 36 ewes were milk recorded in each experiment providing, according to experiment, three or four treatment groups of similar numbers. During the last 10-12 weeks of pregnancy and throughout lactation all ewes were placed in individual pens and individually fed. From about 4 weeks of age the lambs were separated from the ewes, placed in individual pens, and given access to their dams for suckling at frequent intervals each day. Milk production of the ewes was recorded over a 24-hour period once per week using the lamb suckling technique. In each experiment the ewes and lambs were fed a pelleted food consisting of dried grass 66 per cent., maize meal 18 per cent., soya bean meal 10 per cent., molasses 5 per cent., with vitamin and mineral additives. The food contained 66 g digestible organic matter (DOM) per 100 g as determined both *in vitro* and *in vivo*. In experiments where food rationing was imposed, the feeding standards adopted were: 9·2 g DOM/kg for body maintenance and 0·5 g DOM/g of milk production.

The first experiment was concerned with the effect of different levels of nutrition in late pregnancy on subsequent milk production when ewes were adequately fed after parturition. Also, to establish the potential for milk production of Blackface ewes when adequately fed in both late pregnancy and lactation. In this experiment, the food intakes of two groups of ewes were adjusted at intervals during late pregnancy to maintain in terms of plasma-free fatty acids (FFA) and ketone levels, two degrees of undernourishment. One level of undernourishment (M group) was similar to that encountered by hill ewes bearing single lambs. The other was a low level of nutrition (L group) producing undernourishment as severe as that of hill ewes carrying twin lambs. A third group (H group) were individually fed to prevent undernourishment in late pregnancy. A further criterion was that moderate undernourishment depressed lamb birth weights by 10 per cent.; severe undernourishment caused a reduction of 25 per cent.

Mean lactation curves are shown in Figure 2. During the entire lactation there was little difference in milk production between groups of ewes with single lambs; they all reached a similar peak (2·0 kg) at the fourth week then declined to approximately 0·65 kg in week 10. The ewes with twins from the H and M groups had similar milk yields throughout, but although the L group equalled the peak production of 3·0 kg at the third week, their production before and after this time was lower than that of the other groups. However, this difference was not significant. From birth to 5 weeks of age the H- and M-group twin lambs made similar live-weight gains which were non-significantly greater than that of the L-group twins. During the 6-12 week period the H-group twins grew as rapidly as the H-group single lambs and by 12 weeks of age their average live weight significantly exceeded that of the L-group twin lambs.

No appreciable weight loss occurred in ewes, and from the second lactation week all groups made similar live-weight gains, and the weight differential at parturition was maintained after 12 weeks of lactation.

The data suggested that total milk yield and shape of lactation curve is considerably influenced by the appetite of lambs for milk.

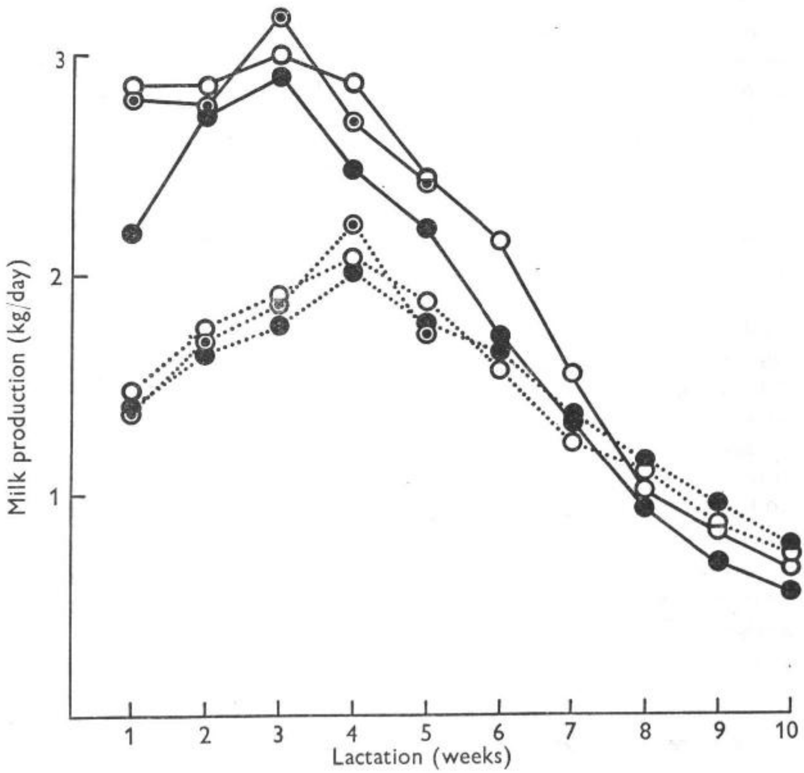

FIG. 2

○——○, H twins ⊙——⊙, M twins ●——●, L twins
○. . . .○, H singles ⊙. . . .⊙, M singles ●. . . .●, L singles

The rapid decline in milk intake and corresponding rise in intake of solid food by lambs show that in some nutritional situations lambs could be in competition with their dams for food at a very early age.

The evidence indicated that, providing nutrition during lactation was not limiting, severe undernourishment in late pregnancy had only a marginal effect on subsequent milk production. However, small twin lambs born as a result of undernutrition of ewes in late pregnancy were unable to maintain growth rates equal to those of lambs with high birth weights. It is possible, therefore, that a principal effect of severe undernourishment during late pregnancy may be to inhibit the growth potential of the lamb and the effect on actual milk production by the ewe is a result of an inability of the small lamb to exploit the milking potential of the ewe.

The data in Figure 1 suggests that the inadequacies of hill pasture for lamb growth are expressed in the second half of the growth period to weaning. However, the first experiment showed that an adequate intake of high-quality solid food could compensate for a lower intake of milk by twin lambs (i.e. per lamb). A second experiment sought further information on the relative importance of milk and solid food in lamb nutrition, particularly the degree to which an increased intake of solid food could compensate for lower levels of milk intake.

During the mid-pregnancy period ewes in good body condition were fed to maintain live weight. About 4 weeks before parturition the ewes were fed *ad libitum*. During the last 4 weeks of pregnancy the mean daily intake of ewes producing single lambs was 30 g DOM/kg and that of twin-bearing ewes was 27 g DOM/kg. Water intakes increased from 2 to 3 litres/day at 6 weeks pre-partum to 5 to 6 litres/day at parturition. *Ad libitum* feeding of all ewes was continued during the first 4 weeks of lactation and the lambs were offered solid food from about 2 weeks of age.

The data recorded between mid-pregnancy and 4 weeks post-partum were used at the latter time to select three similar groups of single-suckled ewes. Experimental treatments were then applied as follows:

Group 1. Ewes and lambs continued to be fed *ad libitum* throughout.

Group 2. Ewes fed *ad lib* throughout. Lambs offered about one-third the quantity of solid food being consumed by group 1 lambs.

Group 3. Food intake of ewes restricted to 9·2 g DOM/kg based on mid-pregnancy weights. Lambs fed *ad lib* throughout.

The lambs were separated from their dams and placed in individual pens but allowed access to their dams for suckling at regular intervals each day. Milk recording was continued at weekly intervals until the tenth lactation week. By this time the yields of group 3 had declined to a point when the accuracy of further measurements of milk intake by lambs was doubtful. A final milk recording of groups 1 and 2 was made in week 12. Immediately following the final lamb suckling of each weekly recording during the 4-10 week period, three ewes from each group were injected with Purified Oxytocin Principle and residual milk extracted by hand.

The mean lactation curves of ewes are shown in Figure 3. The mean yields and shapes of lactation curves of ewes of groups 1 and 2 were almost identical until the eighth week, but during the 8 to 12 week period milk production of the ewes of group 2 was 6·17 kg

TABLE 1

Mean live weights of lambs at birth and at 12 weeks of age, and their mean daily live-weight gain

	Group		
	1	2	3
Birth weight (kg)	4·7	4·9	4·7
Daily live-weight gain (g)			
0-4 weeks	308	302	316
5-12 weeks	382	230	327
Weight at 12 weeks (kg)	34	26	31

greater than that of ewes in group 1. The data suggested that this difference was due to a reduced intake of milk by the lambs suckling ewes of group 1 during the weaning process. The effect on milk production of reducing the food intake of group 3 ewes was immediate and dramatic. After 3 days their mean daily yield declined from 1·75 kg to 1·15 kg, and to 0·85 kg after 7 days. By lactation week 10 the yield had declined to 0·23 kg/day.

All groups of ewes made similar live-weight gains in early lactation and after 4 weeks each group had attained a mean value of approximately 60 kg. Groups 1 and 2 continued to gain weight and in week 12 their respective mean live weights were 67 and 65 kg. The mean live weight of group 3 ewes declined rapidly after week 4, reaching a minimum value of 41·5 kg. The mean daily intake of dry matter by ewes of all groups reached a maximum value of about 2·9 kg/ewe in lactation week 3 and declined to around 2·6 kg in week 4. Food intake of ewes of groups 1 and 2 were almost identical throughout.

