HILL FARM RESEARCH

EDINBURGH: HIS MAJESTY'S STATIONERY OFFICE: 1951

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DEPARTMENT OF AGRICULTURE FOR SCOTLAND

HILL FARM RESEARCH

REPORT OF THE SCOTTISH HILL FARM RESEARCH COMMITTEE

EDINBURGH: HIS MAJESTY'S STATIONERY OFFICE
1951

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SIR PATRICK LAIRD, C.B., F.R.S.E.,
Chairman,
Scottish Agricultural Advisory Council.

Sir,

SCOTTISH AGRICULTURAL ADVISORY COUNCIL

HILL FARM RESEARCH COMMITTEE REPORT

We were appointed by the Secretary of State on 1st November, 1945, for a period of three years, to be a Committee of the Scottish Agricultural Advisory Council, with the following terms of reference :—

(1) To keep in touch with the progress of scientific research on the specific problems affecting hill sheep farming and also with experiments in new farming methods, and to advise the Department of Agriculture for Scotland through the Council, in consultation with the Agricultural Research Council, what steps should be taken to test promising results with a view to their introduction into general practice ;

(2) To expedite the incorporation into ordinary farming practice of new knowledge proved to be generally applicable ;

(3) To review the problems of farmers in order to advise, in the light of current agricultural policy, on problems needing scientific investigation or increased scientific attention ; and

(4) To advise on the sites for experimental stations and prepare estimates of cost of the research organisation recommended.

Sir John Boyd Orr† was unable to take up his membership of the Committee owing to his appointment as Director-General of the Food and Agricultural Organisation of the United Nations. *Mr. Ian Campbell* resigned in March, 1947, on his appointment as president of the National Farmers' Union of Scotland. Three members representative of scientific and farming interests in the North of England were appointed in October, 1946, since the Border Experimental and Research Station is also to serve the needs of that district : these were *Professor R. W. Wheldon*, King's College, Newcastle, *Professor R. G. White*, formerly Professor of Agriculture in the University College of North Wales, now Head of the Animal Breeding and Genetics Research Organisation of the Agricultural Research Council, the Headquarters of which are in Edinburgh, and *Mr. J. V. Allen*, a farmer from Westmorland. In order to assist in securing co-ordination of the work at the Hill Farm Research Stations, the Principals of the three Agricultural Colleges were appointed to the Committee in May, 1947 ; *Principal Bywater*, North of Scotland College, *Principal Watson*, Edinburgh and East of Scotland College, and *Principal Kirkwood*, West of Scotland College. *Dr. Allan Fraser* resigned from the post

†Now Lord Boyd Orr of Brechin

of Technical Secretary to the Committee in July, 1946, owing to ill-health, and was succeeded by *Dr. J. Allan Campbell.* The Secretary to the Committee, *Mr. J. R. King* of the Department of Agriculture, was transferred to other duties within the Department in September, 1947 and was succeeded by *Mr. O. Beattie* of the Department.

The Committee had its origin in the Report of the Committee on Hill Sheep Farming in Scotland, under the chairmanship of Lord Balfour of Burleigh, which recommended that there should be appointed a permanent Hill Farm Committee with duties as outlined in the terms of reference mentioned above, with the exception of that relating to advising on the sites for experimental stations.

They recommended, *inter alia,* the establishment of a field station situated in a selected hill farming area where it would be in immediate contact with the more serious problems of the industry, and where all the appropriate branches of science could be brought to bear on these problems. This field station should have a director and a small nucleus staff of experienced investigators to which additional investigators could be seconded for particular work from the Research Institutes, etc. Mobility of at least part of the research organisation was also postulated so that field investigations could be extended to other parts of the country since a single locus might not serve for all the subjects of research.

These recommendations were examined by an *ad hoc* Committee of the former Agricultural Improvement Council whose report is given in Appendix 1.

Briefly, they considered that in the circumstances then prevailing the purpose of the Balfour of Burleigh Committee's recommendation for the establishment of a field station, with staff, would be achieved by an organisation comprising three Hill Farms; Glensaugh Farm of the North of Scotland College of Agriculture and two other farms, one in the South-East of Scotland to serve the needs of both sides of the Border, and one in the West of Scotland, *e.g.,* Argyllshire or Western Perthshire. They did not, however, ignore the possible need to review this position at a future date.

They also recommended the development of certain lines of research as outlined in their Report.

We have met formally 17 times and in addition have visited various parts of Scotland (Mainland) observing experimental work in progress and obtaining in various localities first-hand information of particular problems. We have also visited the North of England to obtain information on the problems there.

I. ESTABLISHMENT OF RESEARCH FARMS

Our main task has been to secure a farm to serve the needs of the South-East of Scotland and the North of England, and another to serve the West of Scotland. These farms, together with Glensaugh Hill Farm Experimental Station, would meantime constitute the hill farm experimental and research organisation recommended by our predecessors.

It has not proved easy to secure the two additional farms, but it is satisfactory to be able to report that :—

(1) With the co-operation of His Grace the Duke of Roxburghe and the Edinburgh and East of Scotland College of Agriculture, the farm of Sourhope in the South-East of Scotland was secured on lease as from Martinmas, 1946. A lease was also obtained of the small, adjacent led-farm of Auchope and the two farms together form a compact unit, situated in Roxburghshire and march-

ing with the English Border. This unit comprises 2,765 acres of hill land typical of the Cheviot Hills. Improvements to existing farm workers' houses, and adaptations to the farmhouse to provide accommodation for visiting scientists, the erection of laboratories and of a new dipper, etc., are in hand. There has been a disappointing delay owing to present difficulties in connection with building work but part of the building programme has been completed and it is hoped that the farm will soon begin to function fully as part of the research and experimental organisation. Additional housing, however, is required for a resident farm manager.

(2) The farm of Lephinmore, situated near Strachur on Loch Fyne-side, has been made available for research and experimental work as from Martinmas, 1948. The estate of which this farm forms part was acquired by the Forestry Commission for planting, but the Department secured a certain limitation in the planting which will leave a workable hill farm unit comprising approximately 2,800 acres. We feel that in view of the need for close integration between hill farming and afforestation, to the ultimate benefit of both, this farm will prove an excellent locus for studying problems arising from the extension of afforestation of hill land.

We wish to record our indebtedness to the Land Technical Staff of the Department of Agriculture and to the Forestry Commission for their wholehearted co-operation and assistance in the establishment of Lephinmore as a hill farm research and experimental station.

Sourhope Farm is under the day-to-day management of the Edinburgh and East of Scotland College of Agriculture, just as Glensaugh is under the North of Scotland College of Agriculture, but in regard to Lephinmore, it was arranged that the Committee, in the meantime, should exercise full executive control over the research and experimental work. Thus the farm remains under the management of the Department and scientific oversight is provided by a small Sub-Committee. The West of Scotland Agricultural College is co-operating fully in the work proceeding there.

II. REVIEW OF CURRENT RESEARCH

As has been indicated, our action has been mainly exploratory in regard to the organisation and development of field research. We have followed closely various lines of applied research carried out at the Agricultural Colleges and elsewhere and have also been considerably interested in the fundamental work on problems affecting hill sheep farming in progress at certain of the Research Institutes and University Departments.

The following summaries compiled from information supplied by the various Bodies concerned indicates the range of problems at present under investigation by these Bodies and should serve as a useful basis of reference for the planning and organisation of future work on problems related to hill farming.

1. Research Institutes

ANIMAL DISEASES RESEARCH ASSOCIATION

The importance of the sheep in Scotland's economy has led to a major part of the Association's activities being directed to sheep diseases. Work in progress includes investigations into " Scrapie ", " Pyaemia associated with

Tick-bite ", " Tick Infestation " (in association with the Department of Agricultural and Forest Zoology, Edinburgh University), " Tick-borne Fever ", " Cobalt Deficiency Pine " (in association with the Macaulay Institute for Soil Research), " Yellowsis ", " Enzootic Abortion in Ewes " (in collaboration with the Veterinary Investigation Officer of the Edinburgh and East of Scotland College), and " Swayback in Lambs ".

It is satisfactory to note that the causative agent of " Scrapie " has now been defined as a filtrable virus. The characters of this virus are as yet imperfectly understood, however, and further work is in progress with the ultimate aim of evolving means for the control of the disease. The causal organism of " Tick-borne Fever " has also been recognised but so far it has not been possible to devise a preventive vaccine, and work is proceeding to that end. In the course of work on " Tick-pyaemia " it has been demonstrated that the causal organism, a staphylococcus, occurs commonly on the skins of lambs. It has been found impossible to maintain the organism in the tick from one stage (instar) to the next, and it is assumed that the disease in lambs arises from a skin infection when the organism gains entry to the tissues through tick-bite. Prevention of the disease by staphylococcal toxoid is not successful since lambs do not react to injection with an antibody response until they are 6-7 weeks old. By this age they are beyond the danger period in the field.

The problem of control of " Cobalt Deficiency Pine " has to a great extent been solved, and work on this subject has resulted in a large economic saving to the Scottish sheep industry. Clinical evidence, together with spectrographic analyses carried out by the Macaulay Institute for Soil Research has led to the recognition of areas in which pronounced symptoms of malnutrition in sheep correspond to a " real " deficiency of cobalt. In other areas a " relative " deficiency of cobalt has been associated with general unthriftiness of sheep in which clinical symptoms are not apparent. Cobalt treatment has secured beneficial results leading to the alleviation of symptoms in clinical cases, and producing live-weight gains in sub-clinical ones. The application of cobalt-rich dressings to deficient pastures has been widely adopted as a routine practice, and in consequence large tracts of " sheep-pining " land have now been rendered cobalt adequate.

The occurrence in Scotland of the condition in cattle referred to as " Bracken-poisoning " has been recorded over many years, and as a result of a survey made with the assistance of the Veterinary Investigation Officer Service, it has been noted that with very few exceptions, the disease is confined to bracken land south of the line Fort William - Montrose. In collaboration with the Edinburgh and East of Scotland College of Agriculture a detailed study was made on a farm in Gala Water where the clinical and pathological aspects were investigated, and the disease was experimentally produced by feeding bracken. The possibility of an associated bacterial infection merits careful consideration, and bacteriological and histological examinations of fresh material will be initiated in the near future*.

* Following the recognition by Weswig *et al*[1] of the presence of an anti-thiamine factor in bracken, work on this aspect has continued in Scotland. Tests to determine the preventive and curative value of vitamin B1 in bracken poisoning in cattle in the field are being undertaken by the Animal Diseases Research Association in collaboration with the Scottish Veterinary Investigation Officer Service. Feeding experiments on rats, ponies and cattle and the treatment of bracken poisoning by vitamin B1 have been undertaken at the Rowett Research Institute. (Carpenter *et al.*)[2]

[1] Weswig, B. H., Freed, A. M. & Haag, J. R. (1946)—*J. Biol. Chem.*, **165**, 737 ;
[2] Carpenter, K. J., Phillipson, A. T. & Thomson, W. (1950)—*Brit. Vet. J.*, **106**, 292.

The Director of this Institute acts as Consultant and Adviser to the Veterinary Investigation Officer Service operated by the Agricultural Colleges, and through him a close link is obtained with the Scottish Board of Research in Veterinary Science. The Service is mainly advisory to local veterinary practitioners, although *ad hoc* research is conducted on certain problems as they arise.

We wish, however, to record what we consider a matter of considerable importance in the control of certain sheep diseases which still cause considerable losses, namely, "Braxy", "Louping-ill" and "Lamb-dysentery", The causes of these diseases have been defined and specific means for their prevention have been evolved. The use of preventive measures has secured a large monetary gain to sheep farmers, but it has been brought to our knowledge that in a number of districts prophylactics are not being used to the extent warranted by the incidence of these diseases. We are not aware why this should be so ; the treatment is simple and the results assured. It is difficult to believe that failure to adopt these remedies is due to ignorance of their existence : it may be due merely to apathy. Whatever the cause, it is of prime importance that all possible means should be taken to give full publicity to the existence of proven methods of preventive veterinary treatment. This, we feel, is a matter for the Agricultural Colleges who will doubtless consider the use of films, demonstrations and lectures in promoting the control of these diseases.

SCOTTISH SOCIETY FOR RESEARCH IN PLANT BREEDING

The Society consider that one of the main agronomic objectives of their herbage plant breeding programme is the improvement of the diet of animals feeding on natural or rough grazings. In particular their programme aims at creating conditions which would allow the breeding population of cattle in the essentially grazing districts of Scotland to be increased. The actual design of the investigations has to a very considerable extent been based on the following assumptions on the part of the Society :—

(1) that in Scotland the areas likely to benefit most from grass research are those in the high rainfall districts of the west and north-west ; (2) that in such districts it is desirable to increase the numbers of breeding cattle, and (3) that the future prosperity of some of these districts will depend on a greater integration of farming and afforestation, which would mean that some of the better class rough grazings would no longer be available as pasture.

The Society are impressed with the degree of deterioration which has taken place in the limited arable ground in many hill farming districts, and they consider that a more immediate benefit can be obtained by increasing the output of the arable acreage than by general reseeding of upland grazings. The improvement of low altitude and arable grassland along orthodox lines, however, could never lead to more than very moderate stock increases, since the amount of ploughable land is usually small and the number of animals which can be grazed full-time even on the best of grass is strictly limited. Experiments conducted at the Plant Breeding Station show clearly that both yields of dry matter and percentage of crude protein in the dry matter can be raised to exceptionally high levels by the appropriate choice and treatment of herbage plants. This leads to the production of a very rich diet, in itself unbalanced, which can be used as a supplement to the basic diet of hill herbage, and consequently means that animals would only use the arable grass part-time instead

of whole-time. This system involving the joint use of natural and high-protein-yielding cultivated grasses is termed the system of complementary grazing.

Attention is being given to finding strains of grasses which will fit such a programme of spring and summer complementary grazing together with summer silage cuts. Although work on winter-active grasses is in progress, it is felt that as far as the high rainfall districts of Scotland are concerned the conservation of summer grass is the more reliable method of meeting winter requirements.

We have twice visited the area at Dundonnell, Ross-shire, where work by Dr. Gregor on complementary pastures is in progress. The cost of creating and maintaining areas of cultivated complementary grass is high and it is impossible at this stage to say whether the results justify the expense. While it is clear that from the botanical standpoint the production figures are encouraging, the value of the system as a practical farming proposition must remain in doubt until its economic aspects have been critically examined. We were, however, greatly interested in its potentialities and consider that these experiments should be replicated on farms where strict scientific oversight can be provided by specialists in the various branches of work involved. It is unsatisfactory in our opinion to carry out this work in its initial stages in so relatively inaccessible a district as Dundonnell. Should the idea of complementary pastures prove capable of general application, it might entail important changes in hill farming practice. But we emphasise that it must be examined thoroughly from all aspects.

MACAULAY INSTITUTE FOR SOIL RESEARCH

(1) *Lime and Fertiliser Requirements of Hill Lands*

From examinations of soil samples from various hill sheep grazings throughout Scotland, it may be said that, almost without exception, the soils have very low contents of lime and phosphate while the potash content is on the whole relatively more satisfactory.

It is doubtful if much response could be obtained from the application of potash until deficiencies in lime and phosphate had been remedied. It is not possible to state the rate of dressing of lime and phosphate needed to meet the full requirements. In the Institute's experience applications of more than 5 tons per acre of ground limestone would be theoretically necessary in many areas, but dressing at such a rate would exceed the limit of economic feasibility. Owing to the demand for lime and phosphate to meet the needs of better class land, it is suggested by the Institute that applications at the rate of 15 to 40 cwt. of ground limestone and 3 to 4 cwt. of a phosphatic fertiliser per acre would be about the economic limit. Sub-optimal rates of dressing do undoubtedly help, and it is thought that the problem will have to be approached from the aspect of the minimal beneficial rate.

(2) *Trace Elements affecting Animal Health*

It appears from results so far obtained that there are considerable areas of hill land where the vegetation contains insufficient cobalt for the maintenance of animal health. The problem is complicated by the marked variations in soil and vegetation which may occur within relatively small areas of hill country. Information is available on the seasonal variation of contents of Cobalt, Nickel, Molybdenum, Titanium, Vanadium, Chromium, Zinc, Copper

Manganese, Barium, Strontium and other elements in various hill pasture plants. Investigations on this subject are in progress to develop a working basis for definition of normal contents.

The Institute is the centre in Scotland for the development of spectrographic analysis of " Trace " and " Minor " elements in soil. We are pleased to note that as a result of a recommendation by our predecessors spectrographic apparatus is now in use at the Edinburgh and Glasgow Agricultural Colleges. Work at these centres will be mainly advisory, while research work and development of techniques is the province of the Macaulay Institute.

ROWETT RESEARCH INSTITUTE

This Institute is concerned with problems of animal nutrition. In investigations carried out before 1940 it was demonstrated that sheep allowed ample nutriment during the last 4 to 6 weeks of the gestation period produced lambs equal to those of sheep which had received ample food throughout the greater part of gestation. Their milking capacity also appeared to be equal. On the other hand, sheep on a diet just sufficient to maintain bodyweight or to allow a 5 per cent. weight loss during the gestation period, produced lambs which were under weight and in which there was a high mortality, and their milk yield was seriously impaired. Underfeeding during pregnancy or a period of starvation about 4 to 6 weeks before parturition resulted also in cases of ketonaemia. The conditions stated above appeared to be more related to quantity than to the quality of the food.

From 1945 to 1947 the work was continued in more detail and the results are meantime being prepared for publication. In 1946-47 two groups of pregnant Sutherlandshire Cheviot ewes were fed identically up to the 70th day of gestation from which time the ewes in one group (high plane of nutrition) were fed to allow a bodyweight increase of about 25 per cent. by lambing time. Those of the other group (low plane of nutrition) were made to lose 5 to 10 per cent. of their bodyweight by lambing time. All ewes were fed individually indoors.

The low plane of nutrition had a marked retarding effect on the development of the udder and many ewes in this group had little or no milk at parturition. Consequently some lambs died from lack of milk. The conditions imposed on this group are much the same as those which occurred during the prolonged snowstorm in the spring of 1947 when death-rates up to 50 per cent. in lambs were reported.

A film has been made to illustrate part of the experiment.

Bracken poisoning—*vide* footnote p. 8.

2. Agricultural Colleges

WEST OF SCOTLAND AGRICULTURAL COLLEGE

(1) Experimental work on bracken control at Touchmollar, Stirling, demonstrates clearly that machines which cut or completely sever the bracken fronds are much more effective than rolling or bruising machines.

The rate of recovery between 1942 and 1948 has been very much more rapid on plots which had previously been subjected to bruising treatment between 1937 and 1942 than on those plots where the bracken was cut.

Studies on the spread of bracken in Argyll have shown a number of relatively small incipient stages of invasion (many areas of only 10 to 70 square yards) in regions where bracken has not hitherto been particularly abundant.

These observations indicate the need for the application of vigorous control measures to small bracken plots.

From trials carried out continuously since 1935 it has been demonstrated that cutting bracken in the period mid-June to mid-July gives more effective control than later cutting. Bracken has been practically eliminated for the past five years from those plots where cutting was carried out more than once per season.

Observations have been continued on the utilisation of pasture plants at Ballochraggan. Rough estimates have been made of the response of herbage to different manurial treatments. In general weedy plants like ragwort, thistles and rushes are more frequently eaten now than they were five years ago when the observations were started. An increased tendency on the part of stock to consume roughage is presumably related to a general improvement in the level of their nutrition.

The area at Ballochraggan reserved for sheep since 1944 is now demonstrably inferior to the adjacent part to which both cattle and sheep have access.

The seasonal use of the various secondary plants is interesting. Certain sedges like the yellow sedge (*Carex flava*) are eaten earlier in the season and over a longer period than most of the others. Stool Bent (*Juncus squarrosus*) is readily grazed at Ballochraggan. Whether preference is due to palatibility or accessibility is not yet known.

(2) Dipping and inoculation techniques give a measure of protection to adult sheep against tick-borne diseases, but no really effective measure for lambs has hitherto been found. Further, the presence of untreated lambs acting as tick hosts is a serious loophole in any programme of tick-control. With the object of remedying this defect, field-trials have been conducted over the years 1946-48 in Argyllshire, Perthshire, Ayrshire and Kirkcudbrightshire involving the use of an anti-tick salve on lambs within three days of birth.

Dr. D. S. MacLagan states that in the treatment of nearly 700 lambs distributed over twelve farms, (i) no adverse effects on the skin have been encountered, (ii) the lambs were given a high degree of protection from ticks for the first critical month of life, (iii) the death-rate was lower, and (iv) smeared lambs were 8-10 per cent. heavier at speaning-time than untreated lambs. He concludes : " Without claiming that the anti-tick salve is perfect, there is no doubt of its value in protecting lambs from the direct and indirect effects of ' tick-bite '. By relieving young lambs of their tick-burden, the salve not only provides protection from tick-borne diseases but obviates that check in growth which heavily tick-infested lambs sustain ".

(3) Dr. Dunlop, Advisory Officer in Animal Husbandry, has carried out work on many problems pertaining to hill farming. In the field of animal nutrition attention has been paid to the important role of minerals.

(*a*) The results obtained in wide scale dosing trials in south-west Scotland demonstrates that areas of cobalt deficiency are more extensive than would be assumed solely from the occurrence of clinical symptoms in sheep. There was a significant increase in fertility among ewes which received a dose of cobalt before tupping, and while this was most marked on pining or vinquish grazings, improvements were also obtained on farms outwith these areas.

(*b*) On the basis of strong presumptive evidence it was concluded that infertility in otherwise healthy hill cattle was frequently due to phosphorus deficiency. This view was confirmed by experiment. A high phosphate

mineral mixture was fed to the cattle *ad lib* commencing early in June when the bulls were turned out for the season. At marking time (late June) the following year the mineral fed group showed greatly improved calf records, approaching those typical of better grazings.

NORTH OF SCOTLAND COLLEGE OF AGRICULTURE

(1) Since the experimental farm of Glensaugh was acquired by the College in 1943 it has provided a very valuable means of focussing attention on hill problems and most of the College officers have been concerned to varying degrees with the implementation of programmes there. A brief summary of research work at Glensaugh is included in Appendix 2.

(2) *Improvement of Hill Grazings* : In addition to work done at Glensaugh, and largely as a result of it, many programmes of pasture improvement have been undertaken on hill farms in this province. These have generally included, amongst other measures, improvement of the grazing by direct reseeding and the introduction of cattle or an increase in their numbers. As a result output has been considerably increased and, on certain farms, it has been more than doubled.

Experience in the North of Scotland area may be summarised as follows :

(*a*) A well planned programme should aim, first, to improve the natural grazing, e.g., by the introduction of cattle, by surface drainage, systematic moor burning, etc.

(*b*) Supplies of winter keep must be increased by the improvement of the arable area (if any) and by direct reseeding of suitable areas of the open grazing.

(*c*) In order to prevent rapid reversion, reseeded areas must be fenced, cattle must be introduced in sufficient numbers to control summer growth and periodic applications of fertilisers, particularly phosphates, must be given.

(3) *Work by Veterinary Investigation Officer* : The most extensive of the specific investigations undertaken amongst hill sheep and cattle in the north of Scotland have been on "Black Disease", Hypocupraemia, and Aphosphorosis.

(*a*) "*Black Disease*" *in Sheep*

The first report of the occurrence of this disease was made by Jamieson, Thomson and Brotherston (1948)[3]. This report referred to the work commenced in 1946. Since then the disease has been shown to be widespread in Caithness and has been identified in widely separated areas in England.

As a result of large-scale field experiments it has been shown that the disease can be effectively controlled.

(*b*) *Copper Deficiency in Cattle*

Jamieson and Russell (1946)[4] reported the first occurrence of suspected copper deficiency in this country, in pasture which had been reclaimed from peat land and directly reseeded.

Following upon this work the existence of a form of the condition known as Hypocupraemia was reported by Allcroft (1946)[5].

[3] Jamieson, S., Thompson, J. J. and Brotherstone, J. G. (1948)—*Vet. Rec.*, vol. **60**, no. 1, pp. 11-14.

[4] Jamieson, S. and Russell, F. C. (1946)—*Nature, Lond.*, vol. **158**, p. 22.

[5] Allcroft, R. (1946)—*Nature, Lond.*, vol. **158**, p. 796.

Experiments have now been completed by Jamieson and Allcroft which prove the existence of Hypocupraemia in Caithness in an entirely new clinical form not previously reported. At the same time a blood- and liver-copper survey which is still in progress indicates that the condition is widely distributed in Caithness and occurs on hill farms in Inverness-shire.

Five long term experiments are in progress from which it is hoped fundamental knowledge of this important trace element deficiency will be forthcoming.

(*c*) *Aphosphorosis*

Following the recognition of Aphosphorosis in Skye in 1948 an extensive survey has been started throughout the Hebrides. Information already forthcoming indicates that its influence upon fertility in hill cattle may be considerable but the work is in its early stages and precise information is not yet available.

(4) *Sheep Dipping and Spraying*

Dr. W. Moore has been actively concerned with many aspects of dipping and spraying for the protection of sheep against blowflies and ticks. He has recently developed a technique for spraying sheep at convenient penning places on the hill using a small portable power unit. Farm workers can readily acquire the technique, and with a team of 5 men it has been shown that 800 sheep can be treated in $4\frac{1}{2}$ hours. The technique is still under test.

EDINBURGH AND EAST OF SCOTLAND COLLEGE OF AGRICULTURE

(1) Before initiating research programmes for the research and experimental farm of Sourhope, it was considered necessary to undertake a survey of existing conditions there. The College officers are co-operating to the greatest practicable extent in this work and a summary of the progress to date is given in Appendix 3.

(2) *Work by Veterinary Investigation Officer*

(*a*) Abortion in ewes in the Borders has received particular attention. Bacteriological examinations of large numbers of aborted lambs have been completed, but no pathogenic organism has been isolated from any case. Examinations for filtrable virus by chick-embryo culture have proved negative. Histological work is continuing in an endeavour to demonstrate virus inclusion bodies. A large-scale transmission experiment is also in progress (in collaboration with the Animal Diseases Research Association)*.

There is strong presumptive evidence for the view that tick-borne fever is associated with sheep abortion in other parts of the province. Field experiments in progress have indicated a reduced incidence of abortion in sheep which are made " immune " to tick-borne fever.

(*b*) In view of the inconstant results obtained in large-scale field trials with " orf " vaccine, further studies on the virus of contagious pustular dermatitis have been undertaken. Preliminary work on 8 strains of virus

* This disease has now been shown[6] to be caused by an infectious agent which in its morphological and staining reactions resembles the rickettsial and the psittacosis-lymphogranuloma group of infective agents as described. The disease occurs in flocks on tick free pastures. Work on control is in progress and shows promise.

[6] Stamp, J. T., MacEwen, A. D., Watt, J. A. & Nisbet, D. I. (1950)—*Vet. Rec.* vol. **62**, pp. 251-254.

indicates a considerable range in the characters on which immunisation depends. Work is proceeding on this problem. The bacteriology of secondary invasion of orf lesions is also under study.

(*c*) Orchitis in rams associated with *Corynebacterium pyogenes* infection and progressive face abscesses in sheep due to *Actinobacillus lignieresi* are not uncommon conditions, and are subjects of investigation.

(3) *Bracken Investigation*† : The general chemical composition of bracken samples collected at Buckholm Farm during 1947 agreed with available published data, but the tannin content was not found to vary in the way reported by Shearer (1945)[7] who postulated a relationship between tannin content and toxicity.

Matured dry bracken cut in Autumn 1947 had no nutritive value and contained only 1·43% digestible protein and 1·14% starch equivalent. Digestibility trials with sheep and bullocks showed that growing bracken had a nutritive value comparable to seeds hay in July, but in August the value was greatly decreased, particularly as regards digestible protein. No toxic effects resulted from continuous feeding with fresh bracken *plus* hay between July and September.

In samples oven-dried for analysis about 50 mg. hydrocyanic acid per 100 g. dry matter were obtained from the earliest spring growth. The concentration of cyanogenetic compounds was much reduced in mature bracken. A nitrogen and cyanide balance experiment was carried out on a bullock. The quantity of bracken consumed was low and the animal was able to deal satisfactorily with the cyanide constituent. The total nitrogen balance was negative owing to low food consumption and after only one month of bracken feeding the animal died with symptoms and post-mortem findings characteristic of " bracken poisoning ".

(4) *Improvement of Hill Grassland* : The advisory botanist is conducting a trial on top dressing hill grassland and cattle grazing on a farm near Galashiels.

A 6 acre plot top dressed with nitro-chalk at 2 cwts. per acre in spring 1947 showed earlier growth in 1948 and a marked alteration of its sward is evident. White clover has spread and Yorkshire fog has increased which accounts in part for its spring growth. The Yorkshire fog is readily eaten by the cattle and the plot never became rough during the grazing season of 1948.

(5) *Observations on Hill Vegetation* : Several areas in the Tweed Valley and on the Pentland Hills are examined by Dr. E. Wyllie Fenton at different times throughout the year. Field notes are made annually. These observations have been continued for many years, with particular reference to vegetation succession where heather (*Calluna vulgaris*) has been burned.

3. Miscellaneous Investigations

(1) *Helminths in Hill Sheep*

The assumption that helminths cannot be a major problem in hill sheep on account of the " light " stocking ratio is invalid, since although stocking is light in relation to the whole acreage it is very heavy on the small areas of good grass where the sheep tend to congregate. Conditions for helminth infestations are thus provided. By the summer of 1941 it was shown by

† *vide* footnote p. 8.

[7] Shearer, G. D. (1945)—*Journ. Comp. Path.*, vol. **55**, p. 301.

Dr. D. O. Morgan, Department of Zoology, University of Edinburgh, that an appreciable number of hill sheep, particularly lambs and hoggs carried fairly heavy worm burdens.

Between 1944 and 1946, following a recommendation by the *ad hoc* Committee work was continued with a grant-in-aid from the Agricultural Research Council and it was found that the rate of worm-egg output undergoes seasonal variations with a maximum in spring and a minimum in mid-winter.

In 1946 the Agricultural Research Council approved a considerable extension of this work, and a survey was begun on the incidence of helminths in hill sheep throughout Scotland. This work is in progress. The results to date indicate that helminthiasis is a major problem in hill sheep, and that losses could be reduced by adequate dosing at the proper time.

Further developments proposed are :—

(*a*) A study of the causes and nature of the " Spring rise " in worm-egg output.

(*b*) The incidence of the various helminth species in different seasons (*e.g.*, the " hook-worm " of sheep is far more common than is generally thought).

(*c*) The testing of dosing programmes.

(*d*) The effect of " wintering " on the worms in hoggs.

(*e*) An intensive study of the rate of development and survival of the various helminths on hill pastures. This work will present many technical difficulties and will probably take a long time. It should, however, place the studies on a sound basis and give a better understanding of the host/parasite relationships in sheep under hill conditions.

(2) *Ecology of the Sheep Tick*

In 1938, Dr. A. E. Cameron, Department of Agricultural and Forest Zoology, University of Edinburgh, initiated a field study of the biology of the Sheep Tick. The outbreak of war interrupted this work. The problem was later taken up by the Technical Committee on Insecticides† of the Agricultural Research Council and in 1943, to complement work in England, a grant was made to appoint a worker under Dr. Cameron to resume the studies in Scotland. This work is now completed, and is in prepartaion for publication.

The following findings are noteworthy :—

(*a*) While the physical environment (microclimate) is a limiting factor to tick-distribution on low ground, it plays a much less significant role on the hills. Experimental evidence indicates that ticks can survive long enough to complete their development within most types of hill vegetation. Relatively greater population densities have been found associated with certain plant communities (e.g. *Agrostis* - Fescue - *Juncus articulatus*) but the broad correlation obtained between tick-distribution and the nature of the vegetational cover is considered to be the result of sheep movements associated with selective grazing, and not to a differential survival rate of ticks.

(*b*) The life-cycle occupies three years : two types occur, in which the active feeding seasons are spring and autumn respectively. In the Border Hills only spring-active ticks are present, while in the Highland and Western regions spring-active and autumn-active populations coexist.

† Now Technical Committee on External Parasites.

(*c*) There is no evidence of the occurrence in Scotland and Northern England of predators capable of reducing tick-populations measurably, and only one insect parasite has been obtained in small numbers from Cumberland.

(*d*) The life-history of the tick presents no " weak points " at which it could be attacked by practical control measures except during its feeding periods, when hosts can be treated with acaricides. The general measures such as cultivation and reseeding suggested by workers in England and Wales are considered largely impracticable in Scotland, and in any case could only provide a partial solution by effecting a temporary reduction of tick numbers. *Further work on tick-control requires to be directed towards the development of effective sheep and cattle dips.*

(3) *Control of Sheep Ectoparasites*

In recent years there has been much local interest in the problems of control of sheep ectoparasites, in particular sheep-ticks and sheep-maggot flies. Trials on behalf of commercial firms had been included occasionally in the work of Veterinary Investigation Officers, and of various other members of staff of the Agricultural Colleges. In addition to such trials, some workers had been engaged on independent investigation of the properties of insecticidal agents applied as *ad hoc* preparations. Materials were supplied according to individual specification, in some cases by the Chemical Research Laboratory of the Department of Scientific and Industrial Research and by commercial organisations in others. Our attention was brought to this field by a letter from Dr. D. D. Pratt of the Chemical Research Laboratory, in which he pointed out that it was not the function of the Department of Scientific and Industrial Research to supply small quantities of insecticidal preparations to individual workers, since the compounding of such materials could not be regarded as chemical research ; and he suggested that it would be more satisfactory if the workers concerned could state their requirements through a co-ordinating body when the Chemical Research Laboratory could give advice regarding the purchase of experimental materials from chemical manufacturers. Further, in view of the fact that none of the Scottish workers was able to devote more than a part of his time to these problems, it was considered desirable that they should be familiar with each other's aims and results, and that their programmes of work should be complementary as far as possible.

With these points in mind, the Committee referred the subject to a Sub-Committee (Convener: Dr. J. Russell Greig) to review and co-ordinate the work.

Work was planned by the Sub-Committee in consultation with all the workers concerned, and with the aid of special grants from the Agricultural Research Council has been carried out under the following heads :—

(i) Field trials with D.D.T. (M.37) against ticks and comparison of dipping and spraying, by methods of biological assay and chemical analysis of washes and fleece.

(ii) Small scale field trials at Glensaugh to compare the action of various toxicants against ticks.

(iii) Trials with salves containing 10 per cent. and 20 per cent. dibutyl phthallate for protection of lambs against ticks.

(iv) A comparison of the skin response of Blackface, Cheviot, and Swaledale - Herdwick lambs to the application of D.B.P. salves, to ascertain the cause of erythema observed in some cases in 1947.

(v) Comparison of D.D.T. (M.42) and Arsenical dips in control of blowfly strike.

In the course of these experiments it has become clearly evident that the whole technique of dip assessment under field conditions requires critical examination, and this is particularly emphasised where trials on blowfly control are concerned. Further, the physico-chemical problems involved in the application of insecticides and acaricides to farm animals are exceedingly complex, and it is considered that there is a large field of work on these fundamental aspects, whose completion is a prerequisite for the satisfactory advancement of work on control in the practical sphere. These questions have been brought to the notice of the External Parasites Committee of the Agricultural Research Council. The report of the Sheep Dips Sub-Committee is included in Appendix 4.

(4) *Bracken Research*

In view of the very serious part it plays on hill farms the bracken problem has received constant attention. We have been fully informed of the results of the work on bracken cutting at Castle Semple and Touchmollar obtained by the Committee set up for the purpose by the Department of Agriculture for Scotland 1934-1943, and have kept in touch with the work carried out on bracken control at Ballochraggan, Stirlingshire. We have visited this farm to view progress and discuss the problem with Professor Braid of the West of Scotland Agricultural College and his assistants. We feel, however, that no real progress can be made until fundamental knowledge on the relationships of this plant in nature has been considerably amplified. This view is also held by the Agricultural Research Council who have set up a Committee to organise and co-ordinate work on the biology and control of the bracken plant. Two of our members serve on this Committee. Under the Council's programme studies on the autecology of bracken are in progress at the University of Glasgow. A detailed study of the life history and the factors which influence it includes the following subjects :—

(*a*) Germination of spores and spore viability.

(*b*) Development of the prothallus.

(*c*) Production of young sporophytes, their development and reaction to different soil conditions.

(*d*) Maturation of the sporophytes. Time of appearance of fronds, distribution of sporangia on fronds and dates of dehiscence.

(*e*) Asexual propagation. Fragmentation, regeneration and bud development in mature rhizomes.

Investigations are proceeding concurrently in England under the Council's programme and include general studies in the synecology of bracken communities, studies on the physiology and nutritional requirements of bracken and trials with herbicides for bracken control.

(5) *Heather Management*

There have been frequent reports on the subject of deterioration of heather grazings in various parts of the country, particularly in the North of England and South of Scotland. It is repeatedly affirmed that the acreage of heather has been diminishing to a marked extent for some years past, and we have been strongly impressed by the urgency for undertaking work on this most valuable food plant. Since the problem of heather management involves not

only the question of securing maximum productivity of heather areas, but also the problem of maintaining its supremacy against undesirable plant competitors, it was considered that research should be undertaken to acquire detailed information on the ecological relationships of heather as well as from the point of view of heather management in the sphere of practical farming.

To this end we have appointed a Sub-Committee (Convener : Professor J. Walton) which includes botanical workers who have previously engaged in work on heather, or who are interested in certain of its aspects (including ecological, nutritional and general management). The function of the Sub-Committee is to determine which lines of work will be most profitable and which can be undertaken with the resources and personnel at present available. At the first meeting it was agreed that, before detailed consideration of programmes could be contemplated, a comprehensive review of existing British and European literature on the subject should be prepared. With the aid of a grant from the Agricultural Research Council a worker was appointed to review the literature under the direction of Professor Walton in the Department of Botany, University of Glasgow. The report and recommendations of the Sub-Committee and the review of literature are given in Appendix 5.

(6) *Distribution of Fertilisers by Aircraft*

The Balfour of Burleigh Committee laid particular stress on the restoration of fertility to the hills and the inby land. They had four main objects in view—

(*a*) adequate nourishment of the ewe stock,
(*b*) home wintering of ewe hoggs,
(*c*) better finishing of store sheep, and
(*d*) cattle-keeping capacity.

The restoration of fertility of inby land we feel is a matter for the application of existing knowledge and not our direct concern except in so far as it may be affected by the work on complementary pastures, already referred to, being undertaken by the Scottish Society for Research in Plant Breeding.

With regard to hill land, the Balfour of Burleigh Committee suggested the possibility of using aircraft. The relevant part of their Report, page 26, paragraph 67 states :—

" The use of aircraft for the distribution of lime and manure on steep or rough hill land has been suggested. The idea is attractive, and aircraft have been successfully used for certain agricultural purposes in other parts of the world. We recommend that experiments be put in hand immediately through whatever agency may be found most convenient for the purpose of seeing whether this new instrument of immense power and range can be used to restore fertility to the hills."

Preliminary enquiries were made by the Committee which preceded us, and they recommend that the subject be pursued.

We have held discussions with the R.D. Airborne Division of the Ministry of Supply, and the Mechanical Engineering Branch of the Royal Aircraft Establishment, Farnborough. It was concluded :—

(i) That with present resources only two types of aircraft were available which could be used to raise sufficiently large loads, namely Lancaster and Lincoln Bombers.

(ii) That the load could be carried in underslung canvas slings and released by the bomb-release mechanism.

(iii) That before trials could be made in a hill area it would be necessary to carry out preliminary tests in a Ministry of Supply dropping zone in England to examine the effect of different methods of packing the loads, upon their spread after release, and scatter after impact.

With the wholehearted co-operation of these bodies, preliminary trials have been completed, and it has been shown that the technique can be adapted to produce a very satisfactory distribution of 10,000 lbs. of lime in one flight at the rate of from approximately one to five tons per acre as required.

A report on these trials is given in Appendix 6.

Although the trials indicate great promise the expense of employing this type of aircraft renders it improbable that the technique referred to could be adopted in practice. The problem should be kept under close review, however, and the possibility considered of employing new types of machine such as transport aircraft carrying the load in the fuselage, and helicopters capable of raising greater loads, when they are developed and become available*.

Distribution of minerals, of course, is only one means towards the end of herbage improvement.

