A STUDY of PRINCIPLES and METHODS of PASTURE IMPROVEMENT on NEW ZEALAND HILL LAND, with PARTICULAR REFERENCE to the EFFECTS OF THE CLIMATIC, BIOTIC, and ANTHROPOGENIC INFLUENCES upon the SWARD.

by

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PROLOGUE.

It is interesting to speculate upon what would have been the relative states of advancement of hill and low ground agricultural research and farming techniques had Jethro Tull been born of hill farming stock. Probably conditions would not have been much different; for hill farming has had its "improvers", too, in men such as Sir John Sinclair.

The cause of the undeniable neglect of hill land research is more likely to be found in economic reasons than in any lack of desire to improve this class of land. From the time when products of British hill farming came into competition with overseas produce, through international trade, this industry has been subject to all the vicissitudes of economic marginality. Research has, quite naturally, been devoted to that class of land which is further removed from the uncertainty inherent in this economic phenomenon - the more fertile low ground - because the hill farmer had less certainty that any capital he might invest in improvement would ever be repaid.

Again, remoteness and inaccessibility have added to the cost of any improvements, and have contributed to marginality by increasing the cost of the produce in the urban market, added to which the psychological effect of this remoteness made the hill land seem less important.

In Britain the effect of rising populations, both at home and overseas, rising standards of living and concomitant increased demand for food in countries which were formerly large exporters of primary produce, and strategic necessity have all emphasised the need to improve the productivity of this class of land. Under the Hill Farming Act of 1946 the British Government has made available something over £20,000,000 to reimburse hill and marginal farmers to the extent of 50% of the cost of any comprehensive improvements they may make, in order to get the industry functioning healthily again. It is further hoped that the operation of marketing schemes for such commodities as wool, and guaranteed prices for both meat and wool will give to the industry a measure of economic stability which it has not previously known. But a stable economic skeleton can only become a healthy agricultural corpus if the flesh of sound practice, based on fundamental principles, is superimposed. It is this very technical knowledge which a neglect of hill land research has denied the industry at this crucial period of its development.

In New Zealand, for economic and other reasons, the fertility of hill land has likewise been "mined", and the effects of this are becoming increasingly apparent. As yet there has been no official attempt to subsidise a reversal of this detrimental process. On the other hand, since primary production is the basis of New Zealand's economy, and since hill country in New Zealand is relatively more important, both economically and from the point of view of area, than in Britain, the technical knowledge of improvement principles and methods is probably more advanced.

It seems important that there should be an exchange of administrative and technical ideas between two nations having the same problem in common. A programme of hill land improvement sufficiently comprehensive to rebuild a depleted national heritage is unlikely to be carried out without financial assistance and guidance from official sources.
So far as the exchange of technical knowledge is concerned it is true that conditions are not directly comparable in the two environments, but biological principles are not inflexible, and agricultural techniques are limited in their adaptability only by the ingenuity and imagination of the husbandman.

At all events there is much scope, and an increasingly urgent need for agricultural research the world over to divert or extend its energies from the attempt to squeeze the last calorie from the fertile, and already highly productive low country, where even now practice lags behind technical knowledge, to the vast areas of undeveloped and underdeveloped land, including most hill land, where much larger increases in production may be obtained for an equivalent output of research energy, and where technical knowledge frequently lags behind the desire and the economic capacity to improve agricultural practice. Such a change in the "operational area" of agricultural research would seem essential if the rapidly increasing world population is to be adequately fed.

A. INTRODUCTION.

This dissertation deals with principles rather than with practices. When trying to enfold a vast subject within limited bounds no detailed analysis of practices can be made, for these vary from farm to farm, almost from paddock to paddock, as the aspect, climate, soil type and terrain change. However, practices are based on principles which have much wider application and a cognizance of which is fundamental to the institution of any practice. The essential principles are those of raising fertility where necessary, of introducing species of grass and legume which can either utilise or enhance the increased fertility and themselves provide nutritious and palatable stock feed, and, finally, so to manage stock on these improved pastures that the improvement is consolidated and not dissipated.

Practice, however, is not ignored, but is used rather to demonstrate some of the means by which the ideals underlying the principles may be achieved.

Just as no attempt has been made to catalogue all possible practices so certain principles not strictly within the realm of plant husbandry have been omitted. The most important of these is the necessity for any farming operation to be carried out within a suitable economic context. Where the economic context is unfavourable, practices detrimental to the proper, conservative utilisation of land inevitably come into being, and the deterioration of hill swards thus brought about frequently culminates in erosion. When the economic state of the hill farming industry is favourable, however, deterioration and erosion are frequently the outcome of a failure to appreciate or put into practice the principles which are set out hereinafter.

Detrimental economic effects are, commonly, only temporary in nature, because the declining production of a depressed industry enhances the value of the products of that industry, and the economic pendulum swings back again from slump to prosperity. It is, however, also necessary for any industry to be carried out within an adequate social context. Thus hill land deterioration may be, in part, due to a shortage of labour wherewith to carry out necessary maintenance work, or to apply in practice the principles of improvement. Unfortunately this problem, unlike the economic one, does not contain the germ of its own redress because the attractions of urban life cannot always be computed in terms of cash, and their renunciation so compensated for by higher wages. Moreover, this problem is only in part soluble by reducing labour requirements through the increased use of machinery, and these substitutes are of less value in hill land farming than in other forms of agriculture.

These, then, are two of the principles which are not subjected to comprehensive analysis, although certain economic aspects of more direct practical application are included for the sake of completeness.

Any adequate definition of the term 'hill land' as used in the title and context of this dissertation is well-nigh impossible, as is any delimitation of its boundaries. It may perhaps best be defined and delimited by reference to its chief characteristics. These are slope and/or relatively high elevation, which in turn impart specific climatic and soil conditions, producing a more rigorous environment for plants and animals than is found on low ground. Further, this land may be recognised by the nature of the industry which it supports. This industry is predominantly pastoral, but it differs from low ground pastoral farming in being relatively more extensive and less flexible, and in the limited opportunities for using the plough preparatory to pasture improvement.

The problem of hill sward improvement is largely one of applied ecology. It is one aspect of the problem of animal - pasture interaction under differing climatic and edaphic regimes, with man imposing his influence over all. It is mainly from this ecological standpoint that the subject is discussed and developed.

B. THE IMPORTANCE OF HILL LAND IN THE FARMING ECONOMY OF NEW ZEALAND.

At this stage some justification (more specific than that voiced in the prologue) for studying hill land improvement may be necessary. The question inevitably arises, - why be concerned about the improvement and management of the nation's hill land?

Given that the wealth of New Zealand depends on the production of primary goods, the more intensive is the use of the land the greater will be the national wealth.

In this connection the relative areas of hill country and flat or rolling country are important. Aitken (1950) puts the proportion of land under the 600 foot contour at less than one quarter of the land surface.

Of the 43.1 million acres of land under occupation in 1946-47, the apportionment of areas between hill and flat or undulating land was as follows (Farming in New Zealand, 1950):

Surface sown pasture (mainly on hilly or mountainous country) ...	11,000,000 acres
Tussock and other native grasses (mainly in South Island hill country) ...	13,900,000 acres
Total	24,900,000 acres

On this basis about 58% of the occupied land is pastoral hill country, and this takes no account of 4,700,000 acres of fern, scrub and secondary growth which covers much potentially productive hill land.

Belshaw (1936) observed that a large part of the 24 million acres of occupied but uncultivated land consisted of light hill country, well suited to extensive grazing.

From these estimates, something between 55% and 58% of the occupied land in New Zealand would seem to be pastoral hill country, and a further 10.9% - much of it hill country - is under fern, scrub and secondary growth.

From the point of view of area alone, the hill land of New Zealand is seen to be important, but its importance in the economy of the nation is to be found in other reasons, the chief among which are the following.

I. As a Source of Store Stock and Fat Lambs.

The organisation of the low ground fattening farms of the nation depends upon a regular, annual supply of store lambs and cast-for-age ewes from the hills. Without this supply much of the fattening pasture on the lower country would require to be used for the maintenance of purely breeding flocks, with a concomitant decline in the number of sheep and lambs fattened.

The average number of fat lambs sent to the freezing works annually is between 11 and 12¼ million, representing about 175,000 tons of meat. In 1946 - 47 the export value of New Zealand mutton and lamb was £17,397,000, or over 17% of the entire national income. (Primary Production in New Zealand, 1948). The basis of this trade is the store lamb and the cast-for-age ewe from the hill country.

Smallfield (1947) estimates the number of replacement ewes which must be brought from the hill country into the fat lamb producing districts of the North Island as follows:-

Region	Estimated replacement ewes which must be acquired from other regions.
South Auckland	35,000
Waikato	300,000
Central Plateau	35,000
Taranaki	60,000
Manawatu	125,000
Total	555,000

This table does not show the replacements available locally from nearby hill country, nor are the number of replacements required in the South Island lamb fattening districts indicated. Now, according to Hamilton (1947) approximately 6,000,000 lambs pass through freezing works in the North Island each year. It would seem, therefore, either that a large number of replacement ewes must be moved over short distances (from hill to fattening districts) within the regions set out above, that considerable numbers of store wether and cull ewe lambs are transferred from the hill country annually (for which no statistics are available), or that many easier hill country properties are able to fatten a considerable proportion of their own surplus lambs. This latter proposition is probably more true of North Island hill farms than of those in the South Island.

It seems impossible from the figures available to sort out the relative importance of each of these factors, but this in no way detracts from the role played by the hill country in supplying the major portion of the breeding and store stock from which more than 11,000,000 fat lambs are produced annually.

It has been suggested to the writer by Coop (1951) that this present dependence of the fat lamb and mutton industry upon store and breeding stock drawn from the hills may in the future be much less. The argument is that by pasture improvement, and by increasing lambing percentages through the application of better knowledge of the physiology of the reproductive processes, it will be possible so to increase the productivity of the low ground that much of the hill land may be allowed to go out of agricultural use, while at the same time allowing the national output of mutton and lamb to be maintained at the existing level.

The desire to improve low ground productivity is wholly admirable and may in some measure be achieved, but there seems no reason why such improvement should not lead to an increase in national earnings rather than to an abandonment of hill land - provided the hill land remains economically productive. The present high prices for the products of the sheep farming industry should provide an incentive for carrying out hill land improvement so that this class of land may be moved further from the position of economic marginality which has been one reason for its deterioration in the past.

II. As a Source of Wool.

In 1946 New Zealand exported 365 million lbs. of wool, having a value of £26.6 millions (N.Z.) and forming over 26% of the national income from all exports. In 1950, with wool prices considerably inflated, of a total Dominion income of £194,588,000, no less than £84,589,000, or 43%, came from the sale of wool (Meat and Wool, 1951). Again, apportionment of this sum between hills and low country is not practicable, but the proportion derived from the hill country is undoubtedly the major one.

Not only is the hill country important as a source of wool, it is important as the source of that high quality Merino and Half-bred wool which commands the highest prices. This may partially be demonstrated by quoting the price index of greasy wools sold in various districts in New Zealand. (Monthly Abstract of Statistics, 1950)

Base (100) = Average price in all districts combined for 1945-46.

District	1945-46	1946-47	1947-48	1948-49	1949-50
Auckland	96	113	148	154	244
Hawke's Bay	96	116	151	158	239
Wellington	97	114	154	153	228
Canterbury	110	151	230	240	325
Otago and Southland	102	130	190	186	277
New Zealand	100	124	174	177	260

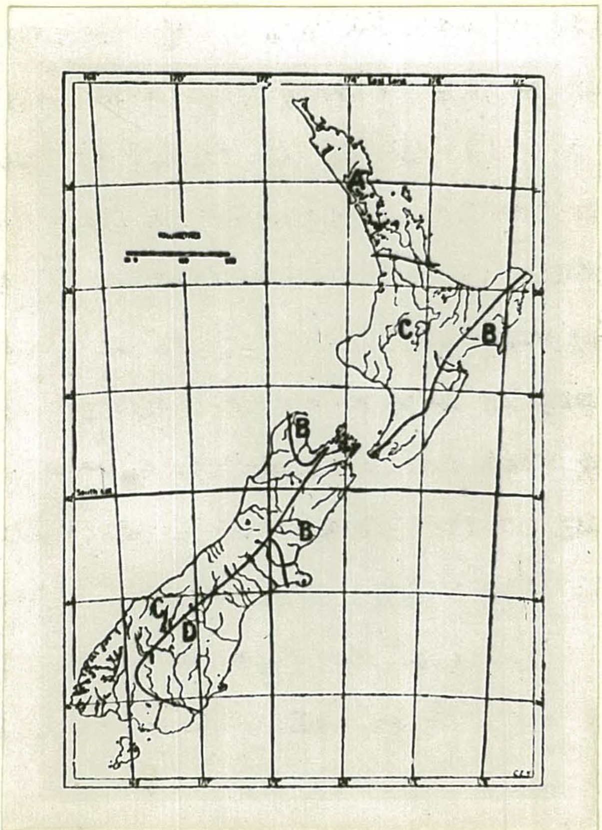
This reflects the sustained heavier demand, and consequently greater price, for the finer quality wools of Canterbury and Otago.

III. As a Source of Employment.

The manpower used directly in the hills as shepherds, musterers, drovers, in shearing and scrubcutting gangs is important in itself, but the indirect employment caused by the farming of the hill lands is probably even more so. The labour involved in the transport, preparation, freezing and shipment of fat lamb and mutton, in the transport, scouring, grading, auction and shipment of raw wool, or its conversion into the manufactured product within New Zealand, in the supply of goods and services to those working on and farming in the hills owes its livelihood to a thriving hill farming industry.

IV. As a Source of Water and Silt.

If a rainfall and a topographical map are superimposed it will be seen, as would be expected, that the rainfall is heaviest in the hill country - usually from 60 to over 100 inches per annum. Heavy rainfall in these areas, if not adequately controlled, may devastate many acres of fertile, low-lying country by flooding and silting. This is most likely to occur where the hills are inadequately covered by vegetation, when run-off is rapid, and erosion severe.



Map I. Climatic Areas in New Zealand. (Kidson, 1936).

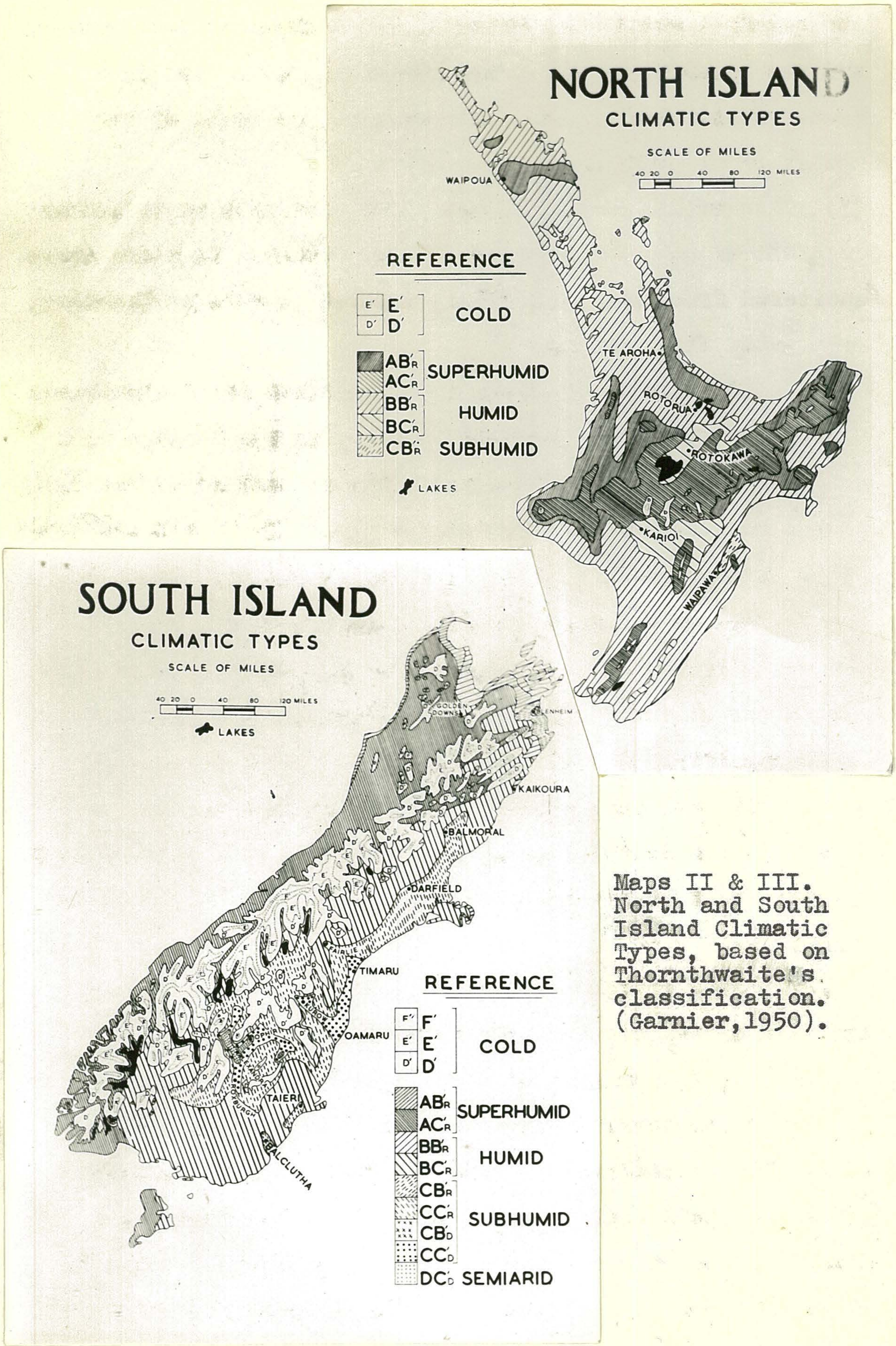
C. A CLIMATOLOGICAL CLASSIFICATION OF HILL LAND IN NEW ZEALAND.

In order to study in some detail a problem of such wide scope and of such great diversity as hill land improvement, it is necessary to subdivide or classify the land into sections such that the country within each section has some basis of uniformity. It is possible to classify the hill land of New Zealand in one or other of several ways - by breed of sheep carried, by purely geological, geographical or administrative boundaries, or by its elevation. However, since this study is primarily concerned with the interaction of animal and vegetation, and since the vegetation of an area is so largely dependent upon the climate of that area, it is perhaps most satisfactory to classify New Zealand hill land according to the climate to which it is exposed. If we first study the effect of climate on the vegetation of each region it will be possible later to study the role which anthropogenic and biotic influences may play in modifying that vegetation.

In common with other countries in middle latitudes, New Zealand lies in the zone of prevailing westerly winds which deposit most of their moisture on the west side of the ranges and produce pronounced föhn effects on the eastern, lee side, reducing the effectiveness of the already limited rainfall on that side. Annual variation of rainfall in New Zealand is controlled by three main factors (Kidson, 1936).

(1) Proximity to the high pressure, low rainfall belt of the sub tropics, which produces on its southern border dry summer and wet winter seasons. The effect of this factor is most noticeable in the northern regions of the country and diminishes southwards.

(2) The effect of the prevailing westerly winds of middle latitudes. These account for the heavy rainfall on the western side of the main ranges. Since the amount of this rainfall is proportional to the flow of the westerly winds,



Maps II & III.
North and South
Island Climatic
Types, based on
Thornthwaite's
classification.
(Garnier,1950).

__Explanation of Climatic Formulae.__

D' - Taiga
E' - Tundra
F' - Perpetual frost and snow.

A' - Macrothermal
B' - Mesothermal
C' - Microthermal

A - Superhumid
B - Humid
C - Subhumid
D - Semiarid
E - Arid

r - Moisture adequate at all seasons
s - Moisture deficient in summer
w - Moisture deficient in winter
d - Moisture deficient at all seasons.

the rainfall maximum in October, the minimum in late winter, and the subsidiary maxima and minima in autumn and late summer respectively, are explicable on the basis of the amount of westerly wind.

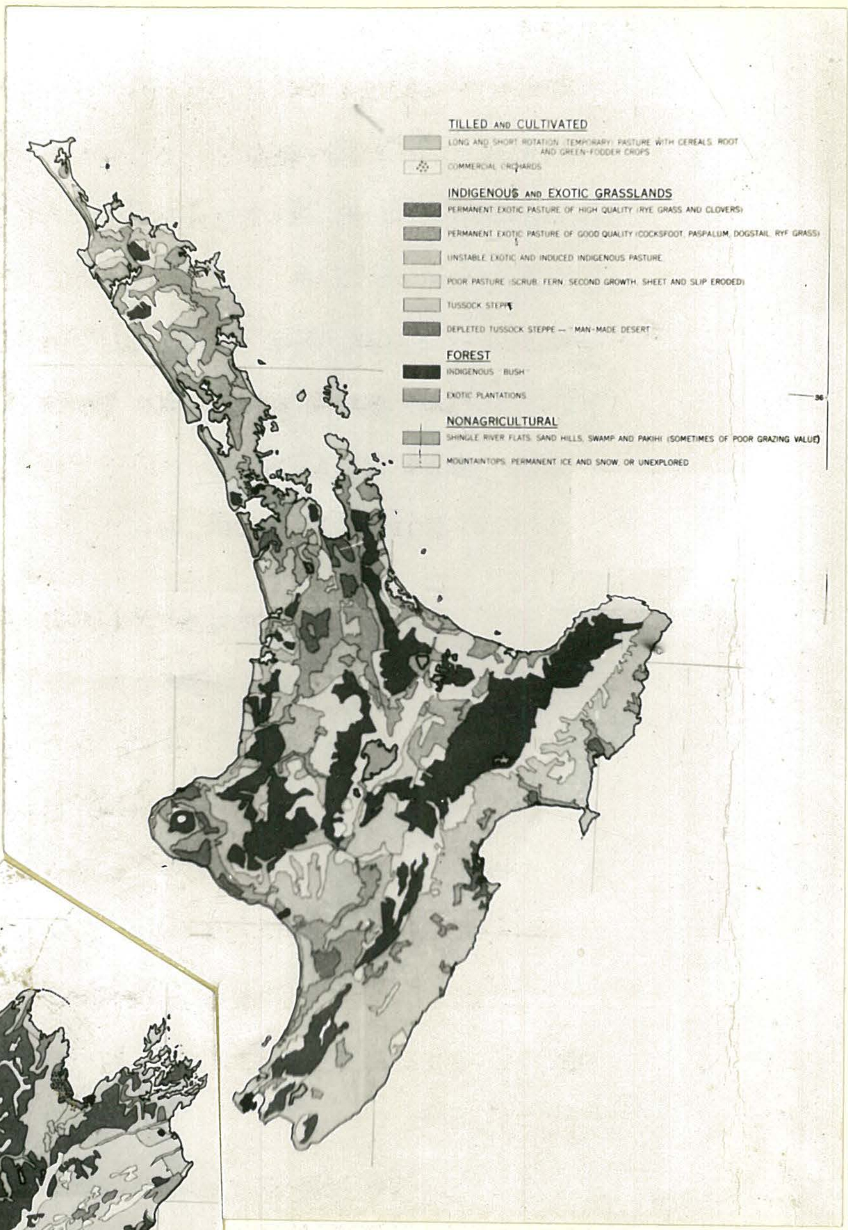
(3) Convection caused by insolation giving rise to summer rainfall of high intensity and short duration in those areas sheltered from warm westerlies, exposed to cold southerlies, and having clear skies.

On this basis alone Kidson divided New Zealand into four major climatic districts as shown in Map I (page 8a). Area A has a summer minimum and a winter maximum of rainfall, as has the northern portion of area B. In area B the total precipitation wanes from north to south and the distinction between summer and winter rainfall diminishes. Area C in the North Island has a fairly evenly distributed rainfall except for diminution in the late summer. The regime of maximum rainfall in October and minimum in late winter, previously explained, operates to its fullest extent in area C in the South Island. Due to factor (3) above, area D receives most of its small amount of rainfall in the summer months.

At a later date Garnier (1950)(i) essayed a new division of New Zealand into climatic zones using Thornthwaite's (1931) method of classification, which takes into account temperature and precipitation efficiency. As Maps II and III, reproduced on page 9a indicate, this method gives a certain refinement to Kidson's classification. Kidson's areas A and B are replaced by climatic types BB'r, BC'r, CB'r and CC'r within the humid and subhumid meso- and micro-thermal, moisture adequate categories. Area C corresponds broadly to climatic types AB'r, AC'r and small portions of BB'r and BC'r in the superhumid and humid, meso- and micro-thermal, moisture adequate range, while Kidson's area D encompasses the types CC'r, CB'd, CC'd and DC'd in the subhumid and semiarid range.

Garnier (1950) (ii) further attempts to emphasise the seasonal variation in climatic type, but for the present any detailed consideration of this work only serves to confuse

Maps IV & V. New Zealand, Cultural Vegetation and Land Utilisation - 1940. (Cumberland, 1941).



The limitations imposed by black and white representation of coloured maps make these two text figures unsatisfactory. It is suggested that reference be made to the original map of Cumberland (1941), or to the grassland maps of Hilgendorf (1935) and Madden (1940).

the picture. The general conclusions which may be drawn from it are, however, of interest. Certain features are common to all seasons. Most significant is the overriding importance of moisture rather than temperature in differentiating the climate of one region from that of another, and the contrast between the wet west coast and the drier east coast in both islands. The exception to this rule is a relatively wet climate in the eastern areas of the North Island in autumn.

In any region in which soils are relatively mature they will tend to have less influence upon their vegetative covering than will those soils which are relatively immature. This is due to the controlling influence of climate upon soil formation, both directly and through the agency of plants, so that with increasing maturity differences in the parent material under any one climatic regime tend to be eliminated and a soil type typical of that climate is formed (Glinka, 1927).

New Zealand hill soils, however, are for the most part immature, and as such will tend to have a considerable influence upon the vegetation covering them. Nevertheless, it is striking to note the broad correlation existing between the climatic zones of Kidson and the vegetation zones as shown in the maps of Hilgendorf (1935), Madden (1940) and Cumberland (1941) (Maps IV and V, page 10a). The refinements in climatic district boundaries introduced by Garnier serve only to emphasise the supreme importance of climate in determining the vegetation covering at least the North Island soils. In the South Island overall climate is again important in determining the vegetative cover, but in this instance certain micro-climatic influences, discussed more fully in a subsequent section, which are not amenable to Thornthwaite's system of overall climatic evaluation play a more significant role.

By comparison of Maps I, II and III on pages 8a and 9a with Maps IV and V on page 10a it will be seen that the superhumid area of evenly spread rainfall in the North Island (Kidson's area C) encompasses most of the bush, scrub and eroded country, while area B in the North Island, the drier, summer minimum rainfall area, delineates the extent of the major browntop (Agrostis tenuis), Danthonia (Danthonia spp.), hair grass (Aira spp.), sweet vernal (Anthoxanthum odoratum), dogstail (Cynosurus cristatus) and suckling clover (Trifolium dubium) associations.

In the South Island, area B (here having a diminished and more evenly distributed rainfall) encompasses browntop and danthonia associations around Nelson, and passes into a tussock and indigenous grass association extending southwards through Marlborough and Canterbury, merging into the depleted areas of Otago as the drier portions of semi-arid area D are encountered.

It is on this basis, having a common foundation in climate and vegetative association, that a classification of New Zealand hill country will be made for the purposes of this dissertation. Kidson's area C in the North Island will be termed the Wet Hill Country; area B in the North Island, the Dry Hill Country, and areas B and D in the South Island, the Tussock Hill Country.

Such a broad classification necessarily introduces errors and borderline cases, but in the ensuing discussion of the principles involved in the improvement of the hill land in these three areas, this classification seems the only feasible one to adopt. Each area has sufficient homogeneity to justify its being discussed as a separate entity.

D. THE RECENT ECOLOGICAL HISTORY OF NEW ZEALAND HILL LAND.

It is an ecological truism to say that grassland is a biotic community; it is dynamic; it is perpetually changing in conformity with and becoming adapted to those external influences which make up its environment. By understanding these external influences, and by tracing their history, we may the better understand why the hill pastures of New Zealand are as they are today.

I. Wet Hill Country.

If it be granted that the subtropical rain forest which covered the majority of this region prior to the advent of the European was the climax vegetation, then the conversion of that forest to grassland must, ecologically, be regarded as a retrogressive succession. Given the opportunity this grassland will revert to scrub or "secondary growth", comprising bracken fern (Pteridium aquilinum), water fern (Histiopteris incisa), manuka (Leptospermum scoparium), kanuka (L.ericoides), tauhinu (Cassinia leptophylla and like species. These in turn are the precursors of the typical rain forest trees which, in their early stages, will flourish in the shade of the scrub.

The superhumid climate which this area possesses normally supports rain forest vegetation (Thornthwaite, 1941), whereas grassland is normally dominant under subhumid conditions. Under these subhumid conditions rain forest will not become the dominant vegetation, but grassland, on the other hand, is capable of producing abundantly under superhumid climatic conditions. The drawback is that under superhumid conditions grassland must endure constant competition from other forms of vegetation constituting later stages in the sere which has rain forest as its climatic climax. Until man, with the aid of the agricultural techniques now in his possession, by management of his grassland and his stock on that grassland, weighs the ecological scales in favour of grassland, the threat of reversion to scrub and forest will remain. The chief weapons which man possesses in the battle for grassland stabilisation in a superhumid climate are fire and the grazing animal. In the absence of one or other of these influences, reversion to rain forest over most of this area is inevitable. By judicious use of one or both, grassland should become the climax of the modified environment, provided always that edaphic factors are favourable for the growth of grassland.