The mean live weight of lambs at birth and at 12 weeks of age are given in Table 1. From 4 to 12 weeks of age the lambs in the three groups made live-weight gains at different rates and during this period the average daily gains by lambs of groups 1 and 3 were each significantly greater than that of group 2 lambs, and the daily gain of group 1 lambs was significantly greater than that of group 3 lambs. During lactation week 5 the mean intakes of solid food DM

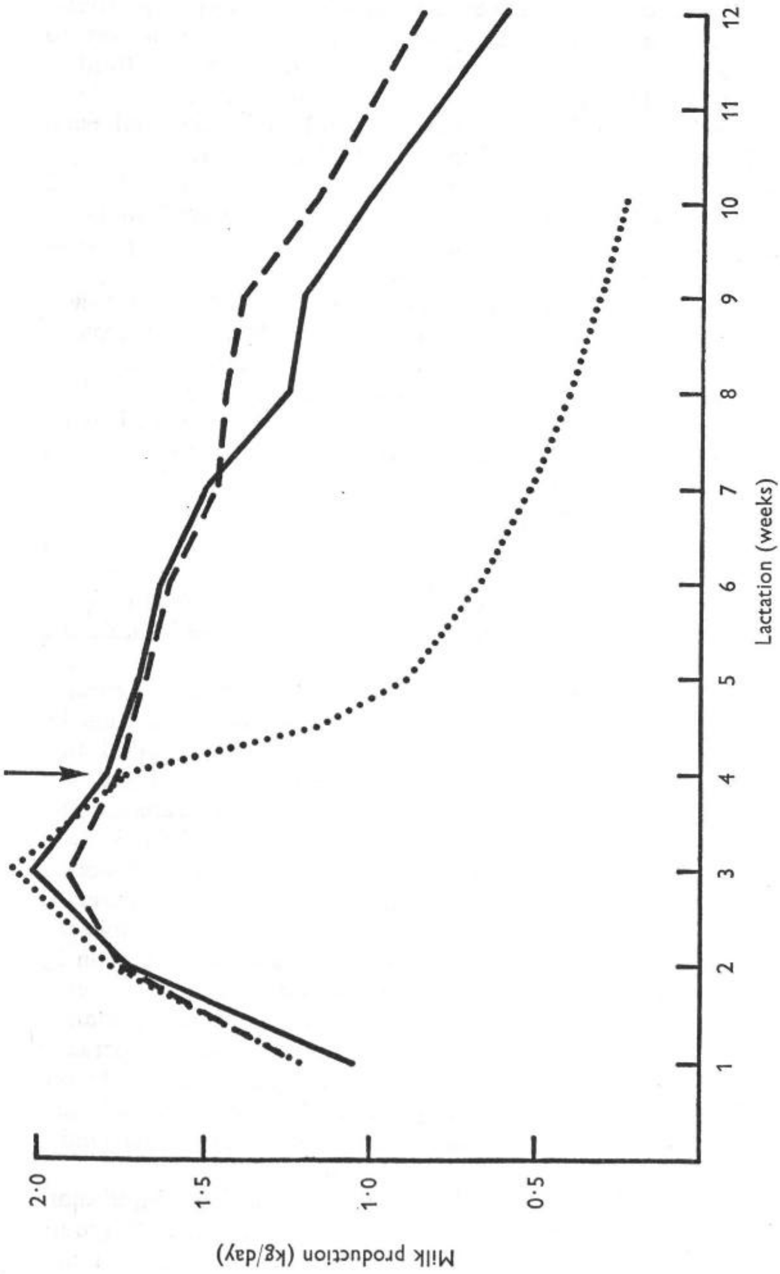

FIG. 3.—Mean lactation curves.

—— group I   - - - - - - group II   . . . . . . group III by lambs of groups 1 and 2 were 2·1 and 1·6 g DOM/kg respectively. Thereafter, the mean voluntary intake of group 1 lambs rose to 27 g DOM/kg while group 2 lambs were restricted to one-third of this amount. The reduced intake of milk by group 3 lambs was immediately reflected in an increased intake of solid food from 7·5 g DOM/kg during week 5 to 36 g DOM/kg in week 12.

The difference in milk production between ewes of groups 1 and 2 in the 8-12 week period was probably due to a reduced intake of milk by the lambs of group 1 during the normal weaning process. It follows, therefore, that the additional removal of milk by the lambs of group 2 resulted in a more sustained lactation by their dams. The main response to the removal of milk by lambs in group 2 occurred during lactation week 8. This established a consistently higher level of milk production for the remainder of lactation. The restriction of food intake to the ewes in group 3 resulted in an immediate and dramatic reduction of milk production. Although these ewes drew on body reserves for milk production, this process clearly could not sustain yields.

The increasing amounts of residual milk which were obtained from ewes in group 1, compared with decreasing amounts obtained from ewes in group 2 provided further evidence that the lambs suckling ewes in group 2 were consuming more of the available milk during the later stages of lactation.

The significantly greater average live-weight gain made by group 1 lambs showed that the reduced intake of solid food and milk by lambs of groups 2 and 3 respectively, restricted lamb growth during the 4-12 week period. Nevertheless, the growth rate of group 3 lambs was high compared with that of similar lambs reared on hill pasture. In groups 1 and 3 the correlations of daily milk intake with daily live-weight gains of lambs were mainly negative from week 6 onwards, but within group 2 the correlations were positive, increased and remained high until week 10. These observations emphasise the importance for lamb growth of a sustained milk production by hill ewes on hill pastures, but also indicate that milk production in more favourable nutritional situations would be of less importance, particularly during late lactation. Very high correlations between solid food dry-matter intake and live weight of group 3 lambs showed that the heaviest and, presumably, better developed lambs in this group were able to consume more solid food than smaller lambs, and this was associated with greater live-weight gain.

During the 4-12 week period the ewes in group 2 produced more milk but gained less live weight than those in group 1. Both groups had almost identical intakes of DOM/kg, showing that the voluntary intake of group 2 ewes did not increase to meet the demands of a higher level of milk production. It is possible, therefore, that the lower live-weight gain of the ewes in group 2 was a consequence of their higher milk production.

The first experiment confirmed the conclusions of Barnicoat *et al.* (1949) that nutrition during lactation is the primary factor influencing milk production of ewes, though maximum production is dependent on adequate nutrition in both late pregnancy and lactation. Most published data show a reduction in ewe live weight in early lactation, but Peart (1967*b*, 1968*a*) has shown that weight loss need not occur in Blackface ewes if nutrient intake is sufficiently high. However, all data relating to live-weight changes in ewes during early lactation are confounded by increased appetite following parturition and consequent increase in gut-fill, and also by the body condition of ewes in relation to nutrient intake. In a hill environment ewes are vulnerable to factors which may reduce nutrient intake and it has been demonstrated that substantial decreases in live weight and milk production occur when nutrient intake is restricted (Peart, 1968*a*). A third experiment was undertaken to assess the effect of different levels of nutrition during lactation on the milk production of similar groups of ewes between which substantial differences in body condition and live weight had been created during mid-pregnancy and maintained until parturition.

At approximately 15 weeks before parturition, different nutritional treatments were imposed on three similar groups of ewes to increase the live weight and body condition of all ewes in groups A and B to a score of 3-4 (fat) and to decrease the body condition of group C ewes to 1 (very lean). The body condition scores were based on standards suggested by Jefferies (1961). From approximately 6 weeks pre-partum, food was rationed to the ewes in quantities based on the food requirements of Blackface ewes in late pregnancy as determined by Russel *et al.* (1967). All ewes were rationed on the assumption that they were twin-bearing. Checks on the nutritional state of individual ewes were made during late pregnancy and early lactation by the determination of the plasma-free fatty acid level of blood samples.

Immediately after parturition and throughout lactation food was rationed to the ewes according to their individual post-partum live weights. The ration scale was adjusted to meet the requirements for milk production predicted from lactation curves for Blackface ewes established by Peart (1967*b*, 1968*a*). After 2 weeks of lactation the food ration was maintained at a constant level for the remainder of lactation. Ewes in groups A and C were fed the full requirement for body maintenance and milk production and group B were fed the full requirement for body maintenance plus half the requirement for milk production. The food ration scale is given in Table 2 and

TABLE 2

Food ration scale during lactation. (g DOM/kg based on post-partum live weights)

Group	Lactation weeks		
	1	2	3-10
At, Ct	27·4	31·4	36·0
Bt	18·4	20·6	22·6
As, Cs	21·4	26·6	29·4
Bs	15·4	18·0	20·0

from lactation week 3 the mean daily food offerings to ewes in groups A, B and C with twins (t) were respectively 2098, 1283 and 1782 g DOM per ewe, and to ewes in groups A, B and C with singles (s) were 1665, 1143 and 1410 g DOM per ewe respectively.

TABLE 3

Mean total milk production of ewes (kg)

Group	Lactation weeks		
	0-5	6-10	0-10
At	81	45	126
Bt	69	39	108
Ct	90	52	142
As	60	43	103
Bs	49	32	81
Cs	57	35	92
Means compared			
Bt-Ct	**	n.s.	*

** = $P < 0{\cdot}01$, * = $P < 0{\cdot}05$

Differences between means of other comparable groups were not statistically significant.

The shape of lactation curves and values recorded from A and C groups of ewes which were fed full theoretical nutritional requirements, were almost identical with predicted values. Milk production of group B ewes was appreciably lower and they had flatter lactation curves than those of the other groups but the difference was statistically significant only between groups Bt and Ct. Total milk production during the 10-week lactation period is given in Table 3.

The levels of nutrition imposed during the 15-16 week pre-partum period increased the live weight and body condition scores of groups At and Bt to similar mean values of approximately 59 kg and 3·1 respectively, and that of groups As and Bs to approximately 55 kg and 3·2. During the same period the corresponding values of group Ct were reduced to 47 kg and 1·2 and that of Cs to 44 kg and 1·5. All groups of ewes made substantial live-weight gains during late pregnancy (10-14 kg) and the weight differentials which had been created at 6 weeks' pre-partum were retained at parturition.

Except for group As, which maintained live weight in lactation week 1 then increased, the mean live weight of all groups of ewes declined in early lactation. Thereafter, the weight changes of all groups varied and consistent live-weight gains were not made until late lactation. Changes in mean body condition scores followed similar trends to changes in ewe live weights during lactation.