(7) *Sheep Breeding*

It was the intention to establish a hill farm for genetic research on hill sheep. This will now form a part of the Animal Breeding and Genetics Research Organisation under Professor R. G. White. We have, however, had carried out by Professor J. E. Nichols of University College, Aberystwyth, a survey of breeding systems and practices in hill sheep flocks, with a view to exploring the possibilities for future research on this subject. His report is given in Appendix 7, and it will prove very useful when the actual programme of research comes to be planned.

We have noted with interest the recommendations made by Professor Nichols and have discussed in particular his suggestion that a Hill Sheep Production Research Station should be established. At this stage, however, it is difficult to appreciate in concrete terms the implications of the phrase " physiology under field conditions ". We agree without reservation that a

* Independent work on aerial top-dressing of hill land has been carried out in recent years in New Zealand. Hill land vegetation there has been shown to respond to low rate application of superphosphates alone, and using aircraft of considerably smaller capacity than those described in Appendix 6, New Zealand workers have developed a method of distribution from the air employing pelleted materials distributed by gravity flow through a hopper. (*Vide* Campbell, D. A.[8] and others.[9, 10]) The method has been developed commercially in New Zealand.

Following the New Zealand work the Bristol Aeroplane Company have developed the technique further employing the Freighter Type 170 which has a payload capacity of 6 tons. In conjunction with the *Farmers Weekly* they have carried out trials on the Filton Airfield (*vide* Farnes[11] and Smith[12, 13]), and a public demonstration at Plynlimon. Their results show a satisfactory solution to the technical problem of top-dressing hills from the air at rates up to 2 tons per acre, and it would appear that future consideration should be concerned with the economic aspects.

[8] Campbell, D. A. (1950), "Aerial top-dressing in New Zealand."—*Soil Conservation & River Control Council*, Misc. Pub. No. 9.

[9] Lynch, P. B. (1950), " Top-dressing Hill Country by Aircraft."—*N.Z. J. Ag.*, vol. **80**, No. 4, p. 309.

[10] Hadfield, W. V. (1950)—*British Agricl. Bulletin No.* 11 (In the Press.)

[11] Farnes, W. R. (1950), " Farming from the Sky II."—*Farmers Weekly*, vol. **32**, No. 12, p. 54.

[12] Smith, C. S. (1950) " Farming from the Sky III."—*Farmers Weekly*, vol. **32**, No. 17, p. 52.

[13] „ (1950) " Fertility from the Air."—*Farmers Weekly*, vol. **33**, No. 10, pp. 46-51.

fuller knowledge of the physiology of sheep is greatly to be desired, but we cannot envisage the techniques which would be applicable under field conditions. There is still room for a considerable amount of work under controlled conditions and more information from this source would appear to be a prerequisite for undertaking physiological investigations under the complex conditions of the hill farm. We are unable, therefore, to support this recommendation at the present juncture and suggest that it should be reconsidered when further experience has been gained from the organisation of research on the three Hill Farm Research and Experimental Stations.

Following the publication in *Scottish Agriculture*[14] of an article by Dr. Allan Fraser in which he suggests that the hardiness of Blackface sheep has been impaired in recent years, we have had discussions on the subject with the Blackface Sheep Breeders' Association, and have begun an enquiry to ascertain whether there has been such a deterioration. This enquiry, which is being conducted by the Animal Breeding and Genetics Research Organisation, will also secure information on changes which have taken place in the breeding and management of Blackface sheep during the last 30 or 40 years. An interim report on the progress of the enquiry is given in Appendix 8.

(8) *Destruction of Vermin*

We have been reminded on several occasions of the losses sustained by farmers through foxes, crows and gulls. The Blackface Sheep Breeders' Association has drawn our attention to the lack of any practicable method of poisoning.

As a result of preliminary enquiries we understand that sodium fluoroacetate has been used in the United States of America, but it is extremely toxic to sheep and consequently could not be considered.

In Norway baits drugged with barbitone and phenobarbitone have been used with success for recapturing foxes escaped from fox-farms. These agents induce deep narcosis and the animal can easily be taken. The possibilities of using the barbituric acid drugs as a means towards humane destruction of vermin might be explored.

III. ECONOMICS

The great importance of a need for economic research has been kept constantly in mind. It was originally hoped that an agricultural economist would have been attached to the Committee but, on account of the great shortage of personnel, this requirement has not yet been fulfilled and we have had no opportunity to consider the organisation of such research. We wish to emphasise that economic research must be initiated at the earliest possible opportunity and studies on the economic aspects must form one section of the activities at the research farms.

IV. CONTACTS WITH THE INDUSTRY

While our activities have been concerned principally with matters of research and experiment, we have taken steps to preserve a proper perspective by maintaining contact with the sphere of commercial farming. In this we have received considerable assistance from our practical farming members, and

[14] Fraser, A. (1947)—*Scot. Agric.*, vol. XXVI, No. 4, p. 185.

through the Principals of the Colleges we have had opportunity to keep in mind the regional differences which occur in the problems of the industry.

We have made periodic visits to various parts of Scotland not only to observe experimental work in progress, but also for the purpose of meeting sheep farmers to discuss with them first hand the particular problems raised in their areas. A profitable tour of the North of England hill farming districts was arranged by Professor R. W. Wheldon and a report of this visit is given in Appendix 9.

An interesting tour of hill farms in Aberdeenshire was arranged by Mr. Maitland Mackie and we were impressed by the initiative shown by farmers in that area in the application of technical knowledge to effect improvements in their holdings. A brief note on this tour is given in Appendix 10.

We held a conference on Hill Pastures and their Improvement in the Department of Agriculture, University of Edinburgh, and a second one on External and Internal Parasites of Sheep in the University Department of Zoology. This method of bringing together scientists and technical advisers along with the practical farmer has much to be said in its favour, and we consider that conferences on other subjects could be arranged with advantage. While these conferences were both held in Edinburgh they could be repeated profitably at other centres, e.g., Perth, Inverness, Oban and Aberdeen.

V. RECOMMENDATIONS

1. Immediate Requirements at Hill Farm Research Stations

Steps should be taken to complete as soon as possible the constructional work planned by the Committee at the Sourhope and Lephinmore farms, namely, conversion of farmhouses into hostels for visiting scientific workers, erection of cottages for the farm staffs, reconditioning and reconstruction of farm steadings, construction of laboratories, post-mortem rooms, dippers, etc., so that these farms can be operated at the earliest possible date as Research Stations.

(It may be noted here that the slow progress of such constructional work at Sourhope has created a considerable delay in initiating research work at this farm.)

The preliminary and general survey work at these farms, as regards soil, vegetation, stock and their diseases, etc., should be carried out immediately, this being an essential prerequisite to the formulation of the research programme.

As soon as these preliminary surveys have reached the necessary stage, the Hill Farm Research Committee (reconstructed as we recommend later) should prepare a fully co-ordinated plan of observational and experimental research embracing all three research farms : Glensaugh, Sourhope and Lephinmore.

2. Research Work to be Prosecuted

The range of research work related to the problems of the hill farming industry has been outlined in detail in the Hill Sheep Farming Committee's (Balfour of Burleigh) report (pp. 62 and 63) and the relevant sections quoted by the *ad hoc* Committee in their report which is given in Appendix I. The *ad hoc* Committee further recommended the development of research on certain problems which they specified as of primary importance. We have

kept constantly in mind the recommendations of our predecessors, and in a previous section we have indicated the extent to which investigations on these problems are being prosecuted and progress which has been achieved. While it has not been possible previously to undertake integrated investigations under satisfactorily controlled field conditions, the establishment of the three research farms recommended by the *ad hoc* Committee has considerably extended the potential scope for such work. In consequence, we have now to consider not merely an expansion of research facilities but the possibility of new avenues of approach to the problems in question. It is convenient to divide the work into two main heads, namely :—

A. BASIC WORK

This includes those subjects which can be studied satisfactorily under conditions of relative isolation in Research Institutes, University Laboratories, or on commercial farms, etc. Under this head we should include such subjects as :—

(1) *Improvement of Hill Pastures*

i. General systematic surveys of hill pastures. Chemical analysis of soil and herbage. Botanical surveys, etc.
ii. Detailed studies on individual plant species, e.g., heather.
iii. Improvements by cultivation, drainage, etc.
iv. Weed control, e.g. bracken, coarse grasses, etc.
v. Cultivation for winter feeding.
vi. Breeding of species and strains of pasture plants suitable for hill conditions.
vii. Use of aircraft for the distribution of fertilisers and trace elements on inaccessible hill lands.

(2) *Physiology and Nutrition of Sheep and Cattle*

i. Nutritional values of various herbage plants. Mineral and other nutritional deficiencies.
ii. Minerals (including trace elements) in relation to sheep metabolism, e.g. the condition of pine.
iii. Physiology of rumination, lactation and reproduction in sheep.
iv. Dentition of sheep.

(3) *Animal Diseases and Parasitic Infestation*

(See also under Applied Research)

i. We recommend that particular attention should be paid to :—
   (*a*) those diseases whose etiology and/or control remains unsolved, e.g. tick-borne fever, tick pyaemia, scrapie, yellowsis, enzootic abortion of sheep, and bracken poisoning of cattle.
   (*b*) control of ectoparasites.
   (*c*) control of heminthiasis.

(4) *Sheep Breeding*

i. Analysis of the characters and qualities of sheep.
ii. Assessment of the importance of the respective characters in the survival and productivity of animals kept under different conditions, including those of extreme rigour.

iii. The correlation of various characters—for instance, conformation with milk production, fertility, fattening qualities and activity ; thickness of skin with fleece characters and milk production.

iv. Heritability of the different characters.

v. Influence on growth, fertility, milk production and fleece characters of environmental conditions, rain, wind, temperature, various levels of nutrition and kinds of food at different ages and different seasons.

vi. Study of the differences between breeds and types, including longevity, fecundity, milk production, ability to thrive and to utilise food of the very different kinds found on hill land.

vii. Systems of breeding—inbreeding, outbreeding, out-crossing—and their effects.

viii. Efficiency of different methods of selection, including progeny tests.

ix. Vital statistics of the sheep industry—e.g. size and duration of flocks, migrations of stock and age distribution.

(5) *Economic Studies*

B. APPLIED RESEARCH

Under this head we include those lines of work which cannot be studied in isolation, but which must be conducted under the natural conditions of a hill farm. In the broad sense, the aim of such work is to analyse the component factors of the environmental complex operating in the sphere of hill farming, and thus to assess precisely the resultant effects of different types of farm practice. We consider that the hill stations Glensaugh, Sourhope and Lephinmore should be employed to the greatest possible extent in this connection, and that work on isolated problems should be undertaken elsewhere whenever possible. The hill farm environment should be studied in close relation to the results obtained from fundamental work carried out at the appropriate Institutes, University Departments, etc., on the one hand, and to the technical and economic problems raised by practical experience on the other. Two classes of work may be envisaged on the Hill Farm Research and Experimental Stations, namely :—

Observational, by which is meant the systematic accumulation of data on all aspects of hill farming, without the introduction of any major alterations in routine farm management.

Experimental, which involves the introduction of one or more factors which were not previously operative (i.e. experimental work implies an alteration of the environmental complex).

(1) *Observational Work*

This branch of the work which will, for some time at least, be the more productive, should be carried out on common lines at all three farms and should include the following items :—

i. Primary surveys of botanical and soil patterns on all three farms.

ii. Continued vegetation records.

A continuous survey of the herbage composition should be made on all farms to establish a basis for :—

(*a*) Studies on changes in vegetation balance in relation to such factors as the effects of animals and their selective grazing habits, and of accepted practices (e.g. burning) in the management of " black " and " white " land on competition between different plant species.

(*b*) Assessment of the factors which produce pasture deterioration and reduction of heather acreage, and which cause imbalance in favour of undesirable plants such as bracken, bessom moss (*Polytrichum commune*), deer's hair (*Scirpus caespitosus*), and on better land moor mat-grass or white bent (*Nardus stricta*) and purple moor-grass or flying bent (*Molinia coerulea*).

(*c*) The effect of afforestation on the ecological balance.

iii. *Records of Stock*

All sheep should be numbered so that individual records may be kept of fertility, lambing histories, milking qualities, wool growth and quality, dentition, nutrition and hardiness, and the growth of lambs. Records should also be kept in such a way that analyses can be made of the breeding policies adopted, and the basis of selection of lambs for the breeding flock critically examined periodically. Detailed records of the incidence of diseases and pests should also be kept.

Similar records of cattle herds should include breeding, fertility, crossing, production and disease data.

iv. *Meteorological Records*

The establishment of the three research farms as official meterological stations will provide invaluable information regarding the effect of geographical differences, and year to year changes in climate on the environmental complex.

v. *Economic Records*

In addition to routine farm accounting, it is important that precise details should be kept of the economic aspects of all experimental projects, so that new methods can ultimately be assessed in relation to the economic structure of hill farming in the various districts.

We consider that the results of careful observational work on the above lines will lead to a much more accurate appreciation of the nature and significance of the problems of hill farming, and will suggest lines upon which future experimental programmes can be framed. They will also provide an indication of the questions upon which fundamental information is most lacking.

(2) *Experimental Work*

The utilisation of the Hill Research Stations for experimental purposes is a matter which will require very careful consideration at a later stage. We recommend, however, that when it is decided to embark upon experimental programmes involving, as they will in some cases, a radical change in the general environment of the farm, the following conditions should obtain :—

i. There should be adequate agreement among the workers concerned that the observational work has reached a stage where there will be no serious loss of information through premature alteration of conditions.

ii. The number of projects launched on each farm should be limited to avoid interference of the requirements of one series of experiments with the controls of another.

iii. The experimental programme should be framed so that the work is distributed over the three farms according to the facilities that each presents and that this programme should represent, to the greatest possible extent, *an attempt to solve the general problems of Scottish hill farming, and should not distintegrate into a series of three programmes concerned with individual farm problems.*

The initial experimental programmes will depend in part upon the specific problems presented by the farms and problems of the districts in which they are situated (as well as problems arising out of the observational surveys), since it would be impossible with specific problems outstanding to achieve a satisfactory relation between particular cases and general conditions. Examples of such specific problems would include :—

(*a*) Abortion in sheep at Sourhope.

(*b*) The particular problems of the Cheviot breed at Sourhope.

(*c*) The factors causing the low lambing rate at Lephinmore.

(*d*) Ticks and blowflies at Lephinmore and Glensaugh.

(*e*) The changes in farm organisation involved through afforestation at Lephinmore.

(*f*) The factors causing infertility in cattle at Glensaugh.

(*g*) Tick-borne fever at Sourhope and Glensaugh.

For some time at least it would be desirable to continue work at Glensaugh on the lines already begun and to concentrate on the various aspects of grassland improvement, together with studies on wintering of stock.

Among the experimental projects which could be studied to advantage on the Research Stations, we would include the following :—

(*a*) Improvements by cultivation, manuring, and reseeding hills ; and by establishment of complementary pastures.

(*b*) The effects of cattle grazing on pasture conditions.

(*c*) Methods of wintering sheep and cattle. Home and away wintering in relation to later development on hill grazings.

(*d*) Studies on sheep grazing habits. The relative importance of different plant components of sheep diet.

(*e*) Ecology of sheep pests—blowflies, liver fluke, and stomach and intestinal worms.

(*f*) Methods of conservation of winter food.

(*g*) Shelter belt planting.

(*h*) Disease problems.

Apart from the question of specific disease problems on individual farms, it is possible that an experimental approach could be made to some problems of etiology and epidemiology of certain sheep diseases in relation to nutritional, husbandry, and other factors.

3. Organisation of Research

(1) *Management of Farms*

To provide uniformity of organisation, the management of Lephinmore, at present in the hands of the Department, should be undertaken by the West of Scotland College on behalf of the new Committee. The day-to-day management of the farms should be in the hands of competent farm managers under the supervision of the College Principals. Farm management should be regarded as subordinate to the interests of research (experimental and observational) in all respects and the duties of the farm manager should be precisely defined in this regard. The manager should understand clearly that his duty is not necessarily to develop what would normally be regarded as good farm management, in fact at times he may be required to carry out measures in the interests of the research work which on a commercial farm would be considered wrong. For example, the policy regarding sale and purchase of stock should be decided by the Committee in consultation with research workers engaged on the farm. It is desirable that the farm manager should not only be interested in the investigations but that he should engage himself to a large extent in the collection of records, particularly records of the livestock. He should be directly responsible for arranging collections of stock and for notification of workers concerned.

(2) *Recording*

Day-to-day records would be kept by the resident farm manager, assisted by a resident recorder. For those lines of research work where records would be made at wider intervals, e.g. vegetation records, it is probable that perodic visits by specialist workers would be required. According to local circumstances the specialist recording might be undertaken by College Officers—e.g. in botanical and veterinary fields—or by other workers such as helminthologists, or in some cases it may be found necessary to appoint special officers. The resident recorder would be responsible for the continuous observations in so far as this work could be delegated by specialists for the intervals between their visits.

(3) *Experimental Programmes*

The responsibility for programmes of experimental work should rest entirely with the Hill Farm Research Committee. The Committee must determine future programmes in relation to the general problem and not merely approve programmes initiated locally. Sourhope and Lephinmore present no difficulties in this respect since there has been no experimental work undertaken at these farms up to date. In the case of Glensaugh, however, some modification of the present state of affairs will be required if the necessary unification of plan is to be achieved. Some limitation of the work in hand may be necessary and all programmes designed primarily for the purpose of demonstration will have to be abandoned. New developments must be closely related to the developments on the other farms on the basis of a unified and closely integrated programme.

The question arises of loss of demonstration facilities to the North of Scotland College, and this may also apply in the other areas. The need for facilities for work which is primarily demonstrational work must be regarded as a separate problem for which further provision should be made in connection with all three Colleges.

(4) *Liaison*

While the Committee can assume direct responsibility for the initiation of research programmes it cannot exert an effective or direct control over their implementation. It is suggested that a Scientific Officer on the Agricultural Research Council staff should be appointed for whole-time duties with the Committee. His apparent dual responsibility, i.e. to the Committee and, as a member of the staff of the Agricultural Research Council, to the Secretary of the Council should raise no difficulties as the Committee will work in the closest consultation with the Council in the initiation, encouragement and supervision of research. Further, the hill farm research programmes must harmonise and fit in to the broader programmes of research which are the responsibility of the Council.

Subject to the above the main duties of the Committee's Scientific Officer might be summarised as follows :—

(i) To receive the instruction and views of the Committee regarding schemes of research including, as they will, projects at Research Institutes, commercial farms, and the Hill Farm Research Stations ; and to report to the Committee on their implementation.

(ii) To maintain liaison with workers engaged on fundamental cognate problems in the Universities, etc., and to arrange for periodic meetings of all workers concerned.

(iii) To assist the Committee in keeping under review the practical problems of hill farming.

(iv) To take such steps as the Committee may recommend to maintain contact with developments in hill farming outside Scotland (United Kingdom and abroad).

It is considered highly desirable that the Scientific Officer should himself take an active part in research work and his duties should be devised so that opportunity is provided for him to pursue personal research.

(5) *Committee*

The development of an organisation as detailed above implies some degree of change in the function of the Committee, involving the assumption of certain executive functions along with the advisory duties of the existing Committee.

The terms of reference of the Committee might include the following :—

(i) To keep under close review the importance and urgency of practical problems arising in hill farming in Scotland and the North of England.

(ii) To frame and implement programmes of work for the research farms.

(iii) To advise the Department and the Agricultural Research Council regarding such steps as may be necessary to obtain extended facilities as the need arises, including additional research staff attached to Universities, Colleges or Research Institutes, or specially appointed for hill farm research.

To meet these requirements it is anticipated that some modification in the structure and personnel of the Committee will be necessary. Membership, which we think should be mainly scientific, might include :—

(*a*) Two nominees of the Agricultural Research Council.

(*b*) Three nominees of the Ministry of Agriculture and Fisheries.

(*c*) The Principals of the Agricultural Colleges, representatives of appropriate Research Institutes, and University scientists whose experience and knowledge would be helpful (appointed in consultation with the Agricultural Research Council).

(*d*) Three persons representing various hill farming interests.

(*e*) One or two members of staff of the Department of Agriculture.

The Organisation detailed above should be put into operation for a period of three years and would be subject to review at the end of that period or earlier if the Committee so desire.

4. Relationship between Research and Practical Farming

The Committee should maintain the closest possible contacts with the hill farming industry so that they are fully acquainted with the practical problems of farmers and with the results of field trials and new methods undertaken by farmers themselves, so that promising results can be confirmed by carefully controlled scientific experiments.

The Committee should endeavour to convey to the industry existing knowledge of practical importance, by arranging in co-operation with the Agricultural Colleges for appropriate lectures to be given and conferences to be held in various centres in England and Scotland. We may go so far as to say that the fullest application of modern knowledge and methods depends largely upon adequate training being given to shepherds and we should like to feel that this problem will receive attention in the proper quarters.

5. Veterinary Services in Relation to Research

The veterinary services available to the hill farming industry should be extended and improved, so that no hill farmer will lack the personal advice and guidance of a Veterinary Officer in dealing with problems of animal health and disease. We specially emphasise the need for such intimate veterinary service, for we consider that there is much economic loss in hill farming through lack of veterinary investigation and advice, particularly in parts of the country remote from the main centres. We are also impressed, from recent experiences, with the great possibilities of field investigations on prevalent conditions of disease by specially qualified veterinary officers and we regard an extended Veterinary Service as one of the most important instruments in hill farm research.

6. Sheep Breeding

Among the most important and fundamental problems of the industry at the present time are those concerned with the rationale and basis of practical sheep breeding, and particularly the selection of breeds and types suitable for the various districts. The *ad hoc* Committee recommended the active prosecution of research on sheep breeding and the institution of a special experimental farm for the purpose. Since then the Agricultural Research Council's Animal Breeding and Genetics Research Organisation has come into being, and the work referred to will now fall within the province of this organisation. The Hill Farm Research Committee, however, should play an important part in promoting and assisting work on this subject.

7. Agricultural Machinery for Improvement of Hill Lands

The Committee should maintain close contacts with the development of agricultural machinery applicable to hill farming, e.g. in draining, ploughing and reseeding, distribution of fertilisers, etc.

They should also take steps to keep themselves informed regarding future developments in transport types of aircraft, and trials should be made when aircraft become available which would be suitable for the distribution of fertilisers and trace elements. When satisfactory results have been obtained in preliminary trials, field trials should be carried out in appropriate hill areas.

8. Economic Research

We are disappointed that no progress has yet been made in providing for more research to be undertaken into the economic problems of hill farming. The importance of this branch of research was stressed by the Balfour of Burleigh Committee and by the *ad hoc* Committee which preceded the present Committee. We, ourselves, pressed, in the first instance, for the appointment of an officer, on the Department's own staff, to undertake specific research on hill farming problems but we understand that shortage of trained and experienced staff has so far prevented such a specialist appointment. We express the hope that this initial development, to be complemented by an increasing contribution from the Colleges, will not be much longer delayed. Our broad plan for an intensified scientific attack on the complex problems of the industry will be incomplete without the research economist. He is required not only for his own contribution to the solution of many problems which are essentially economic in character but also for collaborative work with other research scientists who are at present too often handicapped for lack of a just appraisal of the economic implications of the problems they are facing or of the economic soundness of possible solutions to these problems.

ACKNOWLEDGMENTS

We wish to record our high appreciation of the able services rendered to the Committee by our Secretaries, Mr. J. R. King and Mr. O. Beattie, and of the valuable technical and scientific assistance we have received from our Technical Secretaries, Dr. Allan Fraser and later over a period of nearly three years, Dr. J. Allan Campbell to whom we are also specially indebted in respect of the preparation of this Report.

(Signed) T. J. MACKIE, *Chairman*
J. V. ALLEN
T. L. BYWATER
J. RUSSELL GREIG
JOHN KIRKWOOD
MAITLAND MACKIE
MICHAEL G. MCDIARMID
W. H. SENIOR
J. FAED SPROAT
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J. A. SYMON
JOHN WALTON
STEPHEN WATSON
ROBERT W. WHELDON
R. G. WHITE

J. ALLAN CAMPBELL, *Technical Secretary*
O. BEATTIE, *Secretary*
22*nd March*, 1949.

APPENDIX I

SIR PATRICK LAIRD, C.B.,
Chairman,
Agricultural Improvement Council for Scotland.

SIR,

AGRICULTURAL IMPROVEMENT COUNCIL FOR SCOTLAND

HILL FARM COMMITTEE REPORT

We were appointed a Committee of the Agricultural Improvement Council to examine in detail the recommendations on research of the Balfour of Burleigh Departmental Committee on Hill Sheep Farming in Scotland, and to report to the Council. In examining these recommendations we have given special consideration to the means whereby they could be best implemented.

We have met three times and in addition have visited the Glensaugh Experimental Station of the North of Scotland College of Agriculture, Fettercairn ; Ben Challum Ltd., Glenlochay, Killin ; the bracken eradication experimental area of the West of Scotland Agricultural College at Portend, Port of Menteith, and typical hill farming country in South-West Scotland and in Sutherlandshire. We were particularly impressed by the improvements effected on pasture conditions by the application of existing knowledge, as exemplified by the work done and in progress at Glensaugh, Glenlochay and Portend.

1. Research and the Need for Expansion (pages 62 and 63 of Hill Sheep Farming Committee's Report)

The relevant part of the Report is quoted :—

" There remains great scope for organised research related directly to the problems of the industry. Such research is wide in its range and of considerable complexity, but it may be broadly outlined and exemplified by the following brief summary :—

A. THE IMPROVEMENT OF HILL PASTURES AND THE MARGINAL LAND OF FARMS

(1) Systematic surveys of hill pastures : chemical characters of soils, deficiencies in essential elements, botanical characters of herbage, grazing value of herbage.

(2) Improvements by cultivation, manuring and reseeding : implements, manures, and their selection and methods of application, effects of manures on growth and persistence of pasture plants, selection of seeds and values of different species and strains of pasture plants for hill conditions (see paragraph 67 in regard to the use of aircraft).

(3) Improvements by irrigation from natural springs.

(4) Effects of cattle grazing on pasture conditions.

(5) Effects of rotational heather burning.

(6) Methods of bracken control.

(7) Cultivations for winter feeding of sheep and cattle

B. PHYSIOLOGY, NUTRITION AND GENETICS OF HILL SHEEP, AND THEIR HUSBANDRY

(1) Nutritional values of various types of pasture herbage, results of nutritional deficiencies (e.g. mineral, vitamin, etc.) ; supplementary feeding to remedy deficiencies.

(2) Part played by various minerals in the metabolism of sheep.

(3) Physiology of ruminant digestion.

(4) Genetical and other factors influencing growth and character of wool.

(5) Physiology of lactation of sheep.

(6) Fertility and sterility.

(7) Hormonal influences on reproduction, lactation and metabolism.

(8) Methods of wintering sheep in relation to their later condition on hill grazings, and methods of home wintering.

(9) Breeding policies, in relation to " hardiness " on hill grazings : inherited adaptation to adverse environmental factors, and selection of rams.

(10) Meat quality from the nutritional and genetical standpoints.

C. CAUSATION AND CONTROL OF DISEASE, INCLUDING THE CONTROL OF PARASITIC INFESTATION

(1) Ecology of the tick (*Ixodes ricinus*) in various areas of Scotland, factors influencing its prevalence and survival, and the chemical control of tick infestation of sheep and cattle ; methods of clearing tick infested land.

(2) Ecology of maggot-flies, factors influencing myiasis by these flies and their chemical control.

(3) Control of infestation by helminth parasites, anthelmintics and their practical application.

(4) Causation and control of " pine " in various areas of Scotland.

(5) Prevention and treatment of tick-borne fever.

(6) Causation and prevention of pyaemia of lambs following tick-bite.

(7) Vaccination of lambs against louping-ill.

(8) Causation and prevention of scrapie.

(9) Nature and prevention of pregnancy toxaemia.

(10) Causation and prevention of enzootic abortion.

(11) Photosensitisation and " yellowisis ".

(12) Influence of nutritional deficiencies on susceptibility to microbic diseases and helminth infestation.

If in the future, as we hope, extended use is made of hill grazing for the rearing of cattle, additional problems in connection with the husbandry of these animals will also require investigation.

D. THE ECONOMICS OF FARM ORGANISATION AND MANAGEMENT

(1) Economic analysis of various types of hill farm organisation and management.

(2) Economic value of associating other farming enterprises with the breeding of sheep.

(3) The problem of the most economical size of holding.

(4) Critical evaluation of improvements as regards practicability, productivity and economics.

We have considered this comprehensive programme of research on hill sheep farming problems and have ascertained that at present most of the subjects specified are under investigation at Agricultural Research Institutes, Agricultural Colleges, or University departments, and, further, that quite recently steps have been taken by the Agricultural Research Council to intensify and extend research on certain problems, notably in regard to the eradication of bracken, while plans are being made for developing organised research on other subjects referred to in the programme. The Balfour of Burleigh Committee recognised, of course, that many of the subjects mentioned were already being inquired into but felt bound to emphasise the special importance of intensifying investigations likely to solve the many difficult problems of the industry.

Accordingly our recommendations on this part of the Report are directed mainly towards the development of research work on particular problems which we consider of primary importance.

We therefore recommend :

(*a*) that immediate arrangements should be made for organised systematic surveys of hill soils and hill pastures.

We have noted that, in regard to work on deficiency of trace elements the only suitable spectrographic apparatus available for such work in Scotland is at the Macaulay Institute, and we recommend that similar spectrographic apparatus be supplied for use at (1) the West of Scotland Agricultural College, Auchincruive, and (2) a centre in South-East Scotland where problems in animal nutrition, as distinct from purely soil studies, can be investigated.

(*b*) that work on the comparative nutritional value of pasture plants should be developed ;

(*c*) that research on breeding of species and strains of pasture grasses should be intensified and extended, including work on the possibility of adapting to Scottish hill lands new types of pasture plants, e.g. from other parts of the world ;

(*d*) that research work on the effects of grazing cattle on hill pastures should be extended and along with this a study should be made of the problems of cattle husbandry in hill conditions ;

(*e*) that methods of providing winter keep on hill farms should receive further immediate attention, particular regard being paid to the securing of accurate data in order that the economic significance of the results may be assessed ;

(*f*) that enquiries be pursued with a view to throwing further light on the feasibility of using aircraft for the distribution of lime, etc., on steep or rough hill land.

In this connection we have been in communication with the Air Ministry, Department of Civil Aviation, who have asked for the following information :—

(i) the precise location of two or three sample areas that might be treated in order that they could examine the topographical and meteorological difficulties to be overcome ;

(ii) the densities of the substances to be applied and the minimum interval that should elapse between applications of lime and phosphate ;

(iii) the total application of the substances per acre ;

(iv) whether the cost of any experiments would be met by the Department of Agriculture.

We consider that this matter now calls for administrative action by the Department of Agriculture if the Improvement Council and the Agricultural Research Councils approve the enquiry.

(*g*) that dental defects of sheep in relation to nutrition should be thoroughly investigated. A review of the existing knowledge of this subject is particularly required and it is suggested that the Imperial Bureau of Nutrition should be asked to undertake this ;

(*h*) that immediate attention be given to genetical research in relation to hill sheep. We have taken evidence on genetical matters from Dr. Nichols of the Imperial Bureau of Animal Breeding and Genetics, and Dr. Greenwood, Acting-Director of the Institute of Animal Genetics, Edinburgh University, and in light of that evidence, with which we are in full agreement, we regard it of importance ;

(*a*) that there should be carried out in Scotland an objective survey by a geneticist of breeding systems and practices, and of breed structures with a view to assessing the present genetical status of sheep stocks and the practical significance of those problems likely to be most directly susceptible to attack by genetical methods, and

(*b*) that an experimental farm solely for genetical research should be instituted with a flock of about 600 ewes.

We suggest that the objective survey might be undertaken by Dr. Nichols.

(*i*) that though much work on the ecology of the tick and of the maggot-fly and on the control of these parasites is in progress, even further intensification of such research is called for.

We are informed that at the Glensaugh Experimental Station, promising results have already been obtained in controlling tick infestation by means of a new insecticide designated " D.D.T.". It is hoped that this work may be extended next year at Glensaugh and elsewhere in view of the possibility of controlling tick-borne diseases by this means.

(*j*) that, while much work has been done and is in progress on diseases of the sheep for which satisfactory control measures have not yet been discovered, the possibility of extending and intensifying this work should be considered. We have noted the considerable losses this year, particularly in the South-West and the North of Scotland from " Yellowsis ", a manifestation of photosensitisation ;

(*k*) that a research economist should be appointed for the purpose of studying the economic problems of hill farming as indicated in the programme of the Balfour of Burleigh Committee's Report.

In relation to the economics of hill farming we would suggest that The Scots Wool Utilisation Committee recently set up by the Scottish Council on Industry should be asked to ascertain from the users of Blackface wool how desirable it is for that wool to be graded on the farm and in what manner, and whether a demand exists for a finer type of wool or any particular improvements in that wool which could be produced by suitable breeding.

2. Co-ordination of Research (page 65 of Hill Sheep Farming Committee's Report)

We strongly support the recommendation of the Hill Sheep Farming Committee that there should be appointed a Permanent Hill Farm Committee of the Improvement Council with the duties as set forth in their Report (page 65, paragraph 184), viz. :—

(i) To keep in touch with the progress of scientific research on the specific problems affecting hill sheep farming, and also with experiments in new farming methods, and to advise the Department through the Council, in consultation with the Agricultural Research Council, what steps should be taken to test promising results with a view to their introduction into general practice.

(ii) To expedite the incorporation into ordinary farming practice of new knowledge proved to be generally applicable ;

(iii) To review the problems of farmers in order to advise, in the light of current agricultural policy, on problems needing scientific investigation or increased scientific attention.

3. Hill Farming Research Station (pages 65 and 66 of the Hill Sheep Farming Committee's Report)

The Balfour of Burleigh Committee recommended the establishment of a field station, situated in a selected hill farming area where it would be in immediate contact with the more serious problems of the industry, and at which would be brought to bear on these problems all the appropriate branches of science. They also recommended the appointment of a director and of a small nucleus staff of experienced investigators to which additional investigators could be seconded for particular work, from the existing research institutes, etc. " Mobility " of at least part of the research organisation was also postulated so that field investigations could be extended to other parts of the country since a single locus might not serve for all subjects of research.

We have gone into the question of the establishment of a hill farming research organisation in considerable detail and we consider, that in present circumstances the purpose of the Balfour of Burleigh Committee's recommendations would be implemented as follows, and we recommend :—

(i) Three experimental sheep farms (in addition to the farm for genetical research already recommended) should be established immediately, one of which should be the Glensaugh Experimental Station of the North of Scotland Agricultural College, already referred to, on which much work of immediate practical importance to the hill farming industry is already in progress, the other two being located, one in the West of Scotland (e.g. Argyllshire) and one in the South of Scotland (e.g. the Borders). Regarding the last-mentioned the Committee dealing with comparable matters in England has suggested that a

joint station might be set up in the Border country to serve the needs of the North of England and the South of Scotland. We favour this suggestion which, however, we consider is one for mutual arrangement with the English Improvement Council and the Agricultural Research Council.

(ii) The Agricultural Colleges should be responsible for the day to day management of the farms within their respective areas, and research facilities should be provided at the farms for visiting scientific workers from the Research Institutes, Colleges and Universities so as to encourage workers from the central Institutions to take part in field experiments on hill farming problems. Such facilities are being made available at the Glensaugh Station.

(iii) The general management of these farms and the programmes of work to be carried out at them should be subject to the approval of the permanent Hill Farm Committee which would be assisted by a Scientific Sub-Committee on which there should be appropriate representation of the main scientific interests involved.

The Scientific Sub-Committee should consider the national research programme as a whole and could arrange for the delineation of work appropriate to each farm. The Hill Farm Committee would also examine the programmes of work in relation to the needs of the industry.

(iv) A specially qualified scientific officer should be appointed to the staff of the Department of Agriculture who would act as scientific secretary of the permanent Hill Farm Committee and who would maintain the necessary contacts with the Research Institutes, Colleges, etc., and the industry. This appointment is considered necessary as it would be clearly impossible for a committee as such to keep in immediate touch with all the interests involved, and it is felt that in the type of organisation proposed a permanent officer will be required to assist in co-ordinating research work on hill sheep farming throughout the country.

(v) The work on these farms should be essentially experimental and research work. A limited amount of demonstrational work might be included provided research is not prejudiced, but the introduction of new and improved methods in the industry should be secured by developing existing organisations in the Colleges for this purpose and by extension of the existing " demonstration farm scheme ". It would, of course, be one of the duties of the Hill Farm Committee, as indicated earlier in the report, to take all steps necessary towards promoting such application of existing and new knowledge to practical farming.

While we consider that the above recommendations accord in the main with the recommendations of the Balfour of Burleigh Committee on Hill Sheep Farming in Scotland we do not ignore the possibility, should our recommendations be accepted, of it being found necessary at some future date and in light of the experience which would then be available to the permanent Hill Farm Committee, to review the position ; but we feel that the organisation recommended is sufficiently flexible to allow of changes being made, including, if necessary, the establishment of additional experimental farms in other parts of Scotland.

In dealing with the various matters that came before us we have felt that it was inappropriate for a temporary committee to pursue enquiries and discussions beyond a certain point. Our report, therefore, must be regarded as an " interim " one on the wide subject embraced by the research recommendations of the Balfour of Burleigh Committee, but so far as it goes it has

been designed to give some lead towards the implementing of these recommendations. If our proposals are adopted it would be for the Standing Committee to extend and develop the enquiries we have initiated and to advise in further detail regarding the setting up of the Hill Research Organisation, its activities and management.

(Signed) T. J. MACKIE, *Chairman*
IAN M. CAMPBELL
J. RUSSELL GREIG
MAITLAND MACKIE
J. B. ORR
W. H. SENIOR
J. FAED SPROAT
DUNCAN STEWART
J. A. SYMON
GEORGE WILSON

J. R. KING, *Secretary*
11*th December*, 1944

APPENDIX 2

GLENSAUGH HILL FARM RESEARCH AND EXPERIMENTAL STATION

Report on activities in connection with the improvement of grazings and health of stock

Work at Glensaugh on the improvement of hill grazings has been concerned with (I) methods of improvement, (II) studies on the effect of improved grazings on the growth and health of the stock, and (III) studies on the productivity of the natural herbage under controlled management.

I. METHODS OF IMPROVEMENT

(i) Ploughing and seeding on the inverted furrow. Adequate lime, fertilisers, cultivations and a grass and clover seeds mixture in 1944 produced on an area of 37 acres known as Lochhills a sward which has increased by many times the stock carrying capacity. The initial cost of the improvement was £14 10/- per acre.

An additional 7 acres was similarly improved except that 7 different seeds mixtures were sown in order to test the suitability of various strains and combinations of strains for the production of " out of season " grass.

(ii) *Seeding Without Ploughing*

In 1944 an area of 2 acres was seeded after the application of lime and fertilisers. The improvement in stock carrying capacity was not so immediate as in (i), but, at the same time, was quite remarkable. Reliable data of productivity is not available.

In 1948 26 acres of a Calluna dominant area were laid out to determine the relative value of (*a*) burning (*b*) burning+fertilisers and (*c*) burning and fertilisers+grass and clover seeds.

Conclusions from the data obtained from the areas seeded with different species and strains are :—

1. Persistence is a most desirable characteristic. It is most evident in the late " bred " strains, but commercial strains are much less satisfactory in this respect. With careful management, however, the persistent qualities of all strains of grass can be assisted and commercial strains can be successfully maintained. The best cover has been produced by rye-grass S.23 and this has persisted well.
2. When considering the question of wintering the most valuable grass strains are obviously those whose productivity is highest between October and April. For this reason the extreme late strains (e.g. S.23 ryegrass) and extreme early strains (e.g. Danish cocksfoot) have been the most useful.

There seems little doubt that, where ploughing is possible, increased productivity can be obtained more quickly and more certainly thereby than by direct seeding into the old sward. The success of the second method is very dependant on moisture for germination and shelter for the young seedlings. There are of course only very small areas on the hill which are ploughable, and immense areas where the second method in its various degrees is the only possible one.

II. STUDIES ON THE PRODUCTIVITY AND HEALTH OF STOCK ON IMPROVED GRAZINGS

(i) The data presented in Tables 1 and 2 show the number of hoggs wintered on the 37 acres of the Lochhills and the growth and mortality compared with that of a lot of similar hoggs wintered on good lowland temporary pasture. Generally the data shows that 2 to 3 hoggs per acre have been carried for the 6 winter months. About 2 cattle per acre have been carried during the summer except when the sward was undergoing a rest.