The hill country of the district under consideration has been won from this climax rain forest by felling, burning and the sowing of grass seeds - a familiar story. After the original burn, one of three ecological sequences may have followed (Levy, 1926).

In this area of high rainfall a good, clean 'burn' was not always easily obtained. The ground, littered with half burnt logs, may have been sown with grass seed, but the physical obstacles in the way of sheep or cattle grazing were often so great that no control of the pasture could be undertaken, and reversion to scrub and fern began immediately.

If a good 'burn' was obtained and the land sown to good 'English' grasses, as was the practice, several years of profitable grazing might well have been obtained. The sown perennial ryegrass (Lolium perenne), cocksfoot (Dactylis glomerata), smooth-stalked meadow grass (Poa pratensis), timothy (Phleum pratense), red clover (Trifolium pratense) and white clover (T. repens), all flourished in the ash of the bush burn. The value of this ash as a seedbed and as a fertiliser varied with the heaviness of the bush and with the dominant species present, each species having a different percentage composition of mineral elements (Aston, 1915).

This author found that the various forest tree woods yielded from 3% to 0.3% of ash, while their composition of the major plant nutrient elements fell within the following wide ranges:

Potash as K_2O	23% - 0.12%
Phosphate as P_2O_5	8.7% - 0.55%
Lime as CaO	37.7% - 10.0%

while the average compositions were 6.6%, 3.1% and 23.8% of K_2O, P_2O_5 and CaO respectively.

Hudson (1937) has computed the following table on the basis of these figures:

Mineral Content of One Ton of Completely Burnt Ash.

K_2O	P_2O_5	CaO
148 lb equivalent to about 500 lb. 30% Potash Salts	69.5 lb. equivalent to about 350 lb. Superphosphate	533 lb. equivalent to about 533 lb. Burnt Lime.

The number of tons of ash per acre cannot be assessed although Hudson believes "there must have been several tons of ash per acre on average bush country". At all events the dressing of minerals must have been heavy.

The potash in the ash existed as the carbonate, and as such was liable to rapid leaching, at least from the surface ash layers, although considerable fixation would take place in the underlying mineral soil. Loss of Phosphates by leaching was probably negligible, though it is possible that considerable quantities of lime were so lost. The fate of the organic nitrogen depended upon the degree of destruction of organic matter in the conflagration. Aston (1915) states that, "By burning, any nitrogen is lost completely", and so far as the wood ash is concerned this is true. Hudson (1937) observes that, "the heat of the burn ... also had a partial sterilising effect (on the soil), which would result ultimately in rapid decomposition of some of the remaining organic matter by bacterial activity, with the result that a good supply of readily available nitrogen would be present for a time".

The basis of this statement now seems doubtful in the light of present knowledge, though the final outcome - the enhancement of the nitrogen supply - remains unquestioned.

It is true that Russell and Hutchinson (1909 and 1913) found that partial sterilisation of soil led, after a short delay, to a rapid increase in the numbers of soil bacteria, and presumably the putrefactive and nitrifying organisms obey the general rule, but the evidence for any appreciable sterilising effect of a forest fire upon the underlying soil is hard to find. Heyward (1936) found rather differently - "Rapidly burning (long leaf pine forest) fires which created terrific heat above the soil rarely heated the soil below ¼ inch to a temperature much higher than that caused by a hot summer sun".

The truth of the matter, then, may well be that the vigorous grass growth obtained on such a seed bed is explicable partly on the basis of the enhanced mineral status of the soil due to the ash, and partly on the basis of the increased nitrification of the soil organic matter providing ample nitrogen and being due to increased bacterial growth concomitant with the improved lime and phosphate content of the soil rather than to any sterilisation after effect.

The work of Heyward repudiates, too, the tacit assumption that soil humus is to any extent destroyed by a bush burn. The main lesson from these observations is that immediately following a bush burn the soil fertility is no lower, and is probably higher, than previously. However, a forest association forms a virtually closed fertility cycle in which little in the way of nutrients is gained or lost. With the advent of a grazed sward, however, from which animal products are sold, a depletion of nutrients begins.

Such was the case on those vigorous pastures which followed a good bush burn. Fertility declined, the sward weakened and opened up. Overstocking probably - though there can be no certainty about this - played a part in weakening the original sward. Excessively large numbers of stock seem to have been carried in the days before the advent of refrigeration. When wool was the chief saleable product sheep stocks were allowed to multiply as rapidly as natural increase would allow. Animals were retained in theflock until they died a natural death. Sheep stocks consequently rose at an alarming rate (Butler, 1863), and it seems axiomatic that many runs were stocked beyond their capacity. Admittedly the earliest swards could support large numbers of stock, but as fertility declined and stock numbers increased, overstocking almost certainly resulted.

The final result in case two was, as in case one, a reversion to scrub and fern - partly due to the weakened competitive ability of the deteriorated sward, and partly because this sward was incapable of carrying sufficiently large numbers of stock to enable the control of secondary growth to be carried out.

A third course of development has followed the primary burn in some areas. Here the original sown sward has been modified without the intrusion of scrub or secondary growth. Modification has taken the form of invasion to a greater or lesser degree by poorer grasses and flat weeds. So called 'wet country browntop', an ecotype of Agrostis tenuis, is a frequent invader, but in some more favoured areas, such as in the environs of Taihape and Mangaweka, and in parts of Rangitikei County, the reduction in good grasses has been slight, and swards of cocksfoot, dogstail, Yorkshire fog (Holcus lanatus), and white clover are being profitably farmed.

There are, of course, all gradations between the ecological processes set out above, from the good hill pastures to be seen around Taihape, to the complete reversion around Whangamomona.

In the first course of development cited, the need is seen for the careful control of the sward by stock. Where this cannot be accomplished there can be no permanent check on the progress of the natural succession to the climatic climax - in this case forest. Again, in the second instance, anything conducive to the weakening of the sward such as overgrazing and/or a decline in fertility will, by necessitating a reduction in the number of stock carried, and by allowing light to reach the soil surface, permit the germination of scrub and secondary growth species. Alternatively, erosion may set in at some stage when the soil is insufficiently covered by vegetation and a fresh problem will arise.

The aim must, therefore, be to maintain a close sward over the hills. This can only be achieved by maintaining and, where necessary, improving soil fertility, as well as by judicious grazing management, both of which problems form the subject of separate subsequent sections, as does the control of secondary growth.

II. <u>Dry Hill Country</u>.

This area, defined in the earlier climatological classification, extends the entire length of the east coast of the North Island in a narrow strip about 40 miles wide in the Wellington province, narrowing to 10 miles in the direction of East Cape. It differs from the Wet Hill Country in having less rain in spring and summer. A higher temperature in those seasons still further reduces the effectiveness of the precipitation. The northern portion of this area may be regarded as transitional between the Wet Hill Country and the true Dry Hill Country.

A declination in total and an increase in seasonality of the effective precipitation is explained by Thornthwaite et al., (1941), to bring about a change in the climax vegetation from rain forest to lighter, tropical forest, or where the rainfall assumes a markedly seasonal aspect, to savanna. In New Zealand the tendency has been for an association of manuka, tutu (Coriaria ruscifolia) and bracken fern to replace the rain forest as these climatic effects become more pronounced.

Rainfall being lower in this area, it was normally easier to obtain a good burn, with the result that the second and third courses expounded for the Wet Hill Country succession have been most frequently followed. Except for the northern portion of the area, reversion to fern and secondary growth has been slower than in the Wet Hill Country, and depletion of the original sward has more frequently led to invasion by Danthonia and browntop, the former in the drier coastal regions, and the latter in the moister, landward areas.

With the removal of the original manuka - bracken fern association we may assume that the seasonality of the effective precipitation has, through alteration of the micro-climate, become more pronounced. With a lowering in the density of the ground cover, evaporation may well have been enhanced, especially during those seasons when precipitation was already low, and so long as sheep grazing, cattle grazing and burning of the coarse herbage continues, the savanna-type micro-climate will be perpetuated.

In the southern part of the area reversion tends to be a much less serious problem, but it becomes more serious in the more northerly, wetter districts inland from the dry Gisborne flats. On the other hand, these latter areas are less likely to suffer from sward depletion than are the former.

The problem is again one of maintaining and increasing fertility in an attempt to keep a greater proportion of the higher producing grass and legume species in the sward, to lessen any risk of reversion, and so to manage stock on the swards that the tendency for Danthonia and browntop to dominate is reduced and the competitive position of more favoured species, both of grasses and legumes, enhanced.

III. Tussock Hill Country.

The tussock grasslands of this area occupy parts of the eastern lowlands of the South Island, much of the foothill country of the main dividing range, and in places ascend the divide to an altitude of more than 4,000 feet.

There seems little doubt that in a somewhat different

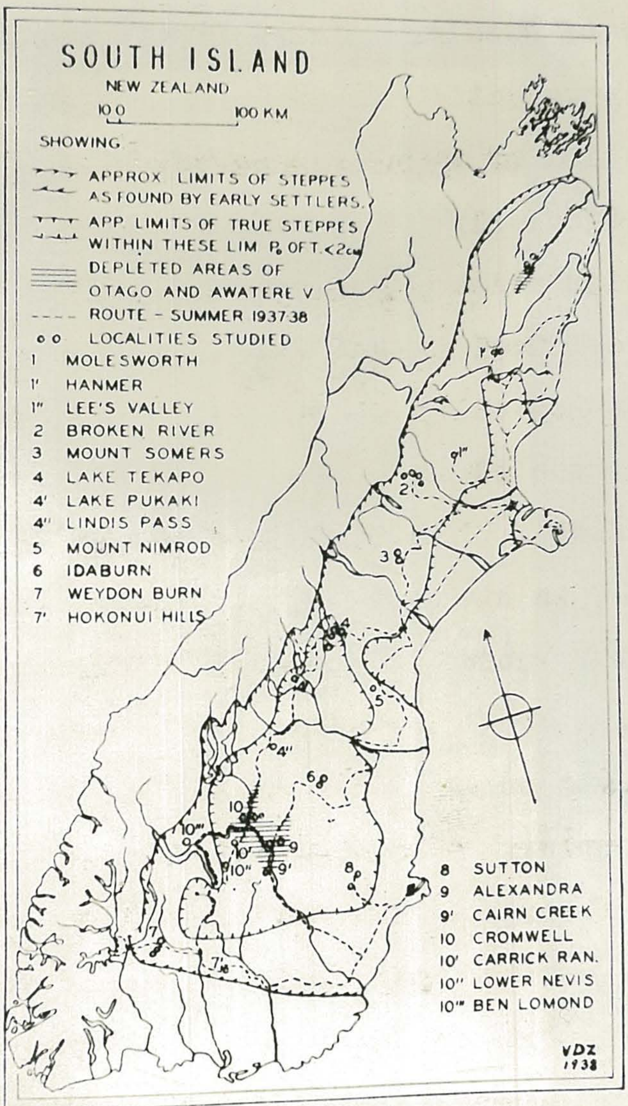


Fig. 2.—Sketch-map of the South Island, showing distribution of characteristic vegetation.

Map VI. (Zotov, 1938).

form, this association was in existence, and was of a comparable extent when the first European settlers colonised Canterbury. Why such an association should exist, at least in certain parts of the area so occupied, has been something of a problem for ecologists. Cockayne doubted whether the tussock grasslands were equivalent to the true steppe grasslands of Russia. Zotov (1938) observes that an effective precipitation (the writer presumes this to be the interpretation of Zotov's undefined term "Po") of 2 cm. per month, particularly during the summer months, is the critical precipitation which separates the steppe climax (having less than this critical amount) from the forest climax. On this basis Zotov logically claims that steppe was nowhere in New Zealand the climax formation much above 600 metres (c. 2,000 feet). Where it is found above that altitude today it is, in his opinion, an induced association, having scattered throughout it remnants of forest - the true climax vegetation. Map VI, showing the extent of true steppe and induced steppe on the basis of the previously mentioned climatic boundary, is reproduced on page 19a.

The cause of the destruction of the forests is lost to history, nor is their failure to regenerate understood. Nevertheless, Zotov's theory would seem to be feasible in view of the succession which has followed the destruction of certain areas of beech forest during European occupation. In these cases the succession has been one in which the variou tussock grassland species have spread upwards to occupy the denuded area, except where erosive forces have stripped off the top soil before it could be revegetated.

Zotov's theory, however, feasible though it may be, is a gross over-simplification of a complex ecological problem, and obscures many important facts. We must assume from his discussion of the origin of the word 'steppe' and from his example of the McKenzie plains as a typical form of the association, that Zotov was using the term in its strict ecological sense of short grassland, growing within the range of Thornthwaite's (1931) precipitation: evaporation (P - E) index of 16 to 31. This being so he can have no justification for claiming "that precipitation of Po = 2 cm. per month..... is the critical precipitation separating climax formations of forest and steppe". No possible explanation of the undefined term "Po" would appear capable of justifying the statement, for there can be no single dividing line between two climatic climaxes which are not naturally adjacent. The tall grass climax normally intervenes between the steppe and forest climaxes. It would, then, be expected that steppe and forest would not be separated by any single, arbitrary precipitation limit, but by a belt of some depth corresponding to the typical tall grassland climate. This belt, however, does not seem to have been recognised in the tussock grasslands. Tall tussock grassland does indeed exist, but this above the normal tree-line (Gibbs et al., 1945).

This lack of any well defined tall grassland belt dividing induced steppe from forest, emphasises the importance of the micro-climate in this situation.

Clements and Weaver (1924) have emphasised the "cyclic" (progressive might have been a better word) nature of ecological changes: "Effects in turn produce reactions, which consequently become causal to the extent that they modify the original causes". And again, "Ecology must not overlook the fact that cause and effect must be inseparably associated, and that effect sometimes affords the readier approach to the problem."

The effect in the instance under consideration is that forest lies adjacent to induced steppe which in turn subjoins true steppe and induced desert, there being apparently little indication of a tall grass association intervening between the forest and the induced steppe - an association which, logically, would be expected.

It is interesting to speculate upon the species which might have formed the more gradual transition from steppe, dominated by Festuca novae - Zealandiae to forest. Cockayne

(1928) (i) gives some indication of the possible stages in this sere.

If true steppe be taken to conform with Cockayne's "low tussock-grass of semi-arid habitat" dominated by Festuca novae - zealandiae, the transition stages may be that of his "lowland tall tussock grassland, confined to the South Otago and Stewart districts. It originally occupied nearly all that part of the Southland Plain where forest was absent, but, further north, it evidently clothed much of the lower hill country". That it did in fact form the missing link in the chain may be surmised from the life forms existent in those limited areas in which Cockayne found it. "The life forms may be classified as follows:- shrubs 12, herbs 25, semi-woody plants 5, grass form 9, rush form 4, ferns 2." The dominant species were Danthonia Raoulii var. rubra and D. Raoulii var. flavescens. These same species are the dominants of the tall tussock grassland now claimed by Gibbs (1945) to be confined largely to altitudes between 3,000 feet and 5,000 feet, but found by Zotov in the wetter parts of the induced steppes. Silver tussock (Poa caespitosa) may form a transition species between short and tall grassland (Allan, 1936).

Having observed the effect, and if the evidence supplied by Cockayne is accepted that this effect is not in accord with the climatic conditions, we may observe the cause to be in the disturbance of the cyclic, or progressive, nature of ecological change. The contiguity of induced steppe and forest may be taken as direct evidence of the supreme influence which vegetation has in determining the micro-climate of this region and (the effect being itself a further cause in the ecological progression) in determining what vegetation will grow subsequently.

Cumberland (1944) points to the lack of appreciation, in "the wealth of available literature", of the value of plants in modifying the micro-climate of this region. The writer would re-emphasise this viewpoint.

In any study of climate in this region, broad generalisations such as those of Zotov are unhelpful. To say, as he does, that "temperatures are extremely uniform throughout the whole length of the tussock grasslands, especially in summer" is to obscure the fact that short periods of extreme desiccation may occur. Such periods, as when the föhn winds blow from the north west, by killing off seedlings may completely prevent regeneration, though a generalised classification of climate, may indicate that regeneration should take place. Again, the evolution of complicated precipitation: evaporation indices ignores the precipitation lost to plants by run-off from the surface of inadequately covered ground; ignores the possibility that at any given temperature more moisture may be lost from a soil of low humus content than from one of high humus content, and the part played by surface mulches of vegetation in reducing evaporation (Kittredge, 1948). The use of air temperature in the evaluation of these P: E indices ignores the fact that temperatures under growing vegetation are considerably lower than those of the air above, and liable to less fluctuation. Denudation evens out these differences.

Under climatic conditions such as operate, for example, in the Wet Hill Country of the North Island, where temperatures are more equable and rainfall abundant at all seasons, these details are of less importance, but where the balance between regeneration and denudation is more fine these lesser elements of the micro-climate may become of major importance. The primary agents influencing the micro-climate of the tussock grasslands are, of course, anthropogenic and biotic - the use of fire by man, the grazing of his livestock, and the depredations of other herbivores introduced by him.

Much investigation would seem necessary to demonstrate the influence which vegetation may have upon the micro-climate in which it grows, and to show clearly the progressive improvement it may bring about in the climatic conditions of its own habitat, so allowing other more hygrophilous forms of vegetation to supersede the original. But if there ever was in the present tussock grassland region the natural gradation from steppe, through tall grassland to forest, which, as has been suggested, should have existed, and demonstrated possibly did exist, then certain theories may be postulated.

(i) That growth of vegetation, if uninterrupted by anthropogenic or biotic factors, and despite the influence of short-lived climatic extremes, will so modify the micro-climate of its habitat as to permit the establishment, as a climax vegetation, of something akin to that which a consideration of the overall climate of the region would lead one to expect.

(ii) That anthropogenic and biotic factors may so modify the vegetation, and through it the micro-climate of its habitat, that a climax vegetation may be formed which is not in accord with that which a consideration of the overall climatic regime would lead one to expect.

(iii) A combination of anthropogenic and biotic factors, together with climatic extremes (even though these latter be of short duration) may so alter the micro-climate that after forest destruction a steppe, or even semi-desert climax may exist alongside a forest climax, both being subject to the same overall climatic regime.

These are held to be broadly true in the South Island tussock grasslands where the climatic extremes referred to are the desiccating föhn winds and wide daily and and seasonal temperature ranges, and where the overall climatic regime is that indicated by total precipitation, air temperature and P: E indices.

If these postulates are valid, several means of preventing further depletion and of instituting improvement become evident. These would be:

(i) The removal or limitation of the anthropogenic and biotic factors.

(ii) The introduction of strains and species of plants capable of withstanding and producing economically under the existing conditions of the habitat - anthropogenic, biotic, climatic and edaphic.

(iii) The lessening of the effect of the climatic extremes by devices such as tree planting.

(iv) A combination of two or more of the above.

The problems of burning and overgrazing implicit in (i) above, are discussed in subsequent sections of similar title, as is the possibility of implementing (ii) and (iii).

E. THE PRIMARY CAUSES OF HILL PASTURE DETERIORATION.

If the national importance of the hill land of New Zealand which was previously claimed be granted, and if it also be granted that in order to enhance New Zealand's national income derived from primary produce export, the hill country should continue to play an important and increasing part in that export trade, then one cannot afford to neglect a study of ways and means of maintaining at the present level, and in the long run improving the productive capacity of this class of land.

First of all the reasons for a declining productive capacity must be understood if this undesirable state of affairs is to be combated and reversed.

In the ensuing discussion use will be made of the term "ecological survival range". This concept in the mind of the writer may best be defined by demonstration. Each pasture species or association of species has a range of edaphic, climatic and biotic conditions within which it can survive. This is called the ecological survival range. As any one, or interaction of several factors of the environment exerts an influence which a plant or association can only just tolerate, and yet still survive, the plant or association may be said to reach the limit of its ecological survival range. In New Zealand's deteriorating hill land it happens that the better species are being driven beyond the limit of this range and are dying out. Broadly, the reasons for this are twofold. The first is declining soil fertility, leading to a declining production from the existing pasture species, and later to a change in the botanical composition of the sward towards species demanding lower soil fertility for survival and being themselves relatively low producers of animal food requirements. The second is associated with the use which man makes of the hill vegetation.

To examine the first of these reasons more fully; soil fertility (in its narrow sense of soil nutrient content) will decline through the agency of two factors - the disposal of animal products and carcases, and leaching.

Levy (1947) quotes the following figures for equivalent manurial losses due to the sale of animal produce and carcases:

One Cattle Beast (1,000 lb. live wgt.)	Sulphate of Ammonia.	Super-phosphate.	3% Potash Salts.	Lime as $CaCO_3$.
Reared and fattened	116 lb.	77 lb.	$5\frac{1}{2}$ lb.	40 lb.
Fattened only		Losses	negligible	
One Sheep (150 lb. live weight)				
Reared and fattened	$17\frac{1}{2}$ lb.	8 lb.	8 lb.	$2\frac{1}{2}$ lb.
Fattened only		Losses	negligible	
Seven pounds of Wool	4.3 lb.	-	4.2 lb.	-

Fraser (1947) (iii) suggests that on extensively farmed hill land, i.e. where carrying capacities are relatively low, the loss of nutrient elements in stock and stock products sold off the farm may not, however, be serious in comparison to leaching losses, especially of lime and phosphates.

Losses of lime even from soils having a high lime requirement are believed to be relatively great. Davies (1938 found that a soil having a lime requirement of 40 cwt. per acre $CaCO_3$, still lost (in the bicarbonate form) one cwt. $CaCO_3$ per acre per annum through the agency of leaching.

In untopdressed hill soils losses of phosphate by leaching may be ignored, and even if topdressing is carried out it is doubtful if much of the added phosphate is leached out (Doak, 1942). A more likely fate is that it will be rendered unavailable by conversion into iron and aluminium phosphates on acid soils, or apatite ($CaX_2.3Ca_3(PO_4)_2$, where X = OH or F) on neutral or alkaline soils (Russell, 1950)(i).

Potassium is unlikely to be in short supply provided it is present in the clay minerals. De Turk, Wood and Bray (1943) believe that an equilibrium is set up in the soil between the available and unavailable potassium. This equilibrium may be represented thus:

K in Clay Minerals ___ K cations adsorbed on colloids ___ K in soil solution

Unavailable — Available — Available

Removal of potassium from the adsorbed state (by contact exchange absorption) or from the soil solution by growing plants tends to cause a slow liberation of potassium from the clay minerals to maintain the equilibrium. However, clay mineral type and soil acidity influence the availability of potassium. Campbell (1949) believes that such factors as a high clay colloid content, especially of the 2 : 1 lattice, Montmorillonite type, and a high soil calcium content, will tend to keep available potassium at a low level. Potassium, like phosphate, has been shown to be relatively immobile in the soil (MacIntyre, 1943).

Russell (1950)(ii) reports the loss of 1,150 lbs. of nitrogen per nine inch acre in 45 years from Rothamsted lysimeters carrying no vegetation. This amounts to 25.5 lbs. of nitrogen (≡ 1 cwt. Sulphate of Ammonia) per nine inch acre per annum. On other Rothamsted plots on which vegetation was allowed to run wild for over 20 years, the annual gain of nitrogen varied from 60 lbs. per acre per annum when the lime status was 0.16% to 92 lbs. per acre per annum when the lime status was 3.32%. The former plot bore in its herbage 0.4% of legumes, the latter 25%. Apart from rainfall, usually attributed with supplying between 2 and 20 lbs. of nitrogen per acre per annum (Russell, 1950) (iii) and free-living nitrogen fixing organisms of the Clostridium, Azotobacter and Nostococcaceae groups, little is known about the natural supply of nitrogen to soils when leguminous plants are absent. Without further information one cannot posit a net loss or gain or a position of equilibrium being attained.

It is as yet too early to evaluate the importance of direct absorption from the air of nitrogen, lime and phosphate aerosols by plant cellulose postulated by Ingham (1950) as a natural source of plant nutrients.

Fertility, then, may be lost through the disposal of animals and their produce from the hills; by leaching, especially in the case of lime and nitrogen, and by fixation in unavailable forms in the case of phosphate in particular.

As soil fertility declines, so does the production of existing pasture species. As higher fertility demanding species reach the limit of their ecological survival range they are replaced by lower fertility demanding species of lower productive capacity, and so the output of animal products continues to decline.

It is with the rectifying of this downward spiral that the next sections on Topdressing and Oversowing are concerned.

As indicated earlier, there is a second major cause of declining productivity on the hills associated with the purely mechanical removal of herbage by grazing animals and by man-made fire. Excellent account of man's depredations on natural vegetation are given by Fenton (1937), who recalls that woods and grassland have been converted into sand dunes or bracken infested slopes by man's mismanagement of his grazing animals, and by Cumberland, who says "No matter how heroic the history of colonial frontier days, it is already reasonably established that the damage done to the productive capacity of New Zealand's area and soils is in parts beyond repair, and elsewhere is rapidly approaching the critical stage." And again, "The carrying capacity of the tussock steppe in general is certainly declining --- overstocking, burning, and the resultant depredations of swarms of rabbits have so completely ousted the tussock --- that the ground is bare except for scabweed cushions".

It is to a part of this second cause of deterioration that the section on Stocking is devoted.

F. TOPDRESSING.

Having discussed the causes of declining fertility, it is fitting, at this stage, to discuss ways and means of replacing that which has been lost.

Topdressing is a term embracing the application of phosphate, lime, potash, nitrogen and certain trace elements to the established pasture. It is not correctly used to explain the incorporation of fertiliser or trace elements in the soil prior to sowing down a pasture, and such basal dressings for pasture establishment purposes are not considered here.

Grange (1944) in his basic scheme for land classification, recognises six classes of land of different "fertility or potential production" in the North Island. Of these, Class 5 is of most importance in this context. It is "hilly or steep land of moderate to low fertility. Light topdressing is required to maintain a cover of grass, and careful management is necessary to prevent soil erosion." It encompasses 2,757,000 acres, or 10%, of the North Island land surface. Since, in such a classification as that employed by Grange, there can be no sharp dividing line between one class and another, some Class 4 land - that is "hilly or steep land which will maintain grass pasture with little or no topdressing", amounting to 2,071,000 acres, or 7%, of the North Island land surface, will also be topdressed; more especially so since it may be desired to improve the pasture and not simply to maintain it at the expense of the natural soil fertility. Consideration must also be given to Class 6 land; "Hilly or steep land which has severe limitations to utilisation, such as low fertility, or erodibility", comprising 14,740,000 acres, or 53%, of the North Island land surface. At the margin of profitability, and on the margin of grassland and forestry uses in times of normal prices for livestock products, much of this land is today potentially profitable as a source of livestock products, and may, by having its fertility raised during these profitable times, be removed, if not completely at least partly, from the no-man's land of economic marginality. Even in cases where erodibility is the cause of marginality, an improved fertility, by sustaining an improved sward, should in many cases allow profitable farming to be carried on without undue soil wastage.

In the 4 inch to 1 mile soil survey maps of the North Island the skeletal soils which make up the majority of the hill country range in map number from 113 to 130d, suggesting that there are considerable variations in these soils in the factors mapped, including soil fertility. Until the bulletin explaining these maps is published no detailed impression can be gained of those soils likely to be highly responsive to fertiliser dressings, those less responsive, or those unresponsive soils of already high fertility or having some other limiting factor. Nor can an indication be gained of those nutrients likely to be in short supply in the various soils, although the majority of topdressing programmes have been directed towards augmenting phosphates. The extensive use of phosphates has been bound up with the desire to enhance soil fertility and feeding value of the sward through the clover root nodule, a cycle too well known to require reiteration here.

While attention has been directed mainly towards topdressing with some form of phosphatic fertiliser, the possibility of lime and potash becoming factors seriously limiting hill pasture production must never be forgotten, the former especially in districts of high rainfall. The need for lime topdressing of hill land has been remarked upon by Livingston (1938) with reference to the Dannevirke district. The results of topdressing trials quoted by Hamblyn (1937), though probably carried out on easier country than is here considered, indicated responses to lime in certain areas of North Taranaki and Wanganui, while in most other areas in which the work was carried out the main response was to phosphate, with lime in some cases enhancing the effect.

Marked response to potash was obtained only in the Taranaki and Waihi areas.

The importance of trace elements in stock health must not be forgotten either. The case may be cited of the Rotorua and Matawai districts of the North Island, and areas of Southland, Canterbury and Marlborough in the South Island, where stock health has been markedly improved by cobalt topdressing.

However, if it is legitimate to argue from the widespread general practice, phosphatic topdressing would appear to be most generally required, and for this reason the subsequent discussion will be concerned largely with this nutrient.

I. Effect of Phosphatic Topdressing.

The primary object of the phosphatic topdressing of hill land is the stimulation of clover growth which, through the action of its nitrogen fixing symbiotic organisms, and provided other soil conditions such as reaction and aeration are adequate, enhances the soil nitrogen content to the ultimate benefit of the grass species in the sward. In this way the total production of herbage is enhanced in a manner somewhat similar to that following a heavy application of nitrogenous fertiliser, although clover nitrogen, being supplied more regularly, gives a more even and sustained growth than is normally the case with nitrogenous topdressing.