Regardless of the level of nutrition or total milk production from 0 to 10 weeks, the percentage of the total yield produced during the 0-5 week period was identical in groups of ewes suckling twin lambs and almost identical in groups suckling single lambs. Similar ratios were obtained in a previous experiment. These data and shape of lactation curves indicate that the total milk production of an entire lactation is greatly influenced by the level of milk production attained in early lactation.

Though mean daily intake of DOM/kg and mean milk production were similar, the mean total daily food intake of ewes in groups Ct and Cs was 18 per cent. less than that of groups At and As. The evidence indicates that ewes in lean body condition have a higher efficiency of food conversion to milk. However, this does not preclude the possibility that, following a short period of undernutrition in early lactation, reserves of body condition may influence the subsequent ability of ewes to attain normal levels of milk production.

In the hill areas of Britain the regrowth of vegetation in spring normally provides a diet of improving quality to ewes in early lactation. However, in some years the regrowth is delayed and this and other factors may reduce the nutrient intake of lactating ewes. Previous experiments (Peart, 1968*a*, 1968*b*) had shown that milk production is substantially reduced when nutrient intake is restricted and also that the total milk production of ewes is greatly influenced by the level of production attained in early lactation. Therefore, experiments were undertaken to provide information on the effect of body reserves on the recovery of lactation by ewes which had been undernourished in early lactation and to indicate if the duration of the period of undernourishment has a significant effect.

In each of two years, Blackface ewes were brought to a high state of body condition at mating and in early gestation. At approximately 16 weeks pre-partum the ewes were divided into two similar groups and fed to maintain the live weight and body condition of one group (fat) and to decrease that of the other group (lean). At 8 weeks' pre-partum mean differences of 14 kg live weight and 2 scores of body condition had been created between groups. During the last 6 weeks of pregnancy food was rationed to all ewes per unit of live weight to provide the theoretical requirements in late pregnancy. Both groups made similar live-weight gains in late pregnancy and blood plasma F.F.A. values confirmed that the ewes had been similarly nourished regardless of live weight or body condition. In early lactation food was restricted to fat and lean groups of ewes for either a 2- or 4-week period followed by *ad libitum* feeding for the remainder of lactation. During the period of restricted feeding, food was rationed to the ewes according to their post-partum live weights corrected to a body condition score of 1.

In the first and second week of lactation the mean daily milk production of groups of both fat and lean ewes was approximately 2·1 and 1·3 kg for twin- and single-suckled ewes respectively. *Ad libitum* feeding following restricted feeding during the first 2 weeks of lactation resulted in increased milk production of both fat and lean ewes to mean maximum values of approximately 2·7 and 1·7 kg/day for twin- and single-suckled ewes. In contrast, groups of ewes which had restricted feeding for the first 4 weeks of lactation showed almost no increase in milk production when fed *ad libitum*. During the extended period of restricted feeding the milk production of twin-suckled ewes which were fat at parturition was significantly greater than that of twin-suckled lean ewes but there was little difference with single-suckled ewes. The data of milk production are illustrated in Figure 4.

All groups of ewes lost similar amounts of live weight and body condition during their respective periods of restricted feeding. In the respective 6-week periods following *ad libitum* feeding the live-weight gain of the lean ewes was significantly greater than that of the fat ewes, but they did not attain parity of live weight by the end of lactation. During their respective periods of feeding *ad libitum* the mean food intake of all groups attained similar maximum values of 2200 g DOM/day.

The results of this experiment show clearly that the stage of lactation is an overriding factor governing the response, in terms of milk production, to increased nutrition and that reserves of body condition at parturition can act as a buffer between nutrient intake

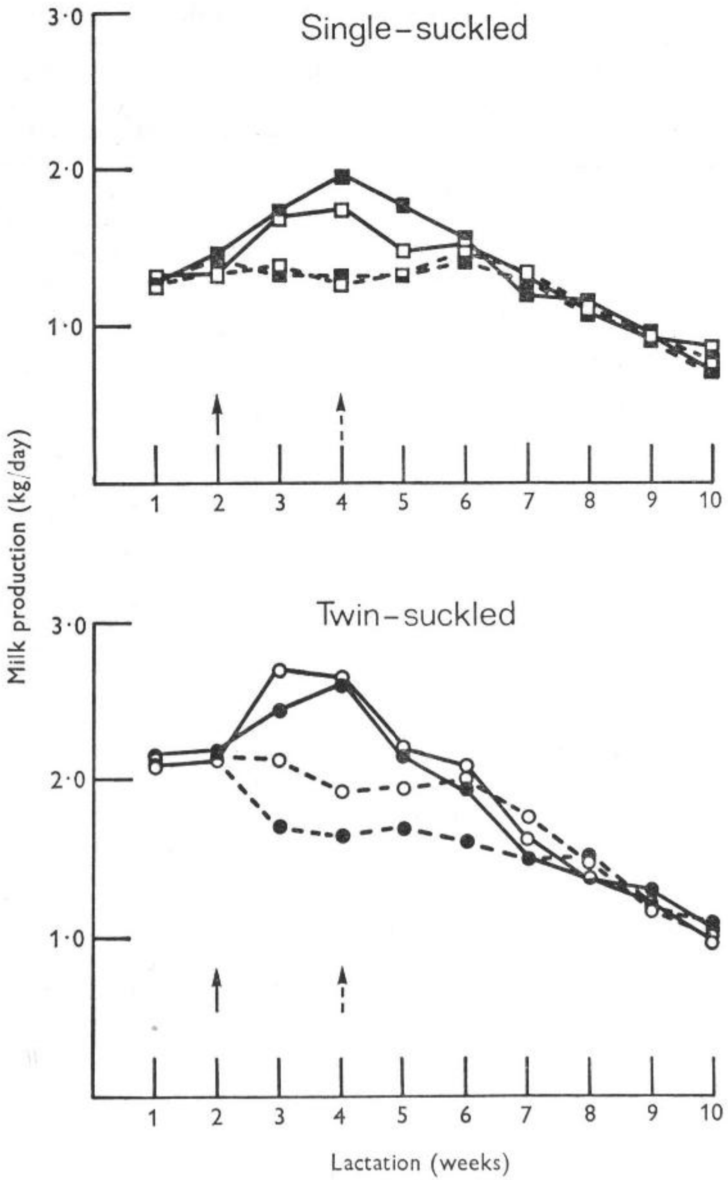

FIG. 4.—Mean lactation curves of ewes.

FAt, ○——○ FBt, ○------○ LAt, ●——●
LBt, ●------● FAs, □——□ FBs, □------□
LAs, ■——■ LBs, ■------■

and nutrient requirements for lactation. From this experiment it is impossible to state precisely at what stage of lactation increased nutrition is reflected in increased milk production. However, the results suggest that Blackface ewes will respond if adequately nourished at a point in time before they would have attained normal maximum milk yield, but improved nutrition at a later stage does not result in significant increases.

The similarity of milk yields and of live-weight change when food was rationed during lactation weeks 1 and 2, suggest that the rate of conversion of body reserves to milk production is more critical than the total amount of reserves available during this period. However, when restricted feeding was extended into the third and fourth weeks of lactation, fat ewes suckling twin lambs were able to maintain substantially greater milk production than lean ewes with twins. Evidence from this and other experiments suggest that when body reserves of ewes have been severely depleted, factors other than nutrient intake may become limiting to milk production.

The growth rates of single lambs were very nearly equal throughout regardless of feeding treatment, body condition of their dams or differences in milk intake during lactation weeks 3-5. The equality of mean intake of milk by all groups of twin lambs was reflected in similar growth rates during weeks 0-2. However, the subsequent growth rates of twin lambs suckling fat ewes were all greater than those suckling lean ewes; some of these differences were highly significant. As in the case of single lambs, groups of twin lambs receiving lower intakes of milk consumed greater quantities of solid food, but this did not fully compensate for the reduced milk intake. The failure of the twin lambs suckling lean ewes to maintain growth rates similar to those suckling fat ewes may also be associated with their lower birth weights. Similar observations were made from data obtained in a previous study (Peart, 1967*b*).

These lactation studies have been confined mainly to the Blackface breed because they greatly outnumber other hill breeds in Britain. However, limited studies with North and South Country Cheviot hill breeds (Peart, unpublished) indicate that their milk production and shape of lactation curves are similar to those of the Blackface breed. It is well known that differences do occur between breeds and, therefore, the response of Cheviots to treatments similar to those imposed in this series of experiments may not be the same.

The use of exotic breeds and crosses of sheep as a means of increasing production is of current interest. In this respect the Finnish Landrace × Blackface cross has been suggested as an alternative to native breeds in certain hill situations. Information under conditions where nutrition is not limiting is being currently obtained on the milking capacity and milk quality of these ewes, particularly in relation to their ability to produce múltiple births. A preliminary examination of the data shows that ewes suckling three or four lambs attain very high milk yields early in lactation which then decline rapidly. Ewes of this cross suckling twin or single lambs have similar maximum milk yields to Blackface ewes, but thereafter their milk production is more sustained resulting in flatter lactation curves and consequent greater total milk production.

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5. HILL SHEEP PRODUCTION SYSTEMS DEVELOPMENT

JOHN EADIE

Introduction

A recent and significant development in the Organisation's research programme has been the initiation of a systems synthesis programme.

The function of the Organisation is to conduct research on hill soils, plants, animals and their interactions which will lead to the development of improved systems of sheep production from hill pastoral resources. That this requires an analytical approach to the various problems to elucidate mechanisms and processes is readily and widely understood. What is perhaps less readily appreciated is the need for a periodic synthesis of the available knowledge, and it is the purpose of this paper to discuss the background to and the nature of this work in the Organisation.