The rate of growth of the hoggs and their continued development have been satisfactory.

(ii) Studies of the health of the stock at Glensaugh have been of greatest interest where the management conditions have been controlled. Disease is not an isolated factor and the health of the animal must be used as a critical index of the value of pasture improvement.

For example, a study of the incidence of tick-borne fever as influenced by the system of wintering suggests that hoggs reared on a tick infected hill like Glensaugh tend to lose their immunity during an absence of 6 months and that it is essential to dip them before they return to the hill so that "immunisation" may take place gradually. Moreover, it has been shown by critical experiment that pregnant gimmers not "immunised by acclimatisation" will abort and often die when exposed to tick infestation.

With regard to control of ticks and protection of stock by dipping, little progress of practical significance can be reported either in the composition of the dips themselves or in the technique of dipping. Nevertheless, some interesting information on the behaviour of dips has been obtained which should be of help in future work.

(iii) On the basis of egg counts on faeces samples taken at intervals from the rectum of numbered hoggs, comparative observations were carried out during two winterings on flocks of hoggs wintered at home (Glensaugh) and away (Craibstone). There was no difference recorded between the worm-egg output of home- and away-wintered hoggs in either of the years. A selection from the data obtained is given in Tables 3-5, where it is seen that the worm-burdens were comparatively small in both years 1947 and 1948. While a spring increase in egg output was noted in 1947 (cf. findings of Morgan and Sloan in Southern Scotland[1]) no significant spring rise was noted in 1948.

[1] Morgan, D. O., & Sloan, J. E. N. (1947)—*Scot. Agric.*, vol. XXVII, No. 1, p. 28.

III. STUDIES OF THE PRODUCTIVITY OF THE NATURAL HERBAGE UNDER CONTROLLED CONDITIONS

Glensaugh Hill is dominated by heather and heather associations. There is no doubt that this plant is valuable at certain times and under certain conditions. Its potentialities under management are little known but studies are proceeding to obtain further information on the subject. The effect of good wintering can be seen in the general " character " of the ewe stock and in the size and weight of the " cast " ewes.

General

While it is probably true that improvements to the grazings have, in general, increased the stock carrying capacity of Glensaugh, it is probably also true that the introduction of cattle in considerable numbers has, in turn, led to further improvement, since in winter cattle consume much of the herbage not edible to sheep. The original purpose in introducing cattle was to improve the grazing for the sake of the sheep, but it is now apparent that the cattle enterprise on this farm has become economically the more important. Since 1944 the number of ewes has remained stationary although their size and productivity have increased, but the number of cattle has increased from 2 to 200. The net income from cattle is now approximately 50% greater than that from sheep. The optimal balance of cattle and sheep stocking has now to be determined, and this will obviously depend upon the supply of winter food.

TABLE 1
HOGG WINTERING DATA

Where Wintered	As HOGGS					As GIMMERS 1–2 yr. old			As EWES 2–3 yr. old			As EWES 3–4 yr. old		
	At beginning of Wintering			At end of wintering										
	Date	No.	Av. Wt. lbs.	No.	Av. Wt. lbs.	Date	No.	Wt. lbs.	Date	No.	Wt. lbs.	Date	No.	Wt. lbs.
1943														
Purchased Away	—	—	—	—	—	16.10.46	68	99·14	15.10.46	40	100·56			
Away	—	—	—	—	—	,,	27	90·34		17				
	—	—				,,	97	89·65		78				
1944 Away	16.10.44	120	65·3	118	70	26.10.45	106	95·73	16.10.46	98	96·8	20.10.47	87	105·9
Home	,,	70	65·67	68	87	,,	68	100·98		64	97·7	,,	55	108·1
1945 Away	15.10.45	80	68·3	79	77·24	16.10.46	52	94·3	20.10.47	44	105·0			
Home	,,	120	68·34	119	65	,,	101	86·25		78	98·9			
1946 Away	15.10.46	100	66·34	92	53·82	20.10.47	82	86·7	15.10.48	77	95·4			
Home	,,	100	66·18	99	59·8	,,	83	88·7		78	97·2			
1947 Away	20.10.47	78	62·47	77	82·08	15.10.48	74	103·4						
Home	,,	80	63·57	80	78·25	,,	77	98·8						

TABLE 2
HOGG MORTALITY

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Total
1945–46 Away (80)	—	—	—	—	1	—	1	18	2	—	1	—	23
Home (120)	—	—	—	—	—	1	—	8	2	—	2	—	13
1946–47 Away (100)	—	—	—	—	—	5	3	1	1	—	—	—	10
Home (100)	—	—	—	—	1	—	1	1	3	1	—	—	7
1947–48 Away (78)	1	—	—	—	—	—	—	2	—	—	—	1	4
Home (80)	—	—	—	—	—	—	—	2	—	—	1	—	3
1948–49 Away (81)	—	—	—	1	—	—	—	—	—	—	—	—	1
Home (81)	—	—	—	—	1	—	—	—	—	—	—	—	1

TABLE 3

Tables 3–5 are selected from Dr. Robertson's data to show the worm burden of two flocks of Blackface hoggs, one flock wintered at home (Glensaugh), one flock wintered away (Craibstone). The figures indicate the mean egg content of one gramme of faeces on each occasion. N=*Nematodirus spp.* ; and Os=other species of Strongyle worms including *Haemonchus contortus, Trichostrongylus spp., Cooperia spp., Ostertagia spp., Chabertia spp.*, etc.

Glensaugh Flock				Craibstone Flock			
Date	Number of Samples	Flock mean Eggs/Gramme Faeces		Date	Number of Samples	Flock mean Eggs/Gramme Faeces	
		N.	Os.			N.	Os.
27.11.46	49	55	432	2.12.46	50	10	374
4.12.46	50	34	290	9.12.46	49	30	510
12.12.46	50	32	380	16.12.46	49	10	369
18.12.46	50	12	348	23.12.46	49	6	418
26.12.46	50	12	392	30.12.46	47	17	363
2. 1.47	50	16	348	6. 1.47	50	10	322
8. 1.47	50	10	330	13. 1.47	49	15	316
15. 1.47	50	8	264	20. 1.47	50	0	222
22. 1.47	50	16	244	27. 1.47	48	0	183
27. 1.47	50	8	236	3. 2.47	40	7	242
5. 2.47	49	4	124	17. 2.47	45	10	288
27. 3.47	49	29	308	10. 3.47	47	31	461
3. 4.47	49	14	344	24. 3.47	47	30	463
10. 4.47	47	68	590	7. 4.47	47	45	382
16. 4.47	48	29	533	14. 4.47	44	55	656
24. 4.47	48	25	650	21. 4.47	42	36	652

TABLE 4

Glensaugh Flock				Balnastraid Flock, Craibstone			
Date	Number of Samples	Flock Mean Eggs/Gramme Faeces		Date	Number of Samples	Flock Mean Eggs/Gramme Faeces	
		N.	Os.			N.	Os.
11.12.47	15	147	180	13.12.47	21	5	76
30.12.47	24	50	179	30.12.47	23	30	130
12. 1.48	24	21	120	13. 1.48	23	9	113
26. 1.48	23	13	113	26. 1.48	21	10	280
10. 2.48	25	16	196	9. 2.48	22	0	140
23. 2.48	24	19	158	23. 2.48	—	—	—
8. 3.48	25	28	124	8. 3.48	—	—	—
19. 3.48	25	32	184	19. 3.48	23	0	73
5. 4.48	19	0	105	5. 4.48	22	0	36

TABLE 5

Combined Flocks at Glensaugh

Date	Number of Samples	Flock Mean Eggs/Gramme	
		N.	Os.
26. 4.48	47	0	80
10. 5.48	45	2	42
27. 5.48	36	0	88
7. 6.48	38	0	84
28. 6.48	45	0	60
12. 7.48	45	0	93
26. 7.48	39	0	164

APPENDIX 3

SOURHOPE HILL FARM RESEARCH AND EXPERIMENTAL STATION

When Sourhope was selected as a locus for an experimental and research centre, it was known to be a farm with a recent history of sheep losses, and in this respect it could be regarded as representative of the Bowmont Water district, which though formerly a prosperous sheep farming area had fallen to the position where farming tenants had become difficult to obtain. There is thus a direct stimulus to experimental workers to seek means of establishing methods to develop a profitable enterprise which would be applicable to this and other areas of the country. Before progressive research can be developed, however, it is a *sine qua non* that changes should be measurable and referable to an established datum. On this account it has been decided to delay efforts to improve the farm so that a precise assessment can be made of the existing situation, and an accurate appreciation can be formed regarding the relative significance of the different problems it presents.

A survey is in progress, and is in the hands of the appropriate members of staff of the Edinburgh and East of Scotland College of Agriculture. The following are the principal aspects :—

I. DISEASES AND HEALTH OF STOCK

A preliminary report on this subject has been published by the Veterinary Investigation Officers[1]. They conclude that the main disease problems are :—

(i) *Abortion and Barrenness.* Out of 1,126 breeding sheep, 247 failed to produce a surviving lamb in the spring of 1948 (i.e. 22 per cent. of the flock), and of these 146 (or 13 per cent. of the flock) aborted near lambing time.

(ii) *Helminthiasis.* During the severe winter and adverse spring of 1947, losses of sheep expressed as percentages of the respective categories included : Blackface ewes 17 per cent, hoggs 27 per cent., Cheviot ewes 12 per cent., hoggs 56 per cent. In view of the occurrence of clinical symptoms of parasitic gastro-enteritis, the particularly heavy mortality among hoggs was significant. Worm populations of from 5,000–20,000 were found in the stomach and intestines of some of the carcases examined. There is little doubt that an epidemic of parasitic gastro-enteritis associated with the overcrowding during hay feeding, etc., was responsible for a large part of the mortality.

(iii) *Tick-borne Diseases.* Although the tick population is very small in comparison to other parts of the Borders, tick-pyaemia is a prevalent condition in lambs of the Schil hirsel. The incidence rate and importance of tick-borne fever have not yet been determined.

[1] Stamp, J. T. & Watt, J. A. (1948)—*Scot. Agric.*, Vol. XXVIII., No. 2, p. 101.

(iv) Several other sheep diseases have been recognised but appear not to be responsible for more than small losses. Cobalt deficiency pine which has been reported to be an important source of loss in this area has not yet been recognised at Sourhope. Controlled dosing experiments are being carried out to determine whether cobalt deficiency does in fact occur.

II. PASTURES AND VEGETATION

A map survey of the hill pasture is being carried out by the Advisory Botanist. About half the area has been surveyed to date, and the major plant communities have been recorded. Bracken infestation is sufficiently serious to demand attention, and it is considered that there is scope for studying not only the practical issues of bracken control, but also for work on the biology of bracken including such features as the rate of spread, the relation to soil and vegetation, and the effect of bracken canopy on the associated herbage.

III. SOILS AND THEIR NORMAL VARIATION

A survey of the soils is to be undertaken by the Advisory Chemist and it is hoped in due course to relate the findings to extended surveys of adjacent farms to determine how far the soil status of Sourhope is typical of the area. Detailed sampling and analysis will be carried out on selected sections to determine the normal variations which occur on hill land of this type. Both major nutrients and trace elements will receive attention. The results of these surveys will be related to the vegetation surveys.

Work in the immediate future will be devoted to a completion of the preliminary surveys and it may be necessary to extend these before a research programme can be initiated.

In addition to the survey work described, records are being kept in detail regarding the development, breeding and production of the stock. When Sourhope was acquired at Martinmas 1946, breeding stock figures were below the level which might be regarded as the carrying capacity of the farm. The heavy losses experienced in the following winter effected a further reduction. It has been essential, therefore, to purchase ewe lambs to raise the numbers to normal levels. Since the farm is situated in an area which was formerly concerned solely with the Cheviot breed, particular attention will have to be paid to this breed and its problems when future work is considered. Not only will the existing Cheviot stock be increased on Sourhope but a flock of North Country (Sutherland type) Cheviots is being built up on the adjacent farm of Auchope which previously carried no sheep stock. A hirsel of Blackfaces is being maintained for comparative purposes. The numbers of breeding sheep are shown in Table 1. A nucleus herd of hill cows (First Cross Highland heifers) has been introduced, and it is proposed to increase this to 25 in the first instance, and at the same time to introduce a herd of 25 Blue-Greys on another part of the farm. The effect of cattle on hill grazings will be the subject of controlled experiment at a later date.

TABLE 1

Breeding-stock (Sheep) Figures

	Nov. 1946 (at Valuation)	1947		1948	
		July	November	July	November
Blackface					
Ewes and Gimmers	833	691	745	715	740
Ewe Hoggs	186	135	112	256	193
South Country Cheviot					
Ewes and Gimmers	274	241	385	382	403
Ewe Hoggs	285	125	29	29	67
North Country Cheviot (Auchope)					
Ewes and Gimmers	—	—	—	67	67
Ewe Hoggs	—	—	—	37	37
Tups and Tup Hoggs (all Hirsels)	38	34	47	41	33
TOTAL	1,616	1,226	1,318	1,527	1,540

APPENDIX 4

REPORT OF SUB-COMMITTEE APPOINTED TO CO-ORDINATE FIELD TRIALS WITH SHEEP DIPS IN SCOTLAND

Membership

Dr. J. Russell Greig, C.B.E., *Convener*

Dr. W. Moore Mr. S. Jamieson	...	North of Scotland College of Agriculture
Dr. D. S. MacLagan Mr. A. L. Wilson		West of Scotland Agricultural College
Mr. J. T. Stamp Mr. J. A. Watt	... ...	Edinburgh and East of Scotland College of Agriculture
Mr. G. B. S. Heath	...	Ministry of Agriculture and Fisheries
Dr. J. Allan Campbell	...	Agricultural Research Council (*Technical Secretary to the Committee*)

The following gentlemen have attended meetings and given valuable assistance—

Mr. T. Dalling	... ...	Chief Veterinary Officer, Ministry of Agriculture and Fisheries
Mr. J. N. Ritchie	...	Deputy Chief Veterinary Officer, Ministry of Agriculture and Fisheries
Dr. R. A. E. Galley	...	Agricultural Research Council
Mr. R. P. Tew	...	Agricultural Research Council
Dr. D. D. Pratt, O.B.E.		Assistant Director, Chemical Research Laboratory, Department of Scientific and Industrial Research.

Six meetings were held when programmes of work were planned and results discussed. Work was carried out on commercial farms in various parts of Scotland, and the Sub-Committee is indebted to the many farmers who kindly provided facilities.

The experiments undertaken included :—

1. Field trials with a D.D.T. emulsion, and comparison of dipping and spraying techniques for tick-control.
2. Small scale trials with new acaricides at Glensaugh.
3. Trials with dibutyl phthallate lamb salves.
4. Comparison of D.D.T. and arsenical dips for control of blowfly strike.

1. Field Trials with a D.D.T. Emulsion M37 for Control of Tick Infestation

In the course of work on sheep dips co-ordinated by the Agricultural Research Council, M37 was one of the D.D.T. formulations prepared by the Chemical Research Laboratory of the Department of Scientific and Industrial Research. It represents the only cationic emulsion examined hitherto in work on sheep dips, and is a miscible oil containing a D.D.T. solution in solvent naphtha acidified by acetic acid, and containing Fixanol C. as emulsifier. M37 was originally introduced for application as a spray, on the principle that a rapid deposition of D.D.T. containing globules would take place on the fleece through polar attraction. Under experimental conditions, however, Mr. G. B. S. Heath found that M37 used in a dipping bath as an anti-tick dip gave rather better results than neutral and anionic dispersions of D.D.T. There was doubt in this connection regarding the precise mode of action, and the significance of its cationic nature. Heath expressed the view that the emulsion in the dipping tank appeared to break after a few sheep had been immersed, and he assumed that the high level of protection afforded against tick infestation was the result of a heavy charge of D.D.T. crystal in the fleece. If this interpretation were correct, it would mean that dipping in M37 would be accompanied by a rapid fall in D.D.T. content of the bath in the initial stages of the operation, with a consequent reduction in protective value for sheep dipped at later stages.

Experiments, designed by the Sub-Committee, were carried out on two farms in Ettrick Valley under the supervision of Mr. J. T. Stamp, and were continued over the tick seasons of 1947 and 1948. In 1948 the scope of the experiments was extended to include a comparison between the normal dipping technique and the method of spraying devised by Dr. W. Moore using a portable power unit. The field evidence was supplemented by chemical analysis of samples of the dipping fluid taken at successive stages in the operation. The experiment involved a comparison of the rates of reinfestation of 6 sheep dipped in a newly prepared bath, 6 sheep dipped in a bath through which 80-100 sheep had passed, and 6 sheep sprayed by Moore's technique. Assessment of results in the field was carried out by the method described by Heath, which consists of estimating daily the incidence of newly attached ticks, and noting their sites of attachment, so that their engorgement rates and detachment times can be recorded during subsequent daily inspections. In this way a complete re-infestation history of all sheep can be obtained, and the effects of different treatments measured by comparison with untreated controls. Routine daily examinations were made by student recorders appointed for the purpose, and the method proved most satisfactory.

The detailed results of these experiments are in preparation for publication, but the general conclusions may be summarised as follows :—

(*a*) Complete protection for 5 weeks was obtained when sheep were dipped in freshly prepared baths containing a 0·5% dispersion of D.D.T.

(*b*) The passage of 100 sheep through a 350 gallon bath reduced the D.D.T. concentration from 0·5% to 0·02%, and sheep dipped at this stage became re-infested by the end of 1 week.

(*c*) After 80 sheep had been dipped in a 450 gallon bath the D.D.T. concentration was reduced from 0·5% to 0·08%, and sheep dipped at this stage were well protected against tick infestation for up to 4 weeks.

There is clear evidence (confirmed by analysis on a small series of fleece samples) that the high degree of protection obtained when small groups are dipped in freshly prepared baths of M37 is due to a heavy rate of deposition of D.D.T. in the fleece, but the rate of bath exhaustion is rapid. Since, however, a 0·08% dispersion of D.D.T. provided adequate acaricidal treatment with good residual properties it is clear that the rate of D.D.T. deposition from freshly prepared baths is excessive for practical needs. Thus, early dipped sheep are overprotected at the expense of later dipped ones, and emulsions of the M37 type are unsuitable for routine sheep dipping. The ideal to be aimed at is a dipping fluid which will readily deposit its active agent without premature bath-exhaustion.

(*d*) Under the conditions of experiment, the technique of spraying examined was quite unsatisfactory since re-infestation occurred within two weeks.

2. Small-scale Field Trials with New Acaricides at Glensaugh

During the summer of 1947 a series of trials was carried out at Glensaugh by Dr. W. Moore, to compare the values for tick control of emulsions containing (1) D.D.T., (2) D.D.T. + Coumarone Resin, (3) Toxaphene, (4) Chlordane (Velsicol 1068) and (5) Azobenzene.

Emulsions were prepared according to the general formula :—

Toxicant 20%
Solvent Naphtha 60% (Emulsion 2 included 20% Coumarone Resin and 40% Solvent Naphtha)
Linseed oil fatty acids 20%

Emulsification was obtained by addition of $1\frac{1}{2}$ parts ethanolamine and $\frac{1}{4}$ part sulphonated castor oil to 200 parts of water then mixed with 100 parts of stock solution. Toxaphene and chlordane were more readily emulsified than D.D.T. In each test the bath concentration of toxicant was 0·5%.

The results were disappointing, and the period of protection did not exceed 20 days in any case. Under comparable conditions of experiment, these preparations were inferior to M37, and the suggested explanation was that the method of emulsification gave dispersions with lower wetting power.

The persistence found was in the order :—

D.D.T.+Coumarone Resin>D.D.T.; Toxaphene>Chlordane>Azobenzene

Azobenzene gave a satisfactory initial kill but its persistence on the sheep was negligible.

3. Trials with Dibutyl-Phthallate Salves

According to previous work by Dr. D. S. MacLagan a salve consisting of dibutyl-phthallate in wool-grease acids was an effective preparation for protection of lambs against tick infestation. In 1947, Dr. MacLagan and Messrs. S. Jamieson and G. B. S. Heath undertook to repeat this work to compare the value of 10% and 20% D.B.P. salves.

Heath and Jamieson reported independently that they encountered difficulty in applying the smear on account of its hard consistency at field temperatures. Heath succeeded in smearing lambs after preliminary heating of the salve. After application by this method, there followed a severe local erythematous

skin reaction which became exudative, and healed ultimately after scabbing. These workers concluded that the preparation was highly unsuitable for the treatment of lambs.

As against these reports, MacLagan reported good results : no difficulties of application were encountered, and no cases of erythema occurred. Tick-infestation of treated lambs was markedly reduced, and at the end of summer treated lambs had greater live weights than untreated controls.

In view of the strongly conflicting evidence reported, chemical analyses were made on samples of salve submitted by the workers concerned, but they revealed no significant differences in chemical properties. In 1948, a test was carried out at Moredun Institute of the Animal Diseases Research Association to investigate the possibility of a breed difference in skin susceptibility. Six ewes and 6 lambs each of Blackface, Cheviot, and Swaledale-Herdwick breeds were smeared, so that every individual received a 10% salve on the groin and axilla of one side, and unmodified base (wool-grease acids) on the other. No case of erythema was observed on any individual. It was concluded that the erythema encountered by Heath in 1947 must have been due to mechanical abrasion of the skin ; this was probably associated with the fact that the cold weather in the spring of that year rendered the preparation too hard for easy application.

It is considered that a further trial with this preparation is necessary before it can be recommended for general use, and it is proposed to carry out a trial to include observations on the tick infestations by the method described in connection with experiments on M37, together with periodic weighings of treated and untreated subjects to determine whether the live-weight differences such as MacLagan reported are statistically significant.

4. Comparison of D.D.T. and Arsenical Dips for Control of Blowfly Strike

Experiments were designed to make a simple comparison between the protective action and its duration of a D.D.T. dip and a commercial arsenic dip. The D.D.T. preparation chosen was the formulation M42 of the Chemical Research Laboratory of the Department of Scientific and Industrial Research. This is a mayonnaise-type emulsion containing D.D.T. dissolved in solvent naphtha with sodium oleate as emulsifier, and Teepol X as a wetting agent.

Farms were selected in adjacent pairs, including all types from arable to hill farms. They were distributed through the counties of Perth, Angus, Clackmannan and Roxburgh, and Argyll, Ayr and Dumfries, and the trials were supervised by the Veterinary Investigation Officers for the respective districts. At one farm in each pair the sheep were dipped in M42, and at the other in the commercial arsenic dip.

The results of these trials have been published by Stamp and Watt (1948)[1] and their conclusions may be summarised as follows :—

(*a*) Over 70% of the strikes occurred on dirty sheep.

(*b*) Neither D.D.T. nor arsenic gave satisfactory control of strike on dirty sheep.

[1] Stamp, J. T., & Watt, J. A. (1948)—*Vet. Rec.* vol. 60, No. 28, p. 335.

(*c*) Assuming a satisfactory randomisation such that all the sheep populations at risk were comparable, there was evidence that the protection by D.D.T. persisted for a longer period (about 40 days) than that by arsenic (about 30 days) in the case of clean sheep.

CONCLUSIONS AND RECOMMENDATIONS

(1) Before new field investigations on sheep dipping are undertaken, it is recommended that work should be carried out on the formulation of new preparations of acaricides and insecticides including D.D.T., Benzene hexachloride, Toxaphene, Chlordane, etc. Such work can only be profitable if it is soundly based on a fuller knowledge of all the factors involved in the processes of dipping and spraying sheep. There is scope for extended work in the laboratory, and at research stations for investigations on the following lines, which we consider to be prerequisite for successful progress in this field of work :—

(*a*) Deposition of parasiticides on sheep fleece, hair and skin.

This would include physico-chemical investigations on the surface reactions, and polar relations between sheep fleece, etc., and the wash.

(*b*) Rate of exhaustion of dipping fluids, and the effect of various factors.

(i) Type of dispersion. Emulsions and their polarity. Dispersable powders.

(ii) Temperature.

(iii) Wet and dry fleece.

(*c*) The rate of deposition, and toxicant content of runoff in the process of spraying.

(*d*) Acaricidal properties *in vitro* of treated fleece and hair.

(i) Estimates of minimal lethal concentrations of different parasiticides.

(ii) Effects of varying modes of preparation and application of the washes.

(*e*) Residual qualities.

This involves chemical, and *in vitro* biological assay on hair and fleece samples taken from sheep at successive intervals after treatment.

(*f*) Mechanical aspects of spraying. Development and standardisation of spraying techniques in relation to items (*a*), (*c*), (*d*), and (*e*).

(*g*) In addition to these more fundamental questions, close attention should be paid to more practical issues such as stability of stock materials (e.g. a serious disadvantage of M37 apart from the features referred to above exists in the instability of the stock solution at low temperatures, when D.D.T. crystallises and resists resolution.)

(2) Following work on the lines indicated, we consider that field trials should be carried out. We believe that such trials are most profitably conducted when assessment is made by the method of Heath described above. Experiments must be carried out in tick infested areas where sheep can be collected daily for examination, and we are satisfied that routine examination can safely be left in

the hands of student recorders. We emphasise that too much reliance should not be placed on favourable reports by farmers whose views important though they are, are not always scientifically critical. In this connection we instance the experience in the blowfly experiment where some farmers who received a commercial arsenic preparation which has been marketed for many years, under the impression that it was a new experimental preparation reported that it was greatly superior to anything they had previously used.

(3) We are impressed by the possibilities of lamb salving for tick control, and consider that work on these lines should be developed, but we recommend that field trials should be made in accordance with the recommendations in paragraph (2).

(4) We are not satisfied with the techniques for assessment of dips for blowfly control since the problem is complicated by too many variables in the field. We suggest, therefore, that endeavours should be made to relate work on control to work on blowfly oviposition behaviour, and consider that the problem will be most readily advanced by studies on strike and its control under standard conditions where sheep can be exposed to experimental fly populations of known dimensions.

We have already brought these suggestions before the Technical Committee on Ectoparasites of the Agricultural Research Council, and note that their opinions coincide with our own, and that they propose to extend investigations on more fundamental lines in the near future.

(*Signed*) J. RUSSELL GREIG, *Convener.*

J. ALLAN CAMPBELL, *Technical Secretary.*

APPENDIX 5

REPORT OF SUB-COMMITTEE APPOINTED TO REVIEW POSSIBLE LINES OF RESEARCH ON HEATHER

Membership

Professor J. Walton, *Convener*

Professor J. R. Matthews	...	University of Aberdeen
Mr. Brynmor Thomas	...	King's College, Newcastle
Professor K. W. Braid	...	West of Scotland Agricultural College
Dr. E. Wyllie Fenton Mr. R. G. Heddle	...	Edinburgh & East of Scotland College of Agriculture
Dr. D. Clouston Mr. J. L. Dawson Mr. K. R. Wilson	...	North of Scotland College of Agriculture
Dr. J. Allan Campbell	...	*Technical Secretary*

There is abundant evidence that orthodox methods of reseeding and pasture renovation have played a big part in increasing the productivity of hill farming, but, with few exceptions, the application of such methods has been, and of necessity must for a long time be confined to the lower accessible slopes. Thus, the advantages to be gained by extension of cultivation are limited severely by the small size of the areas which can be so treated economically. The basis of prosperity of upland farming, therefore, lies in the productivity of the natural upland vegetations and their maintenance. Over a great part of the country, vegetation associations dominated by, or including varying proportions of heather form a considerable natural food source available for hill stock, and even where heather is of secondary importance to grass moors, as in parts of the Borders, it undoubtedly plays a part in serving as a complement to the grasses during winter when these are unproductive, and during periods of snow when they are inaccessible. Moreover, there is evidence that heather is a valuable source of essential minerals.

From reports that the heather sward in many areas is deteriorating, and from indirect evidence that in some instances heather is gradually being replaced by plants of inferior grazing value, it is clearly imperative that the problem should be tackled energetically. There is no doubt that much information is required both on the biology and ecological relationships of heather and upon its productivity for stock-rearing at different stages and under varying conditions, so that methods of management may be designed to give the maximum output compatible with the successful maintenance of healthy heather. Before concrete proposals for future investigations on these aspects could be put forward it was considered necessary that a detailed review should be prepared of all available published evidence on the heather problem.

With a grant-in-aid from the Agricultural Research Council, a review and summary of the literature has been prepared by Miss Isabella Lamont, B.Sc., Botany Department, University of Glasgow, and is given in Appendix 5 (a).

From a consideration of the review it is evident that further investigations are required, and these may be considered under the following heads :—

1. Methods of Heather Management

The features of heather management requiring study include the effects of grazing, manuring and burning. Burning is the chief, and in most cases the only operation of management which is possible, and this implies that from an immediately practical point of view attention should be focussed on this aspect. There must be a large body of empirical information in the hands of shepherds, keepers and others, regarding the immediate effect of, and subsequent regeneration of heather after burning by different methods, at different ages, in different associations with other plants, and on different soils. A wide survey designed to acquire systematically and collate such data would provide an invaluable background of information. This could be carried out most profitably by visiting a variety of heather moorlands, obtaining as far as possible exact information regarding the actual burning history together with complete data of the stocking history, and recording the present vegetational structure, the general character of the ground, and the rate of recovery of heather.

Following upon such a survey it should be possible to make provision for a longer range study of the regeneration of burned sites by selecting typical areas and recording the vegetational changes over a number of years. Areas burned in normal routine management would provide suitable sites for these studies in part, but it is probable that they would require to be supplemented by areas specially selected for experimental purposes, e.g. to investigate the effect of burning at an age earlier or later than the normal practice.

2. Fundamental Aspects of the Biology of Heather

There is need for a better understanding of the factors which influence the distribution of heather, and its capacity to thrive and compete with other plants under various conditions. As a first approach to these questions the growth habit of heather and other hill plants should be studied *in the field* in relation to soil, topography, and biotic influences. Much of this work could, and should be carried out in connection with the survey, and investigations on recovery after burning referred to above. Indeed studies on these lines would be essential for a proper interpretation of the data on regeneration.

In addition to the wider ecological studies in the field more knowledge is required of the life history of heather. Among the subjects requiring further study are included the germination of seed, growth of seedlings, habit and rate of growth, seed production in relation to factors such as soil acidity, mineral content, humus, soil aeration, etc., and the possible significance of mycorrhiza.

3. Further Work on the Nutritional Qualities of Heather

The nutritive qualities of heather have been studied on a Northumberland moor by workers from King's College, Newcastle, and interesting information has been advanced. Further work on these lines is in progress at Glensaugh.

There is good reason to believe however, that the productivity of heather may vary considerably from place to place where the soils are less favourable to heather than those studied on the moors referred to. It is, therefore, desirable that work should be undertaken on the growth, productivity, nutritive value and digestibility of heather from different moors where soil, climatic and other environmental factors are different. Much information on these points could be collected concurrently with the survey referred to above. It is stressed in this connection, however, that there is an urgent need for fuller information on the nutritional requirements of the Blackface sheep, so that work on the productivity of heather and other moorland plants can be viewed in the right perspective.

Recommendations

Arising from these considerations it is suggested that the Hill Farm Research Committee in consultation with the Agricultural Research Council should sponsor work on heather on the following lines :—

(1) A survey of conditions and practices is a desirable preliminary to the initiation on a large scale of experiments on management. This survey should consist of a critical assessment of the conditions of heather moors in different parts of the country and an examination of the detailed history of their management (stocking, burning, etc.) over as long a period as possible with a view to establishing the factors which have produced deterioration and, conversely, the optimal methods of management in relation to varying edaphic and climatic conditions. The survey should be regarded as of such importance that it should be made the special concern of a qualified botanist with ecological training appointed specifically for the purpose. The investigator should be attached to one research centre and have the guidance of a senior worker. It is desirable, however, that he should not be confined to one College area but have assistance from the Extension Staffs of all three Colleges.

(2) There is scope for further studies particularly in the field, on the structure of heather communities and their synecology, and further information is required on the biology of the heather plant. In this connection it is suggested that the Macaulay Institute for Soil Research should be approached regarding the possibility of undertaking work on the mineral and other requirements of heather.

(3) Further work should be undertaken on productivity, nutritional values, digestibility, etc., of heather from different localities and different conditions. It is suggested that the Rowett Research Institute should be asked to take up the question of the nutritional requirements of Blackface sheep in relation to heather and other moorland plants.

(*Signed*) JOHN WALTON, *Convener.*

J. ALLAN CAMPBELL, *Technical Secretary.*

APPENDIX 5(a)

CALLUNA VULGARIS: A REVIEW OF THE LITERATURE ON HEATHER

By Miss Isabella Lamont, B.Sc.

I. GEOGRAPHY

Distribution Area and Boundaries of Species

According to Beijerinck (3, 4), the chief area of *Calluna* extends over the greater part of Europe, with the exception of the south and east of the Mediterranean region. Over smaller stretches and in isolated places it grows in the adjacent parts of Asia and Africa, as well as in easterly North America. In Europe, the northern boundary runs from the extreme north of Norway (Magero, 71°5′N) over the Varanger Fjord to Alexandrovsk and further to the South-east via Yokansko in North Kola to the Kanin Peninsula, where the northern boundary is said to lie between 67° and 69°. In the northern part of the Rybatshi (Fishermen) Peninsula and in the island of Heinasaari, *Calluna* was no longer found, but it was found near Kirkenes (South Varanger). From Kanin, where *Calluna*, as in Kola, advances into the tundra, the northern boundary runs steadily south-east as far as the banks of the Rotshuga and the westerly slopes of the Timan Range, and through the former district of Vologda as far as the Ural. It passes these mountains approximately in the direction Cherdyn-Verchoturj (Ural region), then runs eastward in West Siberia via Turinsk as far as Tobolsk. Here the northern boundary, running south-east, meets the southern boundary, running from south-west to north-east. It begins in Morocco in the coastal area from Tangier to Tetuan, runs over Corsica and central Italy through Dalmatia to Bosnia, and then to the north through Slavonia. Avoiding the Bakony Wood and the Hungarian Plain, it goes in a wide arc southward through Siebenburgen, bends to the north again through Roumania, west of the Moldau, and then via Khotin to Vladimir. From there the boundary of the area bends eastward, round Podolia, and follows the 50th parallel at some distance via Ostrov and Zhitomir to Kiev. Further data for South Russia indicates that the boundary of the closed area runs from Kiev to the north-east, via Glukhov, Trubtshevsk, Bjelev, and Alexin (south of Moscow), and from there eastward in the direction of Kazan as far as Alatyr. *Calluna* also grows in several isolated spots. The Ural-Volga basin, like the basins of the Don, Dnjepr, Dnjestr, and Danube are all avoided with wide arcs.

In the west, the area is bounded by the Atlantic and the Arctic.

Calluna is found in the Azores, notably in Pico and Terceira ; in the British Isles (including the Channel Isles, Hebrides, Orkneys, Shetlands) and in the Faroes. In Iceland it is only absent in the north-west. A separate area is said to extend in East Thracia, from near Constantinople to just south of Burgas. (Beijerinck, 4.)

In America, *Calluna* has become well naturalised, and thrives in several places on the Atlantic coast between Quebec and New Jersey. (Beijerinck, 4.)

Horizontal and Vertical Distribution within the Main Area. (4)

Within the main area, *Calluna* is on the whole restricted to those parts where the following conditions are satisfied :—

(1) A small quantity of assimilable salts.

(2) A hydrogen-ion concentration of the soil between pH=3·5 and 6·7.

(3) No excessive fluctuations in the humidity of air and soil.

(4) In the far north, and the high mountains, a protecting snow cover during the winter months.

(5) Enough light.

Thus *Calluna* is lacking horizontally and vertically :—

(*a*) on the clay soils of river valleys and coastal areas.

(*b*) on strongly alkaline soils (marl, lime, etc.) if there is no acid cover of humus on which the plant can take root.

(*c*) in regions with a pronounced continental and steppe climate, without an efficient screen e.g. trees.

(*d*) on exposed places in the mountains where the winter storms sweep away the snow.

(*e*) in dark woods or other badly lighted places.

Climate. (4)

Calluna is a predominantly Atlantic plant of the cool temperate zone. It is found under the temperate rainy climate of West Europe, the humid boreal climate of East and partly North Europe, and the Mediterranean sea climate, which is also a moderately warm wet climate, but with hot dry summers and wet winters.

In Europe the following groups of vegetation with much *Calluna* may be distinguished :—

(1) *Boreal and Alpine heaths*, characterised by the presence of *Empetrum hermaphroditicum*, *Vaccinium myrtillus*, *V. vitis-idaea*, *V. uliginosum*, *Juniperus nana*, etc. They are spread over Fennoscandia and in the higher Alps. In these, *Calluna* is found as a locally characteristic species in the *Juniperetum nanae* union, etc. (2) *Atlantic Calluna-heaths of Central Europe*. In these *Calluna* appears as a locally characteristic species, together with *Genista anglica*, *G. pilosa*, *Sieglingia decumbens*, *Antennaria dioica*, etc. This vegetation type comprises also the true *Calluna*-heaths of the optimal region round the North Sea. (3) *South European Cistus-heaths*, of which the Mediterranean Cistion ladaniferi is sometimes rich in *Calluna*. Locally characteristic species are *Cistus ladanifer*, *C. salvifolius*, *Erica arborea*, *E. scoparia*, etc.

With these unions, several other local types may be distinguished e.g. in England and Scotland, Calluna-heath with *Ulex nana* and *Erica cinerea ;* in South England, West France, and North-West Spain, the heath rich in *Calluna*, with *Erica vagans* and *E. ciliaris*, in Ireland with *Dabeocia cantabrica*, etc. In East Europe, *Calluna* seems to become more and more of secondary importance e.g. in pinewoods.

Development of Heather Moorland

The conditions necessary for the development of heather moorland, according to Smith (54), are :—

(1) *Altitude.* Heather may occur at all elevations up to 2000 ft. and more. Altitude in itself has no direct effect on the distribution of heather moorland, and is only of importance when considered along with other factors.

(2) *Climate.* Where heather is dominant in Britain, there is a considerable and constant quantity of rain or aqueous vapour, long periods of drought occur rarely, the average summer temperature is low, while the winter is variable, and icebound conditions do not last long.

(3) *Soil Conditions.* The conditions of development of the heather association seem to be the presence of a peaty soil, poor in mineral content.

Development of Heaths on Bare Sand. (54)

The first step towards a heath vegetation on recently deposited sand is the consolidation of the loose drifting sand, and the provision of soil moisture. As a rule, the coast heath vegetation is dry, the heather being short and stunted, while the soil contains little organic matter.

Development of Heather Vegetation from Forest

The agreement between the upper limit of the principal heather area and the higher forest zones in Scotland is suggestive of a possible origin of the heaths from forests, and in many cases this was doubtless so. Graebner (24) ascribes the disappearance of forest to impoverishment of a naturally open soil by rain, assisted by the removal of timber, so that the materials necessary for vigorous growth are no longer available. The development of heath from forests may be accelerated by other changes, such as accumulation of humus and the formation of moor-pan (humus-sandstone). In contrast to Graebner, however, Farrow (17) thinks that heaths replace forests because of the degeneration of the forests by biotic attack of pastured herds and rabbits. It is this degeneration which causes exposure and leaching of the soil.

II. SOIL CONDITIONS

According to Wallace (62), the soil on which heather grows best and quickest is a dry black peat (probably mixed with silt) of sufficient depth to secure the necessary range for the fibrous roots to reach a regular supply of moisture. It grows well on " black topped " soil, which is black from a thin layer of peat, or from humus formed by the accumulations of dead heather leaves, and may lie on boulder clay or on various soils. On very poor soils, a dwarfed and stunted form appears, which grows very slowly.

Tansley (56) describes Callunetum thus :—

Heath comprising " heather moor ", on deep but relatively dry peat, which may be included in	" Grouse Moor "
(*a*) *Upland heath* whose peat is usually thin but may reach 12 ins. (30 cms) in depth ;	
(*b*) *Lowland heath* with a minimum of dry surface peat.	Heath

Farrow (17) carried out diggings on Cavenham Heath in Breckland, to obtain an idea of the soil. (1) Among luxuriant *Calluna*, in the typical heather areas, the surface layer to a depth of about 5 cms. consists of raw humus made up of decaying *Calluna* leaves and fragments of *Cladonia* and varied mosses. (2) A layer of humus and peat, very tough owing to the presence of heather roots ; the lower limit of this layer is indefinite, since the main roots run down locally into the next layer, but its thickness varies between 4 and 8 cms. (3) A layer of dark peaty material mixed with sand ; rather tough owing to the presence of *Calluna* roots, and usually about 8 cms. thick. (4) A very characteristic layer of a dark chocolate colour, consisting of sand darkened by humous compounds ; thickness about 15 cms. (5) A layer of sand particles cemented by humous compounds ; not usually hard, but quite definite, and constituting a moor-pan, a sort of soft black sandstone, usually about 5 cms. thick. (6) A stratum of sand particles cemented by iron compounds, forming an iron-pan, usually about 7 cms. thick, but often sending down cones to a distance of 25 cms. into the next layer (7) which consists of dark red sand and is usually about 30 cms. thick. (8) A stratum of light reddish sand about 30 cms. thick ; below this the sand gradually gets lighter in colour as the depth increases.