That the action of superphosphate upon pasture yield is due to clover stimulation is indicated, though not decisively, by the figures of Sears (1950) (ii):

	Lb. dry matter per acre in 13 months.
Grasses alone + lime + super.	1,800
Grasses and clovers, no fertilisers	9,425
Grasses and clover, lime + super.	11,592

While the mere introduction of clovers had the greatest effect, the addition of lime and superphosphate to the grass and clover sward increased yield by 22% over that receiving no fertilisers, and by 64% over the pure grass, fertilised sward. Unfortunately the influence of lime cannot be separated from that of superphosphate.

Some guidance on this latter difficulty may be obtained from trials held at Marton by Elliot and Lynch (1942) indicating that over a period of eight years the application of lime and superphosphate to a grass-legume sward gave 8% greater dry matter yield than did topdressing with superphosphate alone. While deprecating the lack of a control (no fertiliser) plot in these trials, by which the separate effects of lime and superphosphate, as opposed to no fertiliser, could have been measured, the figures of Hudson et al. (1933) indicate that in the Marton Experimental Area the addition of 4 cwt. of superphosphate annually will increase pasture yield by about 50% compared with the yield where no fertiliser is added. By comparison the increased yield due to lime applications is relatively small within the Marton Experimental Area.

The effect of superphosphate in altering the botanical composition by stimulating clover growth is demonstrated by the previously cited work of Elliot and Lynch, who showed that the percentage of ground covered by white clover rose from 15.9% prior to topdressing with phosphate to 25% eighteen months after topdressing.

As emphasised earlier, until adequate soil surveys are completed, all those areas in which response to phosphate may be expected cannot be recognised, nor can those areas in which response to phosphate depends upon first neutralising excessive soil acidity be traced. Despite the lack of accurate data, however, the results obtained by individual farmers indicate that very many hill swards increase their production in the manner indicated above by the application of phosphatic fertilisers alone.

Apart from the increased total dry matter, another important feature of phosphatic topdressing is frequently overlooked. This is the improvement wrought in the mineral status of the herbage. Hudson's (1933) work demonstrated that application of superphosphate to a pasture consistently increased the percentage of P_2O_5 in the herbage, and also the percentages of lime (as CaO) and nitrogen. While the seasonal fluctuation in the percentage of these elements was not lessened by topdressing with superphosphate, it occurred at a higher level.

Despite the fact that phosphatic topdressing preferentially benefits clover growth, which Doak (1931) and Askew (1933) have demonstrated to contain about twice the CaO present in grass species, Hudson's work would indicate that the CaO : P_2O_5 ratio does not seriously deviate from the optimum value of unity due to such topdressing.

All the foregoing response figures were obtained on low ground pasture growing on lowland soils. It would be unwise to assume that the response of hill pastures would be of an equivalent order. In some cases it might be more, in others less. The demarcation of areas showing a response has not, however, awaited the outcome of soil surveys or other exact scientific investigation. In this regard the farmer has moved ahead of the scientist, and has in many cases, by his own trials, demonstrated the value of phosphatic topdressing for his own particular circumstances of herbage, soil and climate.

A detailed soil survey, such as has been completed for the North Island, will more accurately demarcate the soil types likely to give a response to phosphates, and field trials may indicate optimum rates of application within these areas. At no time, however, should sight be lost of the fact that the degree of the response, and probably also the optimum rate of fertiliser application, will depend to some extent upon the grass and legume species present in the sward.

II. Types of Phosphatic Fertiliser Available.

At the time of writing the whole position of phosphatic fertiliser supply is under review. This is due to the superphosphate shortage engendered by world-wide sulphur shortage. Department of Agriculture, Government and Trade officials have sought to overcome the difficulty by placing on the market three "diluted" forms of superphosphate, believing that farmers will continue to apply the same weight of phosphatic fertiliser as formerly, regardless of its soluble P_2O_5 content. The following types of superphosphate mixtures will be offered:

(a) Standard Mix Fertiliser, consisting of:

15 cwt. superphosphate

2 cwt. ground serpentine rock

3 cwt. ground Nauru phosphate.

(b) Serpentine Superphosphate, consisting of:

15 cwt. superphosphate

5 cwt. ground serpentine rock

(c) Reverted (Basic) Superphosphate, consisting of:

15 cwt. superphosphate

5 cwt. ground limestone

It is anticipated that North African rock phosphate and high grade Belgian basic slag will also be available in limited amounts (Holyoake, 1951).

Little is as yet known about the effectiveness of these new mixtures though, so far as the unmixed fertilisers are concerned, Smallfield (1935) concluded that rock phosphates were generally inferior to superphosphate or basic slag - this no doubt because of the low solubility of the phosphatic rock. Bruce (1931) has compared the citric solubilities of a high soluble basic slag with two types of North African rock phosphate:

	Total P_2O_5	Sol. in 2% Citric acid.	Citric Solubility
Bessemer basic slag	17.5%	15.9	92
Tunisian rock phosphate	26.2%	10.7	40
Moroccan rock phosphate	35.2%	11.2	32

Further, on the score of solubility, the North African rock phosphates are to be preferred to those from the Pacific Islands.

Serpentine superphosphate is a mixture of three parts by weight of superphosphate and one part by weight of ground serpentine rock (MgO). Weight for weight, serpentine superphosphate has been shown to be as effective as 'straight' superphosphate on certain soils although only containing ¾ of the P_2O_5 (Fields Division, 1944). This enhanced effect may have been due either to a soil deficiency of magnesium which the serpentine superphosphate corrected, or to the formation of di-magnesium phosphate which, while being moderately available to plants, prevented the formation of unavailable iron and aluminium phosphates. In the same way the reversion of superphosphate with ground limestone may prevent a certain amount of fixation of phosphate in unavailable forms, especially on acid soils. However, the extent of these benefits is, as yet, rather a matter for conjecture.

Apart from any such benefits arising from increased availability, there would seem to be little difference in the effectiveness of various phosphatic fertilisers other than mineral phosphates. Williams and Reith (1948), working with a large number of phosphatic fertilisers including superphosphate, silicophosphate, serpentine superphosphate, calcium phosphates, triple superphosphate, steamed bone-flour, and ground mineral phosphates from various sources, conclude that there is an "absence of major differences in the over-all effectiveness of phosphates other than mineral phosphates". Further, they found little interaction between fertiliser and soil type: "There is no indication of any appreciable variation in the relative effectiveness of the different phosphates in soils of different geological origin. The mineral phosphates are the only forms showing major variations, and their relative effectiveness in acid soils appears to depend more on the crop than the type of soil. Pedological differences seem more likely to be reflected in the level of yield and in the general response to, uptake of, and need for phosphate".

If these findings are shown to hold good for New Zealand conditions, the question of which phosphatic fertiliser to use becomes one of availability, and price per unit of phosphoric acid. The high costs of cartage (especially important to the hill country farmer) and application militate against any but the most effective and most concentrated forms of fertiliser. For this reason the choice of the hill country farmer will probably be the Standard Mix Fertiliser, (a) above), on account of its higher P_2O_5 content, unless Reverted or Serpentine superphosphate is proved to be as effective, weight for weight, as the Standard Mix, or unless these two former bear some price advantage.

Sulphur component of superphosphate in some cases, v. important! 29.11.57

III. Rate of Application.

The optimum rate of application might logically seem to be a reciprocal of the degree of deficiency. Within narrow limits this may be true, but it must be modified by the rate, degree and nature of phosphatic fixation by the soil, as well as by the efficiency of the plants present in the sward in assimilating added phosphate, for what is not utilised in the season of application will be largely unavailable in subsequent seasons. Cook (1935) has demonstrated the varying ability of different plant species to utilise phosphate, while Williams and Reith state that "it would appear that the residual effects, even of heavier dressings, are generally small or negligible, irrespective of the form (of phosphatic fertiliser) used, and the nature of the response curve suggests that, as a rule, there is little further increase in yield to be obtained from dressings higher than about 80 to 100 lb. P_2O_5 per acre. .... The use of dressings considerably in excess of about 1 cwt. P_2O_5 per acre (say, 5 cwt. superphosphate) would appear to be generally uneconomical. Frequent applications...seem preferable to a single heavy application during the rotation".

These applications were for arable crops producing from 5,000 to 7,500 lb. dry matter per acre. This is probably a considerably greater dry matter production than is expected from New Zealand hill land. Figures by Sears (1950) (i) indicate a yield of 2,909 lb. dry matter from unimproved hill land, rising to 5,129 lb. on topdressing and oversowing, and to 9,338 when stock were concentrated on the topdressed and oversown area.

When superphosphate is applied to New Zealand hill land the average dressing aimed at is usually 2 cwt. per acre. Taking into account the figures of Williams and Reith, and the smaller production demanded from hill land, such a rate of application is probably close to the optimum for hill land of average fertility. While on much hill land heavier dressings would probably give enhanced responses, the law of diminishing returns and the value of the products for sale must always be borne in mind. Thus at 1950-51 prices for wool, heavier dressings might be justified if extra stock could be carried to utilise the extra growth induced thereby.

There would seem to be scope even yet, however, for some exact experimental work, under New Zealand pastoral conditions, to determine optimum rates of application of superphosphate and the new mixtures thereof with lime, serpentine rock and rock phosphates upon various classes of hill country, especially in view of the deteriorating supply position.

IV. Methods of Fertiliser Distribution.

(i) Distribution by Hand.

Until recently the sole method of fertiliser distribution has been by hand, and this method is still the most widely used where the country is so steep as to preclude the use of topdressing machines such as are commonly employed on level land.

Perhaps the main drawback to this method has been the difficulty of obtaining labour to carry out what is an unpleasant task. The labour available has not increased in conformity with the increased popularity of the practice of topdressing hill land. The increasing cost of labour, too, has enabled other forms of distribution to compete with hand distribution from a purely economic standpoint. Hand distribution, too, demands that the fertiliser be packed out

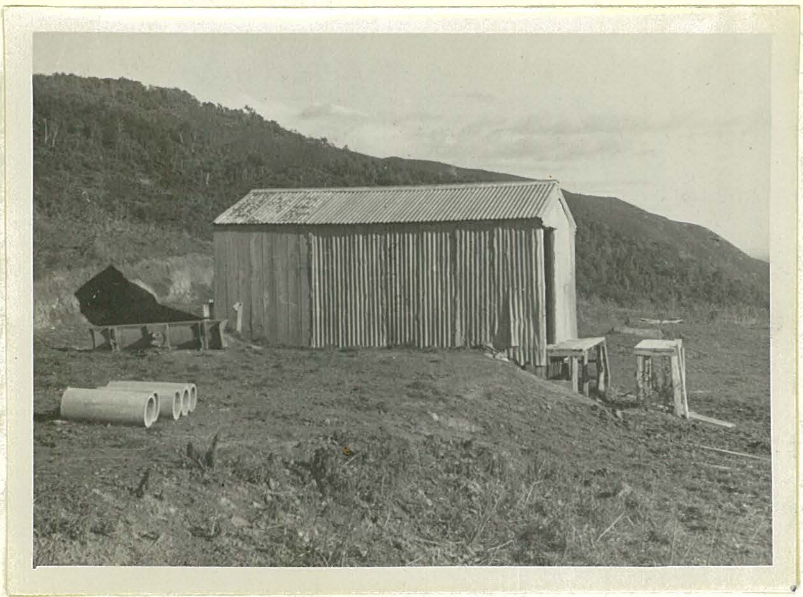


Figure I. General layout of fertiliser storage shed, with parallel loading platforms.

Figure II. Pannier straps being loaded with superphosphate bags from parallel platforms.

Figure III. Backhorse team moves away from the loading platforms.

on to the hill and the bags placed in convenient positions to minimise the amount of walking the sower has to do. One method is to place the bags of fertiliser (superphosphate is in bags of 187 lb. weight) in pairs about 90 yards apart every way, and from each such dump the sower sows the fertiliser 45 yards every way, covering a square of $1^2/_3$ acres in extent with each two bags. There being 12 bags to the ton this gives an application rate of 2 cwt. per acre.

Difficulties of packing on to the hill may be minimised if tracks are available to central storage points, allowing the use of mechanical transport. Easy, dry weather access routes to central points may serve the purpose without the necessity for actual tracking. One such system is known to the writer. During favourable weather the fertiliser is transported by lorry, tractor and trailer, and tractor and sledge, to corrugated iron sheds placed centrally in each block of 500 to 600 acres. Each shed has a capacity of up to 80 tons of fertiliser. From these sheds the fertiliser is packed on to the hill. Loading of pannier straps is simplified by the parallel platform arrangement depicted in the photographs (Figs. I, II & III, page 38a). The straps are laid out on the platform, a bag of fertiliser rolled on, and the straps buckled up. One man can thus load a pack-horse team quickly and with little heavy lifting, thus expediting the work.

Allowing that a 600 acre block is a square of approximately 1,700 yards side, and the fertiliser dump is centrally placed, the maximum distance packed should be less than 900 yards, or half a mile. Thorpe (1951) believes this distance to be the maximum for economical packing, allowing one packman with four horses to keep three sowers occupied by making between 9 and 11 trips to and from the central dump daily. The sowing of 20 acres per man ~~per~~ day which this would entail is probably a generous estimate.

Where packing must be undertaken over longer distances, or in very difficult country, the task becomes excessively slow and laborious, and it is under such conditions that other forms of distribution can compete favourably with that by hand.

Distribution by hand has the advantage that it permits much greater selectivity of placement than mechanical methods. Sowers can preferentially topdress those places which, in their estimation, are most likely to respond, and can avoid wasting fertiliser in patches of scrub and fern - though the custom of some farmers is preferentially to topdress such patches in the belief that such grass as exists therein will be "sweetened" and will attract cattle to graze it, to the ultimate detriment of the scrub and fern.

However, the evenness of hand distribution has been called in question by the advocates of other forms of distribution, and from the writer's experience of topdressing perfectly level hayfields by hand, there may be considerable justification for these doubts.

(ii) Distribution by Blower.

The early hopes held out for this method of topdressing (Hamblyn, 1949) have more recently been belied (Lynch, 1951). The principle of the blowing machine is that fertiliser material is fed through a fan rotating at high speed, and passes into the updraught of the fan. This impells the fertiliser upwards and outwards from the machine for a certain distance, while wind and air currents carry the material still further.

This method has the advantage, according to Lynch (1950), that "costs of application are considerably lower than those of hand topdressing, and the labour requirement is less". According to Hamblyn (cit. supra) it is a rapid means of fertiliser application, rates varying from 1 to 1½ tons per hour.

Recent trials on level ground, reported by Lynch (cit. supra) have proved the distribution (under the conditions of the trial) to be very poor. This finding Lynch succintly sums up thus: "The paradox of blower distribution of fertiliser is that, though the area of deposition of relatively coarse materials can be controlled fairly effectively, the spread of such materials is grossly uneven. Conversely, the spread of finely ground materials is reasonably good, but there is very

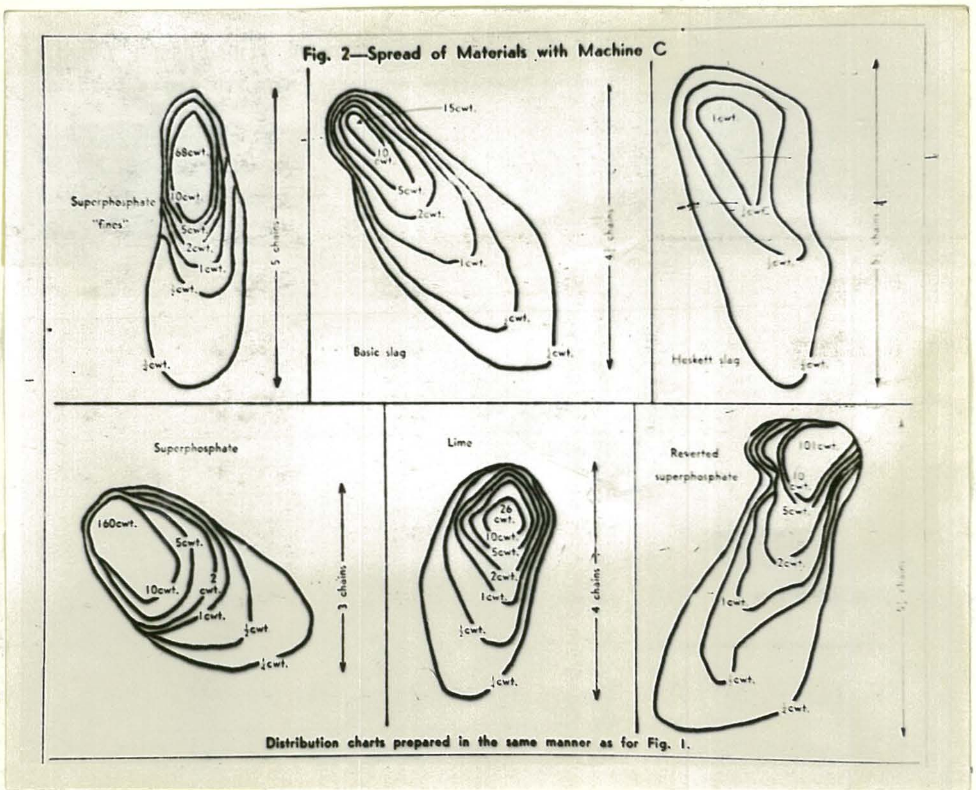


Figure IV. Typical distribution contours for various fertilisers spread by blower topdresser. (Lynch, 1951).

little control over the area on which such materials are deposited".

The fertilisers used, placed in order of decreasing fineness, are tabulated below. The first column shows the maximum density of fertiliser found in the vicinity of the machine, and the figure is taken from the distribution charts (Fig. IV page 40a).

Fertilisers - from finest to coarsest.	Max. dressing cwt/acre.	% fert. accounted for.	% of fert. recovered which landed in the area:		% fert. applied landing in $\frac{1}{4}$ - 5 cwt. per acre area.
			receiving 5 cwt. per ac. or more	receiving $\frac{1}{4}$ - 5 cwt per ac.	
Basic Slag	15	31	40.6	59.4	18.4
Heskitt Slag	1	17	nil	100	17
Lime	26	37	57.8	42.2	15.6
Super. Fines	68	97	89.8	10.2	9.89
Reverted Super.	101	82	88.6	11.4	9.34
Superphosphate	160	100	89.5	10.5	10.5

If, for the sake of argument, a distribution of between $\frac{1}{4}$ cwt. and 5 cwt. per acre is assumed to be satisfactory, it will be seen that in every case less than 20% (a maximum of 18.4% was reached with Basic slag) of the fertiliser applied landed within this distribution range. The coarser fertilisers tended to fall to the ground in the region of the blower's blowpipe, giving gross application (160 cwt. per acre in the case of superphosphate) for an area extending about one chain from the blower. The greatest part (69% of the Basic slag and 83% of the Heskitt slag) of the finer materials became airborne, and was carried completely outside the 'target area'.

Such a distribution is patently unsatisfactory, especially when it is remembered that with this type of machine annual fertiliser dressings will tend to be applied from the same position - from a ridge, blowing down, or from a gully, blowing up - year after year. The blower must be operated from a trailer or sledge drawn along reasonably accessible routes. These routes will almost certainly be limited, and will so limit any variation in operating position, thus condemning certain areas near the operating site to an ever increasing overdose of fertiliser, while the land 3 to 5 chains away is condemned to consistent neglect.

It may be that, in time, an optimum size and specific gravity of fertiliser particle, or more probably an optimum mixture of sizes and specific gravities of particle, will be decided upon, and that this, combined with an improved machine and a better knowledge of optimum wind velocities, will lead to an improved distribution of fertiliser from these blowers. Too great a dependence on uncontrollable factors such as wind velocity should be avoided. The mixing together, in definite proportions, of fertiliser particles of different but definite size and specific gravity, such that a proportion of the material will settle out near the blower, a proportion further away, and so on, yet none be so light as to become airborne in moderate wind conditions, may be envisaged as the most practical method of tackling the problem of distribution from blower topdressers.

(iii) Distribution by Aircraft.

The use of aircraft as farm implements was begun in America shortly after the first world war. Pest control by dusting was an early use; in 1929 rice was first sown from the air, and by 1948, in the State of California alone, aircraft handled over one million acres - spraying with weed killer, dusting and spraying to control pests, and sowing crops of barley, wheat, lucerne and ladino clover (Smith, 1950).

In 1947, after an extremely wet winter in Britain, aircraft were used to a limited extent for sowing grain crops on ground so wet that seed drills could not operate.

In New Zealand this aid to farming has been developed in the post-second-world-war period, beginning with the sowing of lupin seed on 90 mile beach late in 1944, followed by the sowing of copper sulphate on deficient peat land on the Hauraki Plains (Anderson and Cunningham, 1946).

Preliminary trials with the sowing of fertilisers were carried out at Ohakea aerodrome in 1948, Raglan, 1948, and on

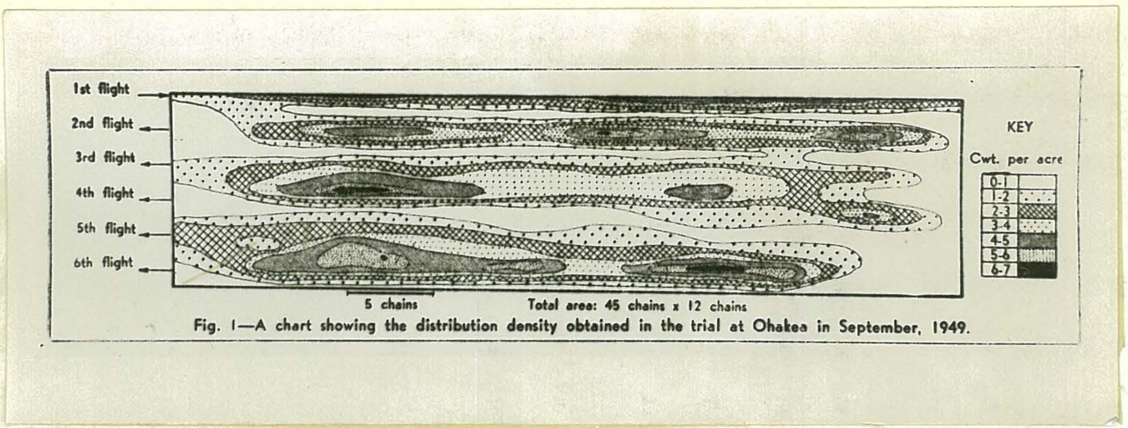


Figure V. Distribution density contours for granulated superphosphate.(Lynch,1950).(Avenger a/c).

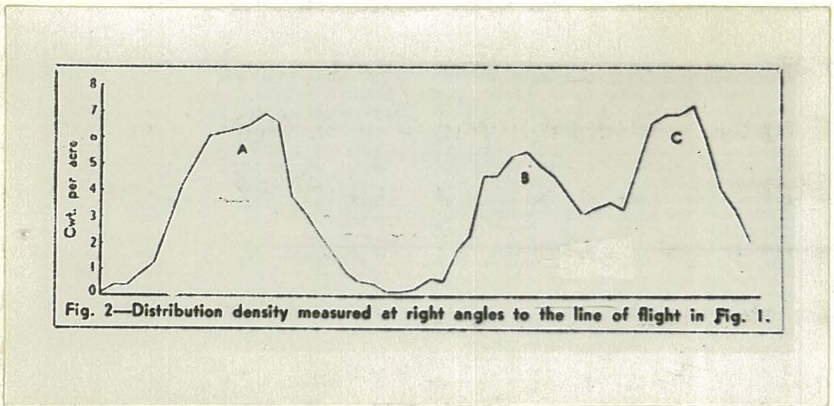
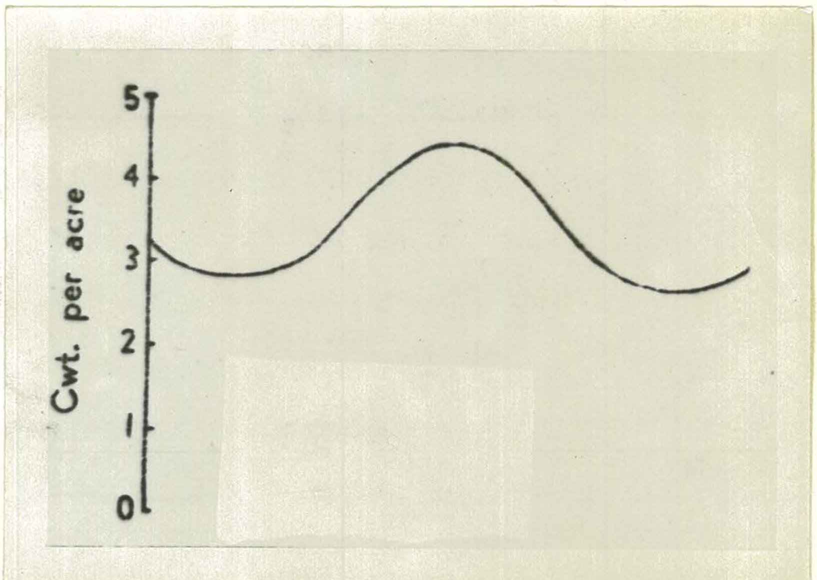


Figure VI. Distribution density measured at right angles to the line of flight in Figure V. Peak A represents the merging of two swaths of fertiliser. Flight lanes 2 chains apart. (Lynch,1950).

Figure VII. Distribution density curve obtained when fertiliser was dropped at 5/7ths of the original rate ($2\frac{1}{2}$cwt instead of $3\frac{1}{2}$cwt), from flight lanes 1 3/7th chains apart. The distribution is markedly improved. (Lynch,1950).



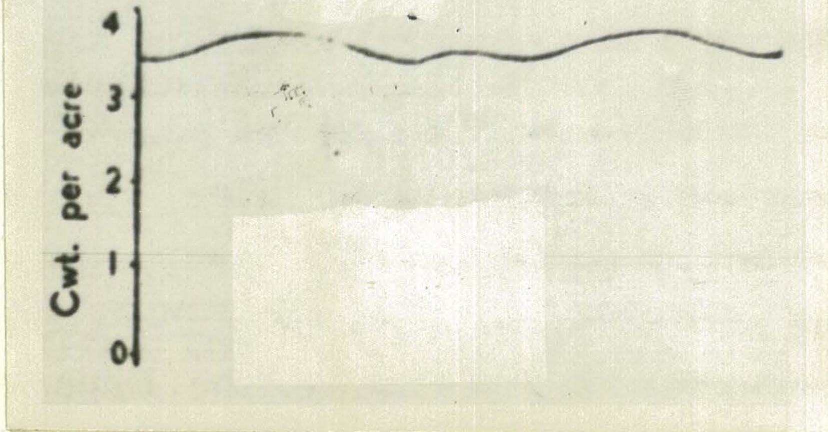


Figure VIII. Almost perfect distribution resulted when application rate was reduced to 4/7ths of the original (2cwt), and flight lanes reduced to 1 1/7th chains apart. (Lynch,1950).

Wairarapa hill country in 1949. These preliminary trials, reported by Lynch (1950), have demonstrated the great potentialities of this method.

Using light aircraft, flying at heights of from 50 to 100 feet, ordinary commercial superphosphate can be distributed with satisfactory evenness. Where the use of heavier aircraft necessitates flying at greater heights, granular material was found to be essential to ensure an even distribution. The evenness of distribution depends partly, as might be expected, upon the distance apart of the flight lanes. Rate of application decreases outwards from the centre of the flight lane, so that by allowing an overlap of the successive swaths of fertiliser laid down, a relatively even distribution may be obtained. Typical distribution charts are presented (Figures V, VI, VII and VIII page 42a). As demonstrated by Figure VIII close spacing of flight lanes gives almost perfect distribution of the granular 'hillside' superphosphate used. The closer together the flight lanes, the lower must be the rate of fertiliser distributed per unit of flight distance in order to give the same per acre dressing of fertiliser as where widely spaced flight lanes are used. This means increased flying distance per acre topdressed, and, therefore, increased cost per acre. The value of perfect distribution must be equated with this increased cost and the loss in productivity entailed by less perfect distribution, bearing in mind always that if topdressing is carried out regularly, ground which is thinly topdressed or missed altogether in one year will, by the laws of chance, probably be adequately topdressed in a subsequent year.

The aircraft most extensively used by private operators of commercial enterprises in New Zealand has been, and is, the Tiger Moth, which, on account of its low landing speed and concomitant short runway requirements, low stalling speed and high manoeuvrability, combined with its relatively low cost and availability in the post-war period, has made it the obvious choice of operators demanding a safe and practical machine at a low price. These aircraft, however, have a very

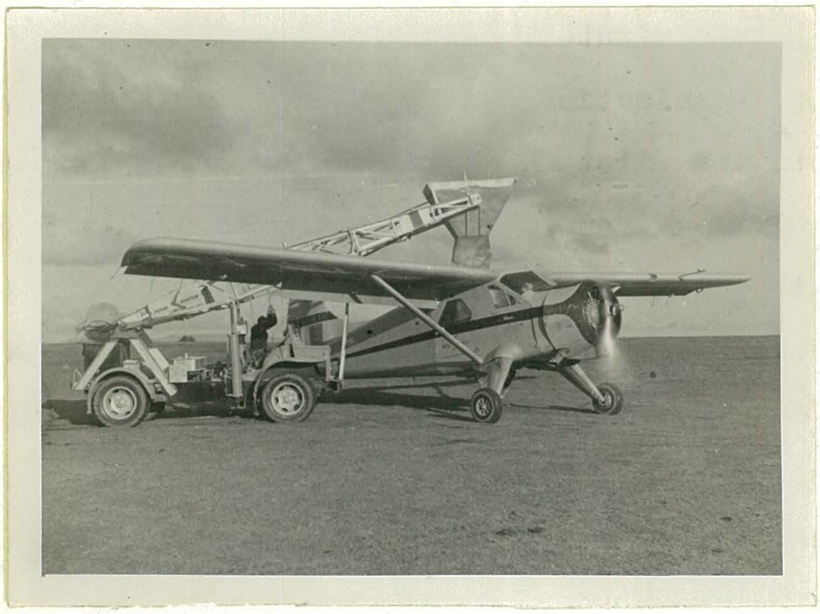


Figure IX. Fertiliser being loaded into Beaver aircraft prior to take-off on aerial topdressing flight. The auxiliary pilot operates the loading truck.

limited load, 5 cwt. of fertiliser, carried in a gravity filled hopper replacing the front cockpit, being the maximum.