The first part of the paper summarises the biological and economic issues which lie behind the system's development programme, and the second part of the paper outlines an approach to some of the problems to be faced in translating the conception to the reality.

I. The Biological and Economic Background

The Biological Issues

Hill sheep production systems are pastoral systems in which pasture production is converted to saleable sheep products. Even at their most intensive they are low output systems of animal production producing in the region of 3-30 lb weaned lamb live weight per acre.

The low output is a function of low stocking rates and poor levels of individual sheep performance. Some 65 per cent. of the hill sheep in Scotland are grazed at intensities between an acre to two, and an acre to five sheep.

Weaning percentages range from under 60 to over 100 per cent., and weaning weights of lambs at around 16 weeks of age may range from under 40 to over 60 lb.

(i) **Pasture Production and Utilisation.** The basis of production is hill pasture growth and the issues relating to the significance of the comparatively low productivity of hill pastures and the efficiency with which it is converted to saleable product have been dealt with at length elsewhere (Eadie, 1970 and Eadie and Cunningham, 1969) and will be briefly summarised here.

A comparative examination of hill and lowland pastoral sheep production systems in the U.K. shows that, in addition to the fact that hill pasture production is poor by lowland standards, being of the order of 20-30 per cent. of that of reasonably well fertilised lowland pasture, the pasture production is also very poorly utilised by lowland standards. The efficiency with which the pasture production is ingested by the sheep population is often only 20-30 per cent. of that of lowland sheep production systems, and the ingested dry matter is converted to weaned lamb live weight at about half the efficiency of that which takes place in lowland systems.

In understanding why this should be so there are two major facts of significance. The first is that hill pasture production is highly seasonal; there is no pasture growth at all for roughly 6 months of the year—in fact the fund of available herbage is declining during this period due to the processes of plant senescence—and during the growing season itself the daily increment of growth varies very considerably.

The second important fact is that against this background of highly seasonal pasture production a set-stocked year-long grazing system operates. Stocking rates are set at levels which will ensure a certain minimum level of winter nutrition from grazed pasture. The fund of material from which this must be provided contains a large proportion (on those we have measured up to 80 per cent.) of very poor quality dead herbage, so that the fund itself is poorly utilised.

Stocking rates set in this way are consequently very low with respect to levels of pasture production during the summer. Ungrazed herbage accumulates, its nutritive value declines and the fund of material conserved *in situ*, so to speak, already, at the beginning of winter contains a substantial amount of poor quality material. This limits the extent to which it can be utilised consistent with the required levels of nutrition and so the vicious circle goes on. It might be thought that the low grazing pressures in summer consequent upon this process would lead to a really good quality diet at that time because of the high degree of selection opportunity offered the sheep. This, however, is not so because diet selection in early summer is from a fund of material which contains a good deal of poor-quality herbage carried over from the previous season. So that the whole process results not only in poor pasture utilisation but also poor year-round nutrition.

All of this is in marked contrast to events in lowland sheep production systems, in which stocking rates are held at levels which relate much more closely to summer pasture production. This is so because surplus summer production is cut, conserved and fed back in winter, in itself a much more efficient process than conservation of uneaten herbage *in situ*, and having the advantage that the surplus is removed and not left to deteriorate and reduce the grazing pressures at which satisfactory nutrition can be obtained at a future grazing.

The conclusion is that many of the deficiencies of hill sheep production systems are a consequence of the management system. It is salutary to consider what would happen to a lowland pasture if it were managed in the fashion of hill grazings.

(ii) **Nutrition and Sheep Performance.** The processes described above inevitably lead to a cyclical pattern of nutrition. Such a cycle has been described (Eadie, 1967). Its major feature is its overall poverty, which gives rise to a cycle of bodyweight change in the sheep in which body condition is substantially poorer than that consistent with good performance.

The available evidence on the annual cycle of nutrition in the hills, animal performance and its components under hill conditions, together with evidence on relations between nutrition and sheep performance, shows clearly that at each and every stage in the annual cycle of events nutrition on the hills is a limiting factor to some aspect or other of sheep performance.

Nutrition during lactation on most hill grazings is too poor to support reasonable growth rates of twin lambs and the growth rates of single lambs are well below those of which hill lambs are capable. Growth rates decline from marking at 5-6 weeks of age, and this is a function of declining ingested pasture quality.

In existing systems mating takes place at a time of sub-maintenance and declining nutrition in sheep which are, at best, in moderate body condition. Reproductive performance is, to an important extent, a function of nutrition and body condition at mating, and post-lactation body condition recuperation is limited in consequence of the decline in ingested pasture quality during the recovery period.

Winter nutrition is poor, but present evidence is that this need not be inconsistent with good performance provided body reserves are adequate. The fact that they are inadequate is a function of poor summer and autumn nutrition.

Nutrition in late pregnancy in most hill environments in some years, and in some hill environments every year, depresses birth weights and lamb vigour to the point of significantly affecting lamb survival. There is little doubt that pre-partum supplementation will improve lamb vigour and survivability in most hill environments, and in the poorer environments in some years, lead to improved weaning weights.

For really significant improvements in sheep performance an overall improvement in nutrition is required and the periods of lactation and the recovery phase are of special importance.

Summary. Poor primary production undoubtedly limits sheep product output on the hills, but this is by no means the only problem. Existing stocking rates, and existing sheep performance, are limited to an important extent by the nature and consequences of existing year-round, free range, set-stocked, systems of hill grazing management.

The problem is therefore basically a pastoral problem and solutions which merely deal with peripheral issues, as have most proposed innovations in hill sheep farming to date, and which fail to deal with the pastoral problem, will be of limited value.

The Economic Issues

The purpose of this section of the paper is twofold. First it is to outline the nature of the current economic problems of hill farming. Second, since biological and economic efficiencies are not necessarily coincident in animal production, it is to discuss the economic framework within which the various biological possibilities which emerge from the analysis made in the previous section of the paper must be constrained in the development of relevant improved production systems.

Hill sheep production is a low output system of animal production. For many decades the low output was matched by a correspondingly low cost structure. But, in recent years, costs have increased greatly and lamb is now valued at only some 80 per cent. of the value of manufactured goods and about half as much urban labour as in the mid-1950s (Raeburn, 1969). This is reflected in the prices of store lambs and cast ewes from hill farms. For example, Duthie (1967) found that, in the decade 1956-7 to 1966-7 in the East of Scotland, the average selling price of both these classes of stock hardly changed and, despite the changes in the value of the £ which took place over the period, net profit per farm remained static whilst government support rose from around 60-70 per cent. to some 130-190 per cent. of the net profit.

A major and distinctive feature of the cost structure of hill sheep farming is the high proportion which labour costs contribute to the total; these often amount to between 30 and 40 per cent. of the costs of production and labour costs may, in the future, follow a greater inflationary trend throughout agriculture and industry.

The implication is that existing levels of output will not indefinitely sustain the increasing cost structure of hill farming.

One approach is to cut costs. To be meaningful this would have to include labour costs. But hill sheep farming is an industry of one-, two- and three-man units where disposing of the services of one man would seriously reduce the labour force, which is almost certain to reduce output significantly. The net result may be worth while in some instances in the short term, but such a policy would do little to solve the long-term problem.

A much more satisfactory approach is to attempt to create a production framework within which unit costs would be reduced to a meaningful degree and, equally important, one within which there would be opportunities, extending well into the future, of reacting to economic change and technical advance. This, in effect, means attempting to establish a production framework which will make possible, in the longer if not in the short term, substantial increases in output.

On the basis of the argument advanced earlier in this paper these possibilities do not exist to the necessary extent in existing hill pastoral systems.

Any 'improved' system will have to be both biologically and economically sound, and a means of examining the technical possibilities for their economic implications is necessary. Such a procedure would, on the one hand, aid the identification of those technical possibilities which appear to have most to offer and, on the other hand, would help to set the context within which it might be worth while to examine others.

The various technical possibilities all require capital investment and, to a varying extent, such capital investment will bring in its train increases in variable costs. It is therefore contended that an appropriate means of assessment in many cases is that of assessing the return to the marginal capital investment, provided the limitations, the chief of which is that the results of marginal capital investment are examined without reference to the present viability of the enterprise, are understood. Harkins (1968) has produced a comparatively simple procedure, based on a break-even budget technique, which enables the calculation of the increase in output, in terms of the various possible combinations of stocking rate increase and sheep performance improvement it is necessary to promote, in order to break even on various levels of capital investment.

By this means it is possible to assess what has to be done to recoup various levels of investment and variable cost increases for any set of existing performance figures, variable costs and prices.

Two general points of interest can be made.

The first is that it is commonly supposed that very substantial increases in output must be necessary to justify even quite moderate capital investments. This is not so. For example a £2000 investment in a flock of 500 ewes can be recouped, writing off the investment over 10 years and charging 10 per cent. interest in the investment, by a 10 per cent. increase in flock size and a 10 per cent. increase in weaning percentage.

The second point is to highlight the importance of increases in variable costs. Quite often capital investments will bring in their train increases in variable costs such as feeding costs. In general terms a 10s. per head increase in variable costs would require a 12 per cent. increase in per head performance, i.e. about the same as a £1200-£1500 investment in a 500-ewe flock. Increases in variable costs have to be very carefully watched.

II. The Improvement of Output

It is now appropriate to consider the processes by which sheep output from hill grazings may be improved. From the analysis made earlier in this paper one can deduce three lines of approach:

(*a*) pasture production may be increased on at least a part of the resource;

(*b*) existing pasture production can be more efficiently utilised; this implies grazing control over at least a part of the resource; and

(*c*) the problems may be short-circuited in that a departure from more or less complete pasture dependence in winter would remove one of the root-causes of the problem.