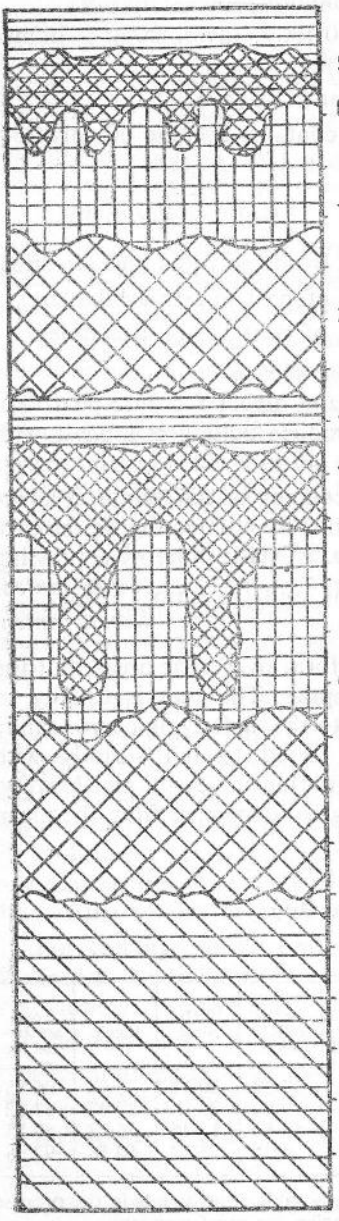
Cavenham Heath, with only slight pans and very moderate production of raw humus, is intermediate between dune-heath formation, from which hard-pan is absent and raw humus scarcely developed, and the typical *Calluna*-heaths of other places associated with hard-pan and abundant humus.

Analysis of sandy humus from luxuriant *Calluna*-heath :—(17)

Moisture determined at 100°C	6·6%
Humus	3·4%
Mechanical analysis of mineral portion :—	
Fine gravel (over 1 mm)	1·34%
Coarse sand (1—0·2 mm)	63·00%
Fine sand	15·50%
Coarse silt	2·45%
Fine silt	1·67%
Clay	3·30%

Calluna is known to be a strong calcifuge. The exchangeable calcium content is low (65), varying from 0·6 to 1·9 m.e., with average 1·2. Degree of unsaturation (i.e. amount of exchangeable hydrogen in the soil) varied from 87 to 94, average 90. The pH value ranges from about 3·5 to 6·0. The soil has a tendency towards rapid change of electric potential (41).

Calluna does however occur on various places on the chalk downs of southern England (49). These isolated and often sharply defined communities are apparently invasions, and occur on areas distinguished by the presence of heavy loamy soil, rich in mineral constituents though poor in lime. Although the thickness of the overlying deposits, and consequently the amount of calcium carbonate present in the rooting medium, apparently determine the distribution of the *Calluna*, functional roots were found in places growing into the chalk rubble, and small lumps of chalk occur occasionally within the rooting area. The soil on which *Calluna* is growing contains a relatively high proportion of magnesia, and it is suggested that this may be of significance, but so far no definite conclusions have been reached. With this exception, no evident edaphic factor was found to account for the successful competition of the heather. The soil was neutral in reaction.



1. SURFACE LAYER OF RAW HUMUS. (Decaying Calluna leaves etc.)
2. TOUGH PEAT Containing main roots of Calluna.
3. DARK PEAT AND SAND. (Rather tough — contains thin Calluna roots.)
4. SAND STRATUM. (Sand stained chocolate - colour by humus Highly characteristic of the Calluna heaths.)
5. BLACK HUMUS PAN. (Soft black sandstone.)
6. IRON PAN.
7. DARK RED SAND.
8. LIGHT RED SAND.

LIGHTER RED SAND.

(Beyond this depth, the sand becomes lighter red in colour.)

DIAGRAM OF TYPICAL SECTION THROUGH THE UPPER STRATA OF CAVENHAM HEATH. (After Farrow).

Water Content of Acidic Peats (13)

Calluna Moor. (28 analyses.) Peat shallow, impure.

(*a*) wet, with *Erica tetralix* present ; water 60-100% (aver. 90%) ; humus 20-50% ; water coefficient above 2·5 (aver. 3·3).

(*b*) typical ; water, aver. 85% ; water coefficient 2-2·8 (aver. 2·3).

Coarse sandy sub-peat, with quartz grains, contains average of only 25% water, but water coefficient is 2·5-3·5.

Wilting of Moorland Plants (13)

When wilting began, peat of soil was taken from the roots and air-dried.

Calluna in pure peat—1/5th of water-content of peat is non-available.

Calluna in sandy peat—1/7th of water-content of peat is non-available.

Water-Content of Air-Dry Soils when Wilting sets in.

Water: humus ratio is highest for heavy loam, and higher for pure peat than sandy peat. Conversely, the time taken to produce wilting is longest with sand and sandy peat, and shortest for loam.

The cause of the divergence of the water-content in different soil-layers is the varying quantity of humus present in them. By eliminating the humus, the real humidity of the habitat can be assessed. This is done by expressing the water-content in terms of the humus-content, and the ratio $\frac{\textit{water-content}}{\textit{humus-content}}$ is called the *coefficient of soil humidity*. (14)

Heather Moor Association. This is very uniform over wide areas, but the humus-content varies considerably with the depth. The peat is usually so shallow that the heather roots pass through it into the underlying coarse sandy soil—the " sub-peat ". The water-content is found to fall steadily with diminution of the humus-content, in spite of variation in season and locality. The coefficient of humidity, however, shows no great departure from the mean value. (14)

Chemical Composition of a Heather-Peat Profile (61)

Percentage of dry material.

Nature of Material	Total Ash	Protein	Ether-soluble material	Alcohol soluble material	Cold water soluble material	Hemi-cellul-oses	Cell-ulose	Lignin	Total accoun-ted for
Calluna stems	1·95	4·77	5·25	8·04	2·68	17·28	20·31	26·57	86·85
Calluna roots	1·41	3·19	2·10	5·93	1·62	19·94	26·28	27·05	87·52
Peat 60 cm deep	3·48	6·95	4·22	2·44	0·32	13·66	12·26	46·22	89·55
Peat 2m deep	6·82	11·08	3·75	2·84	0·34	4·37	3·22	60·56	92·98

Carbohydrates of plant residues are most readily decomposable constituents in the process of peat formation, while ether-soluble substances and lignins are most resistant.

III. COMPOSITION, GROWTH AND HABIT

Chemical Composition and Feeding Value

Various investigations of the composition of *Calluna* have been carried out by Thomas and other workers (57, 58, 59, 60) and by Lauder and Comrie (33). Samples were taken for examination from different places and altitudes, and of different ages, and also at different times of the year.

Average composition of 63 samples of *Calluna* from different places.
(Results as percentage of dry matter) (33)

	Nitrogen	Ether extract	Crude fibre	SiO_2–free ash	CaO	P_2O_5
	1·29	2·73	25·18	2·13	0·54	0·20
Limits	0·84–2·11	1·41–4·51	18·36–32·19	1·28–3·55	0·30–0·87	0·10–0·41

$=8·06\%$ crude protein

It was found that the percentages of nitrogen (proteins or albuminoids), silica-free ash, lime, and phosphoric acid decrease with age, while the percentages of " oil " (ether extract) increase steadily with age (33, 58).

The percentage of nitrogen (albuminoids) generally falls off as winter advances, and a similar decrease is also shown by the ash or mineral matter (32).

As the season advances, there is a fairly consistent fall in the amounts of certain minor elements in the edible parts of heather, most evident in chlorine, sulphur, and manganese, and with less consistency in iron. Sodium alone shows a definite rise during the growing season. In brief, the minor element content of the part of heather eaten by sheep is unaffected by age, but in general declines as the season advances (59). Liming reduced the uptake of magnesium, chlorine, inorganic sulphur, and manganese in heather. It appears that heather provides iron, manganese, copper, and cobalt in relative abundance (59).

It was found (60) that the bulk of the plant increases during a period of about 7 years after burning. The productivity of the crop in terms of edible material produced per unit of gross weight begins to decline at less than 7 years after burning. It was found that unexpectedly large weights of edible material were yielded by heather of all ages from 3 to 9 years, ranging from approximately 30 to 40 cwts. per acre. Admittedly not all of this material was produced in one season, but even if the winter-green foliage be estimated at from 30% to 40% of the whole, the annual yield of dry matter is still high.

For feeding, young heather is best during early summer, and its value declines to a minimum in early winter. In older heather, the season of the year appears to have small effect on the feeding value (58).

The water-content also is subject to very large fluctuations, and is in general smallest during dry and cold periods. The total ash content of *Calluna* ranges from 3·2 to 6·3% and the ash itself contains up to 48% SiO_2 (4).

Substances found in *Calluna* by Krijthe are :—

Albumin—in bark and medullary ray parenchyma.

Fat and suberin—in wood parenchyma and medullary ray cells, cuticles, and the cellwalls of the endodermis.

Glycose—in epidermis, endodermis, bark cells, and medullary ray cells.

Amylum—in wood parenchyma and medullary ray cells.

Inulin—in the whole xylem.

Tannic acid—in epidermis, endodermis, bark, periderm, medullary rays, and wood parenchyma.

Resin—in sub-epidermis.

Urson—mainly in the leaves, little in the stem.

Composition of Heather at 3, 5 and 7 years after burning (58)

		Sampling date :— June 20	July 28	Sept. 12	Oct. 12	Jan. 12
3 years after burning	Crude protein	12·93	10·16	9·55	10·12	8·74
	Ether extract	1·29	2·37	5·10	4·09	3·46
	Fibre	17·89	19·36	21·23	17·99	17·73
	Ash	4·81	4·34	4·26	4·15	4·05
	Nitrogen-free extractives	63·08	63·77	59·86	63·96	66·02
	Including :— True protein	12·26	9·43	8·68	9·36	8·59
	Including :— Phosphoric acid	0·38	0·41	0·30	0·32	0·31
	Lime	0·87	0·78	0·69	0·72	0·60
	True/crude protein ratio	0·96	0·93	0·91	0·92	0·98
5 years after burning	Crude protein	8·59	8·75	8·47	7·86	7·65
	Ether extract	2·94	3·83	4·51	4·28	3·86
	Fibre	19·59	20·62	21·11	20·25	18·05
	Ash	3·46	3·29	3·12	3·55	3·14
	Nitrogen-free extractives	65·41	63·74	63·05	63·30	66·76
	Including :— True protein	7·34	8·52	8·32	7·67	7·56
	Including :— Phosphoric acid	0·27	0·27	0·26	0·23	0·21
	Lime	0·67	0·78	0·81	0·76	0·85
	True/crude protein ratio	0·85	0·98	0·98	0·98	0·99
7 years after burning	Crude protein	7·46	7·52	7·43	7·22	7·10
	Ether extract	3·31	3·51	4·16	4·31	4·24
	Fibre	20·92	21·13	20·84	20·12	20·11
	Ash	3·92	3·79	3·75	3·87	3·18
	Nitrogen-free extractives	64·39	64·05	63·82	64·48	65·39
	Including :— True Protein	6·43	7·03	7·34	7·16	6·95
	Including :— Phosphoric acid	0·24	0·27	0·24	0·23	0·22
	Lime	0·85	0·85	0·82	0·78	0·94
	True/crude protein ratio	0·86	0·93	0·99	0·99	0·98

No certainty could be obtained of the presence of callutamic acid (=quercetin), arbutin, and andromedotoxin. The seeds contain in their endosperm much aleurone and oils. Gums occur between the cell-wall lamellae of the leaf epidermis. Other substances said to be present are fumeric acid, citric acid, catechintannin (with strong dyeing properties), ericolin, pentosans, cutin, myricitrin, carotin, calcium oxalate, and the enzyme arbutase.

Calluna, like most peat species, contains exceptional quantities of fats, which are responsible for the formation of their thick cuticles, and for the " secondary endodermis " below the primary one, and often later for pericyclic cork formed inside the secondary endodermis. The superficial tissues outside this die early, and disintegrate (41).

The abundance of fats is attributed to the deficiency of oxygen in the soil, involving anaerobic respiration in meristematic root cells, so that fatty acids are produced. The sour soils in which *Calluna* grows are deficient in calcium, and comparatively rich in sodium and potassium, giving a high " basic ratio " i.e. $\frac{Na+K}{Ca+Mg} > 1{\cdot}5$. Fatty acids formed anaerobically are carried up through the plant as soluble potassium or sodium soaps. If calcium were present, insoluble calcium soaps would be formed, and deposited on the cell-walls of the roots (39).

Calluna has a clearly marked secondary endodermis, without gaps, in young green stems about 1 inch in length. Endodermal cells relatively large and conspicuous. Nearer the growing point, a primary endodermis, with casparian strip, is indicated. Older stems showed, external to the phloem, 3 or 4 rows of suberised cork cells within the endodermis, cortex withering and easily crumbling away outside the cork. In the root, within the withered cortex, several layers of cork (41).

If peat plants are characterised by an abnormal quantity of fatty acid released as a result of the synthetic metabolism of the growing point, it may be that in the presence of sufficient supplies of calcium, a block of insoluble calcium soaps is produced, which hinders further supplies to the meristem. This would explain the fact that plants characteristic of peat are usually incapable of healthy growth in a soil containing a relatively high proportion of calcium. (It should be remembered that a calcareous soil is not one containing a definite amount of calcium, but a relatively high proportion of this cation as compared with other cations, e.g. potassium, sodium, magnesium, which form relatively soluble soaps with fatty acids) (42).

Seedlings of *Calluna* grown in pure culture, free from mycorrhiza, were examined. A striking feature found was the accumulation of fat in the cells at the base of the meristem of an abortive secondary root. It is suggested that this accumulation of fat may partly account for the lack of further development on the part of this root meristem. Further, it may be suggested that the growth of the meristem under normal conditions may be facilitated by the removal of excess of fatty acids as a result of the digestive activity of the mycorrhizal fungus (42).

Fats of the Seed. Mature seeds of *Calluna* were carefully separated from their fruits, and the fats extracted. When distilled under reduced pressure, these gave golden-brown oils. The weight of fat extracted from these seeds was a high proportion of the dry weight of the seeds taken, while the high iodine numbers (estimated by Wijs' method) indicated the unsaturated state of the acids composing the fats.

Weight of seed used	8·54 gms.
Average proportion of fat in seed	42·5%
Iodine number	132
Refractive Index (at 16°C)	1·4965

When a thin film of the oil was exposed to the air for a few days it dried to a firm elastic film, while a greater depth of fat became covered with a dry " skin ". This property, together with the high iodine values, suggests that the extracted fats were " drying oils ", which readily undergo oxidation in the air to a firm elastic varnish (42).

Rooting System (28)

Rootstock. Short, stout, branched, fairly deeply buried.

Roots. Main and primary lateral roots 1.0 to 1.5 cm. diameter; extensively suberised after first year ; finer non-suberised roots with brown and colourless hyphae in outer cortex ; root hairs absent.

Rooting system. Working depth=0-10 cm. ; maximum depth of penetration=23 cm. Young plants with a well-developed tap-root which is later obscured by stronger growth and branching of laterals. Roots in top 5-8 cms.

of soil tend to run horizontally. At lower depths they are more or less vertical. Top 5 cm. of soil occupied by surface mat of adventitious roots and finer branches of main root system.

Spreading and Germination of Seed (4)

In rain and damp air, the carpels shut, and the seeds cannot be scattered. The seeds are dispersed in dry and windy weather in October and November, sometimes as early as September.

Calluna germinates readily on humus formed from its own refuse. As soon as the older plants die off, usually when between 15 and 20 years old, and more light penetrates to the soil beneath, young plants grow up there and fill the open spaces again.

When samples of soil containing seeds of *Calluna* were taken, and kept till the seeds germinated (10), it was found that germination in the second and third years was equivalent to that in the first. It is probable, therefore, that there is some natural dormancy in the seeds of this species.

Formation of Adventitious Organs (4)

Calluna may develop both adventitious roots and shoots. These arise in three ways :—

(1) From a wound cambium, as a result of mechanical injuries (true adventitious organs). These occur frequently in nature when young seedlings are injured. They will, however, rarely develop in dry surroundings, but do so readily in the moist atmosphere of the moors.

(2) From so-called " dormant " eyes on the stem below places where there have been injuries or disturbances (seemingly adventitious organs). This will occur during the vernal growing period (March-July) e.g. after fire.

(3) From parts of the stem or root, by the influence of the environment, without lesions or disturbances (true adventitious organs). Frequently older and younger parts of stems and roots develop very thin rootlets, especially if the root-system no longer functions normally, if, for example, a thick moss-cover or accumulating humus threatens to smother it.

This ability to form adventitious organs in many places of the plant body greatly increases the resistance of *Calluna*.

Heather sometimes regenerates by layering (62). This can occur on dry hard land, but not to the same extent as on damp mossy moors, where the heather grows rapidly, and to a considerable height. Tall stems chiefly under the weight of deep snow, get laid down, especially on hillsides. The stems then produce adventitious roots at intervals. Layering takes place when neither of the other methods of restoration is possible.

In wind-eroded places, *Calluna* is prostrate in the direction of the prevailing wind, and wave-like in patches. Near peat-mosses it forms a close prostrate mat, and further away it is open and forms parallel wave-like patches at right angles to the prevailing wind. Where there is more rapid accumulation of sand and debris, where vegetation temporarily arrests erosion, *Calluna* grows in more or less rounded cushions with close vertical fastigiate branches, and even greater development of adventitious roots (12).

Water-economy and Metabolism (4)

Calluna is not a succulent, but is rather a sapless plant, or sclerophyte. Its transpiration is average. It has a high conductivity and possesses a relatively very large water-conducting system.

It has xerotropic movements of the leaves, by which the transpiring leaves are pressed as a compact mass against the stem, so it can live in both wet and dry surroundings. It has also the power to take in water pretty evenly at low and high temperatures, with an overcast sky as well as in full sunshine. The loss of water, on the other hand, depends very much on the evaporation, which is very high on the peat moors, especially in the atmospheric layers where *Calluna* grows. This evaporation in the open air is much higher than in the swamps and is exceeded by the xerophytic vegetation on mineral soil by only 20-23%. This explains the use of the large water-conducting system. A slight transpiration involves this sclerophyte in a relatively high loss of water, which must be speedily replenished if disastrous consequences are to be avoided. For this reason also, slight mechanical injuries of the water-conducting system cause the affected parts to die off quickly. One observes that during the dry summer months, *Calluna* soon withers and turns brown if the plants are injured in any way.

Calluna is characterised by—a low water-content, a relatively large surface, a large water-conducting system, and a large evaporating system. Hence :—

(1) the absolute amount of its water-circulation and matter-production is small ;

(2) with respect to the fresh weight it has a pretty large transpiration and production of matter ;

(3) from its xeromorphic structure and xerotropic movements it acquires a great part of its power to live between the extremes of humidity and drought, while

(4) its chemical composition doubtless contributes to this.

If during frost, the water supply through the roots is checked and the transpiration-regulating system retarded or stopped, especially when the frost is severe and dry, conditions become critical for the plant ; it shrivels and may die. This danger is much less with great heat, so that even on the hot Moroccan rocks it may hold out by keeping its transpiration-regulating system in working order and living xerophytically. It easily stands summer drought, but not sudden dry frost.

IV. MYCORRHIZA

Many experiments have been carried out on the mycorrhiza of *Calluna* by various workers.

Rayner, Jones, and Smith (29, 43, 44, 45, 46, 47, 48, 49, 50) were agreed that successful growth of *Calluna* depended on early mycorrhiza infection and subsequent healthy growth of the fungus. Rayner regards the inability of *Calluna* to grow well on calcareous soil as the result of a toxic action on the roots of the seedlings, which upsets the normal relations between plant and fungus. She suggests as possible inimical factors (1) the presence in calcareous soil of a substance toxic to the plant, (2) the effect of hydrogen-ion concentration of the soil solution, (3) differences in effective concentration of the soil

solution, depending on the proportion of colloids present. The bacterial colonies associated with such unhealthy roots are regarded as a secondary effect, due to the unhealthy condition of the plants.

According to Rayner, infection by the mycorrhizal fungus takes place shortly after germination, the source of such infection being the testa. Infection does not cease with the formation of the typical root mycorrhiza, but the fungus is present also in the tissues of stem, leaf, flower, and fruit. The mycelium infects the seed coats of the developing seeds, but the embryo and endosperm of the resting seed are free from infection. In her experiments, she found that sterilised seeds and seedlings failed to develop roots and suffered complete inhibition of growth, but if such sterile seedlings were inoculated with the appropriate fungus, they would grow normally. Rayner suggested that the mycorrhizal fungus should be called *Phoma radicis Callunae*.

She also found that the root mycorrhiza of *Calluna* showed digestion stages similar to those found in Orchids. This digestion is not a phenomenon of senescence. It begins soon after the production of young roots in spring, is carried on through the growing season, during which mycelial activity also reaches a maximum, and continues till growth ceases in late autumn. Rayner, Jones, and Smith have all found evidence in their experiments that the fungus *Phoma radicis Callunae* is capable of fixing atmospheric nitrogen.

In contrast to the results of these workers, Christoph (11), Knudson (30, 31, 32), and Freisleben (21) found it possible for seedlings of *Calluna* to develop quite healthily in the absence of the mycorrhizal fungus. According to them, the relationship between *Calluna* and the fungus is a facultative one, not obligate as Rayner insists. They also claim that the symbiosis is not cyclical. They consider that the fact that uninfected roots in Rayner's experiments were very stubby suggests some growth-inhibitor in the medium. Freisleben states " Such growth-inhibitors are found in peat and peat-extracts, in peptone, malt extract, potato agar, and also in fungal extracts in different strong concentrations. Consequently stimulation of the growth of Ericaceae by fungi is not a direct influence, e.g. by the secretion of growth-substances, but an inactivation, destruction, or absorption of the retarding substances. It is assumed that also in natural soils, the root-fungi and soil-fungi, which we find as components of a peritrophic mycorrhiza, are of a similar importance for the Ericaceae ".

V. PLANT COMPETITION

Bracken can invade well-grown heather with tolerable ease, probably because the soil is not so consolidated, and possibly because it is not so freely grazed. The bracken advances by annual elongation of the main rhizome and its branches, a foot or two per year, but in the early stages there are not very many fronds. Burning old heather gives the bracken a chance to become dominant (6).

Certain years seem to favour the development of bracken from the spore, and these spores seem to thrive under old heather, a foot or more high and relatively open above, with plenty of mosses and lichens below. They are never found associated with young closely-cropped heather. The annual vegetative spread of bracken from all sides of many small patches developed from spores will give a more rapid spread through the heather than the increase from a few large patches (6).

When dead bracken fronds have fallen on any part of a *Calluna* bush, the leaves on that portion are usually etiolated and often killed, while the portions of the same *Calluna* bush where no fronds have fallen and which are still exposed are perfectly healthy. It was found that the dead fronds of *Pteridium* falling over the *Calluna* cut off 1/60th to 1/96th of the light-intensity. *Calluna* is very intolerant of shade, so it is quickly killed. There may also be retention of water by the bracken fronds, with resulting decay of the delicate *Calluna* leaves (17).

Haines (27) carried out some experiments on certain heath plants on Hindhead Common. A method was evolved for determining " Drought Resistivity ", or the degree of fitness for withstanding drought conditions, the resistivity being the property of the plant on which depends its chances of success in dry places in competition with other plants. The method was based on the determination of the " effect ", or extent of the adverse stress imposed by given conditions, the resistivity being taken as the reciprocal of the stress experienced, or the " effect " which given conditions are capable of producing on the rate of water-loss at a time when a certain standard " pressure deficit " has already been acquired. Comparisons of the fitness for dry conditions of different plants can only be made by comparing the " effects ", or true stresses produced, and not by merely comparing transpiration rates.

Of the plants investigated, *Calluna* was the most resistant, except for *Pteridium*. The latter, however, owes its high resistivity to very efficient absorption, and not to keeping down the transpiration rate. There is evidence of the occurrence of different physiological strains of *Calluna*, those at the top of the slopes being more resistant than those in the valleys. The very tall bush *Calluna* which formed luxurious growth on the oldest parts of the heath, was extremely resistant, showing that the resistivity increases with age. Of the other growth forms of *Calluna*, the low creeping prostrate form is most resistant ; the ordinary small thickly-growing bushy form is next ; and the tall thin form, which comes well above the general level of the vegetation, is most affected, which probably accounts for its relatively sparse branching and general meagre appearance.

VI. GRAZING

(a) Rabbits

It was found (17) that rabbits ate *Calluna* leaves. When some *Calluna* in the transition zone between *Calluna*-heath and grass-heath was protected by a rabbit-proof cage, it quickly recovered from previous rabbit attacks, but *Calluna* outside the cage degenerated further. Therefore rabbit attack causes degeneration of *Calluna*-heath to grass-heath.

Rabbits invade *Calluna* between the bushes, establishing tracks, and nibble leaves within easy reach, giving a rounded appearance to the bushes. The association thus becomes open, and grasses and other plants appear. Masses of *Cladonia* develop. The eaten-down *Calluna* branches with the *Cladonia* retain water and are very damp in autumn and winter, so that the branches decay easily, and are broken off, leaving behind a grass-heath association. The *Calluna* roots remain for some time and send up fresh shoots, but these are nibbled away, and eventually the roots die also. The eaten-down *Calluna* is also often smothered by a dense growth of *Leucobryum glaucum*.

When it is protected from rabbit attacks, the Grass-heath rapidly reverts to *Calluna*-heath.

The zoned vegetation round rabbit burrows is :—(1) bare sand and lichens (2) grass-heath zone (3) *Carex arenaria* zone (4) typical heath zone (*Calluna*, etc.) (5) tree zone (pine woodland, etc.).

Variation in the intensity of rabbit attack alone is sufficient to change the dominant type of vegetation in Breckland. The presence of *Pteridium*, however, interferes with the typical zonation, as it can dominate *Carex* and *Calluna* under all intensities of rabbit attack.

The approximate order of depression and extinction are :—(1) *Calluna vulgaris*, (2) *Vaccinium myrtillus*, (3) *Nardus stricta*, (4) *Agrostis-Festuca*, (5) *Deschampsia flexuosa*.

In extreme cases much of the ground may be covered with lichens, and a varying quantity of mosses. Finally even the mosses may become scarce (19).

Rabbits not only eat the food of sheep and cattle, but they foul much of the herbage with their droppings, and heavy dunging by rabbits is sufficient to kill out *Calluna*.

In addition to modifying and altering existing vegetation, rabbits by their burrowing form " screes ", especially where stones lie near the surface of the soil. When a burrow becomes a scree, the rabbits change their quarters, and so cause continuous erosion.

The amount of moisture available is important. If the rainfall is sufficient and evenly distributed, or there is a " flush " near the burrow, then much, if not most of the vegetation will withstand the attack of the rabbits (19).

(b) Sheep

Sheep prefer young heather, and tend to concentrate on places where heather is returning after burning. If new growth is from roots still living, conditions may not be so serious, but if growth is by germinating heather seeds, sheep not only frequently overgraze the young plants, but in grazing pull them up by the roots and destroy them. Where there is a dense sheep population, such areas may cease to be dominated by heather, and become mixed heather and grass. This leads in turn to grassland dominated by *Nardus stricta*.

Grazing of sheep, drought, wind, rain, melting snow and frost, all play a part in arresting, destroying, or causing heavy losses to vegetation which tends to cover bare ground (18).

There is little evidence of heather seed being wind-borne to any great extent. Most seeds accumulate under the plant, and remain dormant until conditions are suitable for germination, e.g. till the loose surface material decays into humus and becomes consolidated into a suitable seed-bed by trampling and settling. It is usually found that the first seedling plants develop along the sides of the sheep roads through the heather, or on bare consolidated spots which include the hollow or flat places surrounding the light fluffy mounds of loose debris with nothing growing on them, which indicate the old sites of the larger heather bushes.

The looser the surface, the longer it is before it becomes consolidated enough to grow seedlings. Looseness increases with the age and roughness of the old heather, not only on account of the greater amount of debris collected, but because sheep have long been warded off it, and prevented from consolidating it with their feet (62).

VII. BURNING

Leach (34) suggests that when heather is burnt, the stem bases of *Calluna* and *Erica cinerea* which lie almost entirely in the top 2 inches of soil, are killed off by the heat, so that these plants must regenerate by seeds. On the other hand, the rhizomes of *Pteridium* are 4-5 inches deep, so are little affected by burning. He thinks that this explains why, when a heather moor is burned, bracken tends to become dominant, and the heather does not regenerate.

Fritsch and Salisbury (23) on the other hand found that this view was not supported by their observations, as some *Calluna* plants penetrated to a depth of 9 inches, while *Erica tetralix*, which invariably rejuvenates, is under 6 inches deep.

Stools which rejuvenate are (*a*) those in which branching of the crown takes place beneath, or in close contact with, the soil surface, (*b*) those in which branching, though occurring above the surface, is so profuse as to rapidly accumulate a mound-like protective covering of humus. This seems to be the determining factor as to whether *Calluna* sprouts or not ; thus all sprouting specimens examined had a crown that was more or less completely buried, while dead specimens had branched *above* the surface.

Fritsch and Parker (22) found that the young growth on burnt patches on Hindhead Common had been much infested by *Cascuta*, which was observed on *Calluna*, *Erica cinerea*, *Vaccinium*, and *Ulex minor*, but the parasite did not seem subsequently to make much headway, as it was almost absent from the greater part of the heath.

Various observations have been made about heather burning (2, 35, 55). Burning should be systematic, extending over a series of years, on a more or less regular rotation. From 8 to 10 years is a common period. The matter depends to some extent on the vigour with which the heather grows, and whether it is mainly re-established from root or seed. Low ground will be in condition for burning earlier than high or wet land. The longest and rankest heather should be chosen, but some patches should be left for sheltering sheep. Any beetle-infested heather should be burned, no matter what its age. Old heather may require two burnings, to burn it completely. It is better to leave heather unburnt than to burn it before it is sufficiently dry. Imperfect burning prevents the growth of grass, and the hard charred stems tear the wool from the sheep. In England, autumn-burning has proved successful. In Scotland, April is the best time.

Old heather should be burned in strips, for when old stick heather is burned, the fire is so hot that the roots are charred and killed ; in this case regeneration can only proceed from seed, and if the burned areas are narrow, self-seeding is materially helped by wind-blown seed. Old heather should, whenever possible, be burned by " back-firing ", i.e. against the wind and against the lie of the heather sticks. This gives a very clean burn—the fire travels slowly and destroys not only a larger percentage of the stalks, but also burns into the moss which surrounds the sticks of old heather.

Wet " flow " ground should be burned if possible once every six years. It usually overlies deep damp peat, and it is therefore protected from the full effects of the fire, so the heather regenerates quickly from the root.

Heather can be burned at all times of the year in England. In Scotland it is confined to between November 1st and April 10th, or April 25th on high wet moors. In Wales, burning is usually done during the spring months.

A quick return after burning may be expected where the heather grows on peat or peaty soil which is generally moist, but not stagnant. A slow return is generally found on hard soils with little humus, such as are common on steep dry slopes or exposed tops.

VIII. DISEASES

(1, 5, 7, 15, 16, 26, 36, 52, 67)

Saccardo (52) reports the presence of the following fungi on *Calluna* :—

Amphisphaeria ericeti—in old wood.
Aposphaeria schizothecioides (Preuss) Sacc.—wood.
A. stigmospora Lamb & Sacc.—branches.
Cenangella ericae (Niessl.) Rehm—branches, leaves.
Chaetosphaeria pileo-ferruginea Crouan—branches.
Clithris callunae Sydow—dead stems.
Collonema schizothecioides (Pr) Grove—wood.
Corticium apricans (Bourd) Sacc. & Trot.
C. rhizophorum Bourdot & Galz.—bark and wood.
Dasyscypha distinguenda (Karst) Sacc.—stem.
Fusicoccum ericeti Sacc.—dead branches.
Godronia callunigena Karst.—branches.
G. ericae (Fr.) Rehm—leaves, branches.
Gorgoniceps obscura Rehm—branches.
Hypochnus fulvescens Sacc.—dead branches.
Hysterium fraticum Sacc.—branches.
H. pulicare Pers.—branches.
Lasiosphaeria coacta W. Kirscht.—decayed mossy stems.
Lentomita dubia Niessl.—branches.
Leptosphaeria ericae (Fr.) Malbr.—branches.
Melanomma lenarsii (West) Sacc.—stem.
Melaspilea rhododendri (Am & Rehm) Almq.—branches.
Metasphaeria callunae Fautr.—branches.
Mollisia cinerea (Batsch.) Karst.—branches.
Niptera callunae Sydow.—dead stems.
Peniophora vermifera Bourdot—branches.
Pestalozzia callunae—branches.
Pezicula callunae Ful.—dead stems.
Phoma callunae Karst.—branches.
Ph. ericae (Fr.) Sacc.—stems.
Physalospora callunae (De Not.) Sacc.—branches.
P. dissospora Feltg.—branches.
Pirottaea setulosa (Mass. & Crossl.) Saac.—branches.
Plowrightia polyspora (Bref.) Sacc.—branches.
Propolis betulae Rehm. var Callunae Bomm, Rouss, Sacc.—stem.
Pseudophacidium callunae Karst.—branches.
Staganospora lambottiana Sacc.—stem.
Tapesia fusca (Pers.) Fekl.—branches.
T. melaleudoides Rehm.—root.
T. nivea (Lorton) Sacc.—branches.
Thecopsora (?) Pischeri Cruchet—leaves.
Valsa tenella H.Fabre—branches.
Zignoella arthropyrenioides Rehm.—roots.

Other fungi reported on *Calluna* are :—

Clinterium obturatum Fr. (Die Back) has been isolated from dead heather stems. It seems to be one of the commonest saprophytic forms.
Dasyscypha nivea has been seen practically everywhere in the autumn on dead or dying heather, but there is no proof that it is an active parasite.
Fomes annosus has been reported in Denmark, and in Dee.
Melanomma Pulvis-pyrius has been found on old heather wood.
Mucor sp., isolated from dead heather stems in Fife, was not identified further.
Phoma affinis on dead stems of *Calluna* in Warwickshire, June.
Thelephora terrestris (?) A resupinate fructification was found on old dead or dying stems near the base.

Calluna has also been found to be attacked by *Armillaria mellea* (1, 15). The base of the stem of an infected plant was covered by a plate of white mycelium lying between the wood and bark. This occurred just below soil level, and crept about 2 inches up the stem, and could be found in patches on some of the larger branches. The cambium appeared to be destroyed by it. In one case a typical black " shoe-string " was seen running up the outside of the stem, suggestive of the way in which elms, etc., are attacked. No fructifications were present. The probable source of infection were stumps of oak and pine present in the immediate vicinity, which were already infected by *Armillaria mellea.*

The most important fungal disease of *Calluna* is caused by the heather rhizomorph fungus, *Marasmius androsaceus* Fries. In Scotland the distribution of this fungus is—Cheviots, Roxburghshire ; Lammermuirs, East Lothian ; Pentland Hills, Midlothian ; Ayrshire ; Renfrewshire ; Arran, Buteshire ; Garelochhead, Milngavie, Rowardennan, Dunbartonshire ; Blebo, Stravithie, Fifeshire ; Strachur, etc., Argyllshire ; Aberfoyle, Callander, Perth, Sherriff-muir, Struan, Perthshire ; Aviemore, Drumashie, Farr, Newtonmore, Skye, Inverness-shire ; Shieldaig, Applecross, Ross-shire ; Stoer, Sutherlandshire ; Wick, Caithness.

There are two stages in the life history. The toadstool is found from July to November. It is brown when young and black later. It is tough, with a wiry black stalk, and is only about $1\frac{1}{4}$ inches high, with the cap about $\frac{1}{4}$ inch across. The other, more important, stage, is the typical rhizomorph one. The rhizomorphs are horse-hair- or fine shoe-string-like structures up to a foot or more long, and freely branched. They wind round heather stems, penetrating them by the bases of dead side branches, or even by the breathing pores. Once inside they may kill the stem by loosening the bark from the wood or by sending threads through all the stem tissues.

It appears that certain weather and soil conditions are important in governing not only the regional distribution of the rhizomorph, but also the distribution of the rhizomorph itself on diseased heather. Where the air is moist, rhizomorphs tend to develop on the twigs. Under drier atmospheric conditions, but where the plants are old and *Sphagnum* has been able to accumulate beneath them, one may expect to find the rhizomorphs twined round the basal part of the stem. In the case of young heather, it has been observed that the rhizomorph occurs only on the aerial shoot, and not on the basal parts of the stems, this distribution again probably being associated with a moisture requirement.

The establishment and spread of the disease are favoured by wet conditions due to overgrown heather sheltering the rhizomorphs, and poor drainage allowing the accumulation of water-holding *Sphagnum* under old heather plants. Regular burning and draining are therefore to be recommended for controlling this fungus.

IX. INJURIOUS INSECTS

The principal insect enemy of *Calluna* is the Heather Beetle, *Lochmaea suturalis*, one of the Chrysomelidae, or leaf-eating beetles (8, 9, 25).

Injury to Host and Locality of Infected Areas

In July and August, leaves and stems of heather attacked by beetle-larvae turn fox-red, and examination shows them to be chewed and stripped of their bark. The next year this heather turns grey and the leaves drop off. Any age of heather may be attacked. Young vigorous heather up to 8 or 10 years is, however, seldom killed, and on moors where severe damage occurs most of the heather is very old.

Damage may occur uniformly over an expanse of heather, or it may be confined to small patches here and there, and is very often most severe at the margins of small plots and along the edges of pathways and drains. When distribution is patchy, the affected areas are noticeably situated in very wet localities.

Beetles have been found to be present on all kinds of heather moorland, but are much more abundant on wet boggy ground, whether the situation was inland or coastal, and irrespective of altitude and exposure. Well-drained slopes are rarely affected. When attack by the beetle does occur on sloping ground, the soil is usually shallow and kept moist by seepage of water drained from the ground above. When a moor includes large tracts of marshy ground, and the beetles become numerous, there is always the chance that they may invade adjacent dry areas in the spring and feed on the heather there.

The districts from which damage from heather beetle is most commonly reported are those situated on the west coast of Scotland, lying to the south of Oban. In Argyll, Ayr, Lanark, and Cumberland, the pest is well known, but on the extensive moors in the northern and central Highlands it is practically never heard of. It would appear that the insect flourishes best in a mild climate with a high average rainfall, but it is curious to note that after a very wet winter, the beetles are not so numerous as after a dry one.

Characters

Adult. Slightly less than $\frac{1}{4}$ inch long, of olive-brown colour. Head and body are black. Upper surface of middle region of body behind head has 3 quadrangular spots, varying from rusty-brown to black. Head and wing-covers are sculptured with coarse, closely opposed, small pits.

Egg. About 1/30th inch in diameter, roundish, and yellow or yellowish-brown in colour.

Larva. On hatching, the grub is 1/12th inch long, of pale greenish colour. When fully grown, it measures about $\frac{1}{4}$ inch. It is usually more or less curved. Colour deepens to greyish-brown. In its movements it resembles a caterpillar.

Pupa. This stage is pale yellowish-white, with parts of the adult, such as legs, antennae, and wings, readily discernible.

Life-cycle

There is each year only one generation of Heather Beetles, due to the occurrence in the adult of a diapause, consisting of an arrest of the development of the reproductive organs, and later associated with cessation of bodily movements during the winter. The adult life extends to nine or ten months, of which the period from October to March is passed in hibernation. Once the beetle has started to hibernate, it becomes conditioned to such temperatures as normally occur in winter, and it is amply protected by a covering of sphagnum and snow. It is less resistant to spring frosts which may occur after it has resumed its activities.