This fact alone imposes several disadvantages. Airstrip and area to be topdressed must be relatively close together. 3 miles has been suggested as the maximum economic distance between the landing strip and the area to be topdressed (Lynch, 1950). This, in turn, demands a rapid 'turn round' of the aircraft, since loads will be dropped every 3 to 5 minutes during favourable weather. An efficient loading organisation on the airstrip is essential, and, further, the pilot must make a large number of landings per day. If each round trip takes five minutes (and in many cases the figure is lower), in eight flying hours the pilot will require to make 96 landings and takeoffs. These demand considerable concentration on the part of the pilot, and may lead to fatigue with its concomitant danger of accidents, as well as placing an abnormal mechanical strain on the aircraft itself.

Larger aircraft, with the advantage of having a larger payload, can operate economically further from the airstrip, thus reducing the difficulty of finding suitable airstrips in hilly country, and reducing the number of circuits per day, and hence the accident risk. Such aircraft, however, being commonly less manoeuvrable, have to operate at greater altitudes, and require longer runways than do lighter aircraft. As observed earlier, even distribution of fertiliser from aircraft flying at heights of 300 to 400 feet and over demands the use of granular fertiliser. This forms another drawback to the use of such aircraft, since supplies of granular material are very limited in New Zealand at present.

In an attempt to overcome some of these difficulties one private firm in New Zealand is now operating a de Havilland Beaver aircraft (Fig. IX page 43a). This machine, specially designed for cargo carrying work in remote regions of Canada, has similar flying performance to a Tiger Moth, yet with a much higher payload. Information supplied by the Department of Agriculture gives the load as 1,520 lbs. (13½ cwt.)

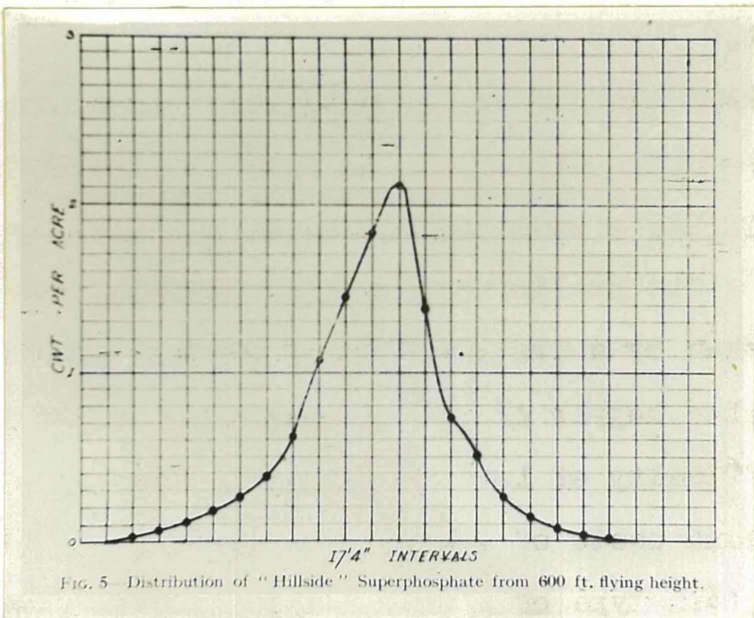


Figure X. Typical distribution graph from trials with Grumman Avenger aircraft. (Campbell, 1948).

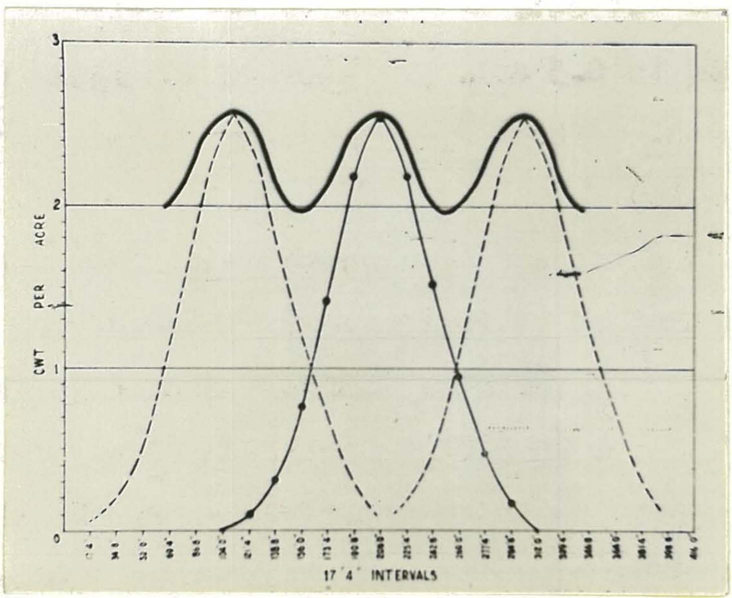


Figure XI. Distribution of 'Hillside' superphosphate from 400 ft. altitude. When flight lanes were placed 90ft. apart, the density nowhere fell below 2 cwt. per acre, and reached a maximum of 2.5 cwt. towards the centre of each swath. (Campbell, 1948).

loaded take-off distance 260 yards; stalling speed 47 m.p.h. A gravity filled metal hopper, which can release its load in $12\frac{1}{2}$ seconds, is built into the aircraft behind the pilot's cockpit. Pilot fatigue is reduced by having a reserve pilot who, while not flying, operates the hopper loading truck. The operators claim that the aircraft normally applies 80 tons per day - covering 800 acres at 2 cwt. per acre.

The preliminary trials mentioned earlier were undertaken by a Grumman Avenger torpedo bomber having a detachable hopper of one ton capacity fitted in the bomb bay. The difficulty of loading the hopper rapidly, and the consequent waste of time on the ground, militates against the use of this type of modified war plane in commercial practice. The Avenger, carrying one ton of fertiliser, topdressed a swath about half a mile long and 44 yards wide, or about 10 acres in extent; flying at 600 feet altitude a maximum density of 2.1 cwt. per acre at the centre of the swath diminished to 0.5 cwt. per acre at the sides of the effective swath width. The distribution is indicated in Figures X and XI, page 44a).

The success of the work with this heavier type of aircraft has led to trials with still heavier machines capable of carrying much greater loads. Such aircraft, it is argued, by carrying the fertiliser direct from airstrips adjacent to superphosphate works or other large central storage dumps, might further reduce the per acre cost of the operation by cutting out rail and road transport to the farm, removing any necessity to bag the fertiliser, and by avoiding much manual handling.

Trials with the Bristol 170 "Freighter" have recently been carried out in Britain. This aircraft is fitted with three hoppers, each capable of holding two tons of fertiliser; a capacity of six tons in all, or sufficient to topdress 60 acres at 2 cwt. per acre. The distribution graph obtained at these trials is reproduced (Fig XII, page 45a) from Smith (1950) (ii), and is not dissimilar to that obtained from the Avenger trials in New Zealand. From considerably higher altitudes than those of the New Zealand trials (between 800 and 1,200

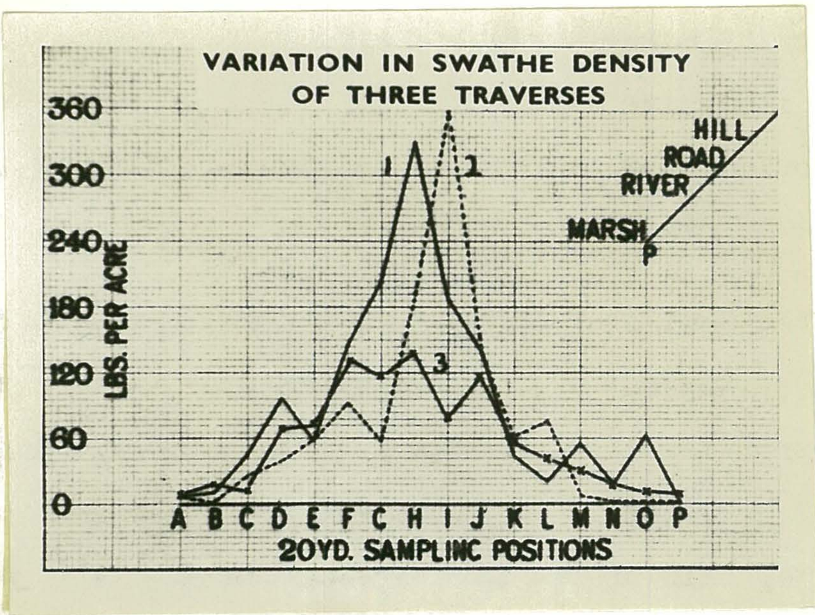


Figure XII. Distribution of granular superphosphate on each of three traverses measured at right angles across the swath. Traverse 1 at 200 yd., 2 at 400 yd. and 3 at 650 yd from the start of the dropping zone. Released from Bristol Freighter at 1,200 feet in gusty wind averaging 30 knots. (Smith,1950)(ii).

feet), the swath receiving more than 0.5 cwt. per acre was 280 yards wide, with a maximum density at the centre of 3.2 cwt. per acre. Traverse 1 was at 200 yards from the start of the dropping zone, traverse 2 at 400 yards, and traverse 3 at 650 yards. This latter indicates a falling off in fertiliser density towards the end of the 800 yard swath.

Farnes (1950) estimates that the Freighter, transporting fertiliser 30 to 40 miles from a base depot, should take 45 minutes for the round trip from take-off to take-off, inclusive of 15 minutes loading. 12 sorties per day would allow 72 tons to be dropped on 720 acres, and would involve six hours actual flying time.

The decision as to which method of topdressing is to be practised depends upon local conditions determining the cost and practicability of the various methods. However, it seems likely that so long as costs of aerial work remain competitive, this method will become increasingly popular, due to its greater convenience and the lesser labour demand which it entails.

V. Economic Aspects.

It is not intended in this section to give estimates of the costs of the various methods of topdressing. The writer concurs with the opinion of Sanders (1949) that "theoretical estimates of costs (of production) are not worth the paper on which they are written". Certainly costs vary so much, in space with circumstances such as the situation of the farm and its topography, and in time, with changes in the costs of fertiliser, labour and all other prices, that they form little basis for comparison between one situation and another, between one period of time and another, or between one method of topdressing and another.

The first intention is to disclaim any suggestion that topdressing can be profitably carried out on every class of country. The writer feels that it would be more valuable if topdressing costs were expressed as being so much per sheep carried rather than per acre. Where topdressing is carried out it is usually envisaged as a recurring cost - perhaps not annually recurring, but certainly periodically, and as such is chargeable against profits. Profits, however, are not a function of acres, but of sheep carried. If evaluated in this manner it would readily be apparent which class of country was at the margin of profitability for topdressing at any given level of prices. Thus, while topdressing costing say £1 per acre may be profitable on land carrying one sheep per acre if, thereby, production is increased by one pound of wool and carrying capacity by 1/3rd of a sheep per acre, it may be patently unprofitable, even if the same increase (per sheep carried) is obtained on land carrying one sheep to five acres, since expense in the second instance would be £5 per sheep carried, compared with £1 in the first instance. Somewhere between these extremes there will be a marginal case.

At this margin there will be cases where topdressing might more reasonably be considered a capital rather than a running expense. In these instances the first topdressing may be necessary to raise the carrying capacity to a level at which subsequent topdressings may be profitable. On the other side of the margin no amount of topdressing can be expected to raise the carrying capacity sufficiently to make it worth while. In these cases, such as in the South Island tussock country, phosphate is not the most important limiting factor.

To be offset against this disability which low carrying capacity country must suffer is the fact that under such conditions the per acre losses of plant nutrients, brought about by the sale of stock and stock products, are much less than in the case of higher carrying capacity land. In these cases, too, where rainfall is frequently the factor limiting pasture growth and carrying capacity, leaching of soluble nutrients will be much less than under high rainfall conditions, while under these conditions of more extreme climate (especially having wide daily and seasonal temperature fluctuations) the debit side of the soil nutrient account is more likely to be offset by the credit balance of the natural soil forming processes. For these reasons the economic disability of this class of country to show a profit from topdressing may not be so serious (though the matter is open to more exact proof) as it would at first seem to be.

G. OVERSOWING.

The term oversowing is that applied to the broadcast distribution of grass, legume or other agriculturally useful seeds upon the surface of the existing sward, without making any attempt to incorporate the seeds into the underlying soil, by the use of discs, harrows, or other implements.

Earlier it was stated that the primary object of the phosphatic topdressing of hill land was the stimulation of legume growth which, through the action of the nitrogen fixing legume symbionts, enhances the soil nitrogen content to the ultimate benefit of the grass species in the sward. Conversely it is very largely futile to topdress with phosphates a pasture which does not contain species capable of responding markedly to that topdressing. Sears' (1950) (ii) figures are worth quoting to demonstrate the effect which the inclusion of clovers in a sward can have upon production:

Yield of Grasses and Clovers Under Mowing at Palmerston North for Period 14/1/48 - 14/2/49.

		Dry Matter per acre, in lbs.
Grasses alone, no fertiliser		1,777
Grasses along + lime + phosphate		1,800
Grasses + clovers, no fertiliser		
Grasses	4,017	
Clovers	5,408	9,425
Grasses + clovers + lime + phosphate		
Grasses	4,564	
Clovers	7,028	11,592

These figures demonstrate the lack of response when a purely grass sward is topdressed, though it may be assumed that the fertility of the soil at the experimental station where these figures were obtained is such that the grasses were adequately supplied with phosphates. Under conditions of phosphatic deficiency the pure grass sward would probably have shown a response. Nevertheless, it is the inclusion of clovers in the sward which has the major effect in boosting pasture production, not only by adding their bulk to that of the grasses, but by more than doubling the production of these grasses, presumably by enhancing soil nitrogen. While an increased production of the same order as that quoted cannot be expected on hill land, the principle of incorporating legumes in the sward wherever possible remains sound. Sears (1949) quotes one series of trials on hill country in which topdressing the original sward had virtually no effect, while topdressing an adjacent paddock and oversowing it with clovers increased production by 100%.

No less sound is the policy of attempting to introduce improved grass strains and species into hill swards, wherever soil and climatic conditions will permit them to thrive, in order to utilise to the best advantage the increased fertility engendered by the growth of legumes.

Clover seed now spread by aircraft at about 5/- lb. i.e. 3 lb/ac costs 1/3 for spreading. [illegible] 29-11-57

I. The Value of Legumes in Oversowing.

There is an unfortunate tendency among many advocates of legume oversowing to invest, without discrimination, all leguminous species with powers of nitrogen fixation which must frequently be beyond their capabilities. Many legumes, it is true, "fix" atmospheric nitrogen with the aid of their specific nodule bacteria. They may fix nitrogen in excess of their own requirements, and, through the sloughing off of nodules, through the excretion of nitrogenous substances from their roots, through the decay of their roots, and through the return of their aerial parts to the soil as dung and urine, they may supply adjacent non-legumes with nitrogen. Levy (1949) estimates that wild white clover will fix 400 lb. of nitrogen per acre per annum in good New Zealand pastures. On the other hand, the virtue of less active nitrogen fixers may largely lie in the fact that by providing their own nitrogen from the air they leave the entire supply of soil nitrogen at the disposal of the grasses.

It is also true that some legumes have a higher percentage of protein in their dry matter than do most grasses, thus enhancing the nutritive value of a pasture which contains a high proportion of legumes, and enhancing the nitrogen status of the excrement of animals feeding on such a pasture. Comparative dry matter nitrogen percentages for white clover and perennial ryegrass are given by Woodman (1948) as 4.4% and 2.9% respectively.

It may be wrong, however, to generalise too far from these particular virtues which white clover and certain other legumes such as lucerne and probably red and subterranean clovers do possess, and to assume that all legumes are necessarily beneficial in the soil fertility building process.

Saxby (1948), discussing haresfoot trefoil (Trifolium arvense) says, "It must be of some value, even though slight, as a slow builder of fertility". The same implication is made concerning Trifolium dubium, T.striatum, T.glomeratum, R.resupinatum, and several Medicks, without apparent justification except for the fact that they are legumes.

Saxby's assumption may be justified, but there are so many factors which may limit and even inhibit nitrogen fixation by legumes that the value of all but vigorous nitrogen fixers as builders of soil fertility must stand in some doubt, while even with vigorous nitrogen fixing legumes inhibitory factors may operate to prevent any enhancement of fertility. In this respect, Virtanen (1928) has demonstrated that while certain clovers may grow in acid soils (down to pH4) the nodule bacteria cannot fix nitrogen until the pH reaches at least 5. Albrecht (1933) has emphasised the need for calcium, and Jensen and Betty (1943) the need for molybdenum in the nitrogen fixation process by Rhizobia. Albrecht's (1944) work also suggests that there may be an optimum ratio of K : Ca for fixation. Russell (1950) emphasises the need for adequate phosphate and calcium, potassium and molybdenum for good fixation in legume nodules.

Again, there are many ineffective strains of nodule bacteria in the soil (Thornton, 1947) capable of forming nodules on legume roots, but incapable of fixing nitrogen, so that the existence of root nodules on legumes does not necessarily indicate that nitrogen fixation is taking place, and inoculation with effective strains of bacteria may be necessary before any enhancement of soil fertility can be expected.

Wyss and Wilson (1941) suggested that nitrogen excretion by legume roots would only occur under certain climatic conditions of which long days with low maximum temperatures and cool nights was probably one, and it was only under these conditions that Roberts (1941) was able to demonstrate that grasses did benefit from association with legumes.

Lyon (1936) at Cornell has demonstrated that leguminous crops such as soy beans and field beans may materially deplete the soil nitrogen, while Russell (1950) (v) concludes that "a leguminous crop can, though it need not, enrich the soil in nitrogen".

It may be said, then, that the extent to which a pasture legume will enhance soil fertility depends upon many factors, some inherent in the legume species, but many of external origin and, doubtless, others of which biological science is as yet unaware.

There is much scope for determining the real value of many legume species for the purpose for which they are sown, namely that of enhancing soil fertility. In practice white clover, subterranean clover and Lotus major are the only legumes commonly used for oversowing, and these are believed, the first from experimental evidence and the other two from experience in the field, to be high in their efficiency of nitrogen fixation when external conditions are satisfactory. On the other hand, farmers who are informed of the futility of topdressing cloverless swards, and the necessity for establishing clovers in such swards if topdressing is to be effective, may be led erroneously to assume that if any legume species is present in their swards topdressing will have the desired effect. This may or may not be the case, but as yet the value of topdressing swards containing only annual clovers (other than subterranean) must be doubted, nor is the position with regard to some perennials such as alsike and red clover at all clear.

II. The Species of Legume Used.

Bearing in mind the foregoing criticisms, the following is based largely on New Zealand practice.

Levy (1948) has, with some justification, called white clover, subterranean clover and Lotus major "the great triumvirate of the hills". White clover is especially valuable, being a perennial which, under favourable conditions, can fix much atmospheric nitrogen and is tolerant of a fairly wide range of edaphic and climatic conditions. In the moister hill country in the west of the North Island, and in the less dry regions of the east, it is probably supreme as a fertility builder, especially where phosphatic fertiliser can be applied. Where soil fertility is too low for white clover, or conditions too damp, it may be effectively replaced by Lotus major. At the other end of the moisture scale, where conditions are too dry or where there is a likelihood of summer droughts, white clover may give way to subterranean clover.

White clover is normally broadcast at about 2 lbs. per acre. Lotus major is best "spot sown" on patches of loose soil. Subterranean clover is usually broadcast at 4 to 6 lbs. per acre (Extension Division, 1948).

Oversowing with legumes should normally follow closely, accompany, or closely precede topdressing with phosphatic fertilisers. Sowing is usually carried out in late summer or autumn and the oversown paddocks spelled to allow establishment of the young plants. Subterranean clover oversowings must also be spelled towards midsummer in the year following sowing to allow this plant (an annual) to set and deposit its seed in the ground.

It has been said that the prime necessity of the South Island tussock hill country is the introduction of a legume capable of thriving and increasing soil fertility under the existing climatic and edaphic conditions. Certainly nitrogen deficiency may well be one limiting factor in the productivity of these tussock grasslands. The writer calls to mind a manurial trial laid down on a hillside covered with typical tussock grassland vegetation on the southern side of the main road west from Christchurch, about two miles beyond Lake Lyndon. Here four one chain square plots had been topdressed with one or another of the four main plant nutrients phosphate, potash, lime and nitrogen. Only this last plot, topdressed with nitrogen, showed any visible difference in apparent vigour of the plants and increased ground cover.

In trials set down by the Department of Agriculture on Selwyn Station, near Burke's Pass, Kentish wild white clover was observed by the writer to be showing outstanding growth and apparently good establishment. Sweet clover (Melilotus alba) was also growing well. Zig-zag clover (Trifolium medium) is also recognised as a possibly valuable legume, though it suffers from the disability of poor seed setting, and must be propagated vegetatively (Allan, 1947).

In the search for new species of legumes for this semiarid region sight should not be lost of Cockayne's (1921) (i) observation of the establishment and ability to withstand heavy grazing of lucerne (Medicago sativa) in the Earnscleugh district of Central Otago, and the same author's (1922) (i) successful establishment of lucerne on his experimental plots on the Dunstan Range, Central Otago. Lucerne was recorded by Tennent (1935) to be still extant and in several instances thriving on twelve of the original fifteen plots.

In lucerne there is a plant species which, according to Klinkowski (1933), originated in the arid, saline "hunger steppes" of Turkestan, which have a "pronounced continental climate". From the three recognised species, Medicago sativa, M. falcata, and M. media, there have evolved by selection under a wide variety of ecological conditions many strains. Roseveare (1948) amplifies Klinkowski's thesis when she observes that "in Argentina an excellent example is afforded of the great ecological range of variation possessed by lucerne", and continues to point out that more than fifty different types of lucerne are being studied in the Juan Lapacette Experiment Station in the province of Cordoba.

The very extent of the variation to be found in

Medicago species would seem to offer much scope to the New Zealand plant breeder in his search for material from which to select and breed a strain of lucerne even more well adapted to South Island hill conditions than the strain sown with considerable success by Cockayne 30 years ago. The trials by the Botany Division of D.S.I.R., established in the Nursery Area at Molesworth to test the value of lucerne (Grimm, Ranger, Cossack, Meaker, Baltic and Ladak strains) (Allan, 1947) must be regarded as an important piece of work.

III. The Value of Grasses in Oversowing.

If legumes are considered as fertility builders, grasses must be considered as fertility utilisers. Most grasses growing at a low or a moderate plane of fertility are probably capable of responding with increased production and improved chemical composition to an increase in the level of fertility. But, as was demonstrated earlier, the application of phosphatic fertiliser will stimulate clover growth more than it will grass growth; likewise any increase in nitrogen status in the soil will stimulate the growth and production of some grasses more than others in a mixed sward. This may be due either to the inherent ability of the "better" grasses to respond to fertiliser application, or to the greater competitive ability of the "better" grasses which enables them to dominate the "poorer" ones.

Martin Jones (1933) demonstrated the principle by comparing a section of a sward receiving a double return of stock nutrients with a section of the same sward receiving no stock nutrients:

Percentage Botanical Composition

	Perennial Ryegrass	Cocksfoot	Poa trivialis	Crested dogstail
No Return	21.6	13.6	4.5	2.3
Double Return	46.9	21.8	5.5	3.0
Percentage increase	117	60	20	30

And the same tendency for the "better" grasses to increase in proportion to the poorer ones is seen in the more recent work of Davies (1950) on the manuring of permanent pastures from which the following table is extracted:

Percentage Tiller Composition.

		Perennial Ryegrass.	Bent (Agrostis spp.)
1946	Control	9.1	37.0
	Manured	11.1	32.4
1947	Control	9.4	28.4
	Manured	17.3	14.1

It would seem, then, that where the more responsive grasses are not represented in a sward they should be introduced in order to utilise fully any fertility built up by the legumes, provided these responsive grasses are also desirable from a stock nutrition and palatability point of view. Again, where such responsive grasses are present only to a limited extent in a sward, and their increase by manuring and stock management alone might be slow, their introduction in greater numbers by oversowing the sward with their seeds may well be considered.

The primary object of oversowing with grasses is to introduce into an existing sward grass species capable of producing at a higher level than the existing species under the new fertility conditions brought about by the earlier application of fertilisers and oversowing with legumes, or to replace those more highly productive species which have, by overgrazing or other managerial defects, been eliminated from the sward. This is, however, only partly true where motives other than the provision of increased stock feed are involved, such as the establishment of some cover or improvement of existing cover for soil erosion control purposes, or, as in the depleted areas of the South Island, where the establishment of any vegetative cover, herb, grass or legume, is seen as a method of improving soil humus content, water holding capacity, and micro climatic conditions through which better species may eventually be established.

IV. The Species of Grass Used.

The grass species used for oversowing will depend upon several variables of which soil fertility and climate are probably the most important, although such a consideration as the role the grass is to perform ranks of equal importance. The role of the grass may be that of providing stock feed, of preventing or diminishing erosion, for land reclamation purposes, or some combination of these.

Within the limits of our present knowledge a perennial ryegrass - white clover sward is believed to be the most efficient and reliable general purpose, permanent pasture for stock feeding purposes. For this reason, perennial ryegrass is usually a major component of all oversowing mixtures for use on the more fertile hills of the wet hill country, and on the less dry hill country of the North Island, that is, on those areas where white clover is the main legume employed. This species may give way to cocksfoot or Poa pratensis in the drier regions of the North Island, while crested dogstail may also be included in mixtures for these drier areas.

The wisdom of sowing grasses further down the scale of value for stock feed purposes - e.g. browntop, sweet vernal and danthonia, is doubted by the writer although it is sometimes recommended. These doubts arise partly from economic considerations, and partly from a belief that in most instances in which these species are oversown one or other of them is already present in the sward and could, if desired, be encouraged by suitable stock management. The same, indeed, is often true of perennial ryegrass, and, economically, it may be more advantageous to apply the stock management methods of Lamont (1939) to increase the representation of this species in the sward. As was seen earlier, where desirable species are already present in a sward an enhancement of soil fertility will assist their increased representation in the pasture.

The necessity of oversowing with grasses much North Island hill country may, then, be obviated by raising fertility and by judicious stock management, thus benefiting and giving a greater competitive advantage to the desirable species.

In the tussock grasslands of the South Island, the writer is of the opinion that the problem is largely one of improving ground cover in an attempt to build up soil humus content, to reduce run-off and erosion, to reduce the detrimental effects of high winds and wide temperature fluctuations at the soil surface by providing a vegetative cover, and by these means to provide a seed bed and a more favourable micro climate for species agriculturally more desirable. In many parts of the less badly depleted areas, as in parts of the McKenzie and Canterbury High Country, and regions of Otago abutting on the western ranges, a more immediately utilitarian viewpoint may be tenable. In these areas species may be chosen predominantly on account of their palatability and nutritive value for sheep, but in no case should this long term utility be allowed to obscure the short term value of a species in acting as a pioneer for future development.

This is not to be regarded as a plea for neglecting to control noxious weeds such as Nassella tussock, thereby encouraging their spread, but rather a suggestion that short and long term utility of a species should be considered when making a selection for the oversowing of this class of country.

The principle of controlling the spread and dominance of species by suitable management was first demonstrated experimentally by Jones (1933) in his classical work at Jeallot's Hill, and similar methods of swinging the ecological balance in favour of a given species and to the detriment of another have been specifically recommended by Stapledon (1944) for the changing of unpalatable Molina dominated swards into swards dominated by Agrostis. In New Zealand the ability of man, with the aid of firestick and sheep, to control, indeed eliminate, the relatively unpalatable tussock species, has caused concern among runholders, ecologists and land conservators alike. The inference is that certain (but certainly not all) plants relatively unpalatable to sheep and useless for sheep grazing may be sown if they have a definite pioneering virtue, without the need to fear that man will be unable to eliminate them and replace them by something of greater value as stock feed when their task as pioneers has been completed.

The pioneer capacity of scabweed (Raoulia spp.) has been emphasised by L. Cockayne (1922) (ii), while A.H. Cockayne (1917) and L.Cockayne (1919) (i) recognise the potential value of Californian thistle (Cnicus arvensis) "in adding humus to the soil, in affording shelter from wind, or in being a nurse plant for species which without such aid could not gain a footing".

The principle is recognised to be contentious to say the least, but the spread of some agriculturally useless grass species may be a lesser evil than allowing the present depletion to proceed to its logical conclusion, for then future generations might at least inherit a topsoil instead of a shingle scree upon which to attempt pasture establishment. In the last resort, the decision upon the introduction of any new species must rest with the ecologist and his estimation of its short and long term value, and its vigour and tenacity of life, should the time come when its elimination is desired.