These are not mutually exclusive solutions but the issues raised and the conceptions which arise from them can be more conveniently discussed by drawing a distinction between those solutions involving offwintering (*c*) and those in which offwintering plays no part.

(*a*) **Year-round Grazing Systems.** The major impediment to easy generalisation about the role of (*a*) and (*b*) in improving hill sheep production derives from the fact that the spectrum of variation in existing hill vegetation and soils is very great, ranging as it does from the Agrostis-festuca grasslands, through the Nardus and Molinia dominant grass heaths and heather (*Calluna vulgaris*) moors, to the heather-cottongrass vegetation of blanket bog.

Briefly, experiments have shown that the better grassy pastures, the Agrostis festuca swards, will produce better nutrition and can be utilised more efficiently simply as a consequence of grazing control. Other inputs, such as lime and slag, would give rise to a greater degree of improvement, and further improvement still would follow the introduction of clovers and perhaps grasses. Technically then, on Agrostis-festuca grassland there is a wide range of improvement possibilities from the comparatively cheap one of enclosure to the comparatively expensive one of re-seeding.

On the poorer types of grassy pasture, e.g. certain types of Nardus and Molinia dominant pasture, grazing control alone will produce an improvement, but this involves botanical change. The improvement will be slow, probably too slow for practical purposes. But the pace of change will be enhanced by liming, and there is no need to stop there since environmental conditions usually permit of all the possibilities, right up to re-seeding.

By way of contrast, right at the poorest extreme, on blanket bog for example, it is not possible to improve utilisation to any marked extent because the nutritional penalty to the sheep would be too high. In this case soils improvement by lime and phosphate and the introduction of sown seeds is absolutely essential.

Therefore, on some hill grazings there is a choice to be made among the various technical possibilities, and on others there is little choice. Where there is a choice it can only be rationally made on cost/benefit grounds, and on such grounds it may well be much better to spend a given sum on a lesser degree of improvement of a fairly large area, rather than on the more dramatic improvement of a much smaller area. Cost/benefit information of this kind is in short supply, but current work is aimed at improving this situation.

For reasons of cost, topography and accessibility, it is impossible to envisage positive improvement measures being applied to the whole of a hill grazing. This, in any event, is unnecessary. The general conception which therefore emerges is for the improvement of specific areas within a hill grazing and the integration of the use of the improved area with that of the open hill.

In applying this concept to any given hill pasture, the choice of the area to be improved and the precise inputs to the improved area would be determined by the nature of the soils and vegetation, the amount of capital available, and on cost/benefit considerations.

Of equal importance to the land improvement itself is the use to which it is to be put. The principle here is quite simply to use the improved pasture area in such a way as to allow it to make its maximum impact on individual sheep performance. On the available evidence the best compromise between this requirement and pasture growth and management considerations is that the limited quantities of better quality feed should be used as much as possible during lactation and lamb growth, and again, following a mid-season rest from around mid-August, during the pre-mating and mating periods.

Changes in system of this kind both require and provide opportunities for associated husbandry changes.

In order to fully exploit the various nutritional improvements, late pregnancy feeding would have to be established as a routine practice and feed provided on an increasing scale to match higher lambing percentages.

There is a good case now to be made for a much greater degree of control at lambing. The case gains in urgency where better overall performance is likely to follow land improvement. In practice, control at lambing as well as the more efficient use of pre-lambing feed can be aided by raddling tups at mating, which becomes a more practicable operation when tupping takes place on enclosed pasture.

Where hoggs are hill-wintered there are advantages in being able to run them separately from the ewe-stock, for example in snowstorm, and in the ability to control their nutrition.

Where ewes are to be fed as a matter of routine in late pregnancy, much of the difficulty experienced in getting them to take feed can be eased by teaching them as hoggs.

These various husbandry changes may well require an elaboration of the basic grazing control requirements and what is possible and sensible will vary from farm to farm. Hill farms have a high degree of individuality.

The single most important cost item in hill sheep farming is labour. It is difficult to talk meaningfully in general terms about labour use in hill farming, but if one generalisation can be made it is that efficiency in labour use is more likely to follow grazing control than any other single measure. This is becoming increasingly recognised and there is no obvious incompatibility on output grounds between the kind of changes in system discussed here and those now being advocated by some on the grounds of greater labour efficiency.

(*b*) **Offwintering Systems.** One suggestion which emerges from the analysis of the problem made earlier is that poor efficiencies of hill pasture use owe much to the fact that existing systems are more or less completely pasture dependent in winter. It follows, therefore, that considerable opportunities might be created by removing the sheep in winter and developing summer grazing systems. But this is a good example of the fact that biological and economic efficiencies are not necessarily coincident in animal production; in fact, the economic issues in this case provide the framework within which the biological issues must be examined if this approach is to have any part to play in the future of hill sheep production.

Whether or not the cost of a house has to be met, offwintering brings in its train a substantial increase in recurrent costs. The cost of winter feeding an inwintered sheep stock is unlikely to be less than £2 per head and, bearing in mind what has been said about the output increases necessary to meet increased recurrent costs, it is hardly surprising to find that in many cases this will exceed 100 per cent. The large part of this additional output will have to come from a stocking rate increase since the limited investigations which have taken place have tended to fulfil the technical expectation that improvements in sheep performance do not accompany inwintering, in the absence of other measures.

The improvement of individual sheep performance requires concomitant improvements in summer and autumn nutrition. But the consequence of such improvements would be a reduction in the stocking rate increase required to break even on the investment. For example, an improvement in individual sheep output of the order of 20 per cent. would virtually halve the necessary stocking rate increase.

It is against the background of these considerations that the potentialities of offwintering, and systems based on offwintering together with land improvement, must be investigated and developed.

It is, of course, recognised that more or less complete pasture dependence and complete independence of the pastoral resources in winter are two extremes in a spectrum of possibilities, but existing knowledge does not yet allow of any adequate postulate regarding the role of the various intermediate possibilities in solving the problems of specific hill environments.

III. Systems Development

General Considerations. It should now be clear that the conceptions of the future possibilities based on the biological and economic arguments outlined imply production systems markedly different in many important respects to those current in the industry. The various ideas require integration, development and economic assessment.

Some research findings suggest the incorporation of a new technique into, or some minor amendment of, existing production systems. But the ideas expressed here require major changes in biologically complex animal/pasture systems in a range of soil/

vegetation environments. The satisfactory development of the possibilities, together with the understanding necessary to make confident extrapolation possible, requires the range of expertise and technical resources with which the Research Service is uniquely endowed.

Furthermore, in many respects existing knowledge of mechanisms and processes is inadequate. Human and technical resources are, and will continue to be, in short supply, which implies that much importance will continue to attach to the question of priorities for further research and their assessment. The priorities for further work will derive at least in part from those areas of ignorance which inhibit the solution of problems arising from the new systems of production. These priorities are likely to be different from those generated by existing systems, and are likely to be easier to determine in the physical presence of the new systems than in their absence.

A research programme, of which systems development is an important part is, too, in accord with the powerful argument that resource utilisation problems, of which this is one, are likely to be more satisfactory and speedily resolved in circumstances in which a continuing cyclical process of analysis, hypothesis and synthesis is easily possible.

The development and testing of the new kinds of system proposed is, for the Research Service, a comparatively novel activity. This does not imply that no previous attempts have been made to develop new systems of animal production, but rather that much has yet to be learnt about how to do this efficiently and well. As yet there are no established precedents, nor does this activity fall easily into any well-recognised category of research or experimentation. Because of its scale (and some of the problems are problems of scale) and the variability of hill land resources this work does not easily lend itself to the statistical layouts and analyses of conventional field experimentation.

However, the problem cannot be avoided for these reasons. In biological terms there are some problems which cannot be resolved, some questions which cannot be answered, other than in studies at the system level of organisation. The complex interactions triggered off by some kinds of changes are so far reaching in their effects that it is necessary to measure the overall outcome in a systems level investigation. In theory it could be argued that with an adequate understanding of mechanisms and processes obtained at 'lower' levels of biological organisation it would be possible to predict the outcome. In the first place at the present level of knowledge this is not generally possible, and in any event experience has tended to confirm that each level of biological organisation has its own inherent characteristics which knowledge at lower levels explains only in part.

The Organisation's problem ultimately exists at the system level, and just as work at other levels uniquely illuminates some facets of the problem so there are others which will only yield to systems level investigations.

The Present Programme

Up to the present time four systems studies have been initiated, of which two are year-round grazing systems. Common to both studies is the integration of areas of improved pasture with the remaining unimproved open hill in such a way as to ensure the maximum impact of improved pasture on sheep performance. The major difference between the two studies derives from the substantial differences between them in their soils and vegetational resources.

In one case the study area totals some 700 acres of predominantly grassy pasture whose traditional stocking has been some 400 ewes and gimmers. To date the improved pasture has been created by simply enclosing three areas, each of some 45-50 acres, of Agrostis-festuca pasture. An additional enclosure has been made for management purposes, winter feeding points have been established and a controlled lambing instituted. Rams are harnessed and crayon blocks are used at mating so that early and late lambing ewes can be identified.

In the other year-round study the land resource totals some 1000 acres mainly of blanket bog. The present study follows a previous large-scale exercise and here the improved pasture falls into two categories, some 24 acres of grassy pasture reseeded several years ago, and two larger areas totalling 170 acres of unimproved Calluna and Tricophorum moorland within which some 15-20 per cent. of the area has been surface-seeded to give a mosaic of improved grassy pasture throughout the whole. The remaining 800 acres is of unimproved open hill, and the study area includes an enclosure of some 20 acres for management purposes. As in the other study, provision has been made for winter feeding-points and controlled lambing. The present stocking of this resource is 370 ewes and gimmers.