In April, on warm sunny days, it often undertakes migratory flights, the cause of which is not clearly understood, as the course taken is haphazard, and may end up on the seashore or on lochs. Pairing occurs in spring, and the eggs are laid on sphagnum in very small numbers at first, beginning in mid-April, but in larger numbers in late May or early June. In July adults become progressively less abundant, and only a few persist in mid-August.

Incubation of the eggs lasts 3 to 4 weeks. Hatching of the larvae begins in early June and the young larvae climb the heather plants to feed on the young shoots and leaves. Each larval stage lasts 2 to 3 weeks.

The pupae are first found at the beginning of August, but they are most abundant from late August to late September. Pupation occurs in the same situations as those in which the adults hibernate. The prepupal and pupal stages take about 4 to 5 weeks. The adults begin to emerge in the latter half of August, but are not abundant till late September. Beetles become less active as winter advances, and enter hibernation when the maximum temperature drops below 9°C.

Control

1. DIRECT

(*a*) *Insecticides.* Toxic substances such as arsenic compounds cannot be used, because of the danger to grouse and sheep, but pyrethrum and derris could be used, especially on the less-active grub in July and August, though this method is rather expensive.

(*b*) *Burning.* This is restricted to between 1st October and 15th April. During most of this time, the beetle is hibernating in the soil, but not deeply enough to be out of the reach of surface fire. The best time is mid-winter. Moors on which a rigid system of rotational burning is practised are less liable to infestation.

2. INDIRECT

Drainage. This discourages the growth of sphagnum, and removes suitable breeding places, besides improving the growth of healthy heather.

3. BIOLOGICAL

(*a*) *Predators.* In Holland, Betrem found that the Heather Beetle was preyed on by adults and larvae of the Ladybird Beetle (*Coccinella hieroglypha*).

(*b*) *Fungi.* Betrem also found a saprophytic fungus, *Sporotrichum epigoeum*, attacking the larvae in their earthen cocoons. He does not state whether fungal invasion occurred before or after the death of infested larvae.

(*c*) *Birds.* Partridge, pheasant, black game and starlings all eat the Heather Beetle in large quantities when suitable opportunities occur.

Other insects injurious to *Calluna* are :—

(1) Heather Weevil, *Strophosomus lateralis*. This is about 3/16th inch long and shiny black. The upper surface is coarsely pitted, with a broad band of silvery scales along either side, and a patch of similar scales at the base of the wing covers. Little is known of its habits, but it is presumed that the grubs feed on the roots of the heather. Certainly dead specimens of heather bore signs of having been destroyed by a root-eating grub. Like the Heather Beetle, it hibernates in the soil as an adult. It appears that the temperature required to immobilise the Heather Weevil is slightly less than that which incapacitates the Heather Beetle. (8).

(2) Vapourer Moth, *Orgyia antiqua*. Its caterpillars feed on leaves of heather in summer. The damage done by the caterpillars is usually confined to an area of less than half an acre, roughly circular in outline, and each year it spreads but slowly from an infested centre, as the female is unable to fly. Control is by burning slightly more than the infected area (9).

X. VARIETIES AND FORMS (4)

A. var. *genuina* Regel 1843—Foliage leaves unhaired or with only a few small prickles or hairs along the edge.
39 forms and numerous subforms are listed by Beijerinck.

B. var. *hirsuta* Gray 1821—Foliage leaves haired, densely or less densely. Beijerinck recognises 8 forms.

XI. ASSOCIATED FAUNA AND INSECT VISITORS

The animal community of a typical Callunetum (51) includes wasps, ants, flies, hover and crane flies, moths, beetles, bugs, leaf-hoppers, psyllids, mealywings, springtails, grasshoppers, spiders, harvestmen, mites, woodlouse, centipedes, millipedes, earthworms, grass snake, yellow hammer, partridge, stonechat, and rabbits.

Insect visitors to *Calluna* (51, 65, 66) include bees, hive bees, humble bees, digger wasps, flies, and moths.

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APPENDIX 6

DROPPING TRIALS OF LIMESTONE FROM LANCASTER AIRCRAFT

REPORT BY DR. J. ALLAN CAMPBELL

1. Introduction

In view of the rapid developments which have taken place in recent years in the employment of aircraft for transport purposes, and in the evolution of methods of free dropping loads during flight, there has arisen a public consciousness of the great potentialities of the aeroplane in the sphere of agriculture. Aircraft have been used with success in many agricultural operations such as pest control, and dispersal of insecticides, and it is a natural consequence that speculations have been made regarding the possible extension of air transport to a wider range of agricultural activities. Low fertility and practical inaccessibility to surface transport suggest the problem of transport and distribution of fertilisers in hill areas as a field where the possible utilisation of aircraft merits early investigation since there would seem to be no alternative solution.

Application of fertilisers (lime phosphates, and trace elements) to hill land implies free dropping of heavy loads, and for such a purpose the heavy bomber (Lancaster or Lincoln) is the only type of aircraft at present available. A method has been developed by which Lancaster aircraft equipped with standard sling carriers can raise and release a load of 10,000 lbs. Five heavy canvas slings of 2,000 lb. loading capacity may be accommodated in the Lancaster bomb bay (*plate* 2) and it is possible with the bomb release mechanism to drop them in flight, separately, in salvo, or as a stick at appropriately timed intervals. Before this method could be utilised for a practical trial of liming in a selected inaccessible hill area, it was necessary to carry out preliminary trials to assess the measurable distribution which could be achieved by this method. Trials with this objective were completed at Ministry of Supply dropping zones at Cannon Heath Range, Kingsclere, and R.A.F. Station, Beaulieu, Hants., and particular attention was paid to the effect of package size on the stowage of the load, scatter in the air after release and resultant ground pattern, and burst, spread and spray of package contents upon impact.

2. Trials

(*a*) Ground limestone delivered in 112 lb. 3 ply valve paper bags and 56 lb. 2 ply paper bags was used in all trials. Small packages of 7 lb., 14 lb., and 28 lb. were made up using commercial brown paper bags. The limestone was filled into the bags, the lips of each being folded and the whole sealed with 1 inch wide adhesive strip paper as illustrated in Plate I.

The 14 lb. bags were made from a machine-glazed Kraft paper weighing 42 lb. per ream of double crown with a Mullen burst strength of 45 lb. (these bags were used also for the 7 lb. packages) ; the 28 lb. bags were made from a much heavier paper (not Kraft) with a Mullen burst strength of 35 lb. The folding, sealing, and handling of the 14 lb. bags was very satisfactory, but considerable difficulty was encountered in sealing the 28 lb. bags on account of the absorbent nature of the paper, and numerous cases of bursting occurred during handling. Some 56 lb. and 112 lb. packages were dropped in the wrappings in which they were delivered from the quarries, and a comparison was thus obtained between sling loads composed variously of 7 lb., 14 lb., 28 lb., 56 lb., and 112 lb. packages.

(*b*) Three sorties were made, one at Kingsclere, and two at Beaulieu, and the packages were dropped in the course of 6 runs. Details of loads, and their release are given in Table I. The figures in brackets in the final column of this table indicate the separate runs, thus, in run 1, a single sling (A) of 213 7-lb. bags was dropped, while in run 4 a stick of 5 slings (i.e. a full aircraft load), F.G.H. (14 lb.) and J.K. (28 lb.) were dropped at successive timed intervals of 0·7 seconds.

(*c*) Packages were dropped from a height of 750 ft. and at an aircraft speed of 160 m.p.h. (I.A.S.). Ground targets and direction strips were laid, and each load release was made when directly over the target. During runs 1, 2 and 3 of the 1st sortie the wind speed was 8/10 knots in a direction 220° magnetic, and the runs were made radially from a common target so that in run 1 the drop was made with a following wind (140° to line of flight), and in runs 2 and 3 drops were made against a head wind (20° and 40° respectively to line of flight). In the 2nd sortie the wind speed was 6/8 knots at 265° magnetic and in run 4 the stick was released against a head wind (30° to line of flight). The wind speed in the 3rd sortie increased slightly to 8/10 knots at 265° magnetic, and the drops in runs 5 and 6 were made against a head wind (30° to line of flight). The wind and flight directions in each run are shown in figures 1-6. These figures also show the distances between target and mid-point of impact of each load, but since single slings were dropped in some cases, and sticks were released in others, the figures are not directly comparable. The distances were in the region of 1,000 or more feet, and as was to be expected were greater when heavier packages were used ; a good example is shown in Plate 8 where there is a clear gap between the impact areas of the 14 lb. bags (1st, 2nd and 3rd slings) and the 28 lb. bags (4th and 5th slings) which were released as a stick at constant timed intervals. The evidence, however, in this respect indicates that a fairly high degree of accuracy could be gained in placing the loads, due allowance being made for the variables of aircraft velocity, altitude, package size and wind direction and speed.

(*d*) Immediately following each drop a ground examination was made and the position of each impact plotted relative to a line parallel to the aircraft heading or track. The ground patterns of load scatter for the respective runs are shown in figures 1-6. The residue (contents remaining in bulk) of each bag plotted was noted in order to obtain a measure of the dispersal achieved, and the results are summarised in Table 5. It had been the original intention to weigh the residues, and on this account the filling

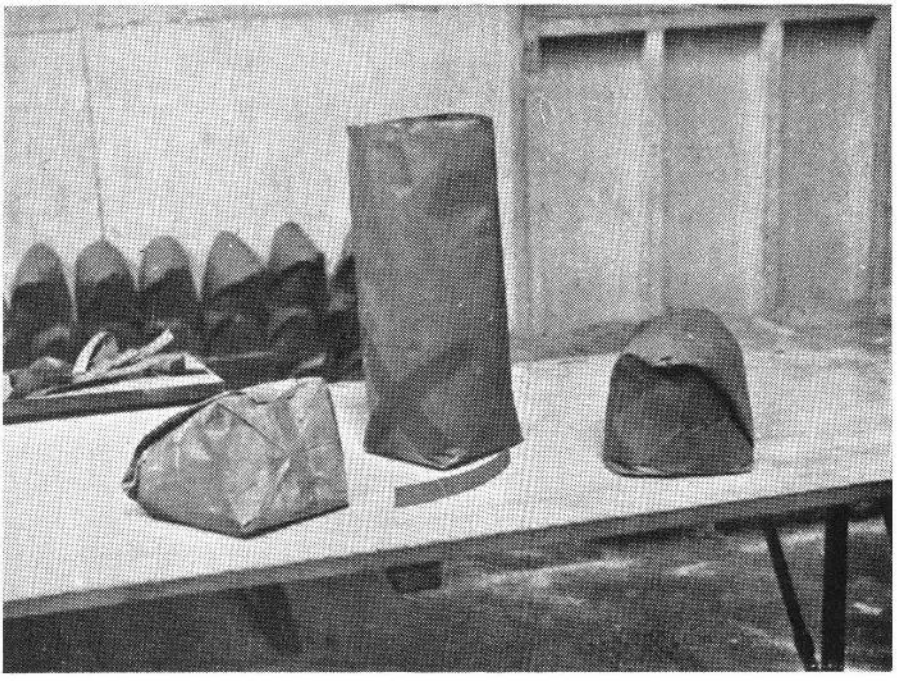

Plate 1. Preparation of 14 lb. bags.

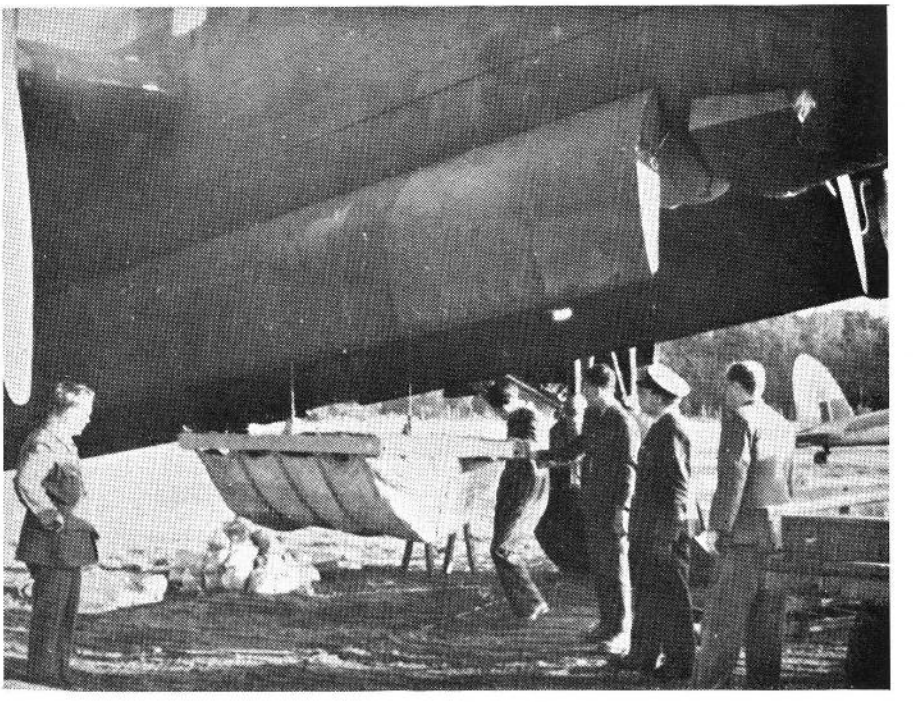

Plate 2. Loaded sling carrier ready for winching.

Plate 3. Release Sling B, 14 lb. bags.

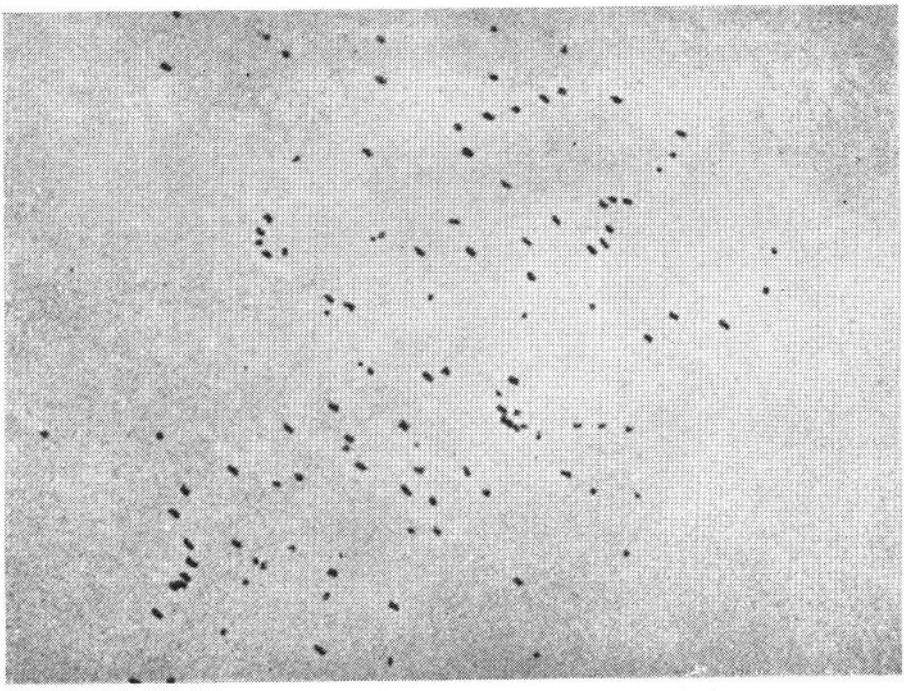

Plate 4. Sling B—Descent.

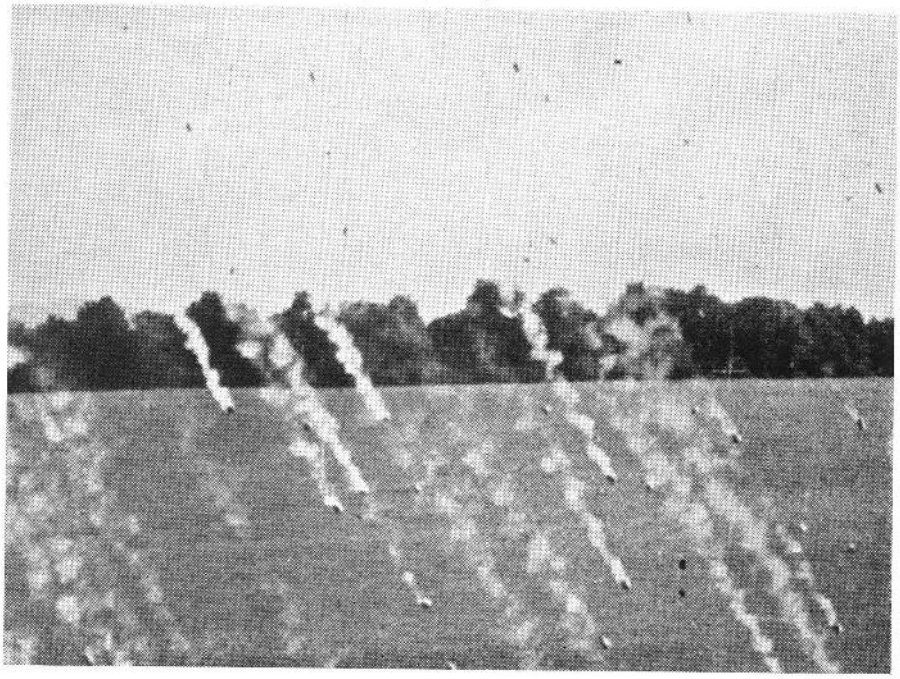

Plate 5. Sling B—Immediately before impact.

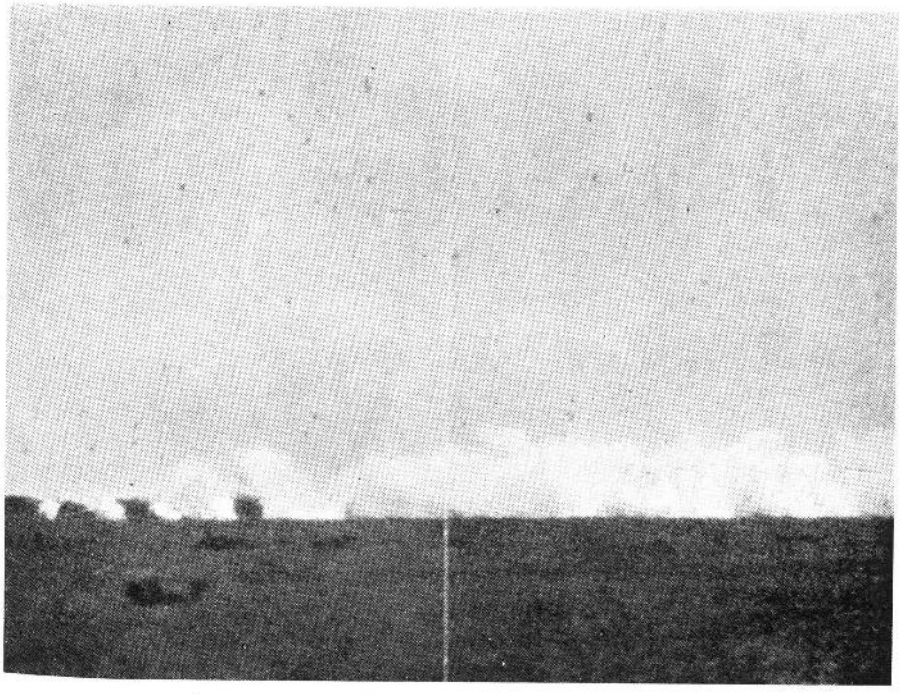

Plate 6. Impact, Slings F-K. 14 lb. and 28 lb. bags.

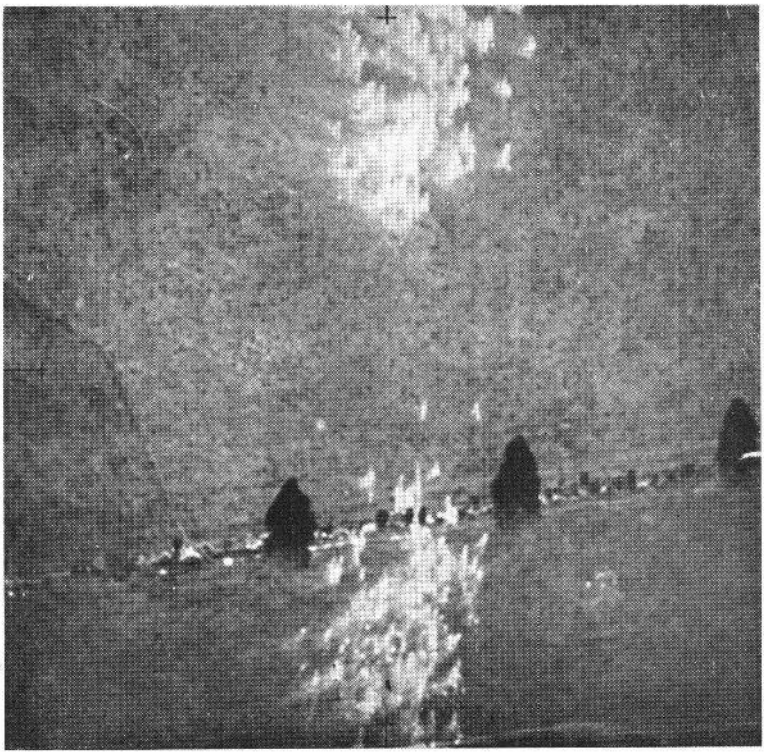

Plate 7. Deposit Area, Slings B (*above*) and D. 14 lb. bags.

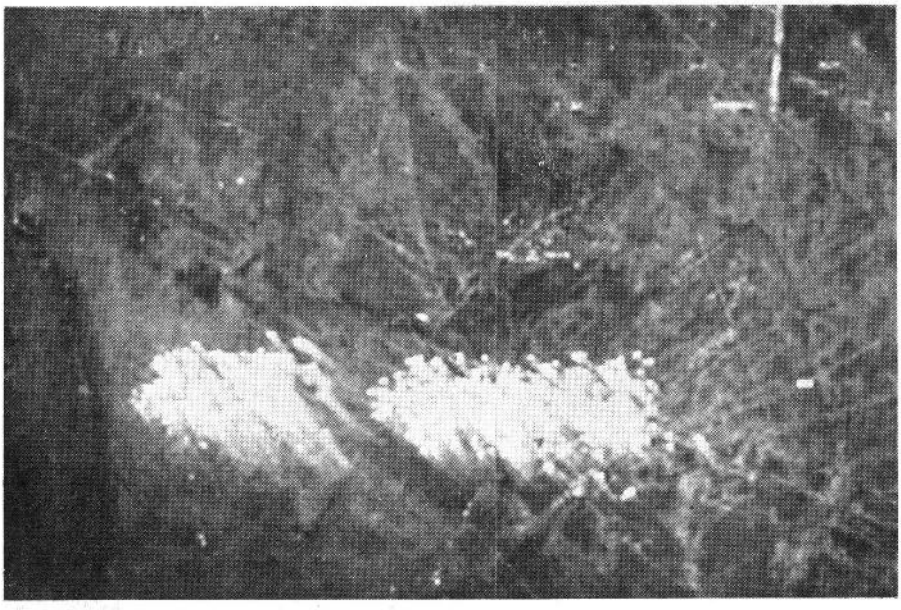

Plate 8. Deposit Area. Slings F, G and H, 14 lb. bags (*right*) and J and K, 28 lb. bags.

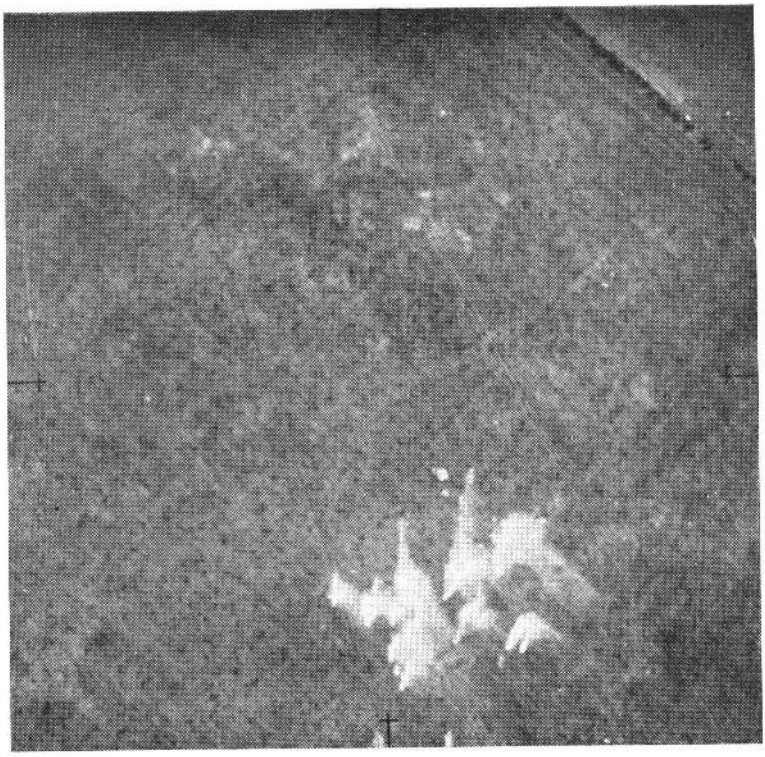

Plate 9. Deposit Area. Sling E, 112 lb. bags.

Plate 10. Kingsclere, spread and spray of 7 lb. bags (A).

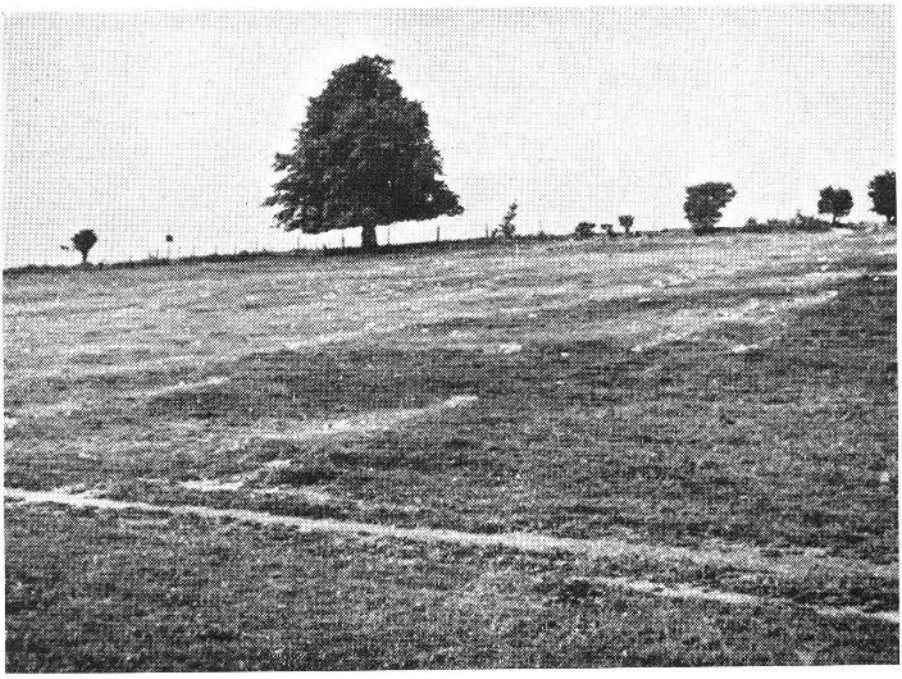

Plate 11. Kingsclere, spread and spray of 14 lb. bags (D).

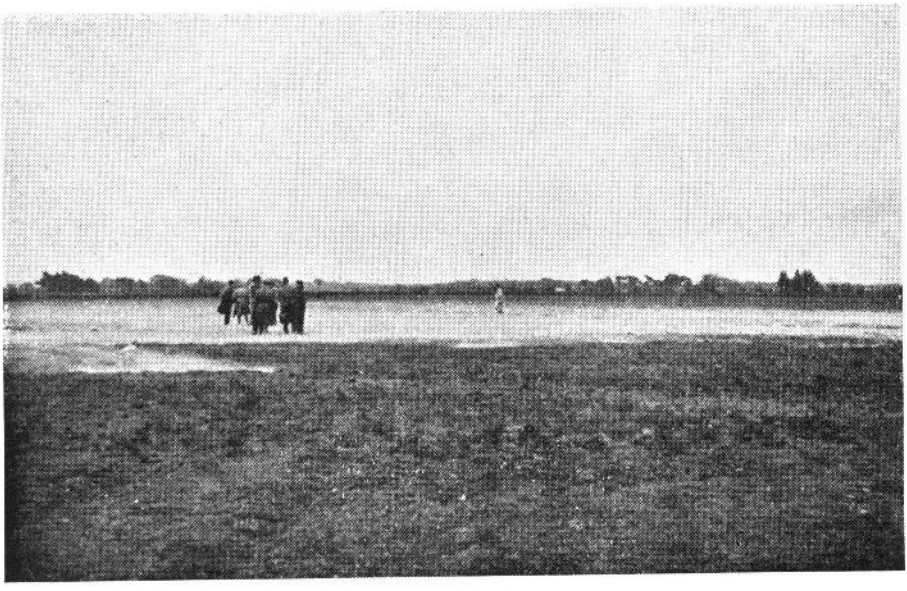

Plate 12. Beaulieu, deposit area 14 lb. bags, F. G, H (*left*) and 28 lb. bags (J, K).

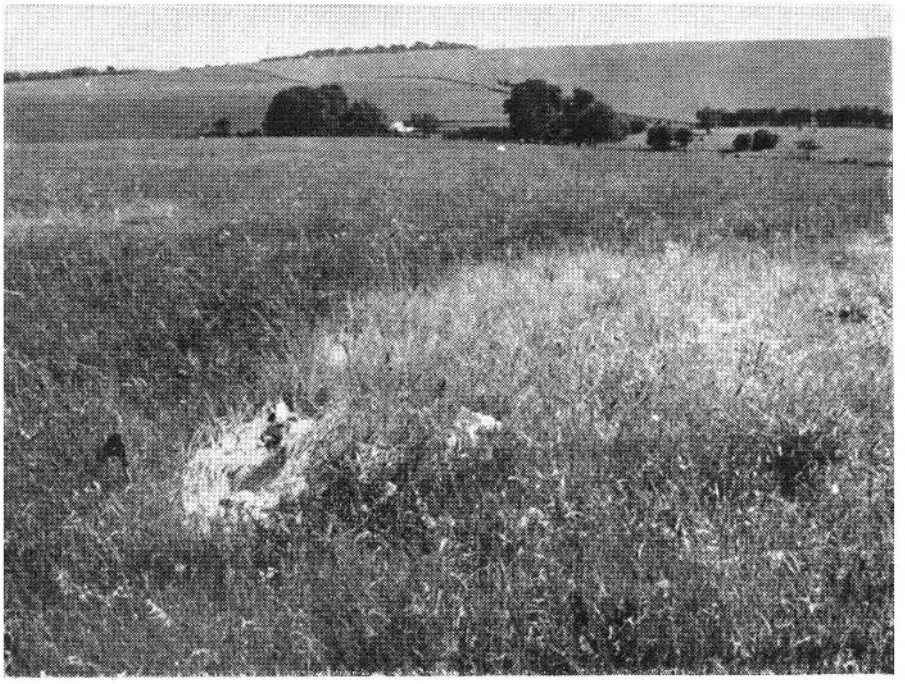

Plate 13. Kingsclere, spray from 112 lb. bag.

Plate 14. Kingsclere, 112 lb. bag partially buried.

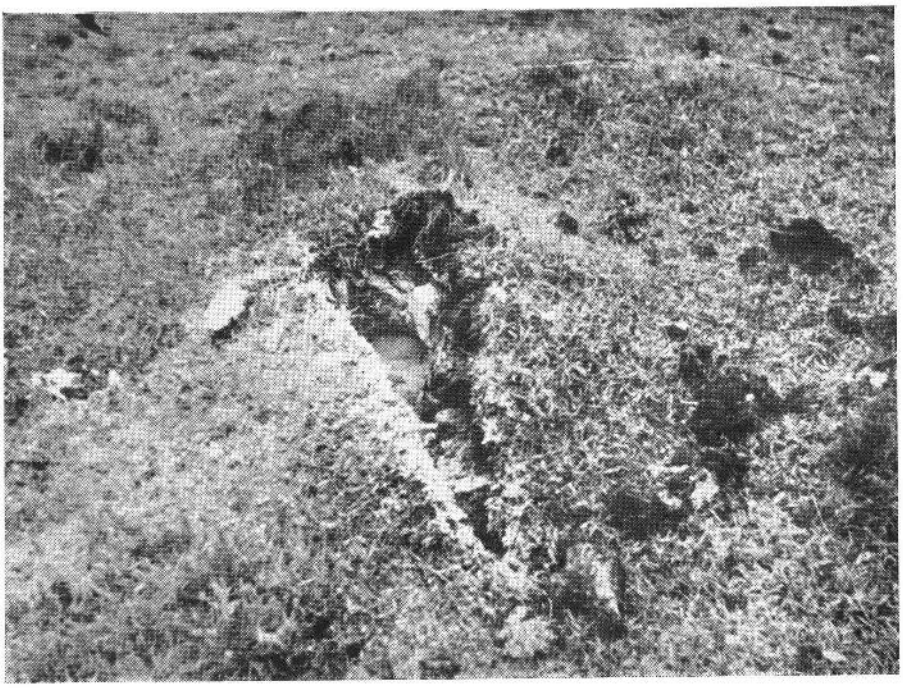

Plate 15. Beaulieu, deep penetration of a 56 lb. bag.

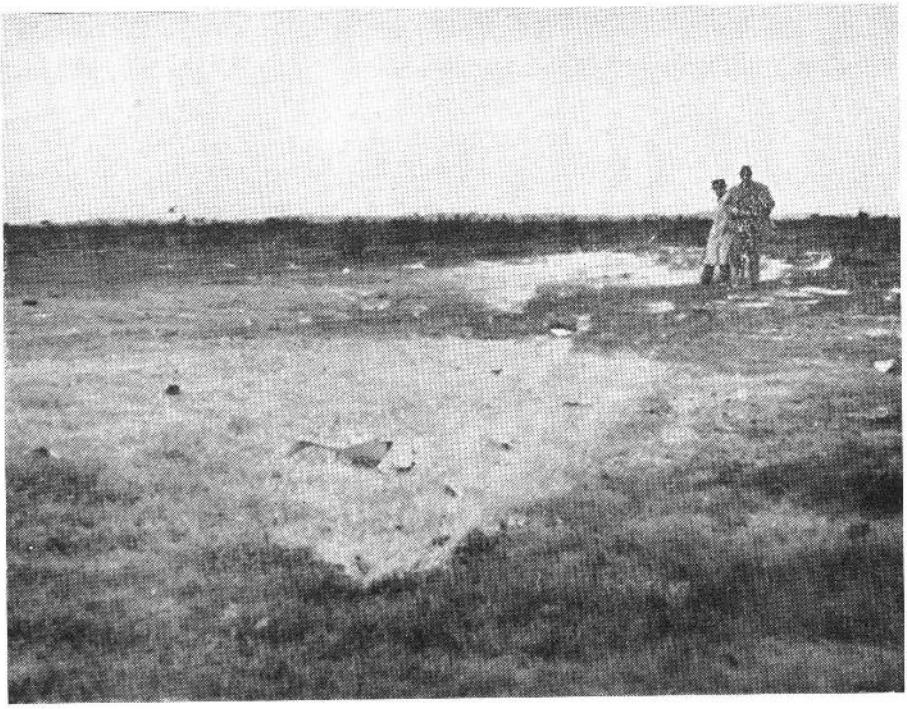

Plate 16. Beaulieu, spray from 112 lb. bag.

of the 14 lb. and 28 lb. bags had been controlled to an accuracy of 0·5 ozs., but on examination of the impacts, weighing proved to be impracticable, and it was decided to evaluate the residue by an approximate assessment, enumerating the bags as full, $\frac{3}{4}$, $\frac{1}{2}$, $\frac{1}{4}$ and less than $\frac{1}{4}$ full.

(*e*) Photographs from ground to air were taken during the course of each drop. After the drop, photographs of the deposit areas were taken from air to ground, and ground photographs were made of some details. A selection is given in Plates 3-6, 7-9, and 10-16.

(*f*) Owing to mechanical and electrical faults in the course of two of the sorties, the original dropping plan was not fully completed. On sortie I, sling C which should have been the middle member of a 3 sling stick of 14 lb. bag loads was not released. Thus two separate deposit areas were obtained with slings B and D. On sortie III, a mechanical fault prevented the release of slings N, P, Q, which should have been the last three members of a five sling stick L, M, N (56 lb. bags) and P, Q (112 lb. bags). In a subsequent run the three slings were jettisoned in salvo, but unfortunately some of the bags fell on the deposit area M so that it was only possible to plot the dispersal of 1 sling load of 56 lb. bags (sling L). The results which were comparable were thus :—

(i) 1 separate sling of 7 lb. bags (A) Deposit area figure 1.

(ii) 2 separate slings of 14 lb. bags (B and D) Deposit areas figures 2a and 2b.

(iii) 3 sling stick of 14 lb. bags (F, G, H) Deposit area figure 3.

(iv) a 2 sling stick of 28 lb. bags (J, K) Deposit area figure 4.

(v) a separate sling of 56 lb. bags (L) Deposit area figure 5.

(vi) a separate sling of 112 lb. bags (E) Deposit area figure 6.

During the early stages of the descent, some bags were observed to be streaming their contents, and this became much more apparent in the later stages of the descent. This may have been due in part to the bursting or unsealing of the lips of the bags during the sling loading (it was more evident for example in the poorer quality 28 lb. bags than in the 14 lb. bags) but was probably due to a greater extent to damage during taxi-ing, take-off and flight, jostling on release of the sling, and airflow effects during descent since it occurred in all loads irrespective of the package size. Plates 3-5 illustrate three successive stages in the descent of one load (sling B—14 lb. bags). The increase of streaming during descent is clearly shown.

Lime which was lost during the drop was carried far away from the area of deposit and must be regarded as completely wasted. In the case of the smaller size of bag some of the bags were lost in the air and this is indicated in the difference between the numbers dropped and the numbers plotted on the ground as shown in Table I. The greatest loss in this respect was encountered in run 4 when 62 out of 414 14 lb. bags (i.e. 15%) were missing from the ground plot.

TABLE 1

Summary of Sorties, Loading, etc.

Sortie	Total Load	Slings	Packages			Number Plotted on Ground	Release	
			Size	Number	Weight in Lbs.			
I Kingsclere	8,939 lbs.	A	7	213	1,491	197	Separate	(1)
		B	14	126	1,764	108	Stick at 0·8 sec. intervals	(2)
		C	14	138	1,932	Not released		
		D	14	124	1,736	106		
		E	112	18	2,016	18	Separate	(3)
II Beaulieu	9,828 lbs.	F	14	126	1,764	352	Stick at 0·7 sec. intervals	(4)
		G	14	144	2,016			
		H	14	144	2,016			
		J	28	72	2.016	141		
		K	28	72	2,016			
III Beaulieu	9,800 lbs.	L	56	36	2,016	32	Stick at 0·7 sec. intervals	(5)
		M	56	36	2,016	41		
		N	56	33	1,848		Jettisoned in Salvo	(6)
		P	112	17	1,904	Not plotted		
		Q	112	18	2,016			

3. Results

(*a*) *Deposit Areas*

The areas of impact were ellipses in which the concentration of bags was greatest towards the centre. In all cases, however, it is most convenient to regard the deposit areas as rectangles in the direction of the aircraft heading of an approximate breadth of 120 feet. These rectangles may be divided arbitrarily into three parallel rectangles including a central 60 feet broad strip in which the greatest concentration of impacts occurred, and two lateral 30 feet broad strips flanking this, in which impacts were more sparsely distributed. There were a few bags of the 7 and 56 lb. sizes where the lateral drift was beyond these limits (i.e. 60 feet from mid-line of flight) and the drift was least with 14 lb. and 28 lb. bags. In the one example where 112 lb. bags were plotted a comparatively large proportion landed outside the 120 feet strip. A summary of these findings is shown in Table 2.

TABLE 2

Percentage of each Load in which Lateral Drift was greater than 60 feet

Sling	Package Size (lbs.)	Number plotted on ground	Percentage of plotted bags beyond 60 feet limits
A	7	197	14
B	14	108	7
D	14	106	5
F.G.H.	14	352	9
J.K.	28	141	7
L	56	32	12
E	112	18	22

If we consider the deposit areas of the slings released separately A, B, D, L, E, we find the extreme longitudinal limits of dispersal were as follows :—

A (7 lbs.) —286 ft. B (14 lbs.)—220 ft. D (14 lbs.)—290 ft.