However, such extreme measures may never be necessary. There are indications that provided grazing, both by sheep and rabbits, is modified, agriculturally useful plants may be successfully introduced and native grasses allowed to regenerate. Cockayne (1922) (iii), summing up the results of his regrassing trials on the Dunstan range, claims that "the following species were successfully established in fifteen months by both the raked and the breadcast methods: Chewing's fescue, chicory, cocksfoot, lucerne, tall fescue, yarrow", this in the complete absence of grazing. Thirteen years later, Tennent (1935) confirmed that these were still the most successful of the sown species.

More recently the Department of Agriculture and the Botany Division of the D.S.I.R. have been carrying out independent investigations into the potentialities of various species, both introduced and indigenous, for revegetating the tussock grasslands. Trials by the Department of Agriculture on the Pisa Flats (between Cromwell and Wanaka) have indicated the possible value of crested wheat-grass (Agropyron cristatum), bluestem (Andropogon spp.), cocksfoot (Dactylis glomerata), Poa pratensis, tall oat-grass (Avena elatior), sheep's burnet (Poterium sanguisorba), Danthonia pilosa, blue wheat-grass (Agropyron spicatum?), yarrow (Achillea millefolium) and Chewing's fescue. In the Molesworth nursery area bluestem, thickspike wheat-grass (Agropyron dasystachyum), New Zealand bluegrass (Agropyron scabrum) and keeled brome grass (Bromus unioloides?) have shown considerable promise (Allan, 1947).

While any or all of these species may be of value, interest at the moment seems to be centering chiefly around two species. Of the first, Agropyron cristatum, Keller (1948) claims that "it is largely responsible for the success of reseeding work on spring-fall ranges of the inter mountain region (of U.S.A.) where several million acres of denuded lands have been restored. ...It is well adapted to sagebrush lands and marginal or submarginal dry-farm lands".

Of the second, Agropyron scabrum, Tennent (1935) reports that on spelling the higher plots enclosed by Cockayne, especially on "dark" faces, rapid recovery was brought about. Cockayne (1921) (iii) points out that there are many varieties of Agropyron scabrum, varying in their rate of regrowth after grazing. These possibly offer opportunities to the plant breeder. Again, the same author (1920) (i) came to the conclusion that this grass, although not highly palatable, was "readily eaten by well fed sheep when in competition only with such grasses as are usual in tussock grassland, and that an increase in the amount of bluegrass in the montane tussock grassland would greatly improve the pasture". More recently Connor (1950) reports that a detailed study of this grass is being made to determine its value for sowing in tussock associations.

Concerning the sources from which plant material may be obtained for the revegetation of depleted tussock grassland areas, the writer would deprecate the attempt of Connor (op.

cit. supra) to belittle the value of plant introduction. To say as Connor does that, "The problem is therefore not to create a new type of grassland for the high country, but to reproduce the type of grassland which Nature deemed fitted to these areas", and to posit as reasons for this "that the tussock grasslands have not been adequately tried out", and that "their structure is climax and as such is suited in its natural areas", is to commit a logical 'petitio principii', and, further, it is to deny man, his grazing animals, his matchsticks, indeed the entire anthropogenic influence, any place in the ecological set-up. This is an untenable point of view unless complete abandonment of the land by man and all his introduced herbivores is envisaged.

The proportion of species which are endemic to New Zealand is high - Willis (1922) suggests 72%, Cockayne (1928) (iii) suggests 78.6%, including 67% of the monocotyledons - which indicates the specialised nature of the flora as well as the unique conditions surrounding its development. "The Nemesis of a high degree of protected specialisation is the loss of adaptability" said Willis, and it is exactly this fate which has overtaken the tussock grasslands of New Zealand. Extensive search must be continued for species better adapted to all the factors of the present ecological regime, climatic, edaphic, biotic and anthropogenic, than the indigenous tussock grassland species would appear to be. At the same time, any promising indigenous species must be given a fair trial and an impartial judgement pronounced.

V. <u>Methods of Oversowing.</u>

(i) <u>Oversowing by Hand.</u>

The case for a careful, accurate and discriminating method of oversowing is based partly on the high cost of the seeds applied, and the wish to cut down seed wastage to a minimum. Fertiliser applied to any but stony ground may have some beneficial effect, especially if an efficient legume can later be established. As observed earlier, some farmers are convinced of the value of topdressing manuka patches. Grass and legume seeds, however, are less likely to be of value if

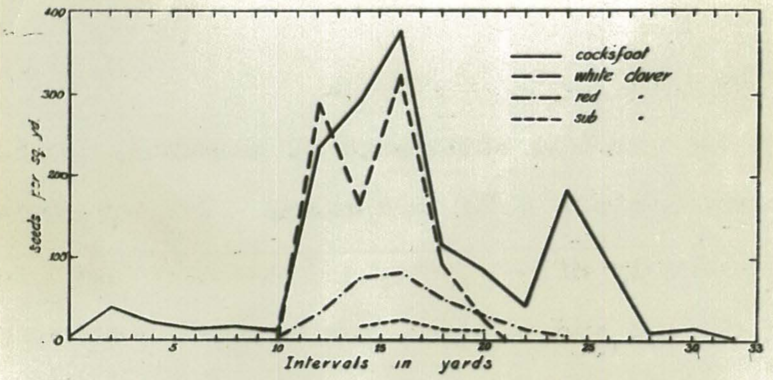


FIG. 7.—Distribution of Seeds released from a plane flying at 100 ft. height into 17 miles per hour wind.

Figure XIII. (Campbell,1948).

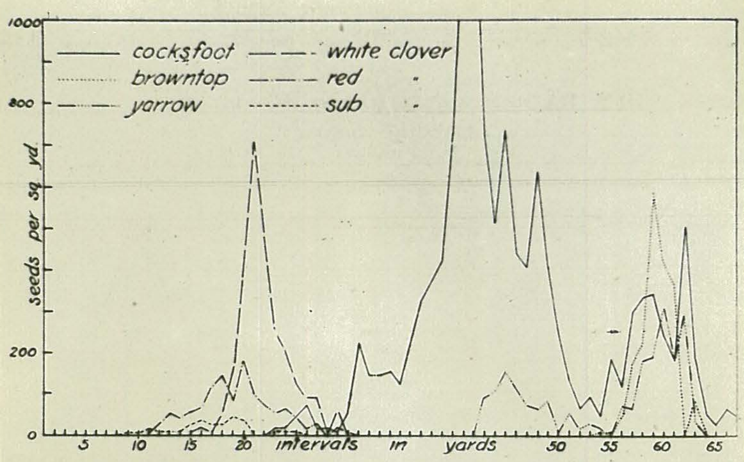


FIG. 8.—Distribution of seeds released from a plane flying at 200 ft. height on a calm day.

Figure XIV. (Campbell,1948).

The distribution of grass and clover seeds varies markedly with the altitude of the aircraft, and the wind force and direction. In the distribution represented by Figure XIII browntop and yarrow seeds were sown but were blown outside the 'target area'.

In practice such discrepancies are probably unimportant since adjacent swathes will tend to overlap and intermingle, while stock movement across the sown area will assist in the evening out of seed distribution in subsequent years.

distributed as ubiquitously, for they may never germinate. For this reason the discrimination allowed only by hand oversowing is valuable, although the method is probably more expensive than aerial distribution.

(ii) <u>Oversowing by Aircraft</u>.

This has the advantage of economy, costing at today's prices approximately 1/8d per acre. At the same time it is rapid, relatively effortless, and enables the whole job to be done at the most auspicious moment. It suffers from the disadvantage of being indiscriminate, and in rough country wasting much valuable seed. Where mixtures of seeds are being sown this method suffers from the further disadvantage that, due to the different terminal velocities and ballistic properties of the seeds of different species, they tend to settle out on the ground in distinct bands, the degree of banding varying with the height of the aircraft, and with wind force and direction, as demonstrated in Figures XIII and XIV on page 61a. Of this method of oversowing Stoddart and Smith (1943) observe that it has not proved as advantageous as was once thought. "Wind currents make seeding very difficult; and, on rough mountainous land, air movement makes the method totally unsuitable".

The pelleting of seed with fertiliser would overcome, to some extent, both of these disadvantages. In the first place a measure of fertiliser placement would be achieved, and germination and subsequent growth might be improved, though these advantages have not yet been clearly demonstrated. The indiscriminate nature of the sowing would be of less consequence Also, by controlling the ballistics of the pellet, more even distribution could be expected. These possibilities are discussed by Saxby et. al. (1949).

So far as white clover seeds are concerned, any unevenness of distribution would seem to be only a temporary disadvantage. Suckling (1950) has demonstrated the feasibility of dispersing hard, white clover seeds from an area on which seed heads have matured to adjacent areas deficient in clovers via the digestive tract of sheep. Any unevenness of distribution within a paddock could, consequently, be ironed out to a large extent by allowing the clover seed heads to mature and then grazing the paddock with sheep. In the same way the cost-free transference of clover seed from one paddock to another could be arranged.

VI. Economic Aspects.

Unlike topdressing, oversowing is not normally regarded as a recurrent expense, except insofar as a small amount of oversowing may be required annually to regrass slips. It may, therefore, be regarded more as a capital investment, rather than as a maintenance cost.

As with topdressing, there are certain classes of land at the margin of economic oversowing, the margin fluctuating with prices and costs. Much of the North Island hill country can probably be economically oversowed with legumes at today's prices. The tussock hill country is, however, a different proposition. In their case the expenditure involved in oversowing a large area would be prohibitive, compared with the income from the existing stock carried. The degree to which successful oversowing would enhance the stock carrying capacity of this type of country can only be conjectured, but it might well be very considerable since stock carrying capacity is a function of the amount of palatable and nutritious herbage available.

Earlier a case was made out to demonstrate that there might be no great need for topdressing the tussock grasslands, since, it was argued, phosphate was probably not the main limiting factor in pasture growth. No such case can be made out for oversowing. The species which can survive the ecological conditions of the tussock grassland area, and at the same time provide useful stock food are not present, or are present only to a very limited extent, over much of the area. These species, once recognised, must be introduced, not only to enhance the carrying capacity of the tussock grasslands, but also to check erosion, and to prevent rain water falling in these areas from devastating much low lying country.

Oversowing in itself is, of course, no panacea, but must be combined with such essentials as rabbit extirpation, conservative grazing management, and improvement of the micro climate for the pasture species. The establishment of palatable and nutritive grasses and legumes in the tussock grasslands is, however, an equally essential part of the process of revegetation, with effects which would extend far beyond the bounds of the tussock grassland areas.

These considerations lead the writer to believe that the problem is one worthy of national financial support and national legislation; but the legislators in their summing up of the economic possibilities of the improvement of the tussock range lands must not be too concerned with the next budget or those of the next ten years. In this matter they will be passing verdict upon half of New Zealand's pastoral hill country. They are trustees for its future.

H. STOCK MANAGEMENT ON HILL PASTURES.

The title of this dissertation emphasises the biotic influences upon the sward. It is, therefore, inevitable that we discuss in some detail the effect on the sward of undergrazing, overgrazing, and controlled grazing, grazing by various classes of stock, as well as the suitability of the present kinds, classes and breeds of stock used on New Zealand hill land.

I. Overgrazing.

Jacques (1948) and many other workers have demonstrated and explained the effect of overgrazing on individual plants.

The primary effect of overgrazing is to reduce root development and shoot growth. When a plant is defoliated, root reserves of carbohydrate are used up in the replacement of the lost leaves. The photosynthetic activities of these new leaves in turn replace the root reserves partly used up in their formation. If this orderly cycle is interrupted by removal of these new leaves before they have completely replaced the root reserves, the root will remain partially depleted. Overgrazing carries this depletion to an extreme where vigour and production of the overgrazed plants are reduced.

That total production will be reduced by overgrazing may be adduced from the figures derived by Weaver and Darland (1947) when they measured the effect of moderate (M) and close (C) grazing on certain American range grasses:

Species	Grazing	Foliage		Roots	
		Height (in.)	Dry Wt. (gm.)	Depth (in.)	Dry Wt. (gm.)
Sand dropseed	M	7.0	4.82	9.0	0.25
	C	4.0	3.27	6.0	0.10
Side-oats grama	M	11.5	6.66	19.0	1.58
	C	7.0	3.02	13.0	0.61
Buffalo grass	M	5.5	3.42	12.0	0.28
	C	3.0	1.37	5.0	0.19
Blue grama	M	11.0	11.21	14.5	1.31

The foliage figures demonstrate the greater growth obtained from the moderately grazed plants when each is allowed to grow from ground level for an equal period. The writer would, however, question whether the author's claim to have demonstrated reduced vigour in all the above cases is justified. In the above table a plant (Sand dropseed, close grazed) which from 0.10 gm. root grows 3.27 gm. foliage may well be considered more vigorous than its moderately grazed neighbour, which from 0.25 gm. root produces 4.82 gm. of foliage. If vigour be judged by the amount of foliage produced relative to the amount of root present, then the moderately grazed Sand dropseed should have produced 8.17 gm. of foliage to be equal in vigour to the closely grazed plant. Similarly, the moderately grazed Side-oats grama should have produced 7.85 gm. foliage. The Buffalo and Blue grama grasses do demonstrate increased vigour with less close grazing, since the moderately grazed plants need only have produced 2.02 gm. and 9.23 gm. of foliage respectively to equal the foliage-per-unit-of-root production of their closely grazed bretheren.

Undoubtedly plant species vary in their ability to withstand grazing, and a degree of defoliation which constitutes overgrazing for one species may not be so for another. It may perhaps be assumed that the close grazing of Sand dropseed and Side-oats grama did not constitute such serious overgrazing as did the same close grazing of the Buffalo and Blue grama grasses.

The effect of overgrazing, however, is dependent on more than the species present in the sward, and the rate of stocking. The ability of plants to recover from defoliation depends to some extent on the climatic conditions immediately following defoliation. Thus grazing a sward in the autumn will cause later spring growth. In a similar way rainfall and soil fertility play a part in determining the reaction of a pasture species or association of species to grazing. Obviously a rate of stocking which constituted overgrazing in Central Otago might well lead to an inefficient use of the available herbage in Taranaki.

Overgrazing, then, must be considered against the background of species, climate, season and soil fertility.

Changes in plant succession may form the best indication of overgrazing and may demonstrate its intensity, for an agriculturally detrimental plant succession is one of the main effects of overgrazing.

Clarke (1943) demonstrated that overgrazing caused a decline in the abundance and productivity of native grasses, while unpalatable herbs and shrubs increased. In years of drought the abundance of desirable forage decreased even on lightly grazed or protected areas.

Haskell (1945) demonstrated on Arizona range land that while a conserved area with a plant density (percentage area cover) of 5.6% had 1.8% of grasses and perennial herbs, and 3.8% of tree and shrub, an "overused" area had only 0.16% density of perennial grasses and herbs, and 8.52% density of trees and shrubs.

According to Weaver and Clements (1938) the early indications of range deterioration are a decrease in the abundance of the more valuable species of grasses; an increase in the less valuable ones and in weeds and brush. They go on to state that if the species which are increasing on an area "represent stages earlier in the successional development than that of the predominating vegetation when the range is at its highest efficiency, the area is being misused, and its carrying capacity is decreasing. If, on the contrary, the species that are increasing are those of the climax stage, or at least higher than the original vegetation as a whole, the plan of grazing is satisfactory". This, of course, is only the case where grassland forms the climatic climax, but its truth may be seen in the tussock grasslands of the South Island.

If stock are forced to eat off the weeds and unpalatable perennials, sward deterioration becomes sward depletion.

All the evils of overstocking stem from the reduced vigour, the lowered competitive ability of the palatable pasture species, with the result that the unpalatable, less heavily punished, undesirable species undergo first a relative and subsequently an actual increase in numbers and in area of ground covered.

The extent and degree of overgrazing due to overstocking and to rabbit infestation in New Zealand is difficult to assess. The Southern Pastoral Lands Commission (1920) included in its findings "the causes of deterioration and ultimate depletion of grassland". One of these was "overstocking with sheep", another "allowing rabbits to become extremely numerous".

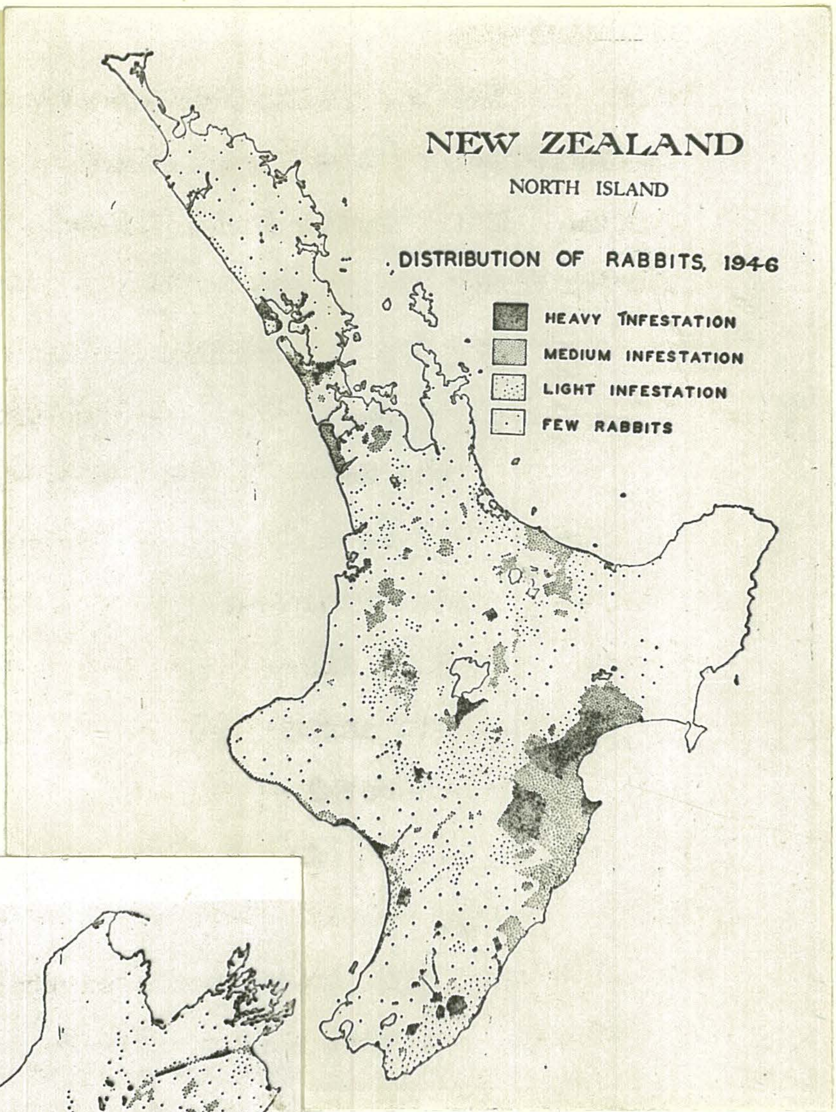
In the evidence presented to the Royal Commission on the Sheep Industry (1947-48) overstocking as a cause of land deterioration was cited by McLeod (High Country Commission), Powdrell (Wairoa), Riddick(Matawai), Parker (Tekapo) Innes (Tekapo), Sim (Wanaka), Rawlinson (Stratford) and Monro (Blenheim). In the absence of any exact data on the extent of overstocking in New Zealand the observations of the leaders of the industry must be accepted.

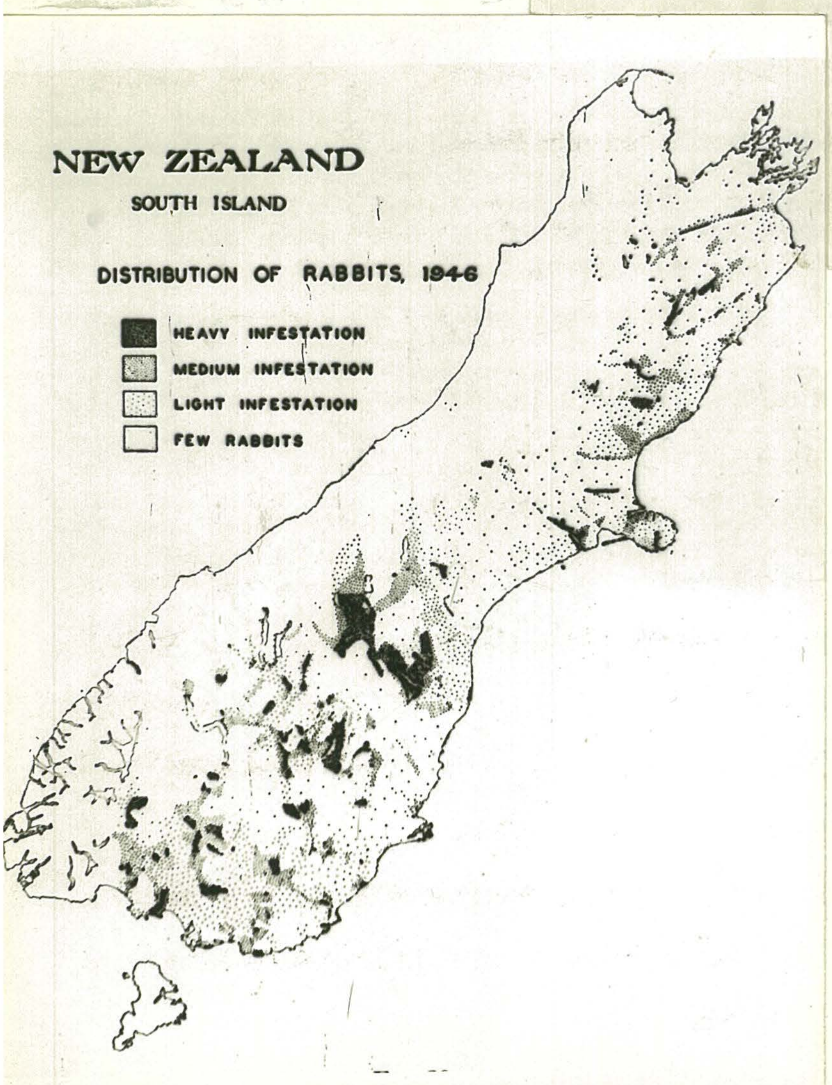
The effects of overgrazing due to overstocking vary in New Zealand with the climate. In all cases a decline in the valuable species of the sward results. However, in the wetter districts of the Wet Hill Country and northern Dry Hill Country the grazing out of the better grasses permits the entry of scrub and secondary growth of fern, manuka and tauhinu. Further south in the drier tussock grasslands, overgrazing is more likely to result in an increase in flat weeds or in the area of bare ground. In this latter case the end point of sward depletion is erosion, whereas in the wetter districts the ingress of secondary growth may well hold the land more safely against erosive influences than did the pasture sward.

In all cases overgrazing decreases the output of the overgrazed land, and dissipates the energy expended in the original conversion of the land to farming purposes.

Maps VII & VIII.

Distribution of rabbits in the North and South Islands of New Zealand. (Wodzicki,1950).





The reasons adduced for overstocking in New Zealand are various:

(i) The importance of rabbits as agents of overstocking varies from district to district even within similar climatic zones. Thus in the South Island, while the watershed of the Rakaia river is infested, that of the adjacent Waimakariri is much less so. Although rabbit infestation in parts of the North Island, notably in Hawke's Bay, is just as great as in areas of the South Island (Wodzicki, 1950) (Maps VII and VIII page 68a) it is from the South Island that their effects are most often reported. This is doubtless because a heavy infestation in a district of slow plant recovery is more serious than in one of more rapid recovery. Wodzicki assumes that a total of 20,619,000 rabbits was taken in New Zealand in 1945. At the rate of 15 rabbits being equivalent to one sheep, rabbits consumed the feed of 1,375,000 sheep. The estimate used here may be conservative; Munro and Wright (1933) suggest that 6 or 7 rabbits equal one sheep, and Condor (1947) gives the same figure.

Wodzicki further claims that "the rabbit is a selective feeder; it takes first the sweetest feed, and when the pastures become dry, consumes seeds and roots". So that rabbits, by virtue of their numbers and selectivity of grazing, promote overgrazing, and by virtue of their dry weather feeding habits, prevent regeneration. Their effect on a high quality sward is indicated by the changed botanical composition shown in Figure XV, page 70a, where rabbits were allowed access to a sward for 15 months.

So long as rabbits remain uncontrolled they make farcical any attempt by the farmer to control the stocking and grazing of his pastures.

(ii) Economic conditions forcing farmers to carry more stock in an attempt to maintain their incomes, or at least to avert too disastrous a decline in incomes.

This trend may be shown by quoting the sheep stock figures for typical areas in the North and South Islands (Smallfield 1947) (ii).

(a) East Cape Counties.

Year:	1920	1930	1940	1945
Sheep Shorn:	2,266,946	2,348,191	2,205,475	2,190,650

(b) Central Otago.

Sheep Shorn:	783026	1,119,543	1,078,169	1,053,995

In both cases the peak of stocking is reached in years of economic depression. The Good Husbandry Clause inserted in Crown Leases on the recommendation of the 1939 Commission demands "that the licensee shall exercise due care in the stocking of the land ....and in particular shall not overstock". However, the mere stipulation of the stock which a run shall carry does not prevent a runholder from overstocking his easier and more accessible country, while abandoning the more difficult portions of his run.

While the farmer may be blamed for evasion of the Good Husbandry Clause in times of prosperity, he can hardly be indicted for any action he may take in order to remain solvent in times of depression.

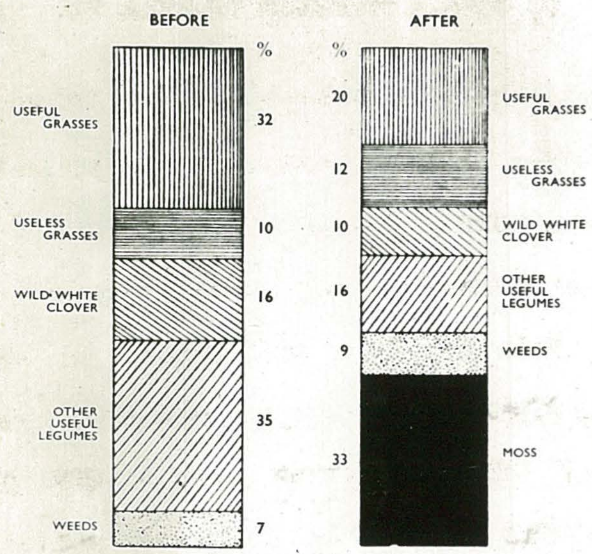
(iii) The system of auction of endowment leases, resulting in high rents being paid; rents which demanded that the country be "mined" in order to make it pay - in the short term.

(iv) Increased erosion which, by reducing the area under grass or the accessibility of parts of the run, necessitated the sheep stock being carried on a reduced area.

In this case, where an effect is also a cause, the vicious downward spiral of overstocking, erosion, and further overstocking is soon set in train.

(v) Labour shortages necessitating the abandonment of outlying blocks and concentration of the entire stock on the more accessible, easily mustered blocks.

(vi) Unbalance between winter and summer country; a deficiency of one or the other, forcing a farmer to stock some



7. Chart showing how rabbits spoil the quality of grassland when they live very thick on the ground. The left hand column shows the composition of the herbage at the beginning of the experiment and the right hand column the composition 15 months later when numerous rabbits had lived intensively on the land.

Figure XV. Botanical changes in a sward grazed by rabbits. (J.O.Thomas).

of his country all the year round.

This trouble is usually attributed to faulty subdivision on the part of former administrative bodies. It is also frequently due to the fact that in some areas the geological conformation is a series of ridges running north and south, so that there is no well defined winter or summer country. Where such a division is not clear cut there is less tendency to spell certain blocks for winter use.

To be true little land must be snow-covered in winter

These, then, are some of the immediate effects of overstocking (and its concomitant overgrazing) on the pasture itself, and the more important reasons adduced for that overstocking. The remedies for these ailments are not due for discussion at this stage. Suffice it to say that the rabbit and erosion problems are being vigorously tackled, while under the Land Act of 1948 endowment leases have been transferred to the Crown, and the normal Crown Lease system operates.

II. Undergrazing.

While this is a less commonly recognised problem than that of overgrazing, it is little less widespread. Set stocking, especially of selective grazers such as sheep, gives rise to the apparently anomalous situation in which overgrazing and undergrazing occur in the same paddock at the same time. The palatable species are overgrazed and depleted, while the unpalatable ones are undergrazed. This fact has long been known to hill shepherds, but it was given scientific recognition only after the work of Boulet (1940?) who, on Cahn Hill, demonstrated that 36% of the sheep grazing days were spent on less than 5% of the area, an island of Agrostis pasture in the surrounding sea of Nardus and Molinia. Under such conditions reversion, depletion, and to some extent erosion go hand in hand, and the carrying capacity of the land inevitably falls.

Undergrazing imples less interruption of the natural plant succession than either overgrazing or normal grazing. The tendency then is for reversion to the climatic climax to take place. In the North Island this means a detrimental reversion to manuka, tauhinu, and bracken fern and other scrub and secondary growth species. In the South Island it may mean a beneficial reversion to the natural tussock vegetation, although in the higher rainfall regions bracken fern, matagouri and other precursors of forest may be engendered.

?? They may be climax!

Undergrazing may be beneficial where it permits the regeneration by seed or by vegetative means of valuable grazing species which would otherwise be eliminated. It is valuable, also, if it allows reversion to take place on areas prone to erosion.

The less obvious effects of undergrazing are no less important. These are a deterioration in chemical composition and palatability as the undergrazed plants tend towards maturity.