In the grassy pasture system the increases in output depend to an important extent on the improved utilisation of the enclosed pasture and a stocking rate increase of 40 per cent. in the first instance is envisaged. In the blanket bog environment the improved pasture is expected to make its major impact on output through improvements in individual sheep performance and in the first instance no stocking rate increase is planned.

In each of these two environments studies are also being made of the possible role of wintering sheep off the pastoral resource.

In the grassy pasture environment two similar units each of 250 acres whose traditional stocking has been in the region of 130-140 ewes and gimmers, are being used. Both sheep stocks are wintered for the same length of time in the same wintering house, and the difference between the units, and an important part of the study, is that in one of them a pasture improvement programme has begun. This improved pasture is being used and integrated with the unimproved hill in line with the arguments advanced for its use in year-round grazing systems.

A similar approach is being made to the same problem in the blanket bog environment where a unit totalling 900 acres of hill and some 30 acres grassy pasture whose traditional carry has been 210 ewes and gimmers has been subdivided. As in the previous case, one of these resources has an associated land improvement programme involving in this instance the surface-seeding of portions of the blanket-peat.

In each of these studies a stocking rate increase of such a size as to double the stocking rate over the next 5 years has been initiated. The stocking rate is applied equally to the units which include land improvement and to those which do not, in order that the effect of the improved pasture can be measured in terms of its impact in sheep performance.

Some Fundamental Considerations

A general description of the systems synthesis programme in H.F.R.O. is that it deals with the testing of methods of integrating and combining resources in the creation of improved whole systems of sheep production from hill land resources in such a way as to quantify the relative contribution of parts of the system to the overall results.

This clearly implies in any such exercise an adequately rigorous definition of the proposed system in terms of objectives and constraints with respect to such matters as land resources, the use of the components of such resources, capital inputs, imported feed, the use of cattle (if any) in the system, and so on.

This is easy enough to do on paper or in theory. It is much more difficult in practice since the constraints must be rigorous enough to lend the necessary stability to the system, but at the same time allow of enough latitude to enable the system to accommodate itself to, e.g., the vagaries of between-year differences in climatic environment which manifest themselves in pasture growth pattern differences.

One major problem which has to be faced has implications with respect to both constraints and to the base-line against which subsequent measurements are made. The problem originates in the facts that sheep output is a function of both stocking rate and individual sheep performance, and that these two parameters are inversely related. The precise relationship is a function of the characteristics of the pastoral environment and of the pastoral system.

Sheep performance data and a limited amount of bodyweight data have been collected from the land resources used for the various systems studies now under way over a 10-year period at static stocking rates and under the traditional free-range, set-stocked, year-long management system. However, it is clear from the above argument that the only really adequate characterisation of a given land resource would be in terms of the relationship between stocking rate and sheep performance, and there is no doubt that such information would be of great value as background. Equally, however, it would be difficult and time-consuming to obtain and would tie up facilities and people, and the question becomes not whether such information would be valuable, but whether it is so vital that its lack would seriously undermine the worth of any systems synthesis exercise on that land resource.

Several issues bear upon the point. Firstly, there is no suggestion that sheep performance will improve in any environment with increasing stocking rate. What little information there is, together with the analysis advanced earlier in this paper, clearly suggests the reverse. Secondly, whilst it would possibly be untrue to argue that only those systems which result in enhanced sheep performance will be of any value, and those which result in enhanced output through increased carrying capacity alone will be valueless, the fact is that there is so much to be gained in terms of labour efficiency, the efficiency with which supplementary feed is used, and in minimising the short-term financial problems inherent in any improvement scheme, that there can be no practical interest in means of increasing total output at some cost to per head performance.

It follows from this that there is no positive development purpose to be served by investigations into relations between stocking rate and performance in the context of existing management systems. The only purpose to be served by such studies would be in terms of the extent to which such information would illuminate and aid the interpretation of the results of systems syntheses. As previously indicated, there is no doubt that such information would be of value.

But the balance of the argument between this consideration on the one hand, and the cost and effort of obtaining it together with the delay to the systems development programme on the other, is dependent to a great extent on the magnitude of the changes in stocking rate and performance. That is, the smaller the changes in stocking rate and in performance generated by the new inputs and the use to which they are put, the more important does this background information become. But the point has already been made that nothing short of very substantial changes in output are of real interest in the Organisation's system synthesis programme, and these will be well beyond the point at which any doubt about whether they are the legitimate consequence of the inputs or system changes could reasonably be sustained.

All of this, however, has an important implication with respect to how the problem of stocking rate manipulation is handled in a systems study. The consequences of any given set of inputs can only be properly assessed when the system to which these inputs give rise has been allowed to reach stability (although it is recognised that stability in this connection can only be a relative term), recognised when ewe bodyweight cycles in a characteristic way over a characteristic range. But the cycle and its associated performance level characterises events at a particular stocking rate only. In a year-round study which invariably has as its major feature either more efficient use of existing, or enhanced pasture production, it is not unduly difficult to calculate roughly what this means in terms of the potential for increased carrying capacity, and to set in train a stocking rate increase which falls short of this calculated potential. The extent to which the initial target stocking rate falls short of the calculated potential will differ as between studies in which, for example, the intention is to measure the impact of more efficient use of existing pasture or to measure the impact of a substantial increment of high-quality pasture obtained by reseeding, because of the different magnitudes of the effect of these two kinds of input on sheep performance. The important point is to ensure that an input is measured at two stocking rates sufficiently different to encompass the point of maximum total output, with the higher one beyond the point at which individual performance has significantly declined.

It will now be evident that an adequate characterisation of sheep performance and its components is of the first importance in systems studies. Apart from the more obvious records such as lamb numbers at birth, marking and weaning, together with the appropriate lamb weights, the collection of adequate ewe bodyweight information at sufficiently frequent intervals and at the right times to characterise the various phases of the production cycle, e.g. early and late pregnancy, the recovery period and so on, is necessary.

Bodyweight data are also required to interpret the response to specific aspects of any synthesis. For example the use of improved pasture in a system has direct and indirect effects. The direct effects may be expected to promote changes in lamb growth rate and in ewe bodyweight recuperation in the pre-mating period. The indirect effects arise since a given seasonal pattern of use of improved pasture will change the pattern of use and the grazing pressure to which the remaining open hill area is subjected. The nutritional consequences of such changes must be measured and the weighing programme must take this into account.

In addition to this basic programme of animal measurement, various other aspects of some studies are being monitored. With respect to soils and vegetation particular interest attaches to the changes which take place in those areas of pasture which are being upgraded by management means. In the Agrostis-festuca grassland enclosures, for example, the soils have been characterised in terms of pH, nitrogen status, extractable phosphorus, extractable potassium and C/N ratio. Particular attention is being paid to the mat layer (A_0 horizon) since changes in the thickness of this layer are expected to manifest themselves fairly quickly. These various measurements are being repeated at appropriate intervals.

The Agrostis-fescue enclosures have been botanically recorded intensively. Interest here centres on the botanical changes and the rapidity with which they occur on the different parts of the enclosures and on the rather different soils included in each enclosure.

In the blanket bog environment the large Calluna-Trichophorum enclosures within which the mosaic of surface-seeded grassland has been established have been botanically sampled with a view to characterising the changes which take place on both the improved patches and on the unimproved vegetation. A classification of the vegetation has been made using a numerical multivariate procedure on the basis of which future botanical sampling will take place.

Attempts are being made, using faeces nitrogen concentrations against the background of previous work, to monitor the quality of ingested pasture when sheep are in the enclosures. It may be possible by this means to introduce a greater degree of objectivity into decision making by this means with particular reference to determining when sheep ought to be removed from any enclosure.

The problem of more objectively determining the quantities of supplementary feed supplied in late pregnancy in both year-round studies and inwintering studies is also receiving attention. Measurements have been made of blood parameters, particularly blood ketones, at weekly intervals on ewes drawn from the various flocks with a view to maintaining undernourishment within acceptable limits. The early results indicate that the regulation of the input of supplementary feed during late pregnancy according to biochemical assessments of nutritional state on a field scale can be successfully accomplished. This approach has, however, highlighted the fact that gimmers pose a special problem in this regard and further research has been directly stimulated in consequence.

It is recognised that unless disease can be controlled or its consequences quantified no accurate analysis of the benefits of the changes promoted by system change can be made. From the point of view of the veterinary monitoring of the systems studies, the priorities have been established from a consideration of the diseases known to be endemic, current disease control practices and their effectiveness, and the possible consequences of the more intensive use of specific areas of pasture. On these considerations attention has been initially directed towards the parasitic diseases and particularly helminth and liver fluke infestation.

A number of pilot studies, based on the comparative productivity of a 'worm and fluke-free' group of sheep and of a strategically dosed group within each of the year-round systems have been made, relating to lambs, hoggs and ewes.

From this work it should be possible to assess the effectiveness of the present strategic dosing programmes and to develop new routines to deal with the problems which may arise from the changing situation.

The ultimate test of the worthwhileness of any of these developments to hill sheep farming will depend upon their economic soundness, and in addition to all the biological data which are being collected, that necessary for the economic evaluation of the various systems is also being recorded.

The present systems programme is by no means comprehensive. In the first place the existing programme is based on hill land resources which are representative of the very good and the very poor, and much of interest in between, and to which similar systems arguments are thought to apply, is not represented.