L (56 lbs.)—273 ft. E (112 lbs.)—210 ft.

Since these results are somewhat irregular it is convenient again to select arbitrary limits for the concentrated area, and a rectangle of 180 feet long gives a reasonable estimate for comparative purposes. Table 3 shows the ground dispersal in relation to rectangles 180 feet long and 60 feet broad.

TABLE 3

Distribution of Impacts on Ground from Single Slings

Sling	Package Size lbs.	Number dropped	Number plotted	Percentage Distribution			
				Lost in air	Central Strip	Lateral Strips	Beyond
B	14	126	108	14	49	31	6
D	14	124	106	14	56	25	5
L	56	36	32	11	61	17	11
E	112	18	18	0	56	22	22

From this Table it is seen that approximately 75-80% of the bags dropped landed in a rectangle of area 180 feet by 120 feet in each case. While the smaller bags (14 lb.) were fairly regularly distributed between the central and lateral strips and beyond in the approximate proportion 8:5:1, the distribution of the large bags (56 and 112) was more irregular (cf. Table 2 indicating lateral drift).

The longitudinal drift was much more marked with the 7 lb. bags (the effect of the following wind must not be overlooked) and the deposit area was consequently more extended. The area of dispersal formed a rectangle of approximate dimensions 120 ft. broad by 270 ft. long, and the distribution of bags was as follows : Lost in the air—8%, central strip—49%, lateral strips—30%, beyond 13%. There was thus a less effective ground concentration with this size than with larger bags.

If we now consider the results from the second sortie when the 5 slings were dropped in one stick we note that slings F, G, H (14 lb. bags) and J, K (28 lb. bags) gave two distinct merged impacts in which the concentrated areas were 135×437 feet and 130×227 feet respectively, separated on account of the different trajectory paths of 14 lb. and 28 lb. bags by a clear area 133 feet long (Plate 8). Taking rectangles of arbitrary width 120 feet as above and lengths of 440 feet and 225 feet respectively the distribution in relation to the rectangles of the 14 lb. and 28 lb. bags is shown in Table 4.

TABLE 4

Distribution of Ground Impacts from 2 and 3 Sling Sticks

Stick	Package Size lbs.	Number dropped	Number plotted	Percentage Distribution			
				Lost in air	Central Strip	Lateral Strips	Beyond
Slings F.G.H.	14	414	352	15	48	29	8
Slings J.K.	28	144	141	2	58	33	7

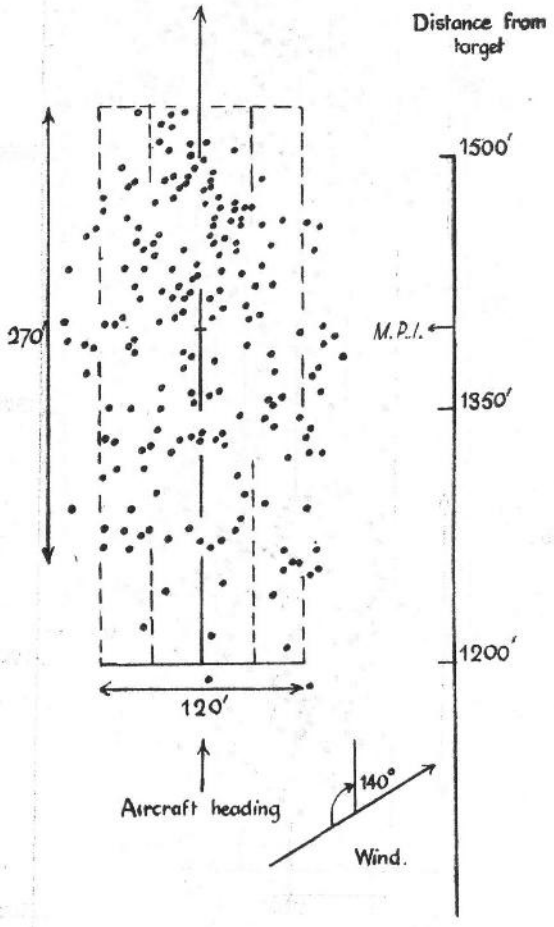

FIGURE 1

Ground Pattern 7 lb. bags Sling A Kingsclere

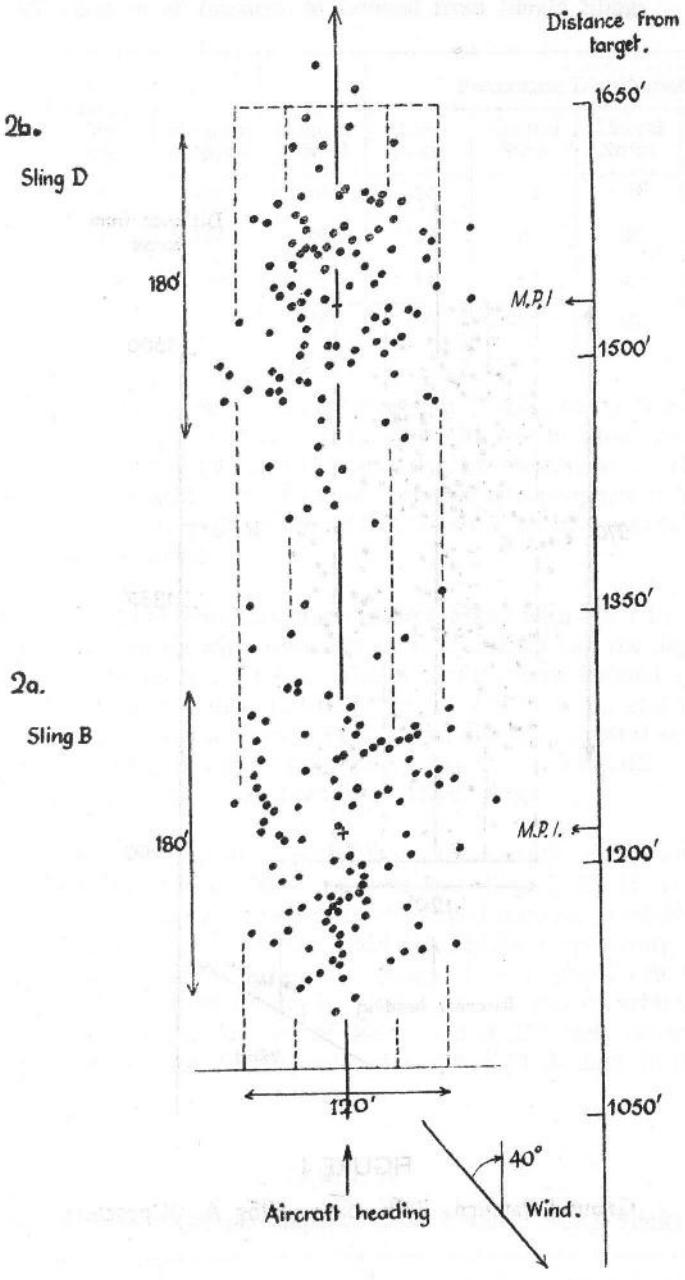

FIGURE 2

Ground Pattern 14 lb. bags Slings B and D Kingsclere

(0.8 sec. stick. Sling C failed to release)

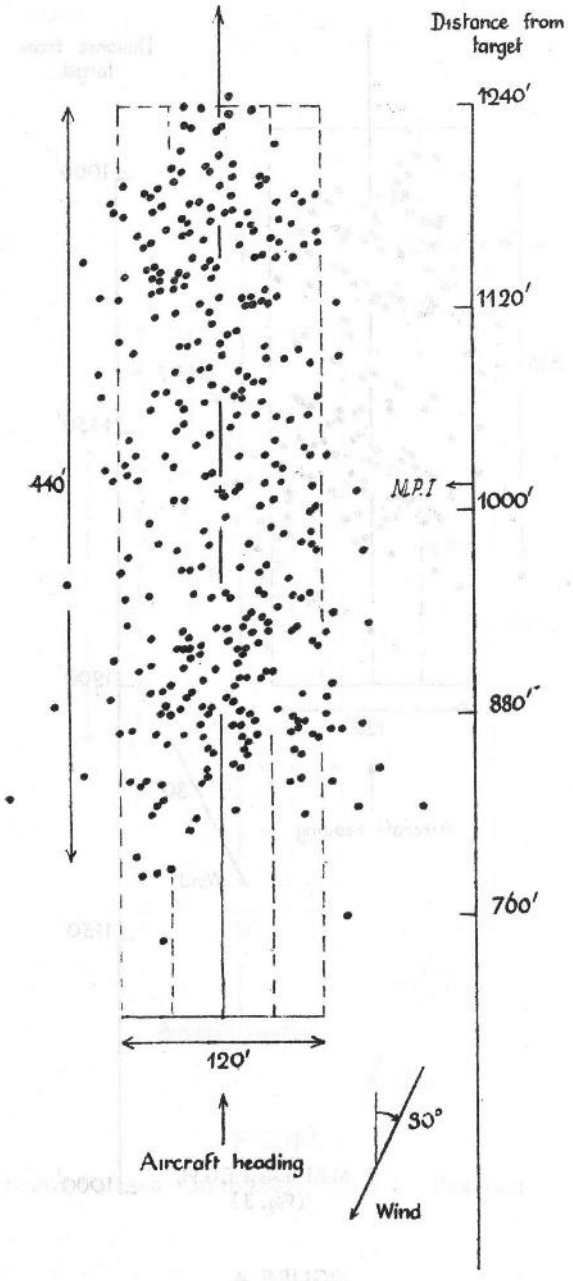

FIGURE 3

Ground Pattern 14 lb. bags Slings F, G and H Beaulieu

(0.7 sec. stick)

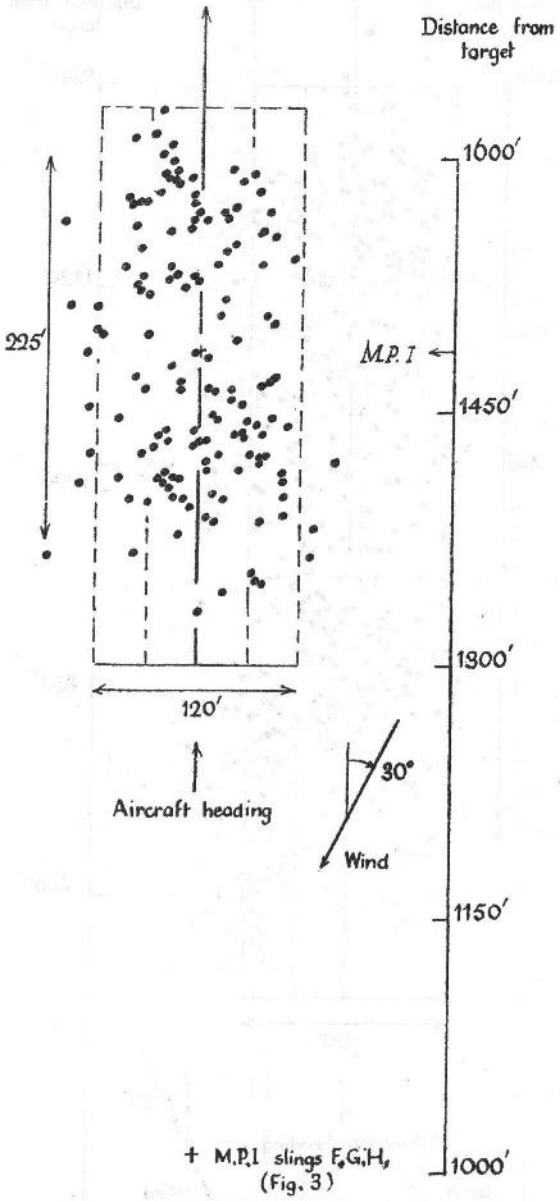

FIGURE 4

Ground Pattern 28 lb. bags Slings J and K Beaulieu

(Five-sling 0.7 sec. stick, lost two slings)

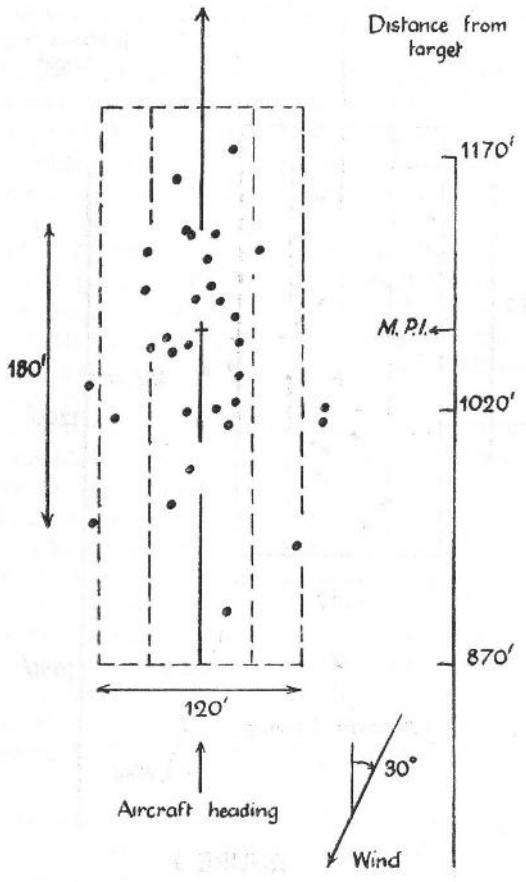

FIGURE 5

Ground Pattern 56 lb. bags Sling L Beaulieu

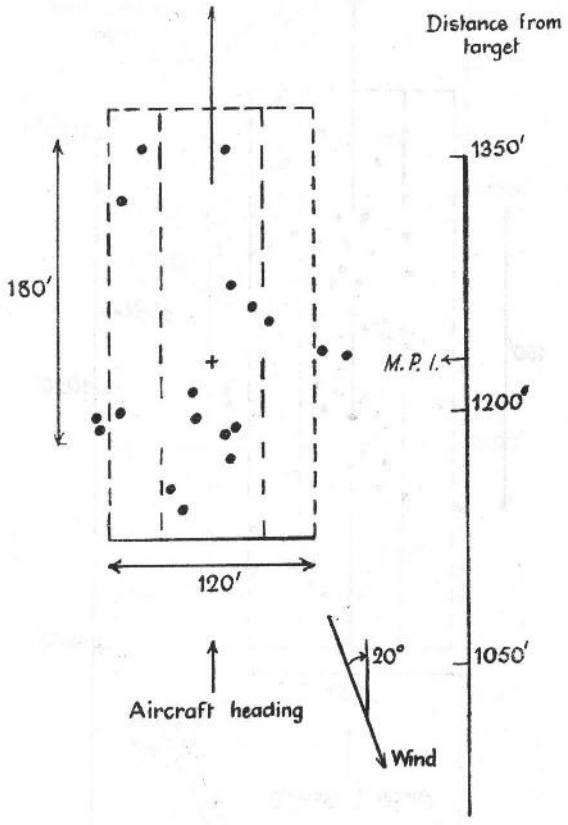

FIGURE 6

Ground Pattern 112 lb. bags Sling E Kingsclere

From the figures 3 and 4 where the plottings are given of these two series of slings it is clearly evident that the aircraft distributor setting giving a time delay of 0·7 seconds between the release of each sling produced a satisfactory merged pattern at the release height and aircraft speed used during the trials.

(*b*) *Dispersal of Bag Contents*

While the data discussed in the preceding section indicate a broad comparison of the ground distribution in favour of 14 lb. and 28 lb. bags, it is necessary to examine the dispersal of lime after impact before it is possible to compare the various droppings from the point of view of their liming efficiency.

Sling A—7 lb. bags. These bags fell on long grass, which cushioned the impact of a number so that they were intact on examination. The majority burst, however, and the maximum forward throw observed was 12 feet.

Slings B and D—14 lb. bags. These fell on medium and short grass respectively. All the bags burst and the forward throw of contents ranged from 4 feet—26 feet.

Slings F, G, H and *Slings J, K*—14 lb. and 28 lb. bags. These bags fell on relatively hard ground with a cover of short heather and grass. The limits of throw were comparable to those in the previous case, and the average was about 12 feet. The degree of penetration of the ground surface was negligible with the 14 lb. bags, but penetration of from 3-6 inches was observed with the 28 pounders.

Slings L, M—56 lb. bags. The forward throw was extremely varied and ranged from nil to 39 feet. Penetration was very marked with many of these bags, the average being about 10 inches, but some bags penetrated up to 24 inches, and became partially buried (Plate 15).

Sling E and jettisoned load (P, Q)—112 lb. bags. Deep penetration and partial burying of some of these led to a very variable result, and forward throws ranged from nil or less than 5 feet (Plate 14) to 33 feet (Plate 13).

The throw on impact of 14 and 28 lb. bags is shown in Plate 6. As a result of this burst and throw, where bags were well concentrated as in the deposit areas of slings F, G, H and J, K, a very uniformly limed appearance was produced (Plate 12). With larger bags (56 and 112 lb.) on the other hand the appearance of the deposit areas was very patchy in comparison (Plate 16).

The photographic evidence of the effect of package size on the dispersal of contents is confirmed by the estimates of the residues obtained after sorties II and III at Beaulieu, and a summary of this data is given in Table 5.

TABLE 5

Estimate of Dispersal of Contents after Impact

Size of bag	Number plotted on ground	Percentage of bags containing residue					Percentage Dispersal of contents (approx.)
		Full	¾	½	¼	Less than ¼	
14 lbs.	352	Nil	0·85	4·25	7·10	87·8	95
28 lbs.	141	4·25	7·1	21·3	12·8	54·6	76
56 lbs.	73	12·3	26·0	15·1	1·3	45·3	60

4. Conclusions

A satisfactory dispersal of lime was obtained when the slings were loaded with 14 lb. and 28 lb. bags, and 14 lb. bags were superior on account of the more complete dispersal of their contents. Smaller bags (7 lb.) were unsatisfactory on account of the labour involved in bagging, and handling during stowage. Moreover, these bags were too light to ensure 100% burst on impact. The larger bags were unsatisfactory for two reasons, first they tended to scatter too much in descent, and the degree of impact spread was insufficient to compensate for their sparse distribution on the ground, and secondly there was too great a loss from the heavy residues remaining consequent upon the deep penetration which occurred.

If the stick of 3 slings F, G, H, is considered further, and allowance is made for loss due to undispersed residue, the rate of liming obtained is found to be :—

0·6 acres at a rate of 1·95 tons per acre (Central Strip), and
0·6 acres at a rate of 1·19 tons per acre (Lateral Strips).

Using these estimates, and assuming the air losses to be the same, a Lancaster aircraft loaded with five 2,000 lb. slings of 14 lb. bags, released at 0·7 seconds interval at a speed of 160 m.p.h. could lime a strip of land 730-750 feet by 120 feet so that the central 60 foot strip would receive approximately 4,800 lbs. and the lateral 30 feet strips together would receive approximately 2,900 lbs., i.e. 1·0 acre at 2 tons per acre and 1·0 acre at 1·2 tons per acre. Of the remainder about 400 lbs. would be lost as residue, 1,500 lbs. would be dispersed in the air, and about 500 lbs. would be scattered beyond the rectangle of concentration.

Alternatively a very heavy concentration on a proportionately smaller area could be achieved by salvo dropping.

If better wrappings than those used in the present test were employed, and the ground surfaces were sloping, it is possible that a sufficient improvement of the impact spread with reduction in the residues would allow a satisfactory use of bags up to 28 lbs. 28 lb. bags would have considerable advantage over 14 lb. bags from the point of view of initial preparation and transport and would facilitate speedier loading of the carrier slings.

Acknowledgments

Sincere appreciation and thanks are due to the Ministry of Supply who financed these trials, to the officers of the R.D. Airborne Division of that Ministry who gave valuable advice, to the officers of the Mechanical Engineering Division of the Royal Aircraft Establishment who carried out the operations, and to Messrs. Imperial Chemical Industries Ltd. who supplied ground limestone. The above report is based on M.E. Test notes 40 and 62 of the R.A.E., and the photographs were prepared by the Establishment's Photographic unit.

LIST OF FIGURES

1.	Ground pattern Sling A	7 lb. bags	Kingsclere
2a.	Ground pattern Sling B	14 lb. bags	Kingsclere
b.	Ground pattern Sling D	14 lb. bags	Kingsclere
3.	Ground pattern Slings F, G, H	14 lb. bags	Beaulieu
4.	Ground pattern Slings J, K	28 lb. bags	Beaulieu
5.	Ground pattern Sling L	56 lb. bags	Beaulieu
6.	Ground pattern Sling E	112 lb. bags	Kingsclere

APPENDIX 7

SURVEY OF HILL SHEEP BREEDING METHODS AND PRACTICES

By Professor J. E. Nichols, M.Sc., Ph.D., F.R.S.E.

FIRST REPORT

Introduction

1. It had been emphasised in evidence before the Committee on Hill Sheep Farming in Scotland and the later Technical Committee, that genetical investigations relating to hill sheep breeding in this country had not been pursued in recent years sufficiently to establish the main genetical problems confronting the breeders of hill stocks. Though isolated programmes of work had been carried out in the past and had yielded interesting and useful results, the present status of the industry had not been adequately considered in the light of modern genetical developments and of work which had been conducted in other countries.

2. In view of these general considerations the Hill Farm Research Committee, concerned with the encouragement and co-ordination of scientific research into matters affecting the welfare of the hill sheep industry, invited me to make a broad survey of present breeding practices in the hill areas of Scotland, and by arrangement with the Agricultural Research Council the survey was extended to include some of the hill areas of the North of England, wherein the breeding problems would be similar in general to those occuring in Scotland.

3. Unfortunately it was not practicable for me to be relieved completely from duties with the Commonwealth Bureau of Animal Breeding and Genetics, so that the survey had to be restricted to series of visits and investigations not involving lengthy absences from Edinburgh. However, largely owing to the invaluable assistance of Mr. J. R. King and Mr. J. T. Steele of the Department of Agriculture for Scotland, not only in the preliminary planning but also throughout the survey, it was possible to arrange tours in selected areas which could give a fairly representative picture of the conditions obtaining at the present time, as well as an opportunity for attaining a reasonable perspective of the changes which have occurred in recent years.

4. Previous familiarity with the South of Scotland and the North of England provided a valuable background to the survey in those areas, but I am greatly indebted to Mr. E. David, formerly Executive Officer to the Northumberland W.A.E.C. and to Mr. Dinsdale of King's College, Newcastle-upon-Tyne, for their helpful interest in the purpose and conduct of the work.

5. The general lines on which the survey was carried out are given below (para. 6) but it must be noted that as yet the sheep areas of the North of Scotland have not been studied, so that the comments offered are with the reservation that they refer specifically to the conditions and areas so far examined. It is considered, however, that the general conclusions drawn may have a wide application and not require drastic modification. It is hoped to conclude the broad survey of the Northern areas during 1947 and a second report will then be submitted.

6. The survey involved securing a comprehensive view of the industry from published material available in official reports and from discussions with individuals whose interests cover the production and utilisation of products drawn from the industry as a whole, that is in both cases from independent sources. Without exception I encountered a remarkable freedom and willingness to place material and information at my disposal and, without being invidious, I wish to acknowledge my special indebtedness and gratitude to Mr. Fergusson of the Scottish Woolgrowers, Mr. Stewart of Messrs. Stewart, Leith, and Mr. Mactaggart of the Ministry of Supply (Wool Control), for their generous assistance. The information derived from such sources was supplemented by discussions with breeders and examination of flocks in the different districts ; the direct help given without any reserve by the many farmers and shepherds has been most highly appreciated. I also wish to place on record my thanks for the stimulating interests of my colleagues Dr. A. W. Greenwood and Dr. H. P. Donald of the Institute of Animal Genetics, the University of Edinburgh, and for the most valuable co-operation of Dr. I. W. Parnell of the Department of Zoology, the University of Edinburgh.

The General Background of the Survey

7. The magnitude and significance of the hill sheep industry have been described in the Reports of the Hill Sheep Farming Committees in Scotland, and in England and Wales ; restatement of the general position is unnecessary here. It may be emphasised, however, that its importance to the agriculture of the country rests not only on the numbers of sheep raised and kept on the hills, but also on the numbers of young stock and of draft ewes which move from the hills to lowland farms for either fattening or further breeding. Moreover, although the products of these hill sheep on the lowlands are greatly affected by the changed environment, their general characteristics, especially of the large amounts of wool yielded, are to a great extent predetermined by the breeding policies on the hill farms. Hence the effects of breeding practices in the hill flocks are not restricted to hill sheep but ramify into a considerable portion of the lowland sheep population also.

Breed Distribution

8. As a basic consideration in this survey, however, attention can be focussed on the areas raising stocks which qualify for the Hill Sheep Subsidy. In 1945, in Scotland, a total of 2,360,208 sheep qualified for subsidy, of which 1,766,622 were Blackface, and 485,467 Cheviot. With the exception of Caithness all counties included some Blackface stocks, while Cheviots were distributed throughout all counties except Bute, Clackmannan, Dunbarton, Nairn, Renfrew and West Lothian. On a purely county basis, therefore, the two main breeds overlap in their distributions, yet for the most part the main

breeding areas are reasonably distinct, and in the majority of counties one or other breed predominates. Taking account only of the mainland, Cheviots are preponderant in Caithness, Sutherland and Roxburgh, slightly in excess in Dumfries, form about one-third of the county totals in Ross and Cromarty and Peebles, attain approximate equality with Blackfaces in Selkirk and also (though the numbers are small) in the Deer Forests. There is, therefore, even on such a broad basis, an indication of tension or competition between the two breeds in certain areas. (The broad distribution of the breeds types has been described by Wood[1] and by Wildman[2].)

9. In the North of England a strict comparison on similar lines is not possible. Qualification for subsidy is not precisely equivalent in that a distinction roughly according to altitude is made so that stocks on the lower grazings are excluded—this tends to eliminate from the figures certain breeding flocks which may be important local factors as ram producers. Also the distribution of breeds in Northumberland, Durham, Cumberland and Westmorland (parts of which counties were included in the survey) is more complex than in Scotland, more breeds are involved, and in certain areas the tension between breeds is relatively more acute. It was mainly for the last consideration that this region was studied.

10. The sheep stocks in these counties of England can be primarily considered in their affinities to those of Scotland. The hill areas north of the Tyne Gap are geographically continuous with those of the South of Scotland, so that the Blackface and Cheviot stocks are of the same provenance as those of the South of Scotland. Yet there is an essential difference in the relationships of the two types to the rest of their breeds. The Cheviots of, for example, the Bellingham and Rothbury areas are not widely isolated geographically from the main breeding centres of their breed and are distinct in type from the neighbouring mountain breeds.

11. The Blackface stocks of the North of England are in a different category. In an historical sense it may be justifiable to regard the Blackface type as one variant derived from a common ancestral form distributed widely along the Pennine Range and the adjacent hill areas. Other variants have arisen in the shapes of the Swaledale and the Rough Fell, but these have remained comparatively closely restricted to their native areas. On the other hand the type which has been developed into the modern Blackface spread from the Northern Pennines, through the Southern Uplands and widely throughout the rest of Scotland, after having attained separate breeding centres in the hills of the Lanarkshire-Lothians-Peeblesshire-Ayrshire regions, and with extensions into Galloway, (see Parnell[3], 1939). In this sense, the Blackface flocks remaining on the northern parts of the Pennines (roughly from Alston north) and in Northumberland north of the Tyne Gap can now be considered as outlying stocks from the main Blackface " bloc ", influenced by the ideas of " type " developed in the Scottish breeding areas.

[1] Wood, R. Owen (1937)—Survey of Sheep Management in Britain. *College of Estate Management. Reports of Travelling Scholars in Agriculture No.* 3.

[2] Wildman, A. B. (Sept. 1944)—Memorandum on the Hill Sheep of Scotland and Their Fleeces with special reference to the Scottish Mountain Blackface. *Wool Industries Research Association. Special Publication No.* 5.

[3] Parnell, I. W. (1939)—Notes on the history of Scottish Mountain Blackface Sheep and some genetical observations on certain breed characteristics. *Scientific Agriculture*, Vol. **20**, pp. 205-233.

12. The local competition, or state of tension, between breeds throughout these areas can be pictured on this background. The present position will only be briefly stated here. (It is proposed to pursue an analysis of the changes that have occurred since the previous study of the ecological aspects of breed distribution, published in 1930-3.) The Swaledale has spread northwards along the Pennines from the Teesdale-Appleby area and has practically driven the Blackface off these ranges except for " islets ", e.g. in West Allendale and Geltsdale ; it has spread westwards to press against the Herdwick preserve of the Lakeland hills (in fact the Herdwick area has contracted) and has pushed out across the Tyne Gap on to the Bewcastle Fells and even into the Otterburn district, bringing it into some local tension with the Cheviot. At the edges of its dispersion there appears to be local disequilibrium. The Swaledale has *not*, however, overrun and swamped the Rough Fell breed, which has remained for long in possession of an area roughly defined by Ravenstonedale-Burneside-Howgill-Lowgill-Tebay-Grayrigg, with an extension to the northwest on to Shap Fells.

13. North from Haltwhistle and between the North and South Tyne the Blackface predominates, and has pressed the Cheviot, also, in turn, in Redesdale and Coquetdale, during about the last 20 years.

14. Throughout the Southern Uplands there are other instances of tension and displacement between breeds. For example, there is evidence that the Moniaive area was originally populated with Blackface stocks, somewhere about 60 years ago the Cheviot was introduced and gained ascendancy, later in about the 1930's there came a definite change back to Blackface. Again, in Liddisdale some stocks are now changing from Cheviot to Blackface, while Swaledale rams are being used in limited numbers in yet other areas.

15. But there is also tension of types within breeds, which is generally somewhat more difficult to define in terms either of areas or of types, but which may be considered, at this stage, from a similar basis as that indicated in para. 11. It has been suggested elsewhere[4] that as a " breed " or recognisably distinct type spreads from its original habitat by migration or introduction over wide areas, it tends to develop local varieties. These may become established as sub-breeds, again recognisably distinct, if any of several isolating mechanisms, in combination, become sufficiently effective to set up milieux within which different genetic constituents may be selected. How far these are involved in the distinctions and tensions between, for example, the Lanarkshire and the Galloway, or Newton Stewart types of Blackface and the Border Cheviot and its West Country, or Lockerbie, type, will be discussed further below.

Genetical Considerations

16. It is frankly admitted that the amount of purely genetical investigation on the breeds concerned has been strictly limited to a few studies ; these have been discussed by Parnell[3] (1939) and will not be elaborated on here. But there has been a sufficient corpus of modern genetical knowledge built up by work on other breeds and species as well as on theoretical grounds, to enable the practically important aspects to be raised in general terms.

[4] Nichols, J. E. (1946)—Breeding Methods in Animal Improvement. *Report of Proceedings of the Fifth Meeting of the British Society of Animal Production.*

17. It must be emphasised, in the first place, that many, if not all, of the characteristics which constitute commercial worth, as well as those concerned in physiological responses, are complex and are affected by environmental factors. (Parnell has indicated some of the environmental effects which may be expressed in Blackface characters.) The environmental influences affect different characters to different degrees, and at different times. From a broad genetical point of view, interest lies in the different degrees of heritability of the various characters, which from a practical point of view also implies the recognition of the possibility and magnitude of environmental effects. In this survey, therefore, note has been taken, in all instances, of the general environmental conditions, such as nutrition, management, disease incidence, climate, altitude, pasture types, etc., and an attempt made to weight their influences so far as possible. It is obvious, however, that knowledge of such environmental factors is not yet precise enough, or adequate, in most cases, to afford specific information so far as the breeds and regions involved are concerned ; hence the information available, at this stage, can only help to get the major issues in perspective so long as it is cautiously interpreted.

18. The variation to be found within the hill sheep population is a complex of the genetical variation as expressed between and within breeds and of environmental modifications. Thus, in so far as environmental effects can be discounted, or allowed for, the major considerations in this survey relate to the inherent variation which may be affected by breeding systems and practices. The first consideration, therefore, must be on a population basis.

19. Taking, in the first instance, the situation in Scotland, the hill sheep population falls mainly into two genetically different sub-populations, the Blackface and the Cheviot, each of which is dispersed over wide areas, and this dispersion in itself permits a considerable range of character expression within each breed. Except in those relatively few cases, where the two breeds are being crossed, the breeding populations are distinct ; the variations in terms of " breed characters " do not overlap (there is a considerable amount of overlapping in the case of the Blackface, the Swaledale, and the Rough Fell) ; and the genetic variation within each breed is affected only by the systems of selection and mating which are followed throughout the breed as a whole. In practice, however, each breed tends to be subdivided according to different environmental niches and the real or fancied need to aim at different types to fit them, the persistence of local type preferences or fashions, the geographical isolation of the various breeding areas, and the like.

20. But, while the nett effect of such influences tends to set up more or less well-defined breeding centres for each breed or variety—the breeding centres usually tending to be in areas in which the environmental complex appears to favour the expression of particular characterisations, so rendering selection in their direction easier—the existence of clear genetical differentiation between such varieties or sub-breeds merits close examination and much investigation.

21. For example, there is evidence that the so-called Galloway, or Newton Stewart, type of Blackface was to a considerable extent isolated from—there being little interbreeding with—the " Lanarkshire " type. At the present time there appears to be a definite intermixing of the two types in so far as a few

breeders of the one appear to be using a few rams of the other. Whether this is affected solely by questions of fashion, or of breeding to meet a market, the gene-migration between the two varieities must be sufficient to lead to a breaking-down of any genetic distinction which may have been set up in the past, or in other words would tend to increase the genetic variability within each variety.

22. Increased variability arising in such a way is of course not undesirable, if in the long run it is used as a basis for subsequent deliberate policies of breeding for relative improvement, but the impression has been gained that any increased variation within a flock gained by this means is more likely to be utilised as a basis for meeting a wider market for breeding stock of different phenotypes. In other words, it appears that such an interchange of rams between varieties is being used more to increase variability to produce stock to meet demands in different localities, than to set the stage for a fresh line of selection and breeding of a uniform type for a particular demand.

23. This impression is confirmed by evidence accumulated that the former practice of flock-owners, in areas distant from the main breeding centres, to breed their own rams for flock use, has largely given way to the practice of buying numbers of fresh rams for flock use. This would not be objectionable provided it were consistently possible to purchase groups of rams of the same provenance and genotype, to fulfil policies of grading up towards a particular type ; but where the rams are drawn from a number of sources or from a flock or area in which breeding policy is fluctuating or high variability being maintained, it is unlikely to be successful in leading to a reasonably uniform type.

24. The significance of these considerations is increased when account is taken of the composition of the population in terms of breeding units. Data provided by the Department of Agriculture of Scotland, and relating to the Hill Sheep Subsidy Scheme, 1945, show that the total numbers of sheep qualifying, i.e. 2,360,208, were included in 16,734 flocks ; 12,456 of these flocks contained up to 100, and 1,286 flocks over 500 ewes, shearling ewes and gimmers. That is, about 74% of the flocks were of a size that required only 2 or 3 rams in service, and some 8% had more than 10-12 rams in service. (The numbers of rams actually in use would of course be somewhat greater.) Data given in Appendix I to the Report of the Committee for England and Wales show that the smaller flocks are relatively fewer in the Northern counties of England.

25. Throughout considerable areas of the hill sheep country, however, it is not the flock which constitutes the basic breeding unit. Flocks are very frequently subdivided into hirsels and further into hefts. The hefts vary considerably in size (i.e. number of sheep), but are, for the most part, to be regarded as self-replacing units. Thus, even in the larger flocks and although in practice rams may be moved to fresh hefts each season, or after two seasons with one heft, the existence of these smaller breeding units, over a great portion of the industry, tends to add to the possibilities of greater genetic variation, as well as to wider ranges of environmental modification. In this connection the practice in parts of Perthshire of running the flocks as wholes, not in hefts, may contribute to the relatively higher uniformity of the clips from those areas.

26. Most valuable information, of a preliminary nature, has been obtained for this survey, directly and indirectly, from wool merchants. The fleece generally is a most useful indicator of environmental effects, fleece characters such as weight and fibre fineness being relatively of low heritability. Seasonal effects can produce marked changes and may be involved in the comparisons shown below (Wool Control) :—

Table I: Average Weights of Fleeces—Scotland area (16)

		1941.	1942.	1943.	1944.	1945.
Cheviot Hog,	unwashed	4·12	4·10	4·21	4·14	4·20
Cheviot Wether,	unwashed	4·03	4·44	4·66	4·29	4·17
Blackface,	unwashed	3·97	4·28	4·64	4·53	4·57

(These would include fleeces grown under lowland conditions—similarly for Table II below.)

27. Marked geographical differences in fleece characters also occur and have been mapped, in broad terms, in connection with this study. So far as fleece weight is concerned, the overall situation for the 1945 clip is revealed by the following figures supplied by the Wool Control. These are, in effect, unweighted averages, obtained from weights of groups of 100 fleeces.

Table II: Estimated Average Weight of Blackface Fleece—1945 clip as supplied by two of the principal wool merchants. (lb.)

Ross-shire	4·3	Clackmannanshire	4·7
Inverness-shire	4·3	Dunbartonshire	4·5
Argyllshire	4·3	Renfrewshire	4·7
Bute	4·3	Lanarkshire	4·7
Morayshire	4·6	Ayrshire	4·1
Nairn	4·6	Dumfriesshire	4·1
Banffshire	3·8	Kirkcudbrightshire	3·5
Perthshire	5·0	Wigtownshire	3·3
Stirlingshire	4·7		

28. Table II, of course, illustrates the well-known tendency for fleeces to be lighter, and finer, in the West and Southwest. In the latter region, comprising the shires of Ayr, Dumfries, Kirkcudbright and Wigtown, there is also a predominance of the local Galloway type with its lighter, softer fleece. Experience shows that the heavier, longer-fleeced animals moved West from Perthshire or from Lanarkshire, tend to exhibit loss of fleece weight, but it cannot be said exclusively that this in itself would give rise to increased variability of fleece weight or character. Circumstantial evidence tends to show that there may be greater variability among the lighter Blackface wools. The figures given in Table III, however, indicate the sort of information which could be forthcoming, and are presented here to show how data similar to that ordinarily obtainable in other countries, e.g. Australia and New Zealand, can be used in a general reconnaissance such as this. They give an analysis of the grading results of clips in the different areas producing the various types of Blackface fleece, but cannot be accepted as representative, since many clips are sold ungraded. Coloured grades have been omitted ; they make up the 100% in each case. (Courtesy of Scottish Woolgrowers Ltd.)

Table III:

Areas producing:	*Type numbers*					
	100	102A	102B	103	104	105
Deep Strong Types	75%	21%	1%	—	—	—
Average Types	12%	75%	3%	2%	2%	1%
Short Fine Types	—	10%	10%	2%	10%	65%
Bradford Quality	28/32	28/32	32/28	28/32	32	40/44
Approximate Yield	70%	70%	70/72%	68/70%	70/72%	70%

Additional data, from the same source, relating to individual flocks in different localities, clearly substantiate the evidence for marked variations of this kind.

29. The variation in fleece characters, geographically and within flocks has recently been studied by Wildman. In so far as his report refers to what may be considered sample flocks, no further discussion is needed here ; his investigations in this sense parallel the studies made in this survey, whereby what amount to samples of the conditions and breeding systems were made in the different areas and breeds. The genetical considerations, however, have been discussed at some length above, because they are essential to a proper assessment of the significance of, and the conditions affecting, the situations as pictured from both the broad and the detailed data. Moreover, they have a similar bearing on other forms of variation, such as conformation, meat characters and fertility, which have a genetic basis, but on which there is yet entirely inadequate data as to the existing variation. (In fact, it may be emphasised again at this point, as in para. 17, that there is as yet a serious deficiency in available data on many aspects of the environmental and ecological aspects of the industry, although the information made available from the Scottish questionnaire, 1942, Report Appendices V.-XII. and that on sheep diseases from the Animal Health Division, Ministry of Agriculture and Fisheries Appendix XIII. has proved of special value in this survey. As against these, however, must be set the lack of a broad grassland survey applicable to the relevant areas of Scotland comparable to that available for England and Wales.)