Sullivan and Wilkins (1948) cite a grazing experiment at Beltsville in which herbage under heavy grazing of one steer per acre contained on a two year average 14.6% protein, 0.75% calcium and 0.32% phosphorus, while the same herbage under light grazing of one steer to two acres contained 13% protein, 0.58% calcium and 0.30% phosphorus.

Undoubtedly some of the decline in protein in lightly grazed herbage is due to the change in botanical composition brought about by the grazing management, notably a reduction in the percentage of clovers in the lightly grazed sward. However, that undergrazing directly affects the chemical composition of grasses may be seen from the following figures derived from a pure stand of Napier grass (Pennisetum purpureum).

Cutting Frequency.	Protein	Ca.	Po_4	Fibre
Every 6 weeks	7.9%	0.46%	0.72%	29%
Every 14 weeks	3.8%	0.26%	0.46%	39%

As long ago as 1886 Wilson stated the theory of declining digestibility and percentage composition with advancing maturity. "As the grass advances to maturity the percentage of water in the green grass diminishes greatly. In the dry matter the percentage of albuminoids diminishes

diminishes greatly, the ash and oil generally diminish, but less regularly and to a less extent. The woody fibre and extractive matter free from nitrogen, on the other hand, increase. The greater the amount of albuminoids, the more easily they seem to be digested, so that the digestibility of albuminoids also decreases as the plant grows older".

The following table derived from the work of Woodman and Norman (1932) demonstrates the point at issue.

Crude Protein Content and Nutritive Value of the Dry Matter of Grassland Herbage under Different Systems of Cutting.

Frequency of Cutting	Avge.% C.P.	Avge.% D.C.P.	Avge. SE/100lb
Weekly	24.74	19.97	67.74
Fortnightly	23.48	18.75	69.87
3-weekly	21.14	16.66	69.39
Monthly	19.35	14.70	67.05
5-weekly	18.33	13.59	64.68

Watson (1939) demonstrates that the total per acre production of nutrients need not suffer, indeed may benefit, from more frequent utilisation. He compared the total protein and starch produced in a hay crop with that derived from two cuts of a similar area taken during the same time as the hay crop took to mature. The hay crop produced 10% more Starch Equivalent than the two earlier cuts taken together, but only 75% of the protein. Watson further quotes Woodman who, at Cambridge, found that weekly cuts produced only half the yield of Dry Matter obtained from a crop of hay and aftermath from a similar area; the Starch Equivalent per acre was almost the same under the two methods of harvest (2,532 lbs. S.E. for continuous cutting, as against 2,880 lbs. S.E. for hay + aftermath); but the continuous cutting gave 750 lbs. per acre of Digestible Crude Protein, as against 460 lbs. when harvested as hay and aftermath.

While undergrazing may be less serious in its ultimate consequences than overgrazing, it is, nevertheless, wasteful of the productive potentialities of the land, and as such is to be deprecated.

III. The Case for Controlled Grazing of Hill Pastures.

It is not intended to suggest from the foregoing considerations that it is practical to manage extensive hill pastures on rigid systems of rotational grazing such as are practised on small lowland paddocks, but rather to demonstrate clearly the disadvantages which arise from under- and overgrazing, and to urge the need for at least a measure of controlled grazing and stocking on hill pastures.

Levy (1937) makes the point that, "Ecologically, the stock factor in subsequent development (of newly burned country) is of paramount importance. The sown grasses in themselves are powerless against the myriads of seedlings and sporelings of shrubs and ferns that arise once the forest shade is removed. ...Success or failure of the grassland sward depends on the number of stock that are maintained on the area, to eat off and tread out fern and scrub growth, and thus to maintain the ecological balance in favour of grass rather than forest. The class of stock and stock manipulation may entirely alter the ecological conditions both for the early precursors of forest and for grass. ...Thus under a system of close and continuous grazing by sheep, we may see either a swing over to hardy, low-producing, light-loving grasses, or to unpalatable fern, scrub, or weedy growths, according to the ecological conditions set up".

Speaking at the same Congress, Stapledon (1937) claims, "The outstanding feature of grassland is its complexity. ... Soil, climate, the grazing animal: which of these three is the most important factor? Most emphatically the grazing animal! Manure right, sow right, and manage the grazing animal wrong, and you are nowhere".

If it is necessary to emphasise further the importance of the stock factor in the management of any sward, reference need only be made to the classical work of Martin Jones (1933) at Jeallot's Hill.

To summarise the necessity for controlled grazing of hill pastures, it may be said that desirable perennial species, if overgrazed continually, or if heavily grazed each year at the time when they should be replenishing root reserves, will be very much weakened and may even be killed out. The way is then open for poorer species of grasses, for weeds and scrub growth to dominate the pasture. If valuable annual species are overgrazed in such a way that seed setting is prevented, they will be killed out and reversion to poorer species will again take place. If, on the other hand, undergrazing is practised, the sward will tend to revert to the climatic climax, which may or may not be a beneficial effect, according to the nature of that climax and to the imminence of erosion. Whatever the ecological changes wrought, the net result is almost always detrimental to the immediate and future stock carrying capacity of the land.

If it is agreed that there is need for some control of grazing on New Zealand hill pastures, that control must be considered from at least three aspects.

(i) Systems of spelling and rotational grazing, especially the practicability of rotationally grazing large hill paddocks.

(ii) The place of different kinds, classes, and breeds of livestock in the grazing of hill pastures. This is discussed in the next section.

(iii) The need for some means of controlling stock. A discussion of this has been relegated to the section concerned with General Management.

IV. Spelling and Rotational Grazing.

It cannot be claimed that the case for rotational grazing is accepted without question by agriculturalists, either experimental or commercial. As long ago as 1817 Sir John Sinclair dismissed the idea, though on somewhat slender grounds:

"It is indeed an important maxim in the management of grazing land, not to adopt the plan of feeding alternately. Fields, in the end, will be ruined by it. To maintain a proper quantity of stock, the land must be accustomed to keep it; the more it has kept, the more it will keep.....for pastures will grow as they have been accustomed to grow, and will not readily alter their habits".

In later years, experimental work has cast some doubt on the value of rotational grazing under certain conditions. Carrier and Oakley (1914) found that, "The practice of alternate grazing is of doubtful value". But this applied only to Poa pratensis swards, and it is now recognised that this grass and some others such as Danthonia can withstand and may even benefit from close and continuous grazing.

Hodgson et. al. (1934) again found little benefit in rotational grazing as compared to set stocking when working with dairy cows. However, both of these experiments dealt with highly productive swards, as shown by the grazing rates of 2 steers to 2½ acres in the first mentioned experiment, and 3 to 5 milch cows to 2 acres in the second.

Such pastures were never at any time in danger of depletion or reversion, and the species comprising them were probably nowhere near the limit of their ecological survival range.

Rotational grazing, and similar devices which will later be discussed, seek to improve the biotic conditions insofar as these are responsible for pasture deterioration; seek to bring the biotic conditions within the survival range of those plant species or associations which it is intended to benefit.

Whereas, on low ground, this survival range may be very wide and favourable edaphic or climatic conditions make up to some extent for unfavourable biotic conditions, on hill country of lower fertility, with a less favourable climate, the range of biotic conditions within which valuable pasture species can survive may be much narrower and may amply justify a control of grazing unnecessary on lower country. Yet it is just on such hill country that control is least practiced and least practicable.

In regard to grazing management Stapledon (1937) has this to say:

"The whole problem resolves itself into management; Rotation in time and rotation in space. Swards will recover from the most villainous malpractices if such malpractices are not too long continued, and if they are not put into operation at precisely the same time of the year, year after year, ...and yet, especially on the ranges and open hills, the management is essentially the same month after month, year after year, for generation after generation".

In New Zealand hill pasture management it is this concept of rotation in time that is most often neglected. In some instances there is rotation in space, such as the rotation between summer and winter blocks in the High Country of the South Island. In some cases the summer country is considered to be that on the south-facing slopes; in others the country lying at the higher altitudes - the sheep are said to "go high up" in summer. The winter country is that on which the snow is less inclined to lie - either on the north-facing slopes or at lower elevations. With the change of season stock are mustered from the one type of country and put on to the other, so that the same country is stocked at the same time each year.

Again, the existence, throughout the entire industry, of such terms as "the hogget block" and "the lambing paddock" imply a neglect of this principle of rotation in time. These terms imply stocking at the same time each year; the lambing paddock at lambing time, the hogget block from summer (say, January - February) to dry shearing time (in, say, October).

Moreover, the existence of the term "set stocking" - the most widespread of all forms of management - implies a neglect of the principle both of rotation in time and of rotation in space.

Levy (1940) re-enforces the argument by saying, "From a feed utilisation point of view, and from the point of view of renewed plant growth, and of the nutritive value of that renewed growth, there is no gainsaying the soundness of rotational grazing".

The questions of topdressing and oversowing have already been discussed as means of hill pasture improvement. The effect of set stocking with sheep, leading to undergrazing and overgrazing, and the wastefulness and detrimental effects of these latter have been observed. The possibility that under relatively adverse conditions of soil, climate and slope the biotic factor may be a potent one in weighting the ecological balance against the better grasses has been posited. Once the expense of topdressing and oversowing has been incurred, and if the observations of Stapledon and Levy are accurate, there can be little argument that some form of spelling, rotational grazing, or other control of stock on the hill pastures is desirable, and consideration must now be given to these methods of grazing and management.

(a) Wet and Dry Hill Country.

On theoretical grounds, then, a strong claim can be made out for some form of rotational grazing, even of large hill paddocks, so far as improvement of the sward alone is concerned. We must now question its practicability under farm conditions, and consider the effect on the stock.

That rotational grazing is practicable on hill sheep farms under certain circumstances there can be no doubt. It has been too often demonstrated, even within New Zealand, though published accounts of such work are scanty.

Linklater (1947), farming in the Ruahine foothills at Pohangina, has demonstrated its effectiveness and practicability. The system used is something as follows:

From weaning to lambing (with the exception of the 2 mating months) the 1,600 ewes are kept in one mob and moved round the farm, paddock by paddock, irrespective of the size of the paddock. While the rams are out in March and April the flock is drafted into two mobs according to wool, and each mob rotates on half the farm. The lambs - reduced to about 500 by the end of February - make the same rotation ahead of the ewes. The sheep are left long enough in one paddock to graze the whole pasture down to an even, short sward. If growth is fast, the lambs are moved ahead further, so that they are on short, fresh pasture. From early April some pasture is 'autumn saved', while the stock rotate on the other half of the farm. This foggage is gradually eaten off by August.

At lambing time the unlambed ewes are shifted every day, while those that have lambed are allowed to stay behind. After 10 - 15 days, when the ewes have made one complete circuit, the first dropped lambs are collected in a mob, together with their dams, and put in a paddock furthest from the homestead. This paddock is filled to its capacity, and then the adjacent paddock filled with ewes and lambs which dropped a little later than those in the first mob. Eventually the late lambers arrive in a paddock near the homestead, while the lambed ewes are in three or four large paddocks further out. The lambs in these paddocks are all roughly of an age, which simplifies docking at 2 - 3 weeks.

After docking, the first mob starts a new rotation of two paddocks. After a short rest the next docked mob is combined with the first, and they rotate on four paddocks, and so on until docking is complete. The full rotation starts again when the lambs are old enough not to be mismothered, and the rotation continues until weaning.

Dry ewes come into the rotation behind the ewes and lambs.

Parts of the property have been manured and oversown, while other areas have been left untouched. Linklater claims that all pastures, whether topdressed and oversown or not, have improved, but how much of the improvement of non-topdressed and non-oversown pastures is due to the transfer of fertility and seed by stock moving in every few days from fertilised and oversown paddocks, and how much is directly due to the effect of alternate eating down and spelling of the sward cannot be accurately determined.

Between 1941 and 1947 the total sheep stock carried rose from 1,200 to 1,750, and the wool clip from 13,250 lb. in 1944 to 14,500 lb. in 1947. Here again the improvement due to fertilising and oversowing cannot be separated from that due to rotational grazing. Good responses are obtained from heavy topdressing on this property, so that the results obtained, despite the low fertiliser applications, are not necessarily due to high inherent soil fertility. Some indication of the part played by topdressing in this instance may be gained from the fact that during the six years in which the carrying capacity was raised by more than one ewe per acre, the total superphosphate used as topdressing was no more than 54 tons.

This on 540 acres averages ⅓ cwt. per acre per annum. Oversowing has been with white clover or subterranean clover only, yet the swards show increasing proportions of perennial ryegrass, cocksfoot, and crested dogstail replacing the browntop and flat weeds.

The other positive advantages claimed for the system are largely organisational, such as the saving of labour by having all the sheep in one mob. Losses in hoggets and ewes are less than previously. Increasing earliness of spring growth, and later growth in autumn and winter, are also claimed for the system. These claims seem reasonable, and are in line with what would be expected on low ground pastures under rotational grazing management.

Livingston (1938) gives an account of rotational grazing on hill country near Dannevirke. Two mobs of sheep (c. 175 per mob) were rotated round three 60 acre paddocks, each mob being shifted once a fortnight and each paddock having one week's spell between grazings. Under this system the number of cattle required to keep the land clean is lessened and the pastures are gradually becoming ryegrass, white clover dominant, while the original tendency for a reversion to Danthonia has itself been reversed.

Hill (1949) likewise attributes the high carrying capacity of two ewes plus replacements and cattle per acre on untopdressed Danthonia pilosa swards in Hawke's Bay to a rotational grazing system in which two mobs of sheep rotate for most of the year on three paddocks each.

American range management includes the device of deferred grazing (Stoddard and Smith, 1943) (ii). "Deferred grazing implies delaying grazing until after the most important forage plants have set seed, although with some plants that reproduce vegetatively, seed maturity has little significance".

By this means regeneration of the forage species is less hindered than under continuous grazing. On the other hand, even store cattle may be loath to eat the forage left after seed head production, with its high fibre and low protein percentages. However, on the American short-grass prairies it has been found that certain grasses, notably the grama grasses (Bouteloua spp.), buffalo grass (Buchloë dactyloides), crested wheat grass (Agropyron cristatum) and needle and thread (Stipa comata) cure 'in situ' towards the end of the summer and provide valuable winter roughage. These measures are used where the sward components are largely the indigenous species which once formed the climax association. Such conditions are not found in New Zealand except in the tussock grasslands of the South Island and perhaps on some of the dry Danthonia pastures of the North Island. So far as the bulk of the North Island hill country is concerned, the deferring of grazing until after seed-setting, which is valuable only in increasing the ground cover, would benefit all species equally, except insofar as the most prolific seeders would be at an advantage. On depleted hill lands - especially those in the South Island - this would be wholly advantageous. In both the Wet and Dry Hill Country of the North Island, however, deferred grazing of this sort might set in train the natural succession by allowing secondary growth species a complete season to develop, or might engender other undesirable botanical changes in the swards by benefiting the prolific seeders - usually those species or strains of low leaf production.

However, a form of deferred spring grazing might well be of value on much North Island hill country. This should be timed to allow ryegrass to benefit by its early spring habit of growth at the expense of lower producing species such as browntop and Danthonia, during whose first growing period grazing would be started. Where it was desired to build up the white clover already present in a hill sward, early grazing with a spell in late spring would be employed. In the Dry Hill Country of the east coast, where the annual, subterannean clover is so valuable, the benefit of a mid-summer spell to allow the formation and deposition of seed, particularly in the first year after establishing the legume, is well known.

Management of this type has been advocated, on theoretical grounds, for New Zealand hill country, by Lamont

(1939), and the same author has described an instance in the Wairarapa where 3,300 acres near Castlepoint carried 4,000 sheep and 250 cattle in 1910, and 8,000 sheep and 700 cattle in 1938, the increase being attributable solely to a system of deferred and rotational grazing, since no fertilisers were applied during that period in which the increase took place.

There are yet other advantages claimed for rotational grazing and spelling of hill pastures.

First among these is the control of weeds. Bidi-bidi (Acaena novae-zealandiae), a pest especially in the drier areas, is normally a low growing plant which escapes severe defoliation. If an infested pasture is spelled the weed becomes more erect in habit, is grazed off, and may eventually be eliminated. The same applies to other low growing, rosette-forming weeds which occupy an area of ground disproportionate to the amount of feed they provide.

Heavy concentrations of stock on a small area for a short time tend to eat off the vegetation more cleanly and evenly, there being less opportunity for selective grazing, than do small numbers of stock on a large area for a long time. In this way rotational grazing, even by mobs of sheep alone, tends to keep fern, manuka and other secondary growth in check.

Rotational grazing, where pastures can be spelled for two or three weeks at a time, provides a partial and automatic control of internal sheep parasites.

Rotational grazing prevents the formation of stock camps - a matter of importance in sward improvement, soil erosion control, and stock thrift.

To sum up the case for spelling and rotational grazing on both Dry and Wet Hill Country in the North Island, it may be said that such methods prevent the anomaly of over- and undergrazing occurring at the same time in the same paddock. Stapledon's maxims of rotation in space and rotation in time are adhered to, and thus a balance is maintained in the sward, since grasses growing at different periods of the year are encouraged by allowing them to develop periodically. A better spread of herbage growth over the seasons is thus obtained, the better grasses are not depleted in vigour by being selectively grazed, and the herbage, on the whole, is kept in a young, palatable and nutritious state.

It has been indicated, by reference to the all too scanty literature, that some farmers in the North Island are applying these methods, and are finding that the advantages outlined above are more than purely theoretical.

The foregoing discussion, as has been indicated, concerns North Island conditions. Under these conditions the writer would venture to claim that some form of spelling and/or rotational grazing is both desirable and practicable in a majority of cases.

Spelling is already an accepted practice under what may broadly be termed set stocking management, but this spelling is usually undertaken simply to allow some roughage to grow for winter keep, or for the negative reason that the stock on a pasture have ceased to thrive, so that before that pasture can be of any use it must be given an opportunity to recover from overgrazing. Too seldom is spelling carried out with the positive intention of improving the botanical composition of the sward, of extending the growing season, or of controlling weeds and parasites.

Rotational grazing is a much less popular practice, the chief argument against it being that lamb weights may suffer due to mismothering, or to excessive travelling and buffeting while being shepherded through gateways. These may well be justifiable arguments, though proof is lacking. However, in many cases the advantages which would be expected in increased carrying capacity, increased numbers of lambs, and increased wool weights, would adequately offset any loss in condition of the lambs. Were this not found to be so, the rotation of stock round the farm might be suspended during the period from lambing to weaning, a period of, say, 4 to 5 months.

The next problem is one of subdivision and mustering. If the earlier argument concerning excessive travelling by ewes with lambs at foot is justified, there must be some maximum size of paddock over which the system becomes uneconomic. There must be a maximum size of paddock (varying according to the difficulty of the terrain), over which the losses in condition due to excessive travelling and curtailed grazing period, due to the time involved in mustering off one paddock and spreading out on the fresh paddock, become so large as to offset any advantages obtained through the improvement of the pastures. More stock may, indeed, be carried, but due to excessive disturbance they may be in much poorer condition.

Here there is much scope for modification of the system. On a relatively small and/or well subdivided holding with paddocks of 100 acres or less, daily, tri-weekly, or bi-weekly shifts may be practicable according to the season, rate of growth, and mob and paddock size. On larger stations, where paddocks and flocks are larger, instead of rotating the whole flock as one mob over the entire farm, thus necessitating frequent shifts, the flock may be divided into two, three or four equal sections, and each section rotated on $\frac{1}{2}$, $\frac{1}{3}$ or $\frac{1}{4}$ of the property, thus reducing the amount of shifting which each mob has to endure to a half, a third, or a quarter of what it would be were they all in one mob.

Thus may a modified form of the system be brought within the range of practicability. It is probable, however, that under this extended rotational system some of the ease of mustering and shifting found when frequent shifts are made would be forfeited. Where frequent shifting is practised it has been found that no mustering has been required, the sheep moving of their own accord when the gate into the next paddock is opened.

Such modifications of the system necessitated by inadequate subdivision should, however, not be regarded as permanent. Subdivision is the major necessity of all hill land in New Zealand. Without it stock cannot be properly controlled on the pastures, and without that control the potentialities of the land can never be fully realised.

(b) Tussock Hill Country.

The concept of rotational grazing has as yet little place in the tussock country of the South Island. For one thing there is virtually no subdivision over most of the area. Blocks are very large; mustering a major operation, laboriously carried out on foot; boundaries a ridge, a gully or a riverbed. The means of stock control are lacking, and until and unless the carrying capacity of the tussock grasslands is greatly improved, the means of control, primarily adequate fencing, will be withheld for almost indisputable economic reasons. If the economic difficulties are solved there will still remain the physical difficulty of erecting stable fence lines on much of this country.

Even if greater control of stock on the tussock hill country were feasible, rotational grazing, as practised on the hill country of the North Island, might not prove effective in sward improvement.

Black and Clark (1942) demonstrated that rotational grazing (on a 28 days on and 28 days off basis) in the southern Great Plains area of the U.S.A. had no appreciable effect on the thrift of the stock carried or on "the appearance of the vegetation" on the range. Hereford yearling steers and spayed heifers were the stock used. The average annual precipitation during the 4-year experimental period was 13.83 inches. Mean monthly temperatures were above 40°F. for seven months of the year, reaching a maximum of 77°F. in July - a month averaging only 0.81 inches of rain.

Under such conditions of aridity and slow growth it is hardly to be wondered at that a 28 day rotation had little effect. A rotation, to be effective, must not be purely mechanical, but must consider growth conditions and the rate of recovery of the plant species. Cockayne (1921) has demonstrated that under conditions of slow recovery a rest period of six or seven months may be necessary before the herbage has recovered sufficiently to be fit to graze.

More valuable than the work of Black and Clark was the earlier work of Sarvis (1923). Under a similar climatic

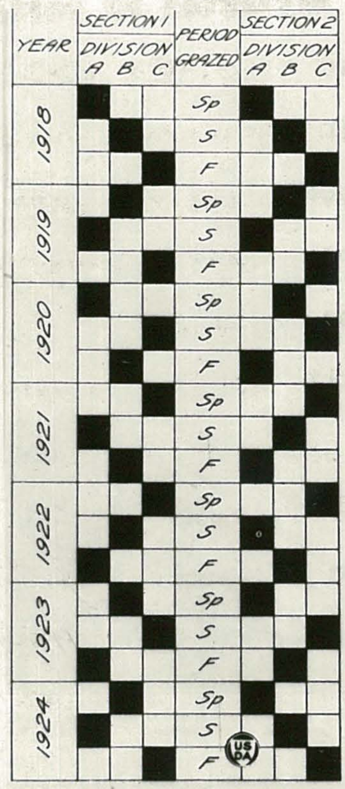


FIG. 2.—Diagram showing the order of grazing the three divisions of the deferred and rotation pasture for a complete cycle and the first season of the next. Columns *A*, *B*, and *C* represent the three divisions of the pasture. Each year is separated into three periods indicative of spring (Sp), summer (S), and fall (F) grazing periods. Grazing periods are shaded, rest periods unshaded. The first part of the diagram designated as section 1 illustrates the plan being followed; section 2 represents a more uniform plan that has been worked out. These sections differ in the order of the rotation. In section 1 the order of fall grazing is *C*, *B*, *A* and in section 2 *C*, *A*, *B*.

Figure XIV. Two systems of deferred rotational grazing. (Sarvis,1923).

regime a system of "deferred rotation grazing was found to give a greater utilisation of the vegetation...with less injury to it than....any other system, and with the greatest total (live weight) gain". Two-year-old grade steers were used.

The system of deferred rotation grazing is designed to allow each division of a pasture to set seed for two successive years before it is harvested by cattle in the autumn of each year. In its third year this previously autumn grazed pasture is grazed in the summer to permit the establishment of seedlings from seed shed the previous autumn. Two systems of this type of grazing are presented in diagrammatic form (Figure XVI, page 85a).

Under conditions of slow recovery this system, in which pastures are grazed only at one season of the year, and in which the season of grazing rather than the livestock is 'rotated' around the various blocks of pasture, is more likely to prove valuable than the more normal rotational system practised on pastures where recovery and growth are rapid.

The previously mentioned New Zealand practice of spelling winter and summer country in summer and winter respectively is, no doubt, a valuable one, though summer country grazed throughout each growing season, and spelled throughout each dormant season when accumulation of root reserves must be at a slow rate, and regeneration through seeding or vegetative growth small, is probably less benefited by the system than might be thought. Winter country has the summer in which to recuperate, but during this time has to contend with the effects of a hot sun and nor'west winds impinging directly upon a partially denuded ground surface. The system, of course, is essential to the survival of High Country sheep flocks, although under existing systems of management the size of these flocks tends to decline due to deterioration and depletion of the ground cover.

The past extent of this deterioration and depletion cannot be measured, although McLeod (1947) reporting on behalf of the South Island High Country Committee said, "During the

90 years of settlement of the High Country there has taken place a serious deterioration and depletion in the nature and value of the natural plant covering". In the same report McLeod quotes a survey by the Economics Department of Lincoln College demonstrating a fall from 12,000 to 9,600 between 1930 and 1946 in the average number of sheep carried on ten properties surveyed. As demonstrated earlier, the high carrying capacities of the 1930 era were partly a reaction against the effects of economic depression, so that the entire amount of the above decline cannot be attributed to pasture deterioration.

Cumberland (1944) demonstrates the decline in carrying capacity which has occurred since the year 1879 on one property of 54,000 acres in the valley of the upper Waimakariri river:

Year	1879	1889	1899	1909	1919	1929	1939	1944
Sheep grazed.	16,200	17,700	16,000	?	11,900	12,000	10,500	10,000

The high figures in the closing years of the 19th century reflect to some extent the higher carrying capacities of the virgin grazings, but also the way in which, when wool was the chief saleable product, and the frozen meat industry not fully developed, sheep stocks were allowed to increase to abnormal levels, there being no market for culls or store lambs. It seems probable that in this era severe overstocking took place, setting in train the sequence of deterioration and depletion which now has to be contended with. Although sheep stocks have been reduced, this has frequently followed a decline in the carrying capacity of the range, and not preceded it, so that despite the reduction overgrazing still occurs.

Dick (1951), in connection with Canterbury Catchment Board erosion control work, is engaged in obtaining for the first time a measure of the rate at which depletion takes place on areas of tussock grassland not obviously overstocked. Adjacent, fixed quadrats, one fenced against stock and rabbits, the other unfenced, are submitted annually to point quadrat botanical analysis. A note is taken of the number of hits on growing vegetation, on dead vegetation, and on bare ground. Although the work has only been in progress for five years and there is little, if any, visible difference between ground cover inside and that outside the rabbit-proof fence, and little sign of abusive grazing outside the fence, the figures demonstrate clearly the year by year progressive increase in vegetative cover inside the fence, and an equally progressive increase in the area of bare ground outside the fence.

The question then arises, if deterioration and even depletion of the range cover is in fact taking place, if rotational grazing as practised in the North Island is inapplicable as a remedy, and if the existing practice of winter and summer spelling is still not sufficient to arrest the deterioration, is there any manipulation of stock which can reverse the deterioration and assist vegetation of depleted areas?

There is considerable evidence that complete exclusion of stock from the range will, in a majority of cases, have these desirable consequences, provided always that rabbits are excluded as well as sheep and cattle. Rabbit extermination, although a paramount necessity is outwith the scope of this dissertation, but for the purposes of this discussion it must be assumed that the farmer has control over all grazing animals on his property.

The work of Cockayne on the Dunstan Range, reviewed by Tennent (1935) has demonstrated the ability of native and exotic species to become established and produce reasonably well when stock are completely withheld from an area. This is especially true of the shady faces at higher elevations, where precipitation both actual and effective, is greatest. In these positions "total recovery (to 100% ground cover) appears to take place in about four years' time. .... In the plots which were opened to stock from June, 1930, till December, 1932 .... it was most noticeable that where the sole of grass was dense no apparent damage of any serious moment had occurred. Cocksfoot, Chewing's fescue, lucerne and yarrow appeared to be standing up particularly well to the hard grazing experienced, but the native tussocks, with the exception of fescue tussocks, were considerably checked in growth. When, however, it is borne in mind that the grazing on these plots was exceptionally severe, in fact they were excessively overstocked, it can be assumed that, given rational treatment, once a sole of native and introduced species is established, it should be quite practicable to retain their presence on mountain slopes by judicious grazing".

Again, Cockayne (1921) (i) remarked on the recovery, after heavy grazing, of certain exotic species growing in the Earnscleugh region of Central Otago. "The most striking feature of the regrowth was the astonishing recovery of lucerne (Medicago sativa), which, to use a familiar phrase, had had 'the heart eaten out of it'. ....No lucerne had been damaged in the slightest degree. Cocksfoot (Dactylis glomerata), which had been grazed quite as heavily as the lucerne, had also grown well. At the close of the grazing, yarrow, chicory and catsear had not merely been eaten to the ground, but the underground stems or roots had been attacked. Nevertheless, all three species showed no signs of this excessive grazing, but they offered food in abundance. With regard to the indigenous tussock grasses, blue grass (Agropyron scabrum)....had in many cases produced a good deal of fresh growth".

These quotations would indicate that there is no one answer to the question posed earlier. Admittedly these trials were of short duration, but they do indicate an interaction between plant, animal, and habitat. Every species in a particular habitat will withstand a specific amount of grazing, and the grazing management will depend upon the species present and the habitat.