In the second place, and this is perhaps a more serious limitation, each kind of systems study in each of the two environments deals with the events consequent upon only one level of capital input, whereas what is really required in any one pastoral environment is the information which would describe the responses to a range of capital inputs within each of the major systems possibilities. The problem can be generalised in biological terms in that what is required in relation to the year-round grazing, two-pasture system concept is the data which will enable the interrelations among the quantity and quality of improved pasture, the area of unimproved open hill, sheep numbers and sheep performance to be quantified. It is likely that the same kind of information will be required with respect to offwintering systems.

There is, therefore, a need to expand the programme to include in each environment at least one additional year-round system in which substantially greater quantities of improved pasture are created, so that over a period of years it might be possible to establish in any one system, in time, two successive levels of capital input and two successive levels of improved pasture production and integration. In this way it would be possible to build up information of the required kind, and in the required quantity, to describe the interrelations of interest and value.

There need be no conflict between setting up systems studies which are relevant to the industry's short-term needs and setting them up in such a way as to generate a body of biological information which can be used in a variety of cost and price situations in the future.

The potential of computer simulated models of production systems is very great and looking to the future it is certainly possible that further progress could be made in this direction from the results of systems programmes in which individual studies are regarded not only as ends in themselves but set up so as to contribute vital information to this wider objective. The assumption which inevitably lies behind this suggestion is, of course, that further research will not lead to systems conceptions so markedly different to those now current as to render the latter obsolete. Although this possibility always exists it seems more likely that further work will better illuminate and clarify existing conceptions.

Finally, the work now under way depends greatly on the willing co-operation of both scientific and Research Farm staffs. It is a pleasure to acknowledge their valuable contributions to this programme.

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6. TRENDS IN LIVESTOCK POPULATIONS IN HILL AREAS IN SCOTLAND

J. M. M. CUNNINGHAM, A. D. M. SMITH AND J. M. DONEY

A DETAILED analysis of the distribution of hill sheep was made by Hunter and Davies in 1952 and this has been used as a baseline to establish subsequent trends.

The data presented are based on the December 4 returns published by the Department of Agriculture and Fisheries for Scotland and have been analysed for selected years only.

Two significant points stand out. First, that in spite of the transfer of hill land to afforestation and the removal of sheep from some estates in the Highlands, the total number of hill ewes has increased slightly up to December 1967. More recent information, not yet available in detail, would suggest a downward trend in numbers over the last few years and especially so in the South-West.

The second point is that although there was an increase in ewe numbers in all areas between 1952 and 1967 this is most marked in the North-East and the Highland areas and is of greatest significance in Caithness, Banff and especially Orkney.

Although there has been a slight rise in ewe numbers in the South-West there has been a substantial drop—12·4 per cent.—in ewe numbers in Kirkcudbrightshire which is an area of extensive forest development.

The distribution of hill sheep throughout Scotland is illustrated in Figure 1 and was derived from the data summarised in Table 1 analysed on a parish basis. This demonstrates clearly the greater concentration of sheep in the Southern Uplands and the low densities characteristic of the Highlands.

It is well known that stocking rates vary widely and this was analysed by Hunter (1952), quoted by King and Nicholson (1964).

The distribution of the hill ewe population based on stocking rate is presented in Table 2 and this indicates that approximately one-third of the ewe flock is stocked at 1 ewe to 2 to 3 acres (Figure 2). Around a quarter of a million sheep (10 per cent. of all hill sheep) require 10 or more acres per ewe, these being mainly in the Highland area, West Perth and the North-East.

However, on analysing this data it was impossible to be precise as to the acreage grazed by sheep in the majority of deer forests and these have been included in the category of 10 acres plus per ewe.

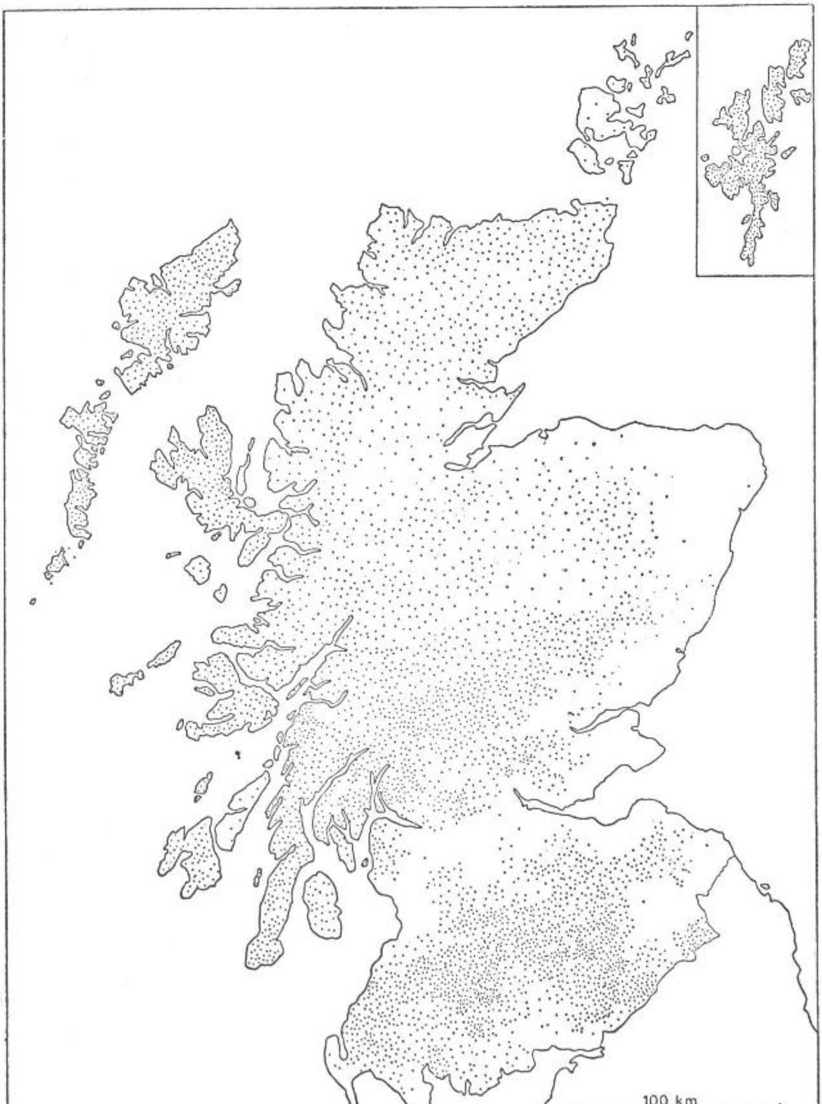

FIG. 1.—Distribution of ewes and gimmers qualifying for the hill sheep subsidy in December 1967. One dot represents 500 ewes and gimmers.

TABLE 1

Total number of sheep eligible for Hill Subsidy during the period 1952-67

	1952	1956	1960	1964	1966	1967
Highland						
Argyll	343,563	350,368	393,446	383,854	378,599	364,627
Inverness	273,138	280,683	296,294	296,549	298,802	296,374
Ross & Cromarty	156,580	149,133	159,883	163,064	167,922	166,279
Sutherland	107,844	104,842	110,848	113,346	120,790	115,001
Shetland	112,161	98,831	111,421	117,475	124,146	126,654
Total No.	993,286	983,857	1,071,892	1,074,288	1,090,259	1,068,935
North-East						
Aberdeen	32,599	31,562	32,128	33,532	35,008	33,817
Banff	12,877	12,504	13,914	14,883	18,233	17,055
Caithness	30,283	28,996	29,276	35,490	45,176	44,224
Kincardine	7,861	7,139	7,001	6,024	6,994	7,167
Moray	9,184	8,876	9,052	8,062	7,902	7,052
Nairn	4,530	4,404	4,623	4,724	3,780	3,331
Orkney	3,858	4,386	4,872	5,584	9,000	9,355
Total No.	101,192	97,867	100,886	108,299	126,093	122,001
East-Central						
Angus	43,485	40,911	43,330	45,068	46,681	46,912
Clackmannan	4,948	4,809	6,451	6,653	6,968	6,584
Fife	4,904	5,195	6,369	6,015	5,413	5,837
Kinross	7,661	7,183	7,350	9,067	9,625	9,585
Perth	238,214	229,890	247,629	249,749	256,196	254,283
Total No.	299,212	287,988	311,129	316,552	324,883	323,201
South-East						
Berwick	25,309	24,402	24,492	23,179	24,209	23,501
East Lothian	16,385	15,509	17,011	16,189	17,201	16,897
Midlothian	30,392	29,789	30,497	29,545	30,794	29,650
Peebles	60,813	58,938	60,290	61,562	61,325	60,158
Roxburgh	91,980	89,210	91,014	87,890	88,621	87,462
Selkirk	62,708	60,768	59,364	58,288	60,111	58,897
West Lothian	618	595	614	407	436	364
Total No.	288,205	279,551	283,282	277,060	282,697	276,929
South-West						
Ayr	130,061	127,538	129,007	132,270	134,622	135,081
Bute	17,769	18,056	17,493	19,200	18,942	17,482
Dumfries	165,486	162,528	168,201	170,517	171,792	167,281
Dunbarton	31,283	30,659	32,340	32,920	33,057	32,098
Kirkcudbright	119,593	110,041	108,946	105,717	105,977	104,771
Lanark	79,019	77,405	78,464	81,383	83,183	82,844
Renfrew	11,083	10,914	11,456	11,212	11,522	10,840
Stirling	39,367	45,673	47,594	48,576	49,244	49,633
Wigtown	38,713	37,577	37,403	38,857	39,932	40,257
Total No.	632,374	620,391	630,904	640,651	648,271	640,287
Total Nos. (Scot.)	2,314,269	2,269,654	2,398,093	2,416,850	2,472,203	2,431,353