Functions and Characteristics of Hill Sheep

30. Though many descriptions have been given, by many authors, in almost dogmatic terms, of the essential characters of hill sheep, it must be admitted that an objective view would cast some doubt on the validity of the various requirements and definitions that have been stated. Statements conflict, and there is insufficient fundamental physiological evidence to establish clearly the basic requirements. Further, it can be argued that just as the very existence of sheep on hill grazings for a long period of time has in itself acted as a biotic factor in changing the grazing environment, so also has it exerted an influence on the physiological make-up necessary to exist under the changed conditions. If a hundred years of sheep grazing has altered the pasturage available, can it be assumed that the type of animal best able to use that pasturage should remain the same ? At the risk of certain criticism, an attempt will be made to indicate some of the characters needing consideration.

31. The hill stocks are essentially maintenance stocks, required to survive, to reproduce, and to produce under relatively severe conditions. For survival they need hardiness, constitution and activity. So much is platitude. Obviously, as characters, these are extremely complex. The inter-relationships between the components need a great deal of investigation, as well as the various manifestations possible and/or desirable in the different breeds. On no particular point is there precise information. For example, and only examples will be given here, the utilisation of rough, but not necessarily sparse, pasturage of markedly fluctuating quality, would seem to require a balance of activity, suitable jaw formation, digestive capacity and efficiency, and a power of accommodation to nutritional changes. There are, apparently, fairly distinguishable gross breed differences, e.g. the preference of the Cheviot for " white " or " green " hills, of the Blackface for " black " hills. In relation to kind of hill and grazing, differences in activity may be significant, e.g. there is evidence that the Swaledale may range more widely, travel better, than some types of Blackface and the Rough Fell. Again within breeds the varieties, or strains, developed in and accustomed to richer, lower, " park " grazings, are generally less suited in activity, build and foraging ability to hill conditions than the truly hill stocks. Activity may be a function of length of leg, length of body, articulation and musculature, which may vary in relative development in the different breeds. Differences in walk or gait are noticeable and may also be significant. These factors may be of survival value as in traversing open drains, travelling over rough land and slopes, or in moving in snow. Freedom from snowbinding, for example, is of great practical importance and in so far as a short leg plus a long fleece may predispose to snowbinding, this combination of characters, physiologically uncorrelated, has acted to the disadvantage of the shorter-legged, blockier, long-coated types of Blackface as compared with the longer-legged, shallower bodied and shorter fleeced types and with the Swaledale in certain areas where snowfalls are frequent and persist for some time.

32. Similarly, fleece characters have some connection with hardiness, if hardiness is regarded as ability to withstand climatic severity over a number of years. Wildman, and others, have discussed this question. But the weather-proofing effect, or character of the fleece is not a straightforward problem ; for example, a certain density of fleece, or a balance of under and outer coats, may resist penetration of rain, but may equally resist a speedy or adequate drying out of the fleece after a thorough wetting, and the latter may be of greater importance to the well-being of the animal. It may be noted also that as yet no attention has been paid in Great Britain to the fat and suint fractions of the greasy fleece in this connection. In addition to the general structure of the fleece in terms of fibre types and growth, attention might profitably be directed to the question of " cross fibres " or " binders ", which, by running from one staple or lock to another, serve to prevent the fleece from opening cleanly to the skin ; their frequency, fibre length, and effective distribution along the lengths of the staples might be involved in the weather-proofing effect of the fleece. Again, the coat formation of the lamb has been considered to be important in relation to early survival; yet observation would tend to show that in this respect the mothering ability, including milk yield and easy access to the udder, of the dam may be of greater practical significance. Yet again, for ability to stand up to weather and climate for a number of years, the question of changes in fleece weight and characters with age is important ; some types, e.g. the Rough Fell, and possibly the Herdwick, apparently retain their fleeces

better with age than do others, e.g. the Swaledale, or the Blackface, or the Galloway type. This in turn affects drafting age and therefore replacements, both of which are discussed more fully below.

33. The foregoing examples by no means exhaust the array of characters which need study ; they are given to indicate the complexity, not only of the general situation but also of the problems of selection and breeding which occur in the industry, in the main breeding centre and wider dispersed " commercial " areas alike. When it is remembered that these fleece characters, particularly, are of low heritability, the question of selection of breeding stock for special environmental niches assumes greater import.

34. Conformation questions require further mention. Recent physiological and genetical work has thrown valuable light on the problems of growth and development involved. Rates of growth and development influence maturity and form, and can be largely affected by nutritional conditions, but, for biological efficiency, the limits are set by the genetical type. Under the hill environment, and under pastoral or extensive husbandry, the mutually compatible limits of nutritional and genetical influences favour slow maturity and tend to establish the longer-necked, longer-coupled, more angular frame, with a higher proportion of bone to flesh and relatively more slender long-bones, as a general characteristic of mountain breeds. But the expression of the combination of correlated responses appears to vary between breeds, and even between varieties; so that conclusions drawn from the common form in one breed may not be entirely valid when applied to another. It is obvious that precise observations on this aspect were impracticable during this survey, but the apparent differences in adult conformation between, for example, the shorter-coupled Herdwick and the Swaledale, neither breed having undergone marked selection changes, would seem to merit further investigation. At the same time one of the major problems in the Blackface and Cheviot breeds, with their varieties, relates to the limits and effects of selection for different kinds of conformation and their compatibility with the requirements of the various hill environments.

35. Two other physiological complexities merit consideration, in themselves and in their inter-relationships with others. Fertility has a genetic basis, greatly modifiable by environment. The breeding season in hill stock is restricted ; the proportions of barren (tup eild) ewes may be fairly high in some flocks, areas, or year ; the proportion of eild ewes may vary similarly ; early post-natal mortality of lambs and losses of ewes are also high as compared with lowland flocks. The proportion of lambs marked per ewes tupped is low. (Relevant data are presented and discussed in paras. 37, 41 and 42, and Appendices VIII and IX of the Scottish Committee's Report.) The supply of replacement stock is therefore restricted and narrows the scope for deliberate selection. The drafting or casting age has, in some areas particularly[5], been reduced from 6 years, to 5 or even 4, which has further restricted selection among replacements ; concurrently the proportion of gimmers to ewes has been raised, and from evidence in this survey the practice of tupping gimmers has increased (though these tendencies vary in different districts). In restricting selection possible on the female side these trends emphasise the need for more careful and more precise selection of rams, if any deliberate breeding aim is to be

[5] Hill Farming in the Northern Counties. Department of Agriculture, King's College, Newcastle-upon-Tyne. 1941.

followed. (In extreme cases, where fertility is low and losses high, it may be necessary to retain old ewes on the hill, casting at up to 7 or more years, to maintain stock numbers ; this sets a low standard of overall production and also entirely excludes any but natural selection among the female stock.) Such trends also suggest the desirability of genetical and physiological investigations (on the lines of recent work at the McMaster Field Station in Australia) on the whole question of delayed accession to sexual maturity, which may operate in our hill breeds and contribute to low overall fertility of the stocks. Moreover, the relationships of sexual to conformational maturity is as yet not defined for these types. With regard to the sheep population as a whole there are also the effects which low fertility, and mothering ability, may have in influencing the competition between breeds in certain localities. For example, the infiltration of the Blackface into Liddisdale and its resurgence in the Moniaive area may be partially attributable to these causes, as well as the spread of the Swaledale over the Northern Pennines and into North Northumberland (cf. paras. 12-14).

36. The milk yield of the ewe is a particularly important feature where the lambs are born and suckled under rigorous conditions. The fact that pregnancy is carried under the most severe seasonal stresses, in any case, is markedly disadvantageous to both ewe and lamb. To my knowledge, no adequate data on milk yields of ewes of the breeds here considered are available ; none comparable, for instance, to those collected by Bonsma in South Africa, exist. Nor are there sufficient data on the early weight increases of the lambs of the different breeds. As far as possible, however, information was sought from breeders and shepherds, and circumstantial observations made. From these it would appear that breed and varietal differences in milking ability do exist and are sufficient to induce results of practical significance. For example, the Swaledale ewe may not produce more milk at the beginning of her lactation, but may have a greater persistency of milk yield than the Herdwick, the Blackface or the Cheviot. For the first few weeks the growth of the young lambs may not differ between these breeds ; but later growth, towards the end of suckling and with more milk to supplement the nutriment of the lamb, appears to be at a higher level in the Swaledale. This affects not only the pure-bred lambs for maintaining the hill stocks, but also the value of the ewe as a draft ewe and for raising cross-bred lambs by longwool rams ; in fact in some cases, e.g. in the North of England, it has helped, through increased survival and growth of lambs, to reduce replacements so that some of the ewestock can be used for crossbreeding on the better hills, the cross-breed ewe offspring meeting good demand for further lowland breeding and the wethers gaining in weight for age, if not for quality of conformation, over the pure-bred types.

37. In view of the great liability of these physiological characteristics to environmental conditions, it is necessary to comment on the significance of nutritional, disease, and management factors, although these do not specifically fall within the purview of this survey. While on general grounds, and on the basis of much work on sheep and other animals in other conditions, it is easy and perhaps justifiable to postulate differential breed responses, nevertheless great caution is needed with regard to evidence suggesting breed differences, as well as in the interpretation of environmental effects. Obviously, conditions of management vary considerably, even from farm to farm, although some practices may be general over wide areas. For example, " raking ", by which the

sheep are moved downhill in the morning and returned uphill later in the day, is a fairly widespread practice ; in my opinion its effects need careful investigation in relation not only to the nutritional regime of the sheep, at various stages of their life, but also to parasitic infestation. The possible interrelationships of states of nutritional deficiency and of parasitism are under close consideration by research workers, both with regard to their acute manifestations and in their subclinical conditions. The gross effects, for instance of worm infestations, on the condition, well-being, growth and fleece characters of the sheep, are well recognised, but it may be remarked that detailed knowledge of the influence of different forms, and intensities, of parasitism on the expression of the different characters at different stages of growth and at the different periods in the annual nutritional cycle, are essential before the real significance of other environmental factors can be revealed. (Cf. the current investigations on *Haemonchus*, etc., in relation to wool-growth, in Australia.)[6] This is not offered as a gratuituous comment on work in these fields at present being conducted in this country—it is made to emphasise the need for standardising, so far as possible, the conditions under which assessment is attempted of the relative genetical and environmental influences concerned in the expression of the complex physiological characteristics of economic importance.

38. Apart from the more complex characters, there are a number of relatively simpler conditions which are of some practical importance, whether this may be ephemeral or lasting. In this category are such characters as face colour, head and horn shape, and extreme variants of coat formation, with nuances varying in significance throughout the hierarchy of breeders, and which offer opportunity for the dictates of fashion. Breeders of the several types have different preferences and prejudices regarding many of these points, and to say the least, it is often difficult to visualise any real reason for attributing any positive physiological value to them at all (especially when, in contrast, comparatively little attention is paid to such matters as jaw malformation, which do have functional significance), none the less there may be some association in certain cases with other characters, which might be useful in indicating performance. Much further study is needed before valid associations can be established ; but since so much attention is given in practice to these characters, or " points ", it may be useful here to mention some of the considerations that arise, though of necessity, in our present state of knowledge, this involves speculation.

39. The brown (" bruchit " ?) animals occasionally appearing in Swaledale flocks are not considered so hardy or such good milkers as the standard type ; some Blackface breeders state that " muffy " sheep are not good milkers and do not give their lambs a good start in life. Both these characters can be regarded as probably fairly simply inherited, the former from its occurrence and its general similarity to other recessive coat colours, the latter because of the relatively speedy way in which the fashion for it has changed, as well as from the various studies of the inheritance of " open v. closed " faces in other types. The reasons for the two observations (beliefs, or facts?) may, however, be widely different. In the Blackface there has been a certain fashion for animals with " muff " and muff became at one time almost a hallmark of excellence in some of the leading ram-breeding flocks of the Lanarkshire type. In about the last 10-15 years this fashion has gone in favour of clean-faced sheep. If

[6] Australian Council for Scientific and Industrial Research. Reports 1945.

while the breeders were preferring and breeding for the muffy type they paid little or no attention to milking capacity, there would be an apparent association between the two characters ; in so far as there is a delay of some generations before the effects of a policy at a breeding centre are spread widely throughout the breed and become revealed, *and appreciated,* in the commercial areas, there would be a tendency to attribute the results to the hallmark rather than to the policy. Moreover, if throughout the same period, breeders of another type, in this case the Newton Stewart, had persisted in favouring the clean-faced animal and had, deliberately or unconsciously, also retained a high milking capacity, the emphasis on the postulated association would be strengthened. Again, at one time a " mealy " or " frosty " nosed face colour was not objectionable in the Blackface, while now a dark face is preferred ; it may be significant that a grey muzzle is a breed label of the Swaledale.

40. In other cases, some utility of " labels " must be admitted, as for instance in the face colour of cross-bred sheep. While even shade or pattern of face markings in themselves may have no relation to feeding and finishing capacities, or to meat quality, the characteristic face colours, for example, of the " grayface ", the Wensleydale x Swaledale, and the Wensleydale x Rough Fell, give a clear indication of origin according to type, and form therefore some of the reasonable criteria on which buyers of crossbred stock, for feeding or for further breeding, base estimates of relative worth. Face colour is highly inherited, though its precise manifestations are influenced by modifying factors ; to a certain extent uniformity of face colour and pattern could indicate careful selection of breeding stock. (Equally well, uniformity in a line of sale stock could indicate careful culling or drafting.) On the other hand, it would not be justifiable, without further critical evidence, to argue that equivalent reliability as criteria of performance should be attribted to other highly inherited characters, such as the pronounced Roman nose may be, to which considerable fashionable importance may be attached from time to time.

41. This last qualification is made to call attention to the fact that throughout the several breed types observed so far in this survey, different situations are found regarding such characters. Breeds such as the Swaledale, the Rough Fell and the Herdwick, with their smaller total populations and more restricted distributions (particularly in the case of the last two breeds), appear to be less subject to the fluctuations of fashion, so that, compared to the Blackface and the Cheviot with their greater populations and their wider environmental ranges, they are less exposed to these additional sources of variations of type. A consistent policy of breeding and selection is more likely to be found, and to be effective, when a breed is freed from the demands of spurious associations or of dictates of fashion. The relatively frequent changes of fashion which have undoubtedly occurred in sections of the Blackface and Cheviot breeds, could fairly be examined in this light.

42. Although the general effects of changes in economic conditions and in demands have been thoroughly discussed in the Hill Farming Committees' Reports, some of their biological implications are pertinent to this survey. But no attempt will be made—valid data are not available—to isolate them, to array them in order of significance, or even to catalogue them. It is clear that changes in the general context of the industry *vis-a-vis* British agriculture have placed

different demands upon the physiological complexes of hill sheep, to varying extents and at different times. For example, the slow trend from a consumer's demand for hill wether mutton towards lamb disturbed the balance of flock composition (and the appropriate conception of regular ages), as well as that of hill stocking ; it also tended to alter the aim from a wether type which would stay on the hill and mature slowly, to one which could soon be put off the hill and mature more quickly. The introduction of fat stock grading has stimulated hill farmers to grade lambs—and also old ewes—where practicable direct off the hill. But recently, during the war, such factors as the increased return from wool, the reduced importations of meat, the acute shortage of skilled shepherds, have encouraged the maintenance of hill wether stocks again in some districts. The recent difficulty, and cost, of " wintering away " has added to these trends. Almost concurrently the demand for hill ewes for cross-breeding on the lowlands developed ; in turn it helped to bring forward the drafting age ; it tended to stress early maturity also in the ewe stocks, lambs, hoggets, and full-grown ewes ; it also tended to encourage some breeders to cross-breed portions of their ewe flocks on the hill, thus again affecting either drafting age or fraction. These considerations raise again the question of the compatibility between the characteristics desired in relation to saleable products and those contributing to survival, not only of individual animals, but of stocks. For if one of the major physiological functions of the hill ewe is to provide offspring for the maintenance of the hill stocks, with a surplus to allow room for adequate selection of replacements as well as for sale for current income, then it would seem indisputable that the female characteristics, plus those for existence and survival, should receive priority—or else that the hill ewe must be regarded as the most multi-purpose beast among farm stock and so the most complicated subject for breeding. (In the latter case there would be an argument for concentrating all constructive breeding into a relatively small breeding nucleus with the stocks at large being only multipliers by some such means as artificial insemination. Yet a practical difficulty is that of the hill ram covering all his ewes—much more than that for the inseminator.) In this light, there is an *a priori* case for an emphasis in breeding policy on ewe characteristics, which in turn raises the question—as in all similar stocks of pastoral conditions—as to how far the criteria and methods applied in the selection of ram characteristics are consistent with or appropriate to ewe production.

General Summary of Breeding Systems

43. Some of the breeding practices employed in the hill stocks have already been indicated. They are broadly similar throughout the areas and breeds surveyed, though there are modifications according to local conditions of management and tenure. For example the condition of " bound stocks " may affect policy and practice ; whether a farmer is near the beginning or towards the end of his tenancy may influence his attitude towards numbers and type ; occupation of a " led " farm or grazing, and its situation relative to the main holding, may alter the flockmaster's ideas regarding requirements in his stock ; the proportion of inbye, or intake, land may vary the possibilities of management in terms of nutrition and other effects.

44. Over the greater proportion of the stocks encountered in this survey there can be relatively little deliberate selection of a consistent direction among the females ; fertility is low, replacements are high. In many stocks, especially

those " bound to the ground ", the practice is to keep the flock in regular ages because of conditions of tenure, custom, or valuations ; but while this age distribution may apply over the flock as a whole, it need not apply equally in the various hefts, which can be regarded as self-contained units (para. 25). Thus, in certain parts of the flock some culling may be carried out in one year, but may only be possible in other hefts another year. The practices, as well as the criteria, of selection vary widely according to circumstances. If drafting old ewes takes place at 5 years of age, fairly commonly a few ewes are kept over to breed as 6-year-olds, but the effectiveness of any selection among old ewes will depend largely upon the survival rate in the flock. Even in this case, however, it does not necessarily follow that this selection is on a basis of survival value, since it may be that ability to lamb early, or the fact of having produced a good sale wether lamb in previous seasons, may influence the breeder or his shepherd, to retain a particular ewe.

45. Some farmers do not pay much attention to the regular age constitution of their flocks and may retain a small proportion of their ewes to advanced ages (a case of a 19-year-old ewe was encountered). Yet this does not invariably mean that such breeders are selecting for longevity, or of necessity affecting the average longevity of their stocks, since such ewes need not leave any more offspring in the flock than the average run of ewes drafted at earlier ages.

46. Where, as in parts of Perthshire, the flocks are managed as wholes, and especially where tupping may be carried out on a flock basis, there would appear to be a better opportunity of culling on a more uniform basis throughout each flock, and this could be reasonably consistent provided that a flock were kept sufficiently long, in terms of sheep generations, in the same hands and that rams of similar genotype were used from one generation to another.

47. Throughout the whole industry, selection of rams is mainly on phenotype. Even in the leading ram breeding flocks few breeders appear to keep pedigree records which might be used to examine the mating systems followed (though a few breeders do keep private flock registers and pedigree books). Little evidence was found that any satisfactory attempt at progeny testing is made. Some breeders claim to have carried out linebreeding policies ; though how far this amounts to linebreeding, in the genetical sense, sufficient to establish definite linebred families of closely related animals, is doubtful. Without proper pedigrees of rams and ewes it cannot be adequately checked. Inbreeding has certainly not been carried out at all as a policy to develop distinct lines ; many breeders would not contemplate mating closely related animals because of either conviction or unwillingness to risk the possible consequences. At the same time, a few cases were met in which breeders admitted to having had outstanding rams, which were the results of, possibly, accidental close-breeding, such as half-brother to half-sister, or grandsire to grand-daughter.

48. The general impression thus gained is that the common system followed throughout these stocks is one of mass-selection, on a purely phenotypic basis. This applies not only in the commercial flocks, but also in the flocks of the breeding centres of the different types, as is in itself obvious from the fact that at the present time rams are sent from the one breeding centre, even from the one ram-breeding flock, to a number of sale centres, e.g. from Lanarkshire to Oban, Perth, and Stirling, where different types, or prices, are in popular

demand. In this connection it is necessary to consider further the flock structure and distribution of the different breeds and types, and the ways in which breeding stock are disseminated or exchanged in them, and the different methods by which stock numbers are maintained.

49. In the great majority of flocks, numbers are maintained by self-replacement ; and it appears that, on the whole, the practice of breeding from gimmers has increased in recent years, which would imply an increasing contribution of the offspring of the younger ewes to flock replacements. A few breeders do, however, bring in, annually or periodically, bought-in gimmers with a result that they can exercise a relatively heavier culling on the flock ewes, thus achieving a phenotypically uniform flock. This uniformity arises from the culling and not from the breeding policy. (When such a practice is followed, the drafted ewes, of all ages, are frequently used for crossbreeding at home.) Again, some breeders buy in older draft ewes from other flocks, but this has only been noted so far in the survey where a farm is changing over from one breed to another (e.g. in the Moniaive area), and the difficulties of " hefting " are either discounted, or reduced by shepherding and fencing. The usual method of changing type is by importing rams, grading the ewe-stocks towards the new breed or type ; it is during this grading process that very heterogeneous flocks can be seen because of the limited culling possible and the difficulty of purchasing a series and sequence of rams of similar genotype.

50. From the foregoing considerations attention must be the more closely focussed on the ways in which the rams are bred and used. Differences between restricted and widespread breeds must be recognised—other than those already indicated, e.g. in para. 41. In the past there were almost certainly localised breeding regions, in which a common objective was shared by the flockmasters who bred and kept a few rams for their own use and for sale or hire to their neighbours, incidentally to the usual commercial production of their flocks. In later years the production and sale of rams has tended to become a specialised enterprise, so that ram breeding flocks and ram breeding centres have developed, and to some extent the flocks of each breed can be considered in two distinct categories : (*a*) flocks in which a high proportion, up to 100%, of the ram lambs are castrated, and (*b*) flocks in which a low percentage are castrated (the latter would include also parts of flocks which are specifically used for breeding rams for sale). As has been pointed out above, the number of flockmasters who breed even a few rams for use in their own flocks has diminished, especially in recent years, and the practice of using only bought rams has correspondingly increased ; the overall demand for rams has remained roughly the same. In the restricted breeds and types, however, it would seem that these tendencies have not gone so far, and even the flocks which have become somewhat specialised for ram production have remained in the same ecological niche as the rest, so that the requirements of ram breeding and commercial production have kept in close approximation. However, in the widespread breeds the two categories of flocks, are more distinct and a trade in rams from one or more breeding areas has developed. It would also appear that in these conditions, few of the specialised ram breeding flocks have subsidiary commercial flocks in other areas for which rams are bred. That is, there is little opportunity of assessing breeding performance from the behaviour of the progeny in the outer areas ; if and when a progeny test is made it is in a similar environment to that of the parental flock. Moreover, this form of ram trade, with its relative

isolation of the breeding centres from the pastoral flocks, tends to stimulate competition between the ram breeding flocks within their own circle and so to emphasise the need for high management, such as special feeding, housing, and preparation of sale stock, which has been so skilfully developed. But not all the rams reared in these breeding centres enter into competition at this level, and (cf. paras. 38, 39) the standard of competition varies. Thus, uniformity within each of these flocks is no advantage ; in fact it is a disadvantage in so far as it restricts the opportunity of selling the " not-so-good " rams for use in other areas.

51. In the genetical sense, this structure of ram production, involving mainly phenotypic selection and resting upon the persistence of a high degree of variability within the central flocks from which rams are passed out for direct use in a wide range of environments, could not be expected to favout the establishment of genotypically uniform lines, varying between lines and genetically suited to the different sets of environmental circumstances occurring throughout the whole breed area. Further, the amount of gene migration which would follow the interchange of only a few rams from one type to another within the breed, would be sufficient to maintain a high store of variability throughout.

52. An interesting departure from the general practice of the ram trade is found in the " hiring " of Herdwick rams. Broadly speaking, there are two forms of this system. Either a ram is hired for a season, the cost covering that of wintering him ; or a ram lamb is hired, " wintered " and " summered ", used for a season and can be kept for a second season on condition that a second lamb is also wintered in this second season. These in effect secure not only a circulation of rams among several flocks, but also provision for overcoming some of the practical difficulties of wintering working adult rams or growing young rams.

53. Under these conditions, in all the breeds, of wide dispersal of rams throughout the populations, and of a negligible selection differential in the ewe stocks, the question of the effective breeding population, as distinct from the total population, becomes important. Even where a number of rams may be used in a flock, in one season, after a few generations the flock may be made up largely of descendants of only one or two of those rams. The flock would be genetically related to only some of the sires originally used. Thus effectively that flock and ultimately the whole breeding population, is a sample of the genetic variability residing in only a small fraction of the total population. Where a breed is numerically small, and its effective breeding population much smaller still, it may be that the opportunities for deliberate selection will be so restricted that the breed can only " drift ". The general lack of adequate pedigree or flock records prevented any serious attempt to get even a rough idea of how far this situation might apply in the various types, though a suspicion remains of the possibility that certain much reduced sections of some breeds may have approximated a stage at which further selection within the type would be ineffective.

Ecological, Physiological and Genetical Questions

54. The genetical aspects, which are closely interwoven with those of the ecological relationships and of the physiological constitution and reactions of the various stocks, have been regarded mainly from the point of view of the

improvement of performance and of greater precision in breeding methods for particular objectives. There are undoubtedly many relatively simple or straightforward characters which could be investigated in genetic terms with great interest, but so far as this survey and this report are concerned, these have been considered of somewhat minor importance ; the possibility, however, that data on the inheritance of colour and pattern, horns and the polled condition, head form, kempiness, etc., can give useful information on gene frequency and distribution has not been, and must not be, overlooked. The inter-relationships of the various aspects can be indicated by the following questions, on all of which more fundamental information is needed :

(*a*) How distinct are the present breeds or varieties ? (This involves zootechnical matters as well as genetical analysis.)

(*b*) How rigid and exclusive are the isolating mechanisms which tend to make the breeds and varieties really or only apparently distinct ?

(*c*) How much of the variation within types is attributable to genetic causes and how much to environmental modification, in respect of the different characteristics of economic importance ?

(*d*) Arising from (*c*) what are the suitable criteria for selection, the accuracy of phenotypic assessment, the requirements, methods and conditions of genotypic selection by means of the progeny test ; and what correlations exist, if any, between juvenile, adolescent, and adult characterisations so that appropriate criteria may be applied for any particular state at any particular age ? At what age can culling for a particular characteristic best be made ?

(*e*) On what bases do the differences in suitability for, or adaptation to, particular environments really rest ?

(*f*) How far do the normal environmental conditions, such as those of nutritional levels, limit or confuse selection for characters like early maturity ?

(*g*) Can the factors involved in the competition and tension between types be resolved in genetical terms so that appropriate systems of selection and mating can be used to influence their frequency and distribution in the type populations ?

(*h*) In what directions and how far can improved performance be achieved by genetic means ?

55. The considerations covered by the last two questions merit further comment, even at this stage, in their relationships to those of question (*c*). Improved performance is to some extent an abstract idea in connection with hill sheep. For example, in fleece characters it has variously been stated as a greater fineness of fibre, a stronger and longer fleece, or an intermediate coat of greater weight, according to the various designs of the would-be improver. Also in conformation and maturity it may be for a good early maturing lamb, or for a 3- or 4-year-old deep milking ewe (cf. para. 36). It is here suggested that, in the first instance, and as a means towards sorting out the immediate problems into the genetic and the environmental, or of appreciating their relative significance, improvement should be regarded as suitability to purpose within a particular class of product and not as need to change to another form

of production. In this light, the evidence shows a lack of uniformity within the constituent flocks of the various populations as well as within the several geographical or environmental fractions of each type population, which it would seem desirable to reduce whatever the demands may be. (The evidence rests not only on broad data such as those mentioned in paras. 26, 27, on studies such as those of Wildman and Parnell, and the authors they quote, and on inspection, but also on individual responses shown incidentally in experimental work, such as that of Fraser and Roberts[7], Fraser and Nichols[8], etc., on selected groups of sheep. It is, moreover, to be regretted, on scientific grounds, that some of the recent opportunities for securing reliable data on environmental changes, provided by the enforced transference of stocks from one locality to another, have not been fully seized.)

Conclusions

56. The breeding of hill sheep presents a formidable array of scientific problems, which ramify into wide, but complementary fields of investigation. It is clear that, on all the aspects here considered, there is prime need for more basic information. More precise knowledge of the effects of environmental factors can only emerge from controlled experimentation with standard and genetically known material, which as yet does not exist. The complexity of the problems need not be regarded as a discouragement, but constitutes an argument for a bold approach.

57. In some fields of study, such as that of fleece characters, a strong corpus of fundamental knowledge and technical experience in investigation already exists, and these should be drawn upon fully in any research programme. For example, in so far as investigation of the wool product of hill sheep stocks are involved, close collaboration with the Wool Industries Research Association through its Wool Fibre Research Committee, would be highly desirable. It is strongly emphasised, however, that in the pursuit of the basic data needed on the genetical aspects of the physiological characters of hill sheep, the essential programmes of work should not be confused with other lines of investigation ; *ad hoc* programmes of work are required. While the first requirement is for known material, once that material is developed, it could well be used in other investigations and at other centres. Not until the basic information is acquired would there be sufficient material available for inclusion in any field station, or stations, on the lines suggested in para. 185 of the Report of the Committee on Hill Sheep Farming in Scotland.

58. A memorandum " Genetical Aspects of the Hill Sheep Industry ", dated 15th August, 1944, was placed before the Scientific Sub-Committee of the Balfour Committee, and evidence elaborating it given by Dr. A. W. Greenwood and myself. The present report relates mainly to items 2(1) and 2(2) of that memorandum.

59. From the survey so far, the following broad conclusions are drawn :

(1) That the breeding systems and practices followed in the hill stocks generally are such as to lead to considerable variation and heterogeneity, not only throughout the breeding populations but within

[7] Fraser, A. H. H. & Roberts, J. A. (1933)—Variation in the Protein Intake of Sheep in Relation to Wool Growth. *Journal of Agricultural Science*. Vol. XXIII, pp. 97-107.

[8] Fraser, A. H. H. & Nichols, J. E. (1934)—Wool Growth in Sheep as affected by the carbohydrate content in the diet. *Empire Journal of Experimental Agriculture*, Vol. 2.

the breeding units (the flocks and hefts), so much so, that efficient expressions of the productive potentials of the stocks in the various environmental conditions are not achieved.

(2) That in general the breeding units are insufficiently large, and the differences between neighbouring units in respect of the genetic constitution of their breeding stocks insufficiently clear, to allow of an adequate assessment of the most efficient genotypes for the various localities.

(3) That the general practice of selection in phenotype, especially as followed throughout the larger breeds and their varieties, is unlikely to lead to a state of affairs in which breeders of the commercial flocks can select stock with high confidence in the breeding results, particularly with regard to consistency of type and performance.

(4) That the activities and efforts of even the most skilled breeders are handicapped by the lack of precise knowledge of the genetical constitution of the various characters of major economic importance and of their responses to environmental modification.

(5) That to elucidate the situation, a comprehensive programme of scientific investigation is needed, with special reference to the physiology and the inheritance of the performance characters.

(6) That, while fundamental in nature, such a programme should be established as an independent entity on a practical and of necessity long-term basis.

(7) That in the first instance the programme might be aimed to secure data on the physiological and genetical bases of conformation (as influenced by rates of growth and development), gross differences in fleece characterisation, and mothering ability, these three groups of characters being judged to be not only of direct practical importance, in themselves and in association, but also amenable to experimental analysis.

In respect of these conclusions, specific recommendations can be submitted to the Committee, if it so desires, on the completion of the survey.

23*rd January*, 1947.

SECOND REPORT

Introduction

1. The purpose and general procedure of the Survey have been stated in the First Report, dated 23rd January, 1947, and submitted to the Committee at its meeting on 3rd April, 1947 ; it remains but to add an outline of the observations made on the extension of the Survey to areas in the North of Scotland during April, 1947, and to submit recommendations in the light of the conclusions drawn from the information collected throughout the Survey.

2. The Northern survey was directed towards conditions in Inverness-shire and the areas north and west of the Caledonian Canal ; it was considerably expedited by preliminary observations and visits made by Dr. I. W. Parnell, who had accompanied me on parts of the earlier Survey and who largely planned the itinerary for the period from 6th to 13th April, 1947, when farms of various kinds were visited in these northern areas, from Strathspey, through the Cromarty Firth district, to Wick, Thurso, Strath-Hallidale, Durness, and via the West coast to Fort William and Rannoch Moor.

3. Thus, it was possible to acquire information from extensive parts of the hill sheep farming regions which could be assessed against the background of the material discussed in the First Report. The present observations are therefore made as supplementary to those of the First Report, to avoid repetition of the general principles and considerations outlined therein, but to direct attention to points of difference or of emphasis.

Breed Distribution

4. With the exception of isolated flocks of Shetlands, the hill sheep population of these northern regions falls clearly into two parts, the Cheviot area covering Caithness, Sutherland and a considerable part of Wester Ross, and the Blackface *bloc* occupying the remainder. The latter is effectively an extension of the Blackface area of the Grampians. On the other hand, the Cheviot area is distinctly isolated from the original home of the breed ; Cheviots were taken up from the south about 140 years ago, formed the pioneer sheep stock, and have persisted as successful immigrants. (The Merino stocks also introduced early in the 19th century were unadapted to the northern conditions and have entirely disappeared.)

5. For the most part the areas of the two breeds are also distinct, the demarcation being roughly a line from Ullapool to Dornoch Firth. Occasional breeding flocks of Blackface exist to the north of this line and in other areas ; down the West coast, where the Cheviot predominates, occasional flocks of Blackface wethers have been introduced in recent years, but mainly as pioneer sheep stocks within deer forests. On the West coast from Ullapool south to near the Kyle of Lochalsh, the two main breeds intermingle, especially in the crofting areas and the stocks of the " Clubs " and Societies. (These small

flocks constitute a separate problem, which is not free from the effects of vacillating breeding policies and the resultant crossbreeding.) From Gairloch southwards there are more Blackface stocks, which approximate in type to the poorer, finer-fleeced variety of West Argyll and provide the finer tweed wools of the West Coast and the Islands, as distinct from the carpet and mattress types of the Central Highlands.

Breed Types and Husbandry

6. To a considerable extent this gradient of fleece types in the Blackface, from the finer and light fleeced forms of the West Coast and Islands towards the coarser and heavier fleeced forms to the East, presents a contrast to the change from the finer tweed types of South Ayrshire, Wigtownshire, and N.W. Kirkcudbright, to the strong mattress wools of Lanarkshire. In the latter case the change is closely associated with the relative distributions of the Galloway and the Lanarkshire types of sheep, or sub-breeds (see First Report), while in the former instance the gradient apparently represents a broad ecological modification of the one parental type, including the effects of less definite selection and breeding policies.

7. The Cheviot stocks of the North and West form a marked contrast with the Blackface. In the western regions south of Ullapool, with a mixed Blackface-Cheviot population, the Cheviot flocks are mainly of South-Country Cheviot type ; north of Ullapool the North-Country Cheviot definitely predominates.

8. Moreover, the main Cheviot *bloc* of Sutherland and Caithness is effectively sub-divided into two forms, that of Sutherland associated with an exclusively pastoral habitat and that of Caithness influenced by the more intensive husbandry possible on the lower arable farming lands. Thus the typical North Country Cheviot of the Caithness variety is larger, longer-wooled, and " softer " than the North Country Cheviot of Sutherland. There are relatively very few " bound " flocks in Caithness ; management of the bulk of the stock approaches that of low-ground flocks and is more intensive ; size and fertility are greater ; in some cases the older ewes are crossed with Border Leicester rams to produce half-bred lambs; a large proportion of the gimmers are tupped and many farms winter their hoggs at home. The very great majority of flocks registered in the North Country Cheviot Sheep Society Flock Book are located in Caithness.

9. The Sutherland Cheviot flocks are almost exclusively managed extensively on hill grazings of low over-all carrying capacity. Many flocks winter their hoggs away, few breed from their gimmers. Fertility is lower ; the sheep are of smaller size and slower growth. In many cases ewes are not drafted before six years of age or more. In many of these pastoral properties there is less of the definite hefting system of the South ; there is also little raking or deliberate daily movement of the stock, and the sheep spread widely over the available low carrying capacity grazing. (It is noteworthy, however, that, while the overall carrying capacity of these areas is low, the sheep tend to congregate in groups on relatively small green areas in the hills, so that the density of stocking on effective grazing areas is high and may even approach that of more favoured lowland areas—it is conceivable that a state of understocking, rather than overstocking, exists on such hill land. Similar conditions have been noted in many areas of the Highlands.)

10. Conditions in Sutherland therefore demand the maintenance of a typical hill sheep, with the characteristics discussed in the First Report (paras. 31-36). Compared to the show or ram breeding types of South Country Cheviot, the Sutherland Cheviot is less stylish and decorative ; indeed it may be regarded as an " unimproved " form, yet essentially adapted to its severe hill habitats.

Breeding Methods, including Selection

11. As between the two main breeds there are marked differences in breeding methods, especially so far as selection and use of rams is concerned. In the Blackface flocks the general practice is to purchase the main supply of rams through the recognised sales, i.e. to draw upon rams bred in other areas. The emphasis on " hardiness " tends to establish the prejudice against obviously housed, or " park " animals, and many Blackface breeders attempt to discount the environmental mask by buying ram lambs, wintering them, and using them as shearlings on the hills. At the same time, general experience shows that strong-coated animals tend to develop finer coats in these conditions—the land fines down and lightens the fleece—and the attempt is made to counteract this tendency by continually importing strong-coated rams. Yet, also at the same time, some breeders recognise that the stronger fleeced stocks may be inferior milkers, and express a preference for " mealy-nosed " types as being better milkers—which effectively narrows still further their scope for choosing their preferred types. (See also First Report, paras. 36 and 39.) The nett position is that the northern breeders largely rely, for their stock rams, on animals drawn as fresh samples each year from the store of variability preserved by the breeding practices in the ram breeding flocks of other areas (see First Report, paras. 22-25). Ram selection is mainly phenotypic ; that some attempt is made to discount the individual modifications in effect serves to emphasise the general conclusion that the commercial breeder can place little reliance on the possibility of getting rams which have been deliberately selected and bred for suitability to his own local conditions. (Contrast, for example, the deliberately bred fine-wool Merinos for " fine-wool areas ", with the strong-wools allowed to be toned down in those areas.)

12. In the same general category must be placed the methods of allocating rams to the Clubs from depots to which the rams are returned each season, and then re-distributed, and their general contrast with the practice in some Societies and Clubs of securing rams from the same parental flock year after year.

13. The major contrast, however, is with regard to the practice which prevails in many of the Sutherland Cheviot flocks, whereby the rams used are bred within the flock or in a special part of it. This practice has very largely passed into disuse elsewhere (see First Report, para. 23), to be replaced by the system of continual importation of rams. Many reasons, of varying significance, may be suggested for its persistence in these flocks that are geographically isolated from the original Cheviot habitat. For instance, (1) the old husbandry systems which were transplanted along with the colonising stocks may have been slow to change—yet other similarly imported practices, e.g. raking, have not so persistently survived ; (2) geographical isolation in itself may have added so appreciably to cost of introducing large numbers of rams that economic factors have tended to make breeders seek their ram replacements at home—yet these flocks are usually of such a size that this considera-

tion is likely to be of little weight in practice and over a long period of time though it would have, and has, considerable importance in aggregations of small flocks ; (3) other economic factors, such as shortage of shepherds, cost of supplementary feeding stuffs, large areas, would militate against the use of large numbers of strange tups ; (4) higher average age of ewes, as indicated by late drafting and non-breeding of gimmers, leading to presumably a longer generation interval, might also be expected to delay adoption of other methods being followed elsewhere, as well as to influence (5) a tendency for rams to have a longer life in a flock as a whole, and (6) a slower reaction to or imitation of any changes in fashionable type which may occur in " ram-breeding areas " ; (7) alterations in type of stock available from sources elsewhere may have created additional difficulties in securing the preferred types for introduction to these areas ; (8) experience may have shown that home-bred tups are possessed to a higher degree of those characteristics of hardiness, vigour, and adaptation to local requirements than imported tups, and are therefore more reliable in use ; (9) knowledge of their pedigree, and the performance of their ancestors, is more precise than in the case of imported animals ; (10) knowledge of their individual nurture and performance is more intimate so that selection can be generally more accurate.

14. Of this, probably not exhaustive, list of influences, evidence from these areas as well as from general principles and observation suggests that the last six are of major importance, with the last three, especially, having the predominant weight. In addition, the scope for progeny testing, and deliberate breeding policies, is wider when such a practice is followed, even although the criteria of performance used may vary from flock to flock and may be arbitrary.