It is important to appreciate the different objects in view in the improvement of North Island and South Island hill country. In the North Island the ideal is to maximise (so far as is economically desirable) the output of stock products from the pastures, and this ideal can be made an immediate objective, attainable by the application of the principles set out in this dissertation, including improved grazing management. In the South Island the ideal may be the same, but a solution of the important problem of preventing depletion of these grazings is more immediately urgent. This may be solved either by removing stock completely and allowing the natural succession to proceed, by introducing species of plants which can withstand the existing ecological conditions, or by choosing a middle course between these two.

To remove stock completely from these depleted lands would be to deny a livelihood to many thousands of farmers and farm workers, and would appreciably reduce the national income. Obviously such action cannot be taken without first having tried the alternatives. There is, however, some evidence that complete removal of stock may not be as beneficial in promoting revegetation of deteriorated range land as some system of controlled grazing. Sampson (1913) demonstrated that more seedlings were established under a system of deferred grazing than on unused ranges, this being due to the improved seed-bed of seeds passing through the gut of stock, and to the trampling in of seed by stock.

The day when plant breeding or plant introduction can provide species capable of withstanding and thriving under the ecological regime extant today may be just 'around the corner'. Until these species are provided, some form of controlled grazing such as the deferred grazing system expounded by Sampson and Sarvis (cit. supra) would seem to be desirable if the present depletion is to be arrested. Even after these species have been introduced, controlled grazing should enhance the speed with which they will become established, and hasten the time when the ideal of maximised production can become the primary objective of improvement methods.

I. KIND, CLASS AND BREED OF STOCK AND THEIR RELATION TO GRAZING MANAGEMENT AND PASTURE IMPROVEMENT.

By 'kind' of stock is meant animal species, e.g. domestic cattle or sheep; by 'class' is meant sex or age group within a species, e.g. cows or heifers, steers or stirks, ewes or wethers etc.; by 'breed is meant a subgroup of a species, having distinctive characteristics, e.g. Aberdeen Angus, Hereford, Romney, Merino, etc.

First, in the consideration of the kind of stock carried on New Zealand hills it must be appreciated that New Zealand is a nation the economy of whose extensive pastoral regions is based on sheep products. In 1946 the sale, for export, of mutton, lamb and wool realised nearly £44 million. All other meats, including beef and pig meats amounted in value to about £4½ million in that year. Of more recent years the inflated price of wool has emphasised even more strongly the importance of sheep, and the relative unimportance of cattle in the economy of the extensively farmed hill regions.

There appears to have been no economic investigation in New Zealand into the relative profitabilities of sheep and beef cattle, although the opinion is widely held that sheep are the more profitable kind of stock to carry. Prior to 1882 the ovine foundation of the economy is explicable on the basis of the necessity for exportable livestock products which were not perishable, namely wool and tallow. Adherence to an economy based on sheep in the years succeeding 1882 indicates that, under the existing circumstances of climate, pasture types, topography, managerial ability, availability and skill of labour, and market conditions, this economy must have been more profitable than one based on beef cattle.

In the absence of exact data, therefore, the verdict of usage must be accepted, and with it the belief that the economy based on sheep has been demonstrated to the farmers' satisfaction to be the most profitable when all circumstances are considered. If, then, sheep are more profitable than cattle, New Zealand's 2 million beef cattle must have some specific merit in the eyes of the farmer, or they might expect to be replaced by sheep.

Stoddart and Smith (1943) (iii) claim that "the most important factors that determine the best kind of stock for each range are (a) topography; (b) amount and distribution of water; (c) character of vegetation; and (d) economic factors".

Each of these factors, too, should play a part in determining which class and breed of each kind of stock is best suited to any given situation. Each of the above four factors will be considered in relation to the kind, class and breed of stock which is run, or which might be better run on New Zealand hill swards, from the point of view of the improvement of these swards.

I. Topography.

It is usually assumed that the steeper the country the less able are cattle to graze it, and the more does it become the sole domain of sheep. The geological history of New Zealand, especially of the North Island, demonstrates the youth of many of the surface sediments. Geological youth, and easily erodible sediments, give rise to steep slopes and deep gullies, both of which may determine the kind of stock carried, militating against the use of cattle, at least those breeds of cattle which it is customary to carry on easier hill country in New Zealand.

Weston (1936) recognises that the question of a breed of cattle capable of grazing efficiently the steeper and more inaccessible country is of great importance. He observes that in the years immediately prior to 1935-36 Aberdeen Angus cattle increased relative to other breeds, due in part, to the efficient way in which they graze steep and difficult country. In respect to this type of efficiency, the breeds are generally considered to be in the following order: Aberdeen Angus, Hereford, Shorthorn. Weston further recognises that there are degrees of agility among cattle: "While the Hereford is a better climber than the Shorthorn many farmers consider that it is not so good as the Aberdeen Angus". It is safe to say that, in the country of their origin, none of these breeds would be considered hill breeds, far less would their ability to climb hills be considered. They are essentially cattle for stall feeding, or fattening on the high quality pastures of mixed arable farms. Climbing, British farmers would contend, was the prerogative of the Galloway and West Highland breeds or their crosses with the Shorthorn. These two breeds have been subject to natural selection pressure on steep land for very many generations. The same sort of natural selection is probably being exercised at the moment upon Hereford, Shorthorn and Aberdeen Angus cattle in New Zealand, but the Galloway and West Highland breeds have several centuries' lead.

It would seem, then, that topography may militate against the efficient use of the three most common breeds of beef cattle found in New Zealand, particularly in much of the deeply divided back country of Wanganui, Taranaki, and the King Country, as well as the steep coastward regions of Southern Hawke's Bay. Topography such as this, and that of much of the South Island tussock grassland area, induces cattle to graze on the valley bottoms or on any small plateaux which they can conveniently reach. However, there are breeds, still largely untried in New Zealand, recognised to be of value in country of difficult topography. It may be that some of the other factors to be considered in this section offset any value these untried breeds may have in this direction, but these will be considered under their respective headings.

Fraser (1947) recognises that "sheep will graze where cattle dare not venture, and a lamb may be raised and a fleece grown on a steep slope where a cattle beast would merely break its leg". Just as there are differences between beef breeds in climbing ability, so there are similar differences between breeds of sheep, and not all breeds of sheep would rear a lamb well or grow a good fleece on the steep country depicted by Fraser.

On this subject White (193?) has this to say: "It is obvious that sheep grazing on rough mountain slopes must possess sufficient activity for the scrambling and climbing necessary to secure food in due season from all parts of their grazing. In general, it may be said that activity depends largely on general body proportions and muscular development, but is also affected by relative size and weight. As regards the form necessary for maximum activity, we need only study wild sheep, which more resemble some species of deer than domestic sheep, and from the butcher's point of view have hardly any merit at all. The further from the wild type we go, and the more we develop the ability to fatten and to meet the butcher's requirements at an early age, the less activity we find". It is a fact that on low ground pastures the heavier, less active, and more rapidly maturing breeds will be the most desirable economically. Quite the reverse may be true on steep country. The truth of this is appreciated by Peren (1948) when he says, "A sheep with a bit of height at the withers, and plenty of driving power in the hindquarters, can climb hills with far less effort than the mutton breeds. This is immediately brought home to one when going around the hills at Tua Paka; the Cheviots are literally twice as active as the Romneys with half the effort. The contrast is quite remarkable. The important point, however, is that the Cheviot, with the advantage of correct conformation, is able to climb with a smaller expenditure of the energy which it derives from its food, than is the Romney. This economy in the utilisation of its food is one of the important advantages which hill breeds have over lowland breeds on steep country".

Within New Zealand there is the anomaly of a more agile breed, the Merino, grazing slopes which are frequently easier than those on which the heavy, less agile Romney, is run.

From the standpoint of more effective pasture utilisation there would seem to be a case for the use of more agile sheep and cattle breeds on the excessively steep country. It should be borne in mind, however, that the expression "effective pasture utilisation" may encompass one or both of two concepts. It may mean the more efficient conversion into animal products of whatever forage is ingested, or it may mean the harvesting of a greater amount of forage by the more agile animal, able to feed more easily on the slope and reach more inaccessible places. The former, as a virtue of hill breeds, is entirely to be desired. The latter virtue, however, may not be so desirable if it means also the denudation, or even the weakening of the plant cover on steep slopes, thereby rendering them more liable to erosion. With improved adaptation of stock to physically difficult terrain improved measures of grazing control, and more extensive topdressing and oversowing must go hand in hand, or the benefits derived from improved adaptation may well be lost in increasing erosion.

Topography has two aspects; slope and elevation. So far only the first has been considered.

The effects of increasing elevation are frequently deterioration of climate, increasing rainfall, more frequent winds of greater velocity, heavier snowfall tending to lie longer and, generally, lowered temperature. The growing season for such plants as do exist tends to be shortened by the lower temperatures.

Cockayne (1928) (iii) has described in detail the genera and species found in various ecological habitats in New Zealand, and has clearly demonstrated the shrub and herb nature of the associations in the high mountain regions, especially in the South Island. Cockayne's "herb-field" also "occurs in the North Island on the Dividing Range from the highest peaks of the East Cape mountains southwards, on Mount Egmont and, to a limited extent on the central volcanoes", and "on all high mountains subject to frequent rain".

Altitude, then, modifies the vegetation to one on which sheep (or goats) are most suited to graze. Stoddart and Smith (1943) (iv) claim that "sheep utilise forbs more fully than any other kind of livestock. Not only do they consume larger quantities of these species, but they consume a greater number of these species. Where forbs make up a large part of the forage, most satisfactory results are obtained with sheep".

It does not seem to be known whether or not there are differences between breeds in their ability to thrive on the same type of vegetation. Would, for example, a Southdown thrive as well on an alpine herb meadow diet as a Merino, other things being equal? This might form an interesting, if academic study. But, in practice, other things are not equal. In the first place whatever breed is used to graze these high lying herb and shrub grazings it must be capable of climbing to and ranging widely upon its grazing ground. In the second place it must be able to survive the more severe climatic conditions found at high altitudes. This demands a dense, close fleece to prevent the penetration of rain and wind; it demands also that instinct, found only in hill sheep, which enables them to anticipate changes in weather, and to seek out situations providing food and shelter before the storm breaks.

In New Zealand the Merino would be considered the breed suited, 'par excellence', to these conditions. Again, comparative trials with other breeds are lacking, but the writer has found one comparison between the Merino and Cheviot breeds made by Patrick Sellar, a Sutherlandshire farmer, in 1920. This is of such interest and pertinance to the present discussion as to merit full quotation:

"Owing to the disposition of the Merinos they are not suitable to these wastes of peat-bog, not that they do not thrive and yield wool in abundance and of the first quality, but that as three-fourth parts of the wastes consist of Alpine plants which they reject, the same quantity of Sutherland ground will keep three hundred Cheviots that will maintain one hundred Merinos, and that with half the care and one third part the risk in winter".

Here is an observation upon the suitability of two breeds to hard conditions: to an Alpine herb diet, and to severe winters in which heavy snowfalls are an annual occurrence. On both counts Sellar found the Cheviot superior.

As, when discussing the relationship of breed to slope, so when considering altitude, the advocate of possible changes in the breeds suited to high country must keep well in mind the possible disadvantages of running on these hills breeds which can utilise more of the herbage available. The possibility of increasing erosion by overgrazing with sheep better adapted to the physical, climatic and nutritional aspects of the hill or mountain environment must never be forgotten. Wherever topdressing and oversowing are impracticable - as they sometimes may be - the advantages of using dry stock, preferably mature dry stock, must be borne in mind. The temptation to convert wether country into ewe country simply by changing the breed of sheep carried from, say, Romney to Cheviot must, unless the fertility drain can be made good, be resisted. Otherwise the higher and steeper hills of New Zealand may end up by carrying only the Scottish Blackface.

II. Amount and Distribution of Water.

This factor is frequently of such importance as solely to determine the kind of stock which can be carried on hill country.

Cattle require relatively large amounts of water. Stanley (1938) found that the average water consumption of range cows in Arizona was 6.3 gallons per day. This may be a conservative estimate since most other investigators give higher figures. Talbot (1926) suggests 10 gallons; Sampson (1923) (i), 10 to 12 gallons. Ritzman and Benedict (1938) have shown that water consumption varies with (inter alia) the amount of milk yielded, so, presumably also with the class of stock, be it dry or wet.

Sheep, on the other hand, are more modest in their water requirements. Talbot suggests 1 gallon per day; Sampson $\frac{1}{4}$ to $1\frac{1}{2}$ gallons per day, and Jardine (1915) in Montana, demonstrated that on non-succulent grass range in high mountains, sheep could "do well" if they obtained a limited amount of moisture in the form of dew, fog or rain, while on succulent weed ranges in the high mountains sheep could be grazed without water, yet make gains comparable to those of sheep grazed on well watered ranges. Thompson and Fraser made the observation that in the later stages of pregnancy the water consumption of ewes almost doubled. Yet again, Fraser (1949) (i) quotes the case, known also to the writer, of some of the smaller islands off the west coast of Scotland where, under conditions of high rainfall (60 to 100 inches), both sheep and cattle thrive although there is no source of fresh water at all.

The water requirements of sheep, and to some extent of cattle, are seen to be related to the class of stock and to the succulence of the pasture. One cannot generalise about the amount and availability of water on hill land, but it seems reasonable to suppose that the difficulties of providing adequate water for cattle increase as rainfall decreases from west to east and from north to south within New Zealand. Water supplies are, however, very dependent on local conditions, such as aspect, geological formations which may give rise to springs, the existence of higher catchment areas or areas of melting snow, and the like. The fact remains that the farmer must either run those kinds and classes of stock whose water requirements are satisfied by existing watering facilities, or he must extend these facilities. The possibilities of extending watering arrangements by use of artesian borings, wind pumps, dams and dew ponds do not come within the scope of this dissertation. Here consideration need only be given to the effect of water availability to stock on the pastures which they graze.

Perhaps the most urgent yet unanswered questions are; How far will stock travel to obtain the water they require for maximum production, and how far is it desirable for them to travel to obtain water? The unwillingness of stock, especially cattle, to travel far from convenient watering places can be a serious cause of local overgrazing and of poor utilisation of herbage growing at some distance from a source of water. Where cattle are required to graze off rank, stemmy pasture, they may fail to do so, unless water is nearby, preferring comparative starvation near the water-hole to thirsty repletion further away. The same applies when cattle are run in a steep paddock rising up from a stream. The lower slopes are heavily grazed by the cattle while the upper ones are neglected. Under these circumstances sheep will probably graze a paddock more evenly than cattle (this not implying that their selectivity is in any way reduced) simply by their ability (or willingness) to travel further from, and survive longer, without water. In the same way, dry stock may use more of the forage available, especially under dry conditions, than ewes nursing lambs.

Looked at from the point of view of the pasture the problem is equally interesting, and several unanswered questions immediately come to mind: Do cattle spread out more over the available range in spring because growth is more succulent and their dependence on free water consequently less, or does the lower air temperature at this time account for their ability to live comfortably with less water? Certainly it is in the hot summer months that cattle are most frequently seen in the vicinity of water holes. It is, of course, in the periods of flush spring growth that the widespread control given by free ranging cattle is most desired from the pasture management point of view, but the point at issue is this: Can pasture management (and thereby the pasture and the stock which it supports) be improved by a better distribution of watering facilities for stock? It seems almost certain that, where the water supply is inadequate, the answer must be in the affirmative.

If cattle are considered essential for the efficient control of hill swards (and this is discussed in the following sub-section) and if the subdivision is not sufficiently close to ensure that cattle graze evenly over the swards, then the even distribution of water over the area would seem to be a means of assisting more even cattle grazing. This is in line with the American method of effecting proper distribution, especially seasonal distribution, and equality of range utilisation by a planned distribution of salt supplements over the range. Closer subdivision itself is not a complete answer to this problem of cattle and water distribution. If there is water laid on in each of several relatively small paddocks there may be less need for the actual subdivision into paddocks, the distribution of water alone providing the necessary control. If, however, cattle are forced, in dry weather, when the forage is dry and fibrous, to graze in an unwatered paddock, they will lose condition rapidly. Whether or not a farmer is willing to allow this to happen depends upon his attitude to his cattle - whether he regards them as implements for pasture control, or as profitable livestock. This latter depends upon economic considerations which will be discussed briefly in the final sub-section of this chapter.

III. Character of the Vegetation.

Stoddart and Smith (1943) (iii) consider this factor of vegetation from the standpoint that browse ranges are best adapted to sheep grazing, while grass ranges are the natural habitat of cattle. These may be termed the natural principles of land use, and where the aim is to make the simplest use of the existing vegetation without altering its character this point of view may be tenable. In New Zealand, however, the economic principles of land use, as dictated by the export market, demand that sheep graze over a much wider vegetational range than Stoddart and Smith would deem natural. Nor is it always wished to maintain the 'status quo' in the character of the vegetation. There is always the desire to improve productivity of the vegetation on the hills by appropriate grazing management, by improving fertility and by introducing better strains and species of grasses and legumes. Equally, there is always the need to guard against the reverse processes of sward deterioration and depletion.

It is with this dynamic concept of grassland in mind rather than the more static American concept, that an approach must be made to the question of which kind, class and breed of stock should be carried on New Zealand's hill pastures when the object is to maintain or improve the quality of these pastures.

Considering kind of stock, let it be said at the outset that there are two opposing schools of thought. One maintains that cattle are essential to the proper management of hill pastures; the other asserts that cattle are unnecessary, and that rotational grazing with large mobs of sheep is just as effective in improving and maintaining pastures. Both schools would agree that set stocking with sheep alone is detrimental, since the highly selective grazing undertaken by a small number of sheep spread over a relatively large area greatly weakens, and may eventually eliminate from the sward, those species most palatable to sheep.

Cockayne (1919) (ii) and (1920) (ii) has made investigations into the palatability of plants on hill grazings in the Hanmer and Earnscleugh districts of the South Island. These investigations demonstrated that it is not sufficient, or necessarily accurate, to state that a grass species is palatable when it is eaten by sheep while adjacent species are neglected. It is only safe to say that the species which is eaten is more palatable than the readily accessible surrounding species. The palatability of a species, then, is only relative, - relative to the palatability of accessible, adjacent species. While Yorkshire fog may remain uneaten in the presence of abundant cocksfoot, it will be avidly consumed if the only alternative forage is fescue tussock.

Again, the palatability of a species appears to vary from one locality to another. Thus the palatability of a species in the high rainfall district of Hanmer was found not necessarily to be an index of its palatability in the drier region of Central Otago.

Thirdly, palatability varies with the season of the year, or probably more correctly with the stage of growth of the plant. At Hanmer white clover (Trifolium repens) was not eaten at all during January and February (midsummer), being then classed as unpalatable. During September, however, sheep in the same paddock grazed it freely. A similar observation applied to sweet vernal. Thomas (1949) observes "Certain plants in certain stages of growth change flavour. This is particularly the case with some leguminous plants, especially red and white clovers. In the pre-flowering stage of growth they become bitter to such a marked degree that stock find them quite distasteful".

The first conclusion which may be drawn from these observations is that, within a confined locality, sheep will eat the same species at about the same time each year. They may not eat the same species all the year round, since the palatability of any given species will wax and wane with stage of growth. This is important, for it means that a valuable species (as is white clover from the soil fertility point of view) may be able to retain a foothold in a sward under conditions of set stocking, or at least its elimination from a sward under these conditions may not be so rapid as certain experiments, based on continuous cutting of the sward, might indicate. However, if grazing occurs at the same stage of growth each year, and if increased palatability coincides with the formation of fresh, young, spring growth, then the species will undoubtedly be greatly reduced in vigour, and eventually will be eliminated from the sward.

The second conclusion of importance is that so long as a species remains relatively palatable and relatively accessible it will continue to be preferentially grazed. If this constitutes overgrazing (as under set stocking conditions it almost certainly does) and that species is totally, or virtually eliminated from a sward, one of four things must happen:

(a) A species which, during the lifetime of the palatable but now eliminated species, was relatively unpalatable may be brought into the diet of the sheep and will be the least palatable plant in that diet. Meanwhile the species next in palatability to the eliminated one will itself be undergoing the process of elimination. So, as relatively more palatable species are eliminated at the top end of the palatability scale, relatively less palatable species must begin to come into the diet of the animal. If this does not happen either,

(b) The carrying capacity must be reduced;

(c) The stock will cease to thrive, or

(d) The more palatable species will be grossly overgrazed if the stocking rate is maintained, thus hastening their eventual elimination and an inevitable return to situation (b).

This is, of course, an oversimplification, for the sake of clarity, of the order in which these processes occur. In practice all four are inextricably intermingled.

The foregoing would be the process of events where sheep were the only stock used, and where, by virtue of each animal having, say, an acre or more on which to graze, it was free to exercise its preferences for those plants which were most palatable to it.

The sheep plus cattle grazing school claims that cattle are less selective feeders than sheep. This, so far as the writer is aware, awaits proof. The assumption is usually made, rightly or wrongly, that it is physically impossible for cattle, having a jaw of greater width than sheep, to be as selective in their grazing as sheep. But Hancock (1950) suggests that even cattle may be capable of being highly selective in their grazing. This observation, however, was made in a paddock in which cattle were the dominant, if not the only stock, and it seems reasonable to assume that on a pasture the majority of which is eaten down to sheep feed height, cattle are less able to exercise whatever selectivity of grazing they possess. The fact that cattle, in a sheep-grazed paddock, will eat down the rough feed unpalatable to sheep is probably not so much due to the fact that they are less selective in their grazing, or that their preferences differ from those of sheep, though these may be contributing factors, but rather that in order to obtain a sufficient bulk of forage to satisfy appetite they must graze a considerable amount of the ranker herbage which the sheep have neglected.

In support of this theory, Johnstone - Wallace (1950) demonstrated that when cattle grazed 4 inch high herbage they consumed 150 lb. of green material containing 32 lb. of dry matter each day. As the herbage became shorter the amount consumed fell rapidly until, on the 7th to 9th days after grazing commenced, when the sward was grazed bare, intake averaged 45 lb. of green material containing 10 lb. of dry matter. Woodman (1948) (ii) gives the appetite satisfying requirements of an 11 cwt. bullock as 25 lb. of dry matter per day.

If, as in a sheep-grazed paddock where the palatable herbage is already grazed short, a cattle beast can satisfy less than half of its appetite requirements from the closely grazed palatable species, it is reasonable to assume that it will eat less palatable species until its appetite is satisfied: it will equate palatability and availability with appetite.

This seems a satisfactory explanation of the claim by the protagonists of mixed grazing that "cattle clean up the roughage neglected by sheep because they are less selective grazers".

Given that cattle will, under the circumstances just considered, graze off species which sheep neglect, the consequences are several.

The unpalatable species are prevented from becoming dominant in the sward through the physical shading effect which they would otherwise exert on the overgrazed species.

Their spread may also be hindered by a reduction in the number of seed heads which they are permitted to send up and mature.

By being eaten down, the growth on the relatively less palatable species will be kept younger, more palatable, more digestible, and of a more nutritious chemical composition. Sheep may then be tempted to widen the scope of their grazing to include some of the younger portions of these less palatable species, and so allow some recovery of the overgrazed species.

The utilisation of the sward as a whole will be improved; more of it will be converted into animal products, and more of the soil nutrients will be returned to the soil in the form of dung and urine instead of being 'locked up' in the uneaten rough growth whose reconversion into available plant nutrients in the soil would otherwise depend on the slower natural processes of plant decay.

In these various ways the grazing of cattle along with sheep may be expected, on theoretical grounds alone, to improve hill pastures and increase their output of live-stock products; nor is there any dearth of opinionative evidence concerning the improvement wrought in sheep pastures by introducing cattle.

Graham (1948) opines that pasture control on hill country is not possible without cattle to clean up the rough pasture. But this view is too dogmatic to go unquestioned.

Harris (1950) credits cattle with an improvement and stabilisation of the country and the firm establishment of better grasses and clovers.

The Balfour Committee (1944) observed that, "those few farmers who have in recent times followed a policy of grazing cattle with sheep have found that it leads to a marked improvement in the quality of the herbage on their farms and in the health and productivity of the sheep". Moreover, those opinions are supported by more concrete evidence.

Heddle and Ogg (1933) divided a uniform Nardus pasture in half and grazed one half with sheep and the other half with sheep and cattle. They observed that where sheep alone were grazed the Nardus set seed and the pasture was rough and tussocky, while on the other side of the fence few seed heads were to be seen and the roughness was much grazed down.

Wilson (1936) converted a poor, 300 acre, Nardus dominant, sheep grazed sward into a more valuable Agrostis dominant sward by grazing with 20 Galloway cattle in addition to the normal sheep stock of 200 ewes. Not only was there no need to reduce the ewe numbers (though the total livestock carried had been increased by 50%) but the lambs actually improved in size and quality. This trial demonstrates the complementary nature of sheep and cattle grazing. Cattle do not necessarily graze at the expense of sheep, but simply utilise more fully the forage grown. This simple fact was first demonstrated by the classical experiments of Gilchrist at Cockle Park (Johnstone - Wallace, 1950) which demonstrated that the per acre production of meat was greatest under a system of mixed stocking, and, moreover, that sheep grazed in conjunction with cattle made greater live weight gains than sheep grazed by themselves.

The advocates of 'mob stocking' and rotational grazing claim that they can maintain in good condition, and even improve their swards by this means without the aid of cattle.

The arguments used are that by crowding, say, 20 sheep on to graze one acre for a day they cannot afford to be so selective in their grazing as can one sheep when it has one acre over which it may graze for a long season. The competition between animals for the available food is such that palatable and less palatable species are grazed indiscriminately, for if an animal spends its time picking and choosing its species it may find that the available herbage has all been devoured by other animals before its appetite requirements are fully satisfied. Moreover, it is claimed that if unpalatability of plant species is partly a function of increasing age or maturity, there will not be such great differences in palatability between species which, under the ideal rotational grazing system, are no more than three to four weeks old at each grazing, as there would be between the palatable, heavily grazed species and the unpalatable, undergrazed species of the set stocking system. Therefore, to carry the argument full circle, sheep under a mob stocking system not only cannot afford to be selective in their grazing, but also will have less desire to exercise selection between species.

Cattle may be used in this system to help control spring flush growth, but their inclusion is minimal on account of their alleged unprofitability.

This system of mob stocking with sheep alone is, at the moment, less well recognised as a method of hill pasture control than is that employing cattle, and the only references to it under New Zealand conditions seem to be those by Linklater (1947), Lamont (1939), Hill (1949) and Livingston (1938) already cited in the section on stock management. Historically it is interesting to note the reference to a similar system of management, involving milch cows, made by Bishop (1839).

It is perhaps necessary to point out that there need be no real conflict between the two systems of mixed grazing and mob stocking if, in the course of time, each is proved to be equally effective in maintaining and improving hill pastures and the quality and amounts of animal products derived therefrom.

The system employing both sheep and cattle is essentially applicable to conditions where subdivision is poor and paddocks large, where, as explained in the previous section, strict rotational grazing may not be feasible. The system of rotational mob stocking, on the other hand, is only applicable on that easier and more productive hill country which is more closely subdivided.

Summing up the effect of kind of stock on the character of the vegetation, it would seem that the effect of the stock cannot be separated from the effect of the management of that stock. Management is probably more important in the maintenance and improvement of a pasture than is the kind of stock carried. A pasture may improve or deteriorate under a system where sheep alone are carried, depending upon how the sheep are graze managed. However, where strict control of sheep grazing is impracticable, some of the deleterious effects of set stocking with sheep alone may be lessened, perhaps even eliminated, by mixed grazing with sheep and cattle. In the final analysis, short term economic considerations are probably more important than any other in determining the kind or kinds of stock carried.

At the moment there seems to be no evidence that different classes of stock have different preferences for plant species, although different classes are capable of having different effects upon the pasture as a whole. The main difference is, of course, that of differing fertility drain between dry and wet stock, and between young stock and mature stock. This comparison has already been made (page 26). It merits repetition insofar as the continuous grazing of a pasture by milking stock or young growing stock is more likely to lead to pasture deterioration and an increasing predominance of lower fertility demanding species in the sward than will grazing by dry and/or mature stock. The tendency towards deterioration in the former case must be overcome by fertiliser application and other methods of enhancing fertility, previously discussed.

So far as breeds of stock are concerned, there is only the slenderest of evidence, though it is gained in the hard school of practical experience, that there is any difference in the use which different breeds may make of the pasture herbage. That evidence is contained in the fact (Fraser, 1949, (ii)) that low ground farmers in Scotland who winter hill country ewe hoggets, charge a higher price for wintering Scotch Blackface hoggets than they do for other breeds. They do this because they find that the Blackface grazes the sward more closely than do other hill breeds. It can be readily imagined that set stocking with this breed, without the intervention of cattle, would have more serious effects than would set stocking with other breeds.

It does not seem to be known whether or not there are differences between other breeds in the closeness of their grazing and the utilisation of their pasture. The matter, however, assumes importance when there is talk, as there is in New Zealand today, of introducing new breeds of sheep and cattle. Is the fact that three Cheviots can be run where two Romneys were carried before due to the inherent ability of the Cheviot to live, produce, and reproduce on a lower plane of nutrition than the Romney, due to the ability of the Cheviot to climb and forage with less expenditure of energy than the Romney, or does the Cheviot punish the sward more heavily, ingest a greater proportion of the herbage grown than the Romney? The answers to these questions may have important managerial repercussions.