TABLE 2

No. of hill sheep—December 1967—qualifying for subsidy at various stocking rates (including sheep grazing on deer forest)

Ac. rough pasture sheep	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	>10	Total
Highland Area	—	41,850	141,428	182,511	141,601	106,635	64,891	38,366	79,935	57,203	214,515	1,068,935
North-East	—	1,772	8,007	9,834	21,156	11,505	10,571	9,416	17,478	12,562	19,700	112,001
East-Central	693	37,261	77,224	89,461	44,359	20,656	33,152	262	—	5,555	14,578	323,201
South-East	—	50,086	177,897	43,534	2,101	1,208	81	799	—	723	500	276,929
South-West	812	76,381	432,002	90,896	30,692	1,992	4,565	1,792	—	50	1,105	640,287
	1,505	207,350	836,558	416,236	239,909	141,996	113,260	50,635	97,413	76,093	250,398	2,431,353
Percentage	0·06	8·53	34·44	17·12	9·87	5·84	4·66	2·08	4·00	3·13	10·30	100·00

The relative proportions of the two dominant hill breeds, the Blackface and Cheviot, have varied very little over the 14-year period examined (Table 3). Apart from an increase of 7·4 per cent. (17,400

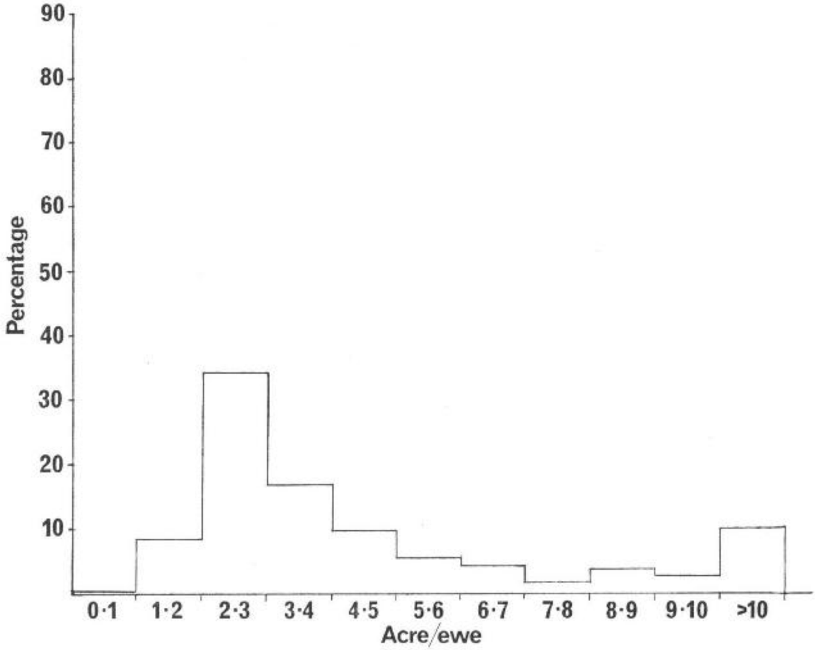

FIG. 2.—Hill sheep stocking rate, 1967.

ewes) in the Cheviot in the North-East the minor changes elsewhere suggest a trend towards a decline in the importance of the Cheviot as shown by the ewe numbers below:

	Blackface	*Cheviot*
1952	1,767,000	420,061
1966	1,923,172	404,149

This is an increase of 9 per cent. in the Blackface and a decline of 4 per cent. in the Cheviot.

Although not presented here a breakdown of the distribution of these breeds on a parish basis is available. The general distribution of the breeds is illustrated in Figures 3 and 4.

Taking into account the areas where South and North Country Cheviot types predominate it would appear that there has been an increase in numbers of the North Country Cheviot at the expense

TABLE 3

Number of Blackface and Cheviot breeds in Scotland and as a percentage of total sheep eligible for Hill Sheep subsidy during the period 1952-66

	1952				1956			
	Numbers		%		Numbers		%	
Region	B.F.	Chev.	B.F.	Chev.	B.F.	Chev.	B.F.	Chev.
Highland	684,230	197,548	68·9	19·9	701,342	184,121	71·3	18·7
North-East	53,350	34,072	52·2	33·4	63,971	32,531	67·0	31·7
East-Central	297,374	1,818	99·4	0·6	285,736	1,973	99·2	0·7
South-East	190,839	97,096	66·2	33·7	190,886	87,531	72·2	31·3
South-West	541,213	89,527	86·0	14·2	535,062	85,182	86·2	13·7
Net total (Scot.)	1,767,006	420,061	76·9	18·2	1,776,997	391,338	78·3	17·2

	1960				1964			
	Numbers		%		Numbers		%	
Region	B.F.	Chev.	B.F.	Chev.	B.F.	Chev.	B.F.	Chev.
Highland	771,993	184,696	72·0	17·2	758,976	196,576	70·6	18·3
North-East	67,644	32,013	67·0	31·7	65,320	41,616	60·3	38·4
East-Central	285,736	1,973	98·9	1·1	313,178	3,237	98·9	1·0
South-East	195,139	86,654	68·9	30·6	188,632	88,307	68·1	31·9
South-West	541,106	89,145	85·8	14·1	558,682	81,573	87·2	12·7
Net total (Scot.)	1,883,646	395,829	78·6	16·5	1,884,788	411,309	80·0	17·0

	1966			
	Numbers		%	
Region	B.F.	Chev.	B.F.	Chev.
Highland	772,553	189,510	70·9	17·4
North-East	69,572	51,473	55·2	40·8
East-Central	320,584	3,431	98·7	1·1
South-East	200,554	78,353	70·9	27·7
South-West	559,909	81,382	86·4	12·6
Net total (Scot.)	1,923,172	404,149	77·9	16·4

The discrepancy in the total of the percentages is accounted for by other breeds and cross-bred ewes.

of the South Country Cheviot although it was not possible to obtain a precise analysis of the distribution and numbers of these types to confirm this.

A limited amount of data (Table 4) has been obtained on hill cows which are mainly of beef type and this indicates a dramatic expansion in numbers, particularly in the upland and marginal areas.

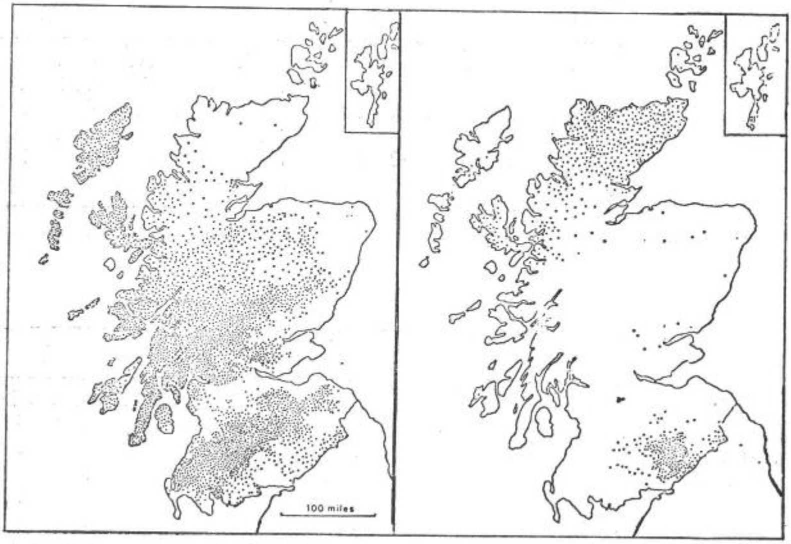

FIG. 3 FIG. 4

FIG. 3.—Distribution of Blackface hill ewes, December 1966. One dot represents 500 ewes.

FIG. 4.—Distribution of Cheviot hill ewes. December 1966. One dot represents 500 ewes.

This has probably been achieved through higher stocking rates made possible by land improvement. Accordingly, the main expansion has been in the better areas of the South-East and also in Aberdeenshire and Kincardineshire but the expansion in Argyllshire is also noteworthy and this would seem to reflect improvement in the productivity of marginal land in that area.

An upward trend in numbers of breeding ewes or cows does not necessarily reflect a proportional increase in animal production but detailed information on this aspect is not available. It is clear nevertheless that upland and hill farms are continuing to make an important and increasing contribution to British agricultural production.

The December 4 returns for 1969 and until October 5, 1970 show a total of 2,359,692 ewes receiving subsidy and this is a decline of 71,661 (2·95 per cent.) since 1967. This drop has occurred mainly in Kirkcudbrightshire, Dumfriesshire and Selkirkshire although some reduction is also evident in Perthshire, Argyllshire and Inverness-shire.

TABLE 4

Total number of hill cows eligible for subsidy showing percentage changes

	1964		1965		1966		1967	
	No.	%	No.	%	No.	%	No.	%
Highland	59,452	100	61,228	103·0	64,153	107·9	66,670	112·1
North-East	79,438	100	85,085	107·1	91,726	115·5	94,417	118·9
East-Central	30,571	100	32,599	106·6	35,861	117·3	36,842	120·5
South-East	25,698	100	27,748	108·0	30,247	117·7	31,646	123·1
South-West	47,946	100	54,497	113·7	66,698	139·1	75,084	156·6
	243,105	100	261,157	107·4	288,685	118·7	304,659	125·3

Numbers of hill cows eligible for subsidy have continued to increase to 334,187 by December 4, 1969, this being 30,528 more than in 1967.

It is of interest that the expansion in cattle numbers is also occurring in those areas where sheep show a substantial decline.

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