15. The home-breeding of rams is carried out in various ways. A " fine " or " shed " flock of ewes may be kept distinct from the main flock on a separate hirsel ; or selected ewes from different hirsels may be " shed " to special rams at tupping time and returned to their own hirsels for lambing. The " shed flock " may be self-replacing ; or fresh ewes may be introduced to it, or it may even be entirely reconstituted, each year. Management of the shed flock may be the same as, or may differ to some extent from, that in the main flock. Such local modifications of the practice would affect the results of the procedure to varying extents, but the essential practice is that suitable ram lambs bred in these special sections of the flocks are retained for service in the general home flock.

16. Moreover, interpretations of the results of this practice in relation to the possible effects and directions of selection are likely to be partly confused by the effects of differences in respect of husbandy between flocks. For example, there is general evidence that ewe hoggs wintered away make more rapid growth than those wintered at home, so that the phenotypic results of breeding or not breeding gimmers would not be comparable in flocks so differing in management. Again, in some flocks ewes with wether lambs are kept below the fence, while ewes with ewe lambs go out to the more open hill ; this would tend to introduce wider nutritional differences as between ewes within the flock and allow a possible bias in selection against smaller sized ewes, especially among the younger age groups. Similarly, differences in regular drafting ages between flocks, or between hirsels within flocks, give rise to different possibilities of selection.

Conclusions and Recommendations

17. It is clear that the complex of ecological, physiological, and genetical problems as outlined in the First Report,, paras. 54 and 55, applies throughout all the hill sheep breeding areas of Scotland, and that the major requirement, from both the practical and the scientific points of view, is for more basic information regarding the vital statistics of the hill flocks, the physiological responses of the sheep that comprise them, and the effects of the systems of husbandry that are possible and practicable under hill farming conditions.

18. Under hill sheep farming conditions a great deal of the variations and vagaries of environment are beyond practicable control ; questions of the suitability of the stock, and of husbandry systems, to the environment, are continually significant. The need, therefore, is for more knowledge not only of the environmental factors themselves, but also of the responses of the sheep to these factors. A great deal of active work is at present being carried out, under the aegis of the Committee, on many aspects of the nutritional environment, and of the control of diseases and parasites which affect hill sheep. The regional hill experimental farms recently established will provide expanding opportunities for different lines of investigation to be focussed upon the practical problems of hill farming.

19. Yet the very fact of the intensification of such work serves to emphasise the deficiency of basic information in other directions, which has been made manifest during this Survey. It is admitted that these matters are not immediately germane to this Survey ; comment on them is only offered with reserve and in the spirit of attempt to place the whole question in perspective. The deficiencies appear to be in three broad categories. In the first place, there is an inadequacy of specific information relating to the plant species which the sheep utilise habitually or seasonally in grazing ; knowledge of the growth, nutritive value and its fluctuations, and the use by the animal of the component species of hill grazings, does not compare with that referring either to lowland species in this country or to species in the range and pastoral regions of other countries. For example, the precise role and usefulness of heather, in its different stages of growth and associations, are as yet ill-defined in relation to the general dietary of the sheep ; also, practically nothing is known regarding the draw mosses (*Eriophorum sp.*), although they have great significance in the practical experience of hill shepherds. Secondly, since throughout a widespread industry broad changes in environmental factors are important, co-ordinated information is necessary so that the distributions of the stocks and types of sheep can be studied in their normal ecological relationships ; this aspect has already been noted in the First Report, paras. 17 and 29. Thirdly, there are, apparently, many difficulties in obtaining comprehensive data on the general context of the industry against which the standards of productivity, or output, of hill sheep flocks can be objectively assessed ; while statistical returns, economic surveys, etc., undoubtedly yield highly important information on the state of the industry, there are as yet insufficient surveys of such aspects as lambing, mortality, and death rates, movements of breeding, surplus and fat stock or replacements, which together comprise the vital statistics of the hill breeds necessary to interpret the broad economic data in biological terms, i.e. in relation to the conditions of animal husbandry within the hill areas. While it may seem an extreme comparison, the objective data on the milk producing industry and the indications they give of its dominant problems, illustrate this point.

20. In so far as this Survey is concerned, and accepting the outstanding importance of environmental considerations, the major problem of improvement of the hill stocks is that of husbandry to raise the standard of efficiency of production in relation to the prevailing environment. In so far as " husbandry " can be regarded as the practical application and integration of knowledge of breeding, feeding, disease control, and management, so that full advantage can be taken of the physiological responses of the sheep in their immediate environment, then the conclusion is drawn that the major weaknesses in the present situation are lack of knowledge regarding the general physiology of production in hill sheep and of application of genetical principles in the breeding of the hill sheep populations.

21. Bearing in mind the general ambit of the Committee's interests, it may be suggested that possible steps to amend the present situation are not confined to scientific work alone. Action on the part of the industry itself is considered as equally necessary as the development of further research, or the extension of advisory services, to collaborate towards progressive improvement in the standards and methods of production. For example : as an aid to more precise knowledge of breeding stock, the systems of registering flocks and pedigrees could well be extended ; the action of the Caithness breeders in forming the North Country Cheviot Sheep Society and issuing a Flock Book could be followed by other groups. Multiciplicity of groups might lead to difficulties, but following the initiative of breeders of the various types, a central registry, such as that set up in Canada, could be established. Systems of approval of rams used in hill flocks would undoubtedly assist improvement if they recognised the value of the breeding test and allowed for local modifications of type. (Documents relating to the scheme launched in Montgomery have been already given to the Committee.) Progeny and performance recording schemes are already in use in other countries, e.g. Sweden and New Zealand ; the possibility of introducing similar schemes should be explored. Close co-operation between breeders could be encouraged in order that the breeding merit of sires and strains under commercial conditions could be revealed. In this connection, it is felt that any organisation of breeders which limits its views mainly to the interests of its members as individuals and neglects the interests of its breed type as a whole, is neither fulfilling its true function nor realising the importance of modern developments of practice and science ; stock sales and breed propaganda are still significant activities, but many organisations are now recognising also the value of their own technical officers and advisory staffs, dealing with breeds as wholes.

22. These suggestions are, however, incidental to the main recommendations, which relate to the scientific problems of hill sheep husbandry, especially breeding. The general trend of the observations recorded in these Reports clearly stresses the need for straightening the line of attack on the formidable array of problems presented by the industry. To do this, it is recommended that the Committee should devote attention to the needs in respect of more fundamental information on the physiology and applied genetics of the hill types of sheep. Close consideration has been given to the question of whether the approach to be recommended should be mainly from the purely genetical or from the physiological angle, although it is recognised that with the larger farm animals the general approach may be termed that of " physiological genetics ". Taking into account the simultaneous lack of scientific information on other aspects

of husbandry, such as the general growth conditions, grazing habits, performance in respect of fleece growth changes, milk production, and conformation, and the effects of selection, environment and management thereon, it is concluded that the bias in the first instance should be directed to elucidating the underlying physiological principles. It is considered that a genetical bias to the investigations would soon reveal the essential need for more physiological knowledge ; a physiological programme would soon provide sound information upon which general genetical principles could be applied. Moreover, it is physiology *under field conditions* which is of major importance.

23. It is therefore specifically recommended that the Committee should consider the establishment of a Hill Sheep Production Research Station*, whose main programme would be to study the growth and development of conformational and fleece characters, the milking capacity and behaviour of hill sheep under reasonably normal and standard—not superlatively good—field conditions. (See also First Report, para. 59 (7).)

24. Such a programme would be complementary to those being carried out at the existing *ad hoc* Research Institutes in Scotland and in the regional hill experimental farms. The suggested Station should, however, have its own specific programme of research which should be aimed more at developing extensions into local applications to be tested at the regional experimental farms, rather than to accommodate extensions of the experimental programmes of other institutes. (In effect, the conduct of investigational work envisaged is closely parallel to that so successfully pursued with poultry by Dr. A. W. Greenwood at Edinburgh.) For example, the Station should not be asked to undertake general progeny testing work, on the lines of the Continental pig and cattle testing stations ; it should be developed as the source of information which can be applied by breeders and/or other organisations in their own breeding programmes, and on which data previously described as " vital statistics " can be interpreted.

25. It is recognised that this recommendation deviates from those made by the two Committees on Hill Sheep Farming, in Scotland and in England and Wales. This is deliberate, in that it is held that the nature of the research required in this field, and the essentially peculiar conditions of the hill sheep farming industry in which artificialities of the environment are greatly reduced in favour of the natural, merit the establishment of a distinct research unit.

26. In the development of the research programme, close collaboration with the National Animal Breeding Research Organisation should be maintained, as well as with the Rowett Research Institute and the Animal Diseases Research Association ; in relation to fleece characters, co-operation with the Wool Industries Research Association should be effective.

27. It is recognised, also, that the administrative mechanism, under which such a Research Station might best operate, would require consideration. It is suggested that a structure whereby administrative responsibility rested in a body representative of breeders as well as of parallel research services would be

* (The title " Hill Sheep Husbandry Research Station " might be more appropriate, but it is understood that such has been adopted for a project of the N.A.A.S. of England and Wales, which is to include hill land improvement in its scope.)

effective and desirable. The composition of the Hill Farm Research Committee, indeed, would form a basis for an executive committee or board of administration.

28. Such a station should obviously be located within the hill farming areas ; any disadvantages attributable to isolation from other research centres would be outweighed by the consideration of suitable field conditions. Definition of an area as " typical " is unreasonable in view of the wide range of natural conditions obtaining throughout the hill sheep regions. Sites in Central Perthshire or Lanarkshire would offer certain advantages in accessibility and in terrain so far as the Blackface breed is concerned, but both these areas produce the mattress type of wool. On balance it is suggested that a site in the intermediate wool areas of N.W. Perthshire might meet the main requirements of location. In any event, an early extension of the programme to include studies of the Sutherland type of Cheviot could be contemplated ; it might be achieved through co-operation with breeders in that area.

29. To implement these recommendations, it is suggested that a farm carrying a flock of some 600 ewes on the hill, with preferably a dry stock hirsel, would be required. This would provide sufficient material to allow different combinations of performance characters to be considered, and yet would not be beyond the reasonably detailed study of the staff. Laboratory accommodation would certainly, and living accommodation probably, have to be provided.

30. An appropriate staff might comprise a director, two senior research officers, four junior research officers, with farm manager, technical assistants, and shepherds. The qualifications of the scientific staff collectively would cover the fields of animal physiology, animal husbandry and genetics.

31. Under present conditions, and without special enquiry, it is difficult to make even tentative estimate of the capital expenditure that would be needed to establish a Research Station on these lines. But, taking account of the general economic situation of hill farming industry, it could be expected that initial outlay on land, buildings, and stock would be relatively low, and might be of the order of some £25,000. Salaries and maintenance charges on the basis outlined above would be in the region of £10,000 per annum ; this is equivalent to about one penny per head of the sheep qualified for subsidy.

32. Finally, it may be noted that such a Station would make an important contribution to the facilities for studying pastoral problems of interest not only to Great Britain, but also to the Commonwealth and other areas overseas. It is confidently suggested that it would attract research workers from many countries ; for this reason it would be highly desirable that, if established, the station should be recognised as an approved institution for post-graduate research by one of the Scottish Universities.

6th December, 1947.

APPENDIX 8

SURVEY OF SCOTTISH BLACKFACE SHEEP

By J. F. Robinson, B.Sc.

Progress Report, March, 1949

1. The survey was started in August, 1948, by the circulation of a questionnaire to breeders in the main Blackface areas, south of the Caledonian Canal. The names of the breeders circulated were supplied chiefly by the Blackface Sheep Breeders' Association, and the Scottish Land and Property Federation. There has been a good response to the questionnaire, and a large number of breeders either completed and returned their questionnaires, or signified their willingness to supply information and records.

Breeders and all approached have been most helpful, and have readily agreed to place information at the disposal of the Committee. This has lighteened the work of the survey and affords some measure of the concern and keen interest taken in the problems under investigation.

2. The writer started the field work in the first week in October and continued until the second week in December. Owing to the amount of travelling and the comprehensiveness of the enquiry, only two or three visits could be arranged for each day. The first visits were made to the breeders who had been circulated. These in turn suggested the names of their friends, often with the comment " he can give you far better and more reliable information than I ! "—so that the survey proceeded with a kind of snow-ball effect. In order to cover the main areas in the time available, the visits had unfortunately to be restricted, so that some of the breeders left out may have been disappointed.

3. The following table gives a rough idea of the areas which have received most attention, the number of visits made and the number of questionnaires collected. Early in the survey it became apparent, that, because of local experience or different personal interests, each breeder has what may be termed " specialities " on which he is more qualified to speak than some of his neighbours. To mention only a few, these subjects might include (*a*) breed points ; (*b*) ram breeding ; (*c*) prolificacy ; (*d*) heather burning ; (*e*) certain diseases ; (*f*) methods of wintering ewe lambs ; (*g*) general management. Discussions of such matters on the spot were usually much more informative than the brief replies to the questions set out in the questionnaire.

In order to obtain some link-up of breed distribution with different environmental conditions, a further period of about ten days in January was devoted to visiting appropriate specialists at the Agricultural Colleges and Universities at Edinburgh, Glasgow and Aberdeen. In addition, visits were made to the Meat and Live Stock Sections of the Ministry of Food at Glasgow and Aberdeen, for information on carcases weights and quality, and on other points.

ACCOUNT OF MAIN AREAS VISITED

Giving Number of Visits and Questionnaires Collected

	(1) Visits (With Quest.)	(2) Visits (Without Quest.)	(3) Total Visits	(4) Quest. (No visits)	(5) Breeders Supplying Actual Records
Galloway area	9	—	9	—	5
Lanark area	9	5	14	2	6
Angus (& East Perth)	8	1	9	1	1
Perthshire	10	2	12	2	8
Argyll	10	2	12	4	4
Inverness	6	1	7	4	2
Deeside (Aberdeen)	3	1	4	2	1
Banff & Moray	4	3	7	3	—
Other areas	3	3	6	5	1
TOTAL	62	18	80	23	28

4. The Committee's main object in having this survey made is to collect evidence of any change in the constitutional hardiness of Blackface sheep, and, if there is any change, to relate this as far as possible to the underlying factors responsible for it. To what extent are changes due to the " ground ", or to the " sheep " or to the methods of their breeding and management ? Though hardiness is an apt and readily understood term, it does not admit of a precise scientific definition. The present survey, like previous work, demonstrates the immense complexity of, and the inter-relation between, the different factors involved.

In the course of the survey most of the relevant aspects have been discussed in great detail, and an immense amount of information and records of various kinds collected. As yet, this material has not been critcally examined, though it may be worth while at this stage to record a few general impressions.

5. The limited number of records which go back for a lengthy period of years is the most satisfactory foundation on which to build, provided it is carefully interpreted. The autumn count of the ewes and the count of the lambs marked in the following spring are the usual records kept. Occasionally, these are supplemented by particulars of the winter losses of ewes and of ewe hoggs.

In some of the poorer areas, there is a heavy incidence of loss of lambs and young sheep, before the age of about fifteen months. Such losses are very serious because they affect the whole economy of the flock. Diseases and bad winters are chiefly to blame. Some may say the sheep are losing hardiness and becoming less resistant to disease. In the writer's opinion infection with some of the diseases is due to fortuitous or chance events. Lamb dysentery, liver fluke, or the various tickborne diseases, for example, are no respecters either of breeds or types. There are areas in Argyll, for example, which in the past have had the greatest difficulty in maintaining their stock because of losses from disease. No one could say to what extent that could be taken as evidence of a lack of hardiness.

6. In regard to the level of stocking, there may be some significance in the fact that the records rarely show an increase. Those going back for the longest periods, are more or less divided between those in which the stocking has been maintained, and those where it has been reduced to some extent. These records, together with the information and the general history provided by the

breeders, give a fairly reliable account of the trend of events on the grazings concerned and will enable some comparisons between different areas to be made. Many more records would be necessary to establish the exact degree of these changes. Unfortunately, the number of records available is inadequate to give a fair representation of the degree of change in different areas.

7. The next point to decide is whether a reduction in stocking reflects a deterioration in the hardiness of the sheep, or a deterioration in the quality of the grazing. Records of the general condition of the grazings and their vegetation hardly exist, except in the memories of farmers and shepherds. Some of the older breeders—and the younger ones too if they have old family connections in the district—are able to give useful information of a general character. Old records of the vegetation or ecology of our hill land are very sparse. However, the general type of vegetation and specific changes in the area of heather and bracken in recent years are stated summarily in the questionnaires.

8. It is difficult to deduce a definite deterioration in hardiness of the sheep from a reduction in the number of ewes kept, unless possibly there is evidence of a concurrent steady reduction in the lambing percentages. The old standards of stocking as determined roughly by the fathers and grandfathers of the majority of present day breeders, are not immutable. It is an over simplification to say that the sheep died down to the right numbers and that a balance of stocking was soon discovered. The old systems were designed for wether mutton and wool, not to mention the exigencies of periodical valuations, for which there were obvious advantages in a full stocking. As indicated in the report of the Committee on Hill Sheep Farming in Scotland, the whole position has now changed, the emphasis being on younger mutton (lamb) and sound draft ewes—less on wool. Indeed, the increasing competition to produce better and more level lots of store lambs and draft ewes, has stimulated interest in " quality " in the stock, and therefore some measure of reduction in the level of stocking. There are also suggestions that a lighter stocking is a part answer to rising wages and the shepherding problem. An analysis of records from the standpoint of hardiness therefore has to be made against this changing economic background.

9. In looking over the records of different breeders, one can say almost without exception, that any very marked fluctuations in the level of stocking or in the lamb crops over a short period can be specifically related by the breeder to chance misfortunes such as those arising from diseases or from bad winters. It appears that the past 30 years or so have been unique for the heavy incidence of disease in certain areas, no less than the changing economic circumstances just alluded to. There is not only the toll of actual loss from disease, which is serious enough, but also other more indirect and subtle effects.

For instance, some of the best Blackface areas, such as Lanark or parts of Angus, are remarkably free of disease. Favourable natural conditions and freedom from disease enable breeders in these areas to dispose of approximately two-fifths of their ewe lambs, which are surplus to home requirements. In contrast, the breeders in poorer areas in the west with lamb crops in the region of about 60%, owing to the heavier incidence of losses from disease and bad weather, have greatly reduced scope for culling. With good lamb crops, it is possible to give due regard both to type (mainly genetic) and to size (mainly environmental) in the selection and culling of ewe lambs. With poor lamb

crops nearly all the ewe lambs may have to be retained in order to maintain flock numbers.

10. It is often said that a successful venture in hill sheep farming in poor districts depends more on good management than on good breeding. Practical proof of this is shown by certain flocks which have been improved almost out of recognition by a few apparently simple revisions of the details of their management. This is an involved subject, but suffice for the moment to say that the heavy incidence of losses from chance misfortunes, such as disease or bad winters, seems to bear inequitably on the poor areas with the better ones.

These notes are not intended to exclude any possibilities of deterioration in the hardiness of breeding of Blackfaces. Judgment is postponed until all the evidence has been critically examined.

11. Many breeders expressed uneasiness about the possible ill effects from the increasing use of " fed tups ", particularly on the hard grazings. Some are of the opinion that heavy feeding not only unfits a ram for the purpose for which it is intended, but also affects his breeding or genetic qualities. Others again were doubtful about the latter, but considered that more harm is done from the priority given to " type " and fancy points in the selection of rams. These subjects will be dealt with in more detail in the final report.

It may be said, however, that commercial breeders, especially those who are handicapped by the lack of " parks " and other " feeding ", are coming to depend more and more on the specialist tup-breeders for their annual requirements of stock rams. In the past, breeders are reported to have selected the majority of their rams from their own or from their neighbour's flocks. Thus it was possible to give due regard to the breeding performance of the mothers and the family history, as well as the " type " and general appearance of the rams being selected.

Unfortunately, with the gradual increase in the demand for purchased rams, the tup-breeders have been hard pressed to supply enough rams which possess a combination of all the desirable qualities. As a result, (*a*) as more rams were kept for breeding, the scope for culling was reduced, (*b*) the trade in ram lambs has tended to increase, (*c*) unscrupulous individuals have bought ram lambs without regard to their breeding and have disposed of them in other areas, occasionally after keeping them for a year and selling them as shearlings.

12. The question of fancy points, and the possible conflict with more useful qualities including hardiness is an involved subject, but it will receive special attention in the main report. It is notable, however, that " type ", to which " fancy points " are related, has changed considerably over comparatively recent years. The breeding policies in the tup-breeding flocks naturally have their eventual repercussions in the commercial flocks in more remote areas. Changes in fashion take place more slowly in these latter situations and they tend to confuse the issue, in relating specific changes in breeding policy to a possible deterioration in hardiness. Any deterioration (or improvement, for that matter) in the breeding of Blackfaces will undoubtedly be manifest throughout the breed, but it is fairly certain that evidence of changes in hardiness will be shown first in the poorer, rather than in the better, areas. In the main report it is hoped to analyse these factors in greater detail, in so far as the information and records obtained will allow.

APPENDIX 9

REPORT ON TOUR OF NORTH OF ENGLAND HILL FARMS: APRIL 1947

By J. Allan Campbell, B.A., Ph.D., M.R.C.V.S.

In a four day tour of some of the hill districts of the four Northern counties of England, farms were visited and conversations were held with hill farmers representing the following localities :—

Northumberland	1. College Valley
	2. Coquetdale
	3. North Tyne Valley
	4. Derwent Valley
Co. Durham	5. Weardale
Westmorland	6. Shap Fells
	7. Kent Valley
Cumberland	8. Lake District

Unfortunately, limitations of time prevented the visit arranged to the Bassenthwaite district of Cumberland, although conversation was held with a farmer from that area ; and bad weather curtailed the programme of visits to farms in the North Tyne Valley. In view of the wide range of varying conditions in so large an area, a short tour of this type cannot be regarded as more than a cursory introduction to the problems of hill farming in Northern England. Consequently the present report must be restricted to a brief general survey, indicating the problems which were emphasised in the discussions.

There appears not to have been any marked material change from the statistical position summarised in the report on a survey of 88 farms, conducted by the Department of Agriculture, King's College, Newcastle-upon-Tyne, in 1941. The following table constructed from the figures presented in that report is included here as a basis for comparison of the areas visited in the tour.

Table constructed from King's College Newcastle Survey, 1941

District	No. of Farms included	Mean Acreage	Mean Area Meadow	Mean Area Arable	No. of Breeding ewes	No. of Cattle
			Per 1,000 acres of Rough Grazing			
North N'land	10	2,700	85	17	770	12
Coquetdale	15	1,450	60	5·5	645	18
North Tyne	7	1,200	135	8·0	645	30
Weardale	17	(b) 1,050+400 (a)	135	6·5	525	40
Westmorland	10	(c) 1,830+500 (b)	160	5·0	680	14

(a) Estimated acreage of common grazing in addition to enclosed land
(b) 1,000 acres rough grazing includes 270 acres stinted
(c) 1,000 acres rough grazing includes 220 acres stinted.

While it was agreed that, in the broader aspects, the conditions of hill farming in Northern England are essentially similar to those in Scotland and that the same types of problems are encountered in both countries, it is evident that in many respects there are pronounced differences in detail. For example, we may cite differences in England regarding such features as :

1. Conditions of land tenure.
   (*a*) Widespread occurrence of holdings on a year to year basis.
   (*b*) Rights of common grazing. Unrestricted and stinted commons.
2. The system of renting flocks, and (in the Lake District) of hiring tups.
3. The greater variety of breeds of sheep (hill breeds and crossing breeds).
4. The frequent practice of the practice of cross-breeding on the hill. (It is a common practice to breed on the hill two or three pure-bred hill lambs followed by two or three cross-breds from each ewe before drafting the ewe.)
5. The greater development in some areas, e.g. Weardale of additional dairying enterprise.

It is proposed to draw attention in particular to those features which were given a rather greater English emphasis.

I. Stocking Densities, and the Problem of Wintering

While it is recognised that the availability of winter keep sets a limit to the stocking capacity of all grazing lands, it is in hill land that the problem assumes its most severe proportions. This question figured prominently in all the discussions, and emphasis was given to the importance of work designed to raise the wintering capacity of hill farms.

Throughout the area, there has been a recent tendency, particularly during the war period, to increase the numbers of both sheep and cattle on the hills, but it has varied within fairly wide limits. (Thus while subsidy policies provide a stimulus for increasing the stock, the ploughing policy has reduced the area of winter grazings, and in the low ground, the cost of hogg-wintering has risen to become an important limiting factor.) Over a longer period, however, there is evidence that the hills now support much smaller numbers of animals than formerly, and even at the present rate of stocking (if the abnormal losses of the past winter are discounted) there is a widespread belief that the hills are overstocked today. In the College Valley, in particular, a marked reduction in sheep numbers has proceeded in recent years. At one farm, for example, 1200 acres which carried 60 score ewes in 1923 now carry no more than 35 score, and it is the intention to reduce the numbers still further.

Numbers of cattle have been increasing to a moderate degree, but they cannot be expected to advance very far until there is an improvement in the wintering capacity ; and/or an improvement in store prices at the end of the year. The cattle stock on the hill has been increased to the greatest extent where one or more of the following conditions obtain :—

1. The hill farmer is farming marginal or arable farms as well as his hill farm.
2. Private arrangements exist between hill and low ground farms.

3. Hill ground is rented for summer grazing to low ground farmers.
4. A greater proportion of hill land has been enclosed and improved thus increasing the wintering capacity.

Examples of all types were seen.

II. Breeds of Sheep and their Distribution

A. THE HILL BREEDS

The hill flocks of Northern England comprise five breeds of hill sheep :—

Blackfaced breeds	1. Scots Blackface
	2. Rough Fell (Kendal Rough)
	3. Swaledale
Whitefaced breeds	4. Cheviot
	5. Herdwick.

The Rough Fell and Herdwick breeds occupy well-defined areas where they have remained comparatively unchanged over a considerable period of time. Within recent years their areas of distribution have become more confined than formerly, in face of competition from economically superior breeds. The Rough Fell occurs in the Shap Fells and the area of granite outcrops between Kendal and Kirby Stephen in Westmorland. The land in this region is high-lying, exposed, and includes large areas of peat bog ; and the Rough Fell breed has proven itself particularly suitable to these conditions. It remains as a comparatively unimproved type of the native Blackface sheep of the Pennines, which is well adapted to the local conditions. Attempts at improvement of the breed have been made by introduction of Swaledale and Blackface tups, but such changes have not been approved by the majority of the breeders. The Herdwick plays a similar role in the Lake District, a region of very high rainfall, and steep, craggy hills with a comparatively unproductive vegetational cover. It is an economically inferior breed, but constitutionally is one of extreme hardiness. Although the claim is made that the Herdwick is capable of living in regions where no other British breed of sheep could survive, it is worthy of note that the breed is losing supremacy in its traditional area, and in some of the valleys (e.g. Duddondale and Eskdale, including some of the least favourable sheep land) the Swaledale has been successfully introduced. Apart from these two examples of the local survival of locally-developed breeds, the remainder of Northern England is stocked with sheep breeds which were largely developed outwith the area. At the beginning of the century the position was comparable with the present day position in Scotland. Two breeds were kept, the Cheviot on the better quality hill grassland (white or flow-land) and Scots Blackface on the heather hills (black-land), and in the higher lying less productive areas. There has been a well-marked trend (as in Scotland) towards replacement of Cheviot by Blackface over a long period of time. More recently the Swaledale has extended its area northwards at the expense of Blackface and Cheviot (and to a lesser extent of the rough and Herdwick breeds). In Weardale, for example, the flocks at one time consisted entirely of Cheviot and Blackface, on the better and poorer land respectively. By the end of the first world war, the Cheviot flocks had been almost completely replaced by Blackfaces. The Swaledale was first introduced during the inter-war period, and it has gained ground to such an extent that today Swaledales are the only sheep in the dale. The same succession is occurring in the North Tyne where

Cheviots are now absent, and Swaledales are in the course of replacing Blackfaces. Even in its district of origin the Border Cheviot is losing ground to the Blackface, e.g. in College Water (cf. Bowmont Water) formerly all the flocks were Cheviot, but Blackfaces have been introduced and their numbers are increasing. In the College Water, attempts have been made to introduce North Country Cheviot blood, but the high wintering requirements of this breed appears to make it unsuitable for the Border conditions.

It is impossible, from discussions with breeders, to obtain a clear picture of the possible causes of this phenomenon of breed-replacement. Local conditions, and personal fancy frequently play a part in lending colour to individual opinions. Numerous reasons have been advanced and it seems likely that a combination of some or all the factors mentioned has been instrumental in causing the change. At least, it is reasonable to assume that where farmers have changed their breed such change has been profitable, and it is a striking fact that the change has been in the direction Cheviot - Blackface - Swaledale, i.e. from the economically better to poorer breed (from the feeders' point of view the order is reversed, good wether lambs bringing prices in the order Cheviot > Blackface > Swaledale).

1. *Loss of Hardiness.* It is widely held among breeders who have changed to Swaledales, that the tendencies occurring in Blackface and Cheviot breeding have produced " over-improved " sheep to the detriment of their hardiness and capacity for survival on the hill. The fancies which have produced modifications of this type have largely been absent from commercial Swaledale breeding hitherto, although fears have been expressed that a similar tendency is beginning among Swale breeders. There is thus some presumptive evidence for the argument that Cheviot and Blackface sheep are less hardy than formerly, and on the whole are less well adapted to hill conditions than Swaledales. It is claimed by some that Swaledales are better rakers.

Against this, it must be noted that the Herdwick has also lost territory to the Swaledale, although it is almost universally admitted that the Herdwick is the hardier sheep (cf. also replacement of Roughs by Swales).

2. *Loss of Fertility of Breeds.* The reason advanced for the introduction of Blackfaces into the College Valley is that they have a higher fertility than Cheviots under those conditions. The Swaledale breeders claim that the fertility of their breed is greater than that of either Cheviot or Blackface.

3. *Mothering Characters.* The relationship between fleece characters and milk yield has received much emphasis. The belief is widely held that Blackfaces have become poorer milkers as the fleece has become coarser, and that the milking capacity of Swales has been preserved with the selection of finer fleece characters. The Swaledale breeders have paid particular attention to milking capacity, and the development of a double coat particularly suitable for wet hill conditions, and it is to the advantage conferred from wise selection in these respects that they ascribe the success of the breed on the hill. It is possible that the Swaledale ewe is a better mother than the Blackface ewe. (While it is claimed and generally admitted that Swaledales are better milkers at the beginning of a lactation, it is also stated by many that the total milk yield during a lactation is no greater than in the Blackface, since the latter breed maintains its milk production at a higher level for a longer period.)

4. *Deterioration of Pastures.* Although there is little direct evidence available on this point (*vide infra*) it appears to be generally assumed that

hill pastures have deteriorated quite considerably during the history of hill sheep farming, and this factor alone would go far to explain the replacement of commercially better sheep by smaller and inferior types.

B. THE CROSSING BREEDS

The breeds are :—

	1. Border Leicester	(x Cheviot and x Blackface)
	2. Wensleydale	(x Swaledale)
in Hexhamshire	3. Hexham Leicester	(Blue Leicester) (x Scots Blackface)
in W. Cumberland	4. Leicester Longwool	(x Herdwick)

There was little opportunity provided in the tour to visit and examine conditions in the marginal farming zone where cross breeding is the main feature of the sheep industry. It is important to note, however, that the practice of cross breeding must be affected strongly by breed changes which occur in the neighbouring hill farms. Large scale breed changes on the hill will ultimately lead to corresponding changes in the relative importance of the different crossing breeds. Thus, replacement of Scots Blackface by Swaledale will lead to a corresponding replacement of Border Leicester by Wensleydale. In the change-over period, obviously, conservatism on the part of individual marginal land mule-breeders will lead to anomalies in the general integration of the different types of farming in a district. An interesting example was seen on one farm in the Derwent Valley, Northumberland. In this district, the hill flocks which were formerly Scots Blackface and Cheviot, are now all Swaledale, but the mule-breeding in parts of the Valley still employs Blackfaces. A foundation Blackface flock is maintained by the annual importation of Blackface ewe hoggs from Scotland (Lanarkshire-Dumfriesshire border), and from this flock greyface mule lambs are bred by crossing with Hexham tups. (The breeder appears to have a particular interest in the Hexham breed, and his practice appears to be guided to some extent by this fancy. Swaledales have been used in trial cases, but he dislikes the resultant Swale-Hexam cross and considers that Blackfaces " make a better lamb ". Consequently a system of breeding is maintained in isolation, which is independent of the general practice and policy of the district.) Elsewhere, where the Swaledale has become firmly established (e.g. the Kent Valley, Westmorland) the Wensleydale is the common crossing type, and Masham mule lambs are bred. In the Blackface and Cheviot districts, the Border Leicester is used to produce Greyface mules and Half-Breds. (The Blue or Hexham variant is common in the Hexham district of Northumberland.) Rough Fell ewes drafted southwards into the Swaledale districts (e.g. Kent Valley, Westmorland) are crossed with Wensleydales, while those drafted northwards into Blackface districts (e.g. Eden Valley, Cumberland) are crossed with Border Leicesters. Herdwicks are similarly crossed with either Border Leicester or Wensleydale depending on the district into which they are drafted, and in some few cases with Leicester Longwools (e.g. West Cumberland).

III. Condition of Upland Grazings

It is quite impossible to generalise about the pasture conditions, since there is so great a range of variation from district to district. Regarding

possible changes which have occurred, to attempt to draw conclusions would be profitless, since critical evidence is completely lacking. Two features, however, command notice.

1. Bracken has invaded considerable areas, particularly in the western districts.
2. Large areas which were formerly heather covered, and good sheep land, now support a poor type of graminaceous vegetation with inferior nutritional qualities.

The replacement of heather by *Nardus*, *Aira*, *Molinia*, etc., has proceeded to a much greater degree on some of the English hills than in Scotland. There is no evidence to show why this should have occurred, but presumably the management of the moors has been at fault. The result of this reduction of heather land is important, not only on account of the replacement of a potentially high source of nutriment by unprofitable types of grass, but also because alternation of grazing on black- and white-land has been a very valuable instrument in controlling the incidence of Border pine, which occurs in flocks grazed exclusively on *Agrostis*-Fescue-*Nardus* grassland in some areas (e.g. North Tyne, Coquetdale).

In Northern England the question of moor management requires particular attention in the case of common grazings. There appears to be little or no concerted policy towards the proper use of commons, and the fate of most common land will be steady deterioration until the responsibility for correct management is satisfactorily settled. In other respects, the North of England hill farms present the usual features.

1. Inadequate fencing.
2. Lack of shelter, etc.

In some districts (e.g. North Tyne, Shap Fells, Pennines) the need for shelter is acute, and it has been further aggravated by the widespread felling of small woods during the war years.

IV. Disease Problems

A carefully conducted disease survey would be of considerable value. From information at present available, there seems to be no particular difference between the disease position in Northern England and Scotland. The following problems were mentioned :—

(*a*) Pregnancy toxaemia*

(*b*) Lambing sickness (P. parturient hypocalcaemia and hypomagnesaemia

(*c*) Tick-borne diseases—Louping Ill
Tick-borne fever
Pyaemia*

(*d*) Gastro-intestinal helminthiasis*

(*e*) Anaerobic Infections—Braxy
Lamb dysentery
Pulpy kidney*

* These conditions received the greatest emphasis.

(*f*) Border Pining* (Trace element deficiencies esp. Co.)
(*g*) Scrapie
(*h*) Blowfly Myiasis
(*i*) Other conditions, e.g. Yellowsis
Periodic Ophthalmia, etc.

Some conditions of unknown etiology were mentioned (e.g. paralysis of lambs in Weardale) and these obviously require careful investigation.

V. Forestry

Considerable areas of land have been acquired by the Forestry Commission for afforestation. The programme of planting extensive blocks of trees will have a direct effect upon hill farming in the locality on account of the loss of both land and labour which the farming industry will sustain. The problem of integration of farming and forestry interests demands immediate attention.

Conclusions

The opportunity of making contact with hill farmers in Northern England was a valuable one, since it is important that English problems should receive some attention when the research programme for Sourhope is drawn up. Many of the points emphasised could be readily examined with profit at Sourhope, and the results of research there could be of assistance to the English hill farming community. Suggestions for work might include :—

1. *Problem of Wintering*
   (*a*) Improvement of method of conservation : hay : silage.
   (*b*) Increase in productivity of haining areas : seeds hay : meadow hays.
   (*c*) Complementary grazings.
   (*d*) Investigations on feeding of sheep. (Critical evidence is needed on the widely held view that haying spoils hill sheep).
2. *Breeding Policies*
   (*a*) Questions such as fertility, hardiness, milkiness, and the relation between these and fleece characters, and carcase production characters require investigation.
   Comparison of Blackface (various types), Cheviot, and Swaledale.
   (*b*) Studies in mule-breeding.
3. *Shelter*

   While this involves the wider field of integration of forestry and agriculture, work on non-timber producing trees of rapid growth would have great value in relation to the problem of planting shelter belts.

On the English side of the border, further surveys would be of assistance particularly as regards :—

1. Management of common land.
2. Incidence of diseases, and their distribution.
3. Economic factors involved in sheep and cattle breeding. Comparison of returns as between different breeds.

APPENDIX 10

REPORT ON A VISIT TO ABERDEENSHIRE IN JULY 1948

By Maitland Mackie, O.B.E.

In many parts of Aberdeenshire the hill farms include a substantial proportion of arable acreage such that the organisation of the hill farming industry is based to a large extent upon an integrated utilisation of low and hill ground. In this respect the hill farms of the county are better placed than those in many other hill districts of Scotland. By making full use of the natural advantages, impressive developments have taken place towards increasing the productivity of the area. In particular, where efforts have been directed towards increasing the wintering capacity of farms, substantial increases in the numbers of cattle and sheep have been achieved. Progress along these lines has not been confined, however, to those farms with a large arable acreage ; it has taken place also on some of the less fortunately situated farms where the low ground is of very limited extent, by an extension of cultivation on to the hill.

In a two-day visit to the county, the Committee saw examples where the productivity of farms has been considerably increased by the energetic application of modern techniques to develop the natural resources available. Three examples are described :—

1. A 2,000 acre hill farm including the Tap of Noth near Rhynie.

Fifty years ago only blackfaced sheep were bred in this district. By an integrated development of both low and hill ground including ploughing and reseeding of a large acreage of original heather hill, the output of the farm has been greatly increased. A stock of 440 ewes is maintained as formerly, but now the farm also carries a herd of 50 Hereford cows with their calves, and an additional 100 hoggs are summered on the hill. All the lambs bred are now cross lambs. Further improvement is contemplated by planting of shelter belts.

2. A 3,000 acre farm near Pennan (about 10 miles west of Fraserburgh).

When this farm was first entered by the present tenant, it was almost derelict and was rented for £30. The sheep stock, which was of very poor quality, was sold off and replaced by a herd of cattle. The farm is situated in a bleak exposed coastal area, but nevertheless a productive enterprise has been developed. Among the improvements observed there was an area of 32 acres ploughed by means of a " Prairie-buster " plough, out of whins and broom, part of which had never previously been cultivated. This area was under oats which were cut green and which provided winter keep for 220 cows. The farmer considers that he obtains greater bulk from oats than from grass silage. His practice is to take three successive crops of oats and then reseed direct.

3. The large hill farm of Lord Glentanar at Aboyne.

Reseeding of hill land plays a big part in the improvement programme of this farm. To overcome the problem of reseeding land which is too difficult to plough, special implements have been devised, and through their agency much progress has resulted. A cultivator possessing 8 tines set on long arms (7 ft. 6 ins.) is taken 3 times over the ground, and the result appears to be quite as effective as ploughing. The length of the arms gives the tines great flexibility, and facilitates their clearance of boulders and obstacles. After the land has been opened up by the cultivator, it is consolidated for the seed bed by a specially constructed set of rollers. Wooden rollers, 9 inches wide and 24 inches in diameter, are mounted 9 inches apart on a wire rope axle, and the set which contains two rows of five in front and four behind is weighed down with heavy stones. The implement is well adapted to the irregular surfaces which are encountered, since the flexible mounting allows individual displacement of any roller without raising the remainder from the ground surface.

These implements permit of improvements on the roughest type of land, and the Committee is impressed with the possible benefits to be derived from their further development and wider use.

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