Posing the reciprocal, it does not seem to be known if there are differences between breeds in their ability to thrive on the same type of vegetation. It seems almost certain that this is so. To take an extreme case, Hagedoorn (1947), speaking of the native 'Indian' sheep of Arizona, points out that these sheep are very small and hardy, and adapted to desert conditions by their small size: "One sheep weighing a hundred pounds has only one head and one set of legs; two sheep weighing a hundred pounds together have two heads and two sets of legs, so that they can be in two different places to hunt the scanty herbs, and for this reason in conditions where the sheep of fifty pounds can just live, a hundred pound sheep must necessarily starve".

Haldane (1946) suggests the possibility of his Type 2 interaction being applicable in this case. The interaction

	X	Y
A	1	4
B	2	3

may be interpreted in more concrete terms:

	Good environment.	Poor environment.
Aberdeen Angus	1	4
Galloway	2	3

the interpretation being that under conditions of good environment the Aberdeen Angus will produce more beef than the Galloway, which cannot respond so favourably to a good environment. Under conditions of poor environment, however, the Galloway outyields the Aberdeen Angus, being more resistant to adverse conditions.

It is conceivable that interactions of this sort exist between breeds of stock in relation to good and poor pastures. For the moment we can only guess at them, or accept as evidence the inexplicable finesse of farmers' preferences.

IV. <u>Economic Aspects.</u>

A discussion of the economic factors which affect, of which may in the future affect the kind, class and breed of livestock carried on New Zealand hill land is really outside the scope of a treatise such as this, and beyond the ability of the writer to deal with in more than lay fashion. However, it was claimed earlier in this section that the factor deciding the kind or kinds of stock carried (and the same might be said of class and breed of stock) was, in the final analysis, probably economic. The picture would be in no way complete if an attempt was not made to look at it through the eyes of the economist, and to attempt not only to see, but, more important, to foresee the effect which economic considerations have upon New Zealand hill pastures, by dictating the kind, class and breed of stock which it is most profitable for them to carry.

Belshaw (1936) (ii) tracing the rise of pastoral farming in New Zealand, emphasises the suitability of the country for pastoral pursuits. Fawcett (1930) gives the stock figures for 1853 as follows:

Cattle - 35,000

Sheep - 300,000.

Later, between 1870 and 1880, Belshaw observes that beef, mutton, butter and cheese were a hopeless glut on the almost entirely local market. By 1881 the stock figures were:

Cattle - 700,000

Sheep - 13,000,000

This was an increase over 1853 of 20 times in the number of cattle and of 43 times in the number of sheep, emphasising that wool, hides and tallow were the most important marketable commodities, and of these wool was the chief. This fact is demonstrated very clearly by Hamilton (1947) in the following table:

Value of the Principal Exports of New Zealand 1853 - 1903 (in thousands of pounds sterling.)

	1853	1863	1873	1883	1893	1903
Wool	67	830	2702	3014	3775	4041
Tallow			67	234	184	518
Frozen Meat				118	1085	3197
Butter				42	255	1318
Cheese				7	100	195
Grain	19		136	1287	583	534
Gold		2432	1987	892	916	2038

Even 20 years after the introduction of refrigeration wool was the chief export from a money value point of view.

It is difficult to assess whether biological or economic factors were the most important in deciding that the Merino sheep should predominate in those early days of the settlement. Certainly the dry conditions of the South Island tussock country suited the Merino; its gregarious habit was valuable in an unfenced country, and especially where predators such as keas were numerous; its ability to travel long distances was equally valuable where runs were of vast acreages. But in a country whose chief export was wool it was natural that the thoughts of the early settlers should turn to the animal which gave the highest priced fleece. In this the Merino admirably suited the prevailing economic conditions, while being to a large degree in harmony with the prevailing biological conditions.

As the bounds of pastoral settlement were pushed beyond the Canterbury plains and Wellington province into the wetter districts, the adaptation of the Merino to the changed biological environment was found to be less. "It was soon found that the wetter climate of parts of the North Island did not suit this breed (the Merino) so well as many districts of the South Island" (Duncan, 1945) (i).

The replacement of the Merino in the North Island by the Lincoln, and English and Border Leicester breeds is another interesting study of the interaction between the economic environment of the times and the biological environment of the particular farming district. Economics still demanded wool, and what the Lincoln lost in quality it made up for in bulk, being the heaviest woolled of any British breed. Moreover, the breed used had to be suited to the wetter conditions of the North Island, while its wool had to be able to withstand the physical abrasion and plucking effects of rough logs and the like, encountered after a bush burn.

In the South Island the Lincoln - Merino cross was evolved to cater for both the wool and mutton markets, the latter expanding rapidly after 1882 when refrigerated transport became a practical proposition. James Little set about breeding his Lincoln - Merino inbred half-bred - the final Corriedale - in 1878. It therefore coincided well with the newly developed market in the 1880's as well as possessing the advantage of having been bred and selected under the environmental conditions in which it was to be kept Little's earlier attempts at Corriedale breeding probably catered for the economic demands for meat subsequent on the gold rushes in Victoria (1851) and in New Zealand (1861) which markedly increased the human population.

At this time, too, the Romney Marsh breed, first introduced in 1853, spread widely throughout the North Island Although there were only 51 Romney flocks recorded when the New Zealand Sheep Breeders' Association was formed in 1894, and only 78 flocks in 1904 on the formation of the New

Zealand Romney Marsh Sheep Breeders' Association, it is probable that Romneys were widely crossed with Lincolns and the latter graded up to the former breed.

The expansion of the Romney stocks, too, has met the demands of the economic situation to a large extent. In times of international crisis the coarser Crossbred wools are more nearly on a par with the Merino and Half-bred wools so far as price is concerned. The Romney has lower nutritional requirements than the Lincoln, and the Romney lamb is acceptable to the export trade, (especially if the ewe is crossed with a Down breed ram) so that fat lamb production has become an enterprise within the scope of farmers on the easier hill country. This is an important influence in stabilising the economy of the hill farmer, and as such merits further consideration.

Andrew and Soler (1947) quote average prices for store and fat lambs for the years 1938 to 1946 showing how "the increased price of fat stock has not been paid to the producer of store stock". It would be reasonable to expect that a proportion, at least, of this increased fat stock price would be passed back to the store producer in the price which the store stock buyer would be willing to pay. This has not always been the case, with the result that the incomes of store stock farmers have fluctuated more widely from year to year than have those of the fat lamb producer

<u>New Zealand, Average Prices - Stock Firms' Sheep.</u>

<u>Feb.</u>	1938	1939	1940	1941	1942	1943	1944	1945	1946
Store lambs	16/3	13/-	16/6	16/6	17/9	16/3	17/6	20/6	18/6
Extra prime Lambs.	25/9	22/6	28/1	27/3	25/9	27/-	29/6	32/-	31/9
<u>March.</u>									
Store lambs	16/-	10/9	19/3	15/6	18/6	15/6	18/6	21/-	19/3
Extra prime lambs.	25/9	23/6	27/3	27/9	27/1	27/3	29/6	32/-	32/9

Any uncertainty in the market is automatically passed back to the store stock producer on the hills. This can be seen in March 1938 and 1939. Between one year and the next the store price fell by 5/3, while the fat price rose by 6d. Within any one year the same sort of thing happens. In 1939, between February and March store prices fell by 2/3 and fat prices rose by 1/-. In 1941 and 1943 a similar state of affairs obtained. The adage about swings and roundabouts could equally truthfully be voiced, for in many years the opposite trend can be seen, as in 1940 when store prices rose by 2/9 and fat prices fell by 10d., and again in 1944 and 1945 when the store farmer benefited from the market.

The important fact remains, however, that the store lamb market tends to be rather more uncertain than the fat lamb market. This uncertainty must inevitably lessen a farmer's willingness to undertake capital improvements or even necessary maintenance. His market is unstable, he cannot depend upon his income. This argument applies less in times of high wool prices than in times of low prices for that product. The argument, however, remains that price instability must react unfavourably on capital invested in the land, and the further the store stock farmer can encroach upon the domain of the fat stock producer the more stable will his price and, therefore, his income become - provided over production does not ensue.

A means of achieving this increased stability by entering the fat lamb trade may result from the work being undertaken with the Cheviot breed. A table showing the disposal of wether Romney and Cheviot Half-bred lambs as fats and stores is shown in Appendix I. (from Peren, 1951). This shows that over the six seasons of the trial the Half breds averaged 95.9% fats, and the Romneys 59.5%. The Half-breds averaged 34.4% fat off their mothers, and the Romneys 16.3%. It is not suggested that these results were obtained under really difficult North Island hill conditions. The hills at Tua Paka on which the trials were carried out would probably be termed moderately hard. Even so the comparative percentages of lambs sold fat off their mothers or later fattened are important.

If, by extending the fat stock markets' relative stability into the more difficult hill country the hill farmer's income could be made more certain, then it would be reasonable to expect a greater expenditure upon maintenance and improvement work, some of which would directly benefit the hill country pastures.

The final important consideration insofar as breed of sheep is concerned is the necessity to attempt to foresee possible future changes in demand and the means by which New Zealand farmers should prepare now to forestall any reduction in their incomes which might result from changed demands coming upon them unexpectedly. In this respect the New Zealand sheep farmer must first be prepared to give thought to the question: Which ovine product, meat or wool, is going to provide the most stable and permanent market in the future?

The answer to this question opens up the whole subject of the competition between wool and synthetic fibres. The extent to which the latter will replace the former is still a matter for much speculation. It is unlikely that many would endorse the sanguine viewpoint of White (1947) when he says "There is nothing that will really take the place of wool. I think a minimum price of wool can be kept", if the implication is that no substitute will be found for wool and that the "minimum price" will also be an economic one at which to produce wool. At the moment this may be largely true, but it would be very wrong for wool producers to assume that this will remain the case for long. Duncan (1945) (ii) wisely points out that, "Sheepfarmers can no longer afford to ignore these new fibres, and merely rest on their laurels with a false sense of security in the knowledge that 'wool is best'. That slogan remains true, but by an ever-diminishing margin". The formation, in 1937, of the International Wool Secretariat was due to the recognition of the threat presented to natural wool by synthetic products, one of which - artificial silk - had by that time broken the textile market for lustre wools. By 1940 synthetic fibres were equal in total production to clean scoured wool, 2,500 million pounds of both being produced in

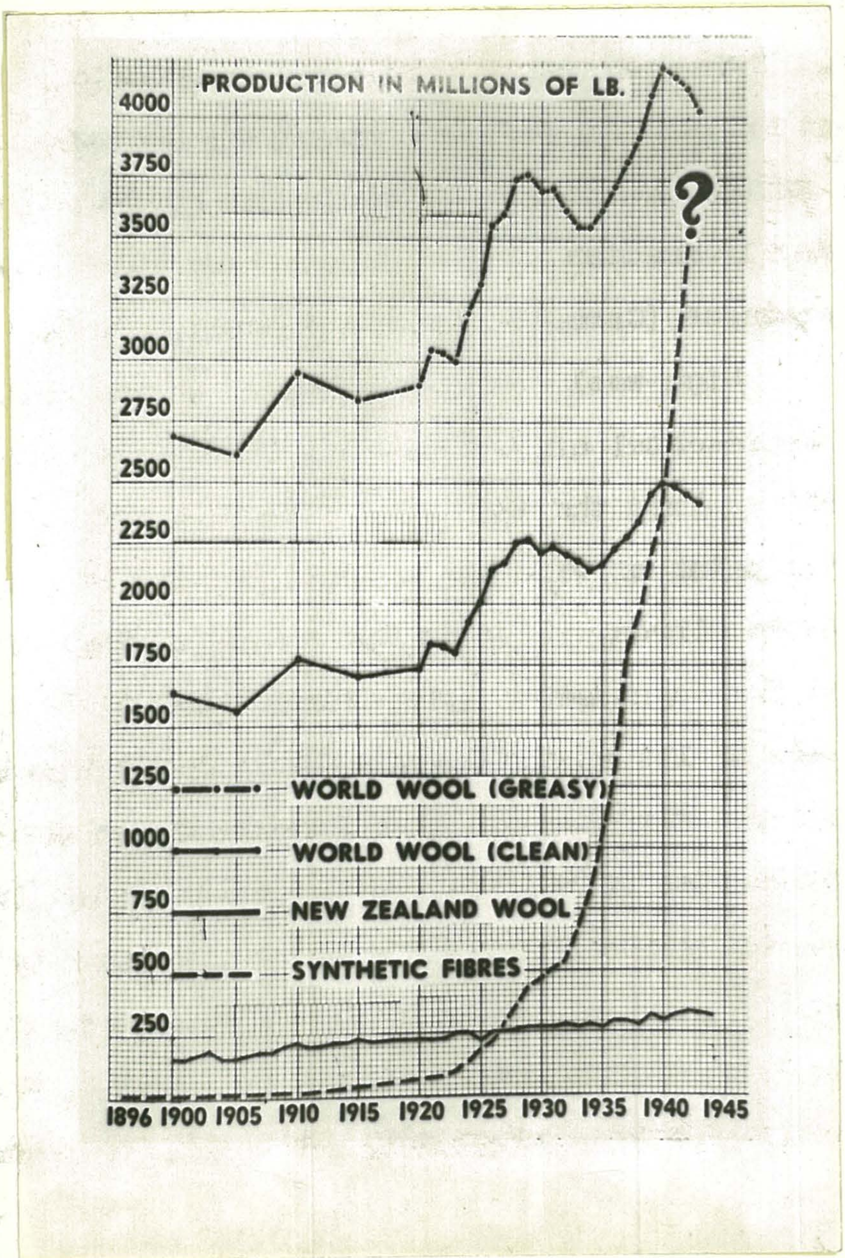


Figure XVII. World production of synthetic fibres compared with World and New Zealand wool production. (Duncan, 1945)(ii).

that year. The trend in subsequent years is indicated in Figure XVII , page 115a.

Synthetic fibres have already replaced wool in many fields such as women's hosiery, underwear, lining materials for suits and coats, furnishing textiles and the like. The much voiced claim that synthetic fibre clothing is not as wasm as wool has recently received a set-back by news of the manufacture of nylon fur flying suits for use by the Royal Canadian Air Force in Alaska under sub-zero temperatures (Canadian Textile Journal, 1950).

High wool prices such as at present exist have a dual detrimental effect upon the future wool market. They greatly enhance the competitive position of synthetics from a price point of view and intensify research for improved synthetic fibres, while at the same time they make the threat from synthetics less obvious than it is in times of moderate or low wool prices. The present high wool prices are undoubtedly the result of increased demand arising from world shortage of all fibres, and from international tension. The possibilities of either situation ending are highly speculative, but no matter what the changes in world fibre supply or world diplomacy may be, the possibility of synthetic fibres detrimentally affecting the position of those New Zealand hill farmers whose economy is based on the sale of wool can readily be visualised.

As yet there is no competitive substitute for meat except cheese, and the competition between cheese and meat as a source of edible protein is more a hypothetical concept of the economist than it is real.

The New Zealand hill farmer should then realise, despite the overwhelming importance today of wool in his economy, that from a long term point of view he would probably be wise to concentrate on the production of mutton and lamb, or at least be prepared to turn to that form of production if and when the profitability of wool declines.

In this connection the Massey College Cheviot and Half-bred trials are important. The latest figures show

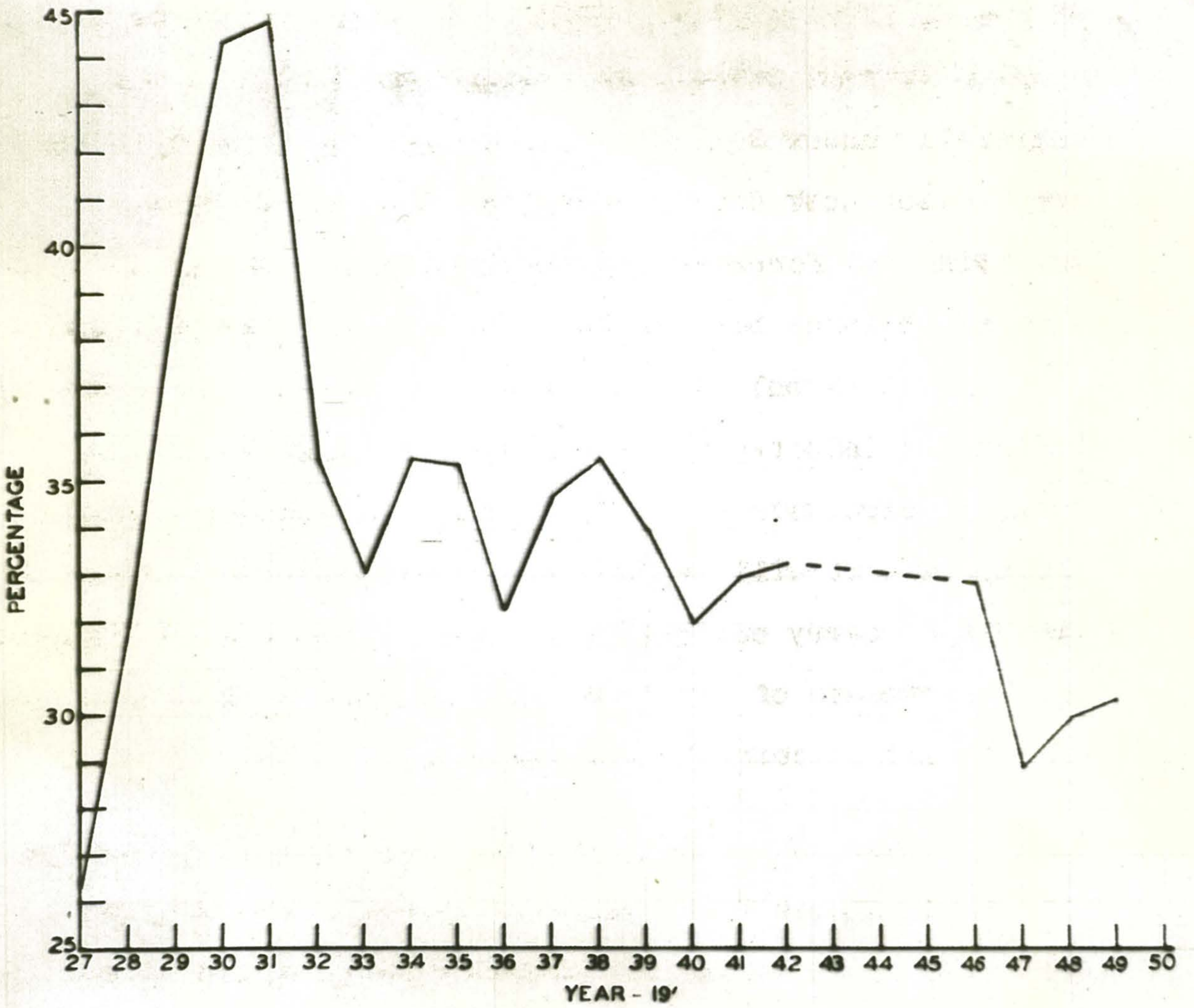


Figure XVIII. Steer and bull calves under one year old, expressed as a percentage of the potential female breeding stock.

that the Cheviot - Romney Half-breds, on account of their high lambing percentage, are only less profitable than the Romney in times of high wool prices such as exist at present. In times of more normal wool prices the average Romney ewe earned considerably less than the average Half-bred. (Appendix II from Peren, 1951). It may be that the Cheviot is not the most satisfactory breed that could be used, especially under South Island conditions. Nevertheless, the Cheviot work demonstrates very clearly one means of combating and forestalling possible future changes in the economic balance between meat and wool in the sheep industry.

It is only by maintaining this sort of flexibility within the industry, thus enabling it to meet changing economic circumstances without too much loss in earning power, that it will be financially possible for individual farmers to carry out the maintenance and improvement work in all departments of their farms, inclyding the pastures which are of most concern in this context.

Just as in the sheep industry the market for the mature wether has declined under pressure from the ewe and fat lamb, so in the cattle industry short term cash economies make the selling of young stock more profitable than retaining them to an older age.

Figure XVIII on page 116 a, compiled from the Agricultural and Pastoral Statistics, gives some indication of this trend. The number of steer and bull calves under one year old expressed as a percentage of beef cows and heifers two years old and over has declined from a peak of 44.86% in 1931 to a minimum of 28.9% in 1947. This might be an expression of declining fertility in beef cows, but there seems no other evidence of this. It might also be due to changed breeding management, as, for example, taking a calf from females only every second year, as is done on some of the more difficult hill country. It is more probably an indication of the increasing extent to which young stock are slaughtered. This in itself indicates a source of potential

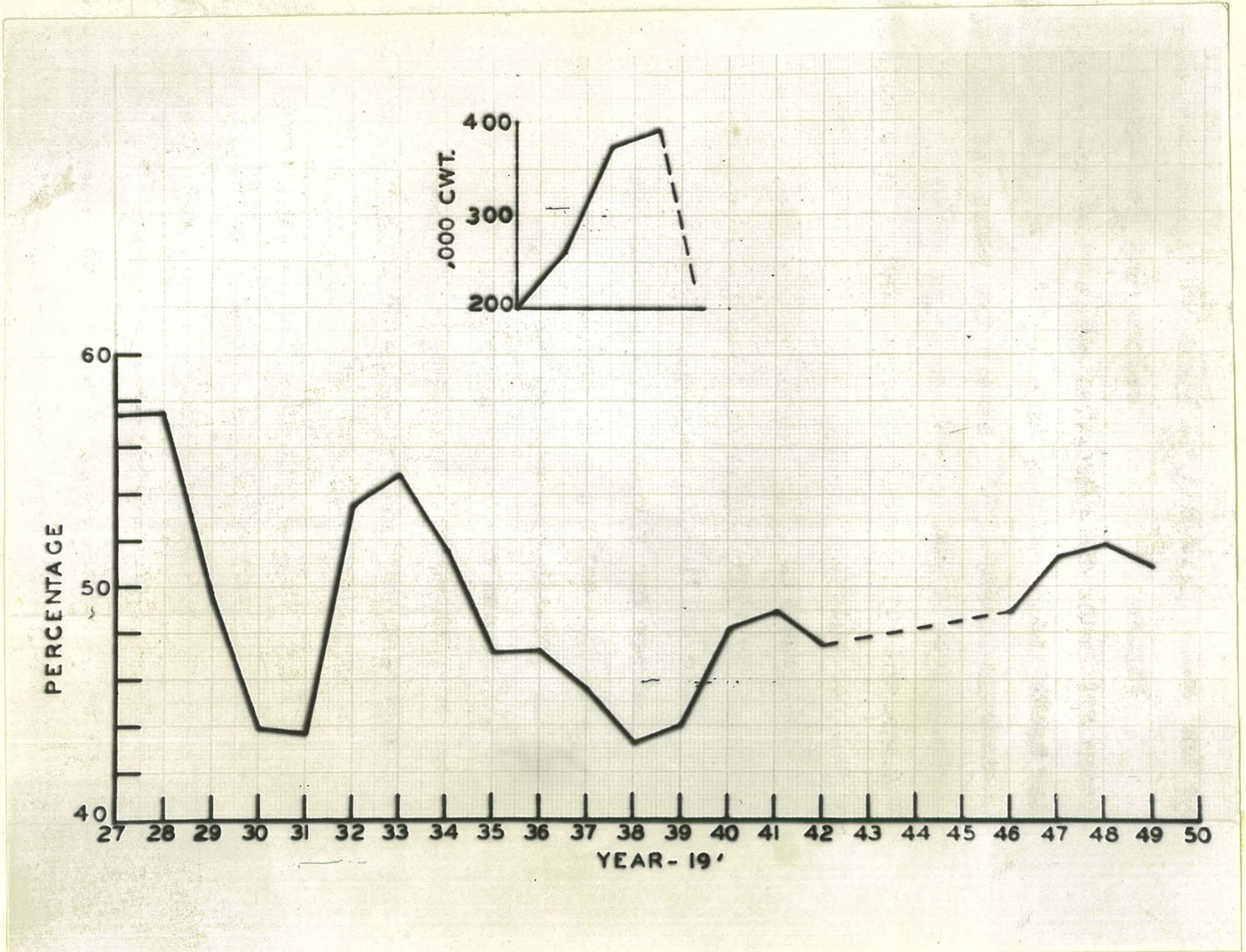


Figure XIX. Percentage of steers and bulls two years old and over sold for slaughter between 1927 and 1949.

fertility drain from the hills, to which must be added the fertility lost from the hills by the sale of young stock to the low ground fattener for which no figures are available.

Figure XIX page 117a showing the percentage of steers and bulls for slaughter which were two years old and over again indicates this tendency to sell steers at an increasingly early age. Steers two years old and over decreased from 57.5% in 1928 to 43.3% in 1938. The effect of excessive selling of dry stock during the slump is evident, and but for this the decline from 1928 to 1938 would probably have been gradual. The situation improved during the war years, but by 1949 the graph had again turned downwards.

The selling of stock at an earlier age means a more rapid turnover for the farmer, and presumably a greater profit from the cattle. At the same time it is the mature cattle beast which is most capable of controlling rank herbage, fern and secondary growth, so that from the point of view of hill pasture improvement the selling of more young stock, or the selling of stock at an increasingly early age is to be deprecated.

It seems probable that the low percentage of older steers slaughtered in 1938 was in some measure a reciprocal effect of the expansion of the chiller beef trade, a graph of whose exports is superimposed on Figure XIX in the appropriate time position. The chiller beef trade demands stock fattened at younger ages - up to 2½ years - and lighter weights - 500 to 600 lbs. At the moment these requirements can only be met by farmers on low country or on the easier, more fertile hills. The extent of chiller beef production might be increased by introducing a breed such as the Galloway which, though slow maturing, is capable of producing quality beef under hard conditions.

It is interesting to speculate, for we can do no more, upon the fate of New Zealand hill country if cattle cease to be regarded as an animated range of implements, and become a really economic product. Present prices for beef cattle make farmers more loath to abuse them as fern and scrub crushers. Will this hasten reversion on a large area of New Zealand hill country? Again, if chilled beef production were to develop and, through the use of other breeds, to extend the range of conditions under which this enterprise could be carried out, would the botanical composition of the hill pastures improve out of all knowledge due to the increased cattling, or would there be an even greater drain on soil fertility (remembering the complementary nature of cattle and sheep grazing) than there is by the present selling off of lambs, wool and store stock, so leading to deterioration and the necessity for still higher applications of fertilisers?

These, then, are among the factors which must be considered when changing economic circumstances demand changes in the kind, class and breed of stock carried on New Zealand hill country.

J. GENERAL IMPROVEMENT ASPECTS.

In earlier sections of this dissertation reference has been made to climatic and anthropogenic influences upon hill land vegetation. For the sake of continuity, and since some of these influences were considered subsidiary to the main theme, it was decided to post-pone full discussion of them until a later section. Burning of rough growth is a common method of pasture control, and there are many claims for and against; stock control has been emphasised as being essential if sward improvement is to be carried out; scrub and secondary growth control has been recognised as a primary consideration in hill land improvement; tree planting has been cited as a possible means of altering, to the benefit of the tussock grasslands, the microclimate of their habitat. For the sake of completeness it seems desirable to consider these more general aspects of improvement in this final section.

I. The Effect of Burning upon Pastures.

Pasture burning in New Zealand is a practice for the most part confined to the tussock grasslands of the South Island, although it has been used and is still used in parts of the North Island to burn off rough herbage. However, with improved stock management practices and the carrying of more cattle it is becoming less frequent in the North Island. The detrimental effects resulting from the burning of the tussock grasslands have led to the practice being widely deprecated, irrespective of the conditions under which it is carried out. Phillips (1936) has called fire in vegetation a good servant but a bad master, the implication being that when controlled and used with discretion it can be of value.

The effects of fire are twofold. It has a direct effect upon the plant, and an indirect effect through the alteration which it brings about in the habitat.

(a) Direct Effect upon the Pasture.

The direct effect of burning seems to be imperfectly understood, and in many cases it is difficult to divorce the direct from the indirect effect.

The removal of dead vegetation is the most obvious direct effect. Annual grasses and herbs may be prevented from setting seed or may have their seed crop destroyed before it is shed. Provided this does not take place annually, however, regeneration will probably take place from seed shed in previous years.

Certain species seem particularly sensitive to fire, while some are not injured at all. Garber (1926) reports the harmful effects of burning upon bluegrass (Poa pratensis), whereas on Kansas pastures Hensel (1923) found that the grass species increased 21% after four years of burning. However, it seems that the effect upon the individual grasses may be a compound interaction between species and rainfall or effective precipitation, as indicated by Sampson (1923) (iii), who found that under drier conditions than those pertaining in Kansas burning was almost as destructive to range grasses as to forest trees.

Burning, too, may stimulate the production of large quantities of seed, as was found by Burton (1944) working with Bahia grass (Paspalum notatum), Bermuda grass (Cynodon dactylon), ribbed paspalum (P. malacophyllum), and the same is true of Aristida stricta and the dropseed (Sporobolus curtissii) (Daubenmire, 1947,i). This type of response could be of value in assisting the dissemination of existing or introduced species.

In some instances the burning of grassland gives earlier spring growth (Hensel, 1923), but this, again, may or may not be due to the direct influence of the fire.

(b) Indirect Effects upon the Pasture.

These are probably more important than the direct ones, and certainly are more readily recognisable. The effects stem from the differential susceptibility of species and from the effect of the fire upon the soil.

Woody shrubs tend to be more susceptible to fire than grasses, and fire may be used to remove the competition which they offer to grazeable species. The burning of sagebrush (Artemisia tridentata) ranges in the intermountain regions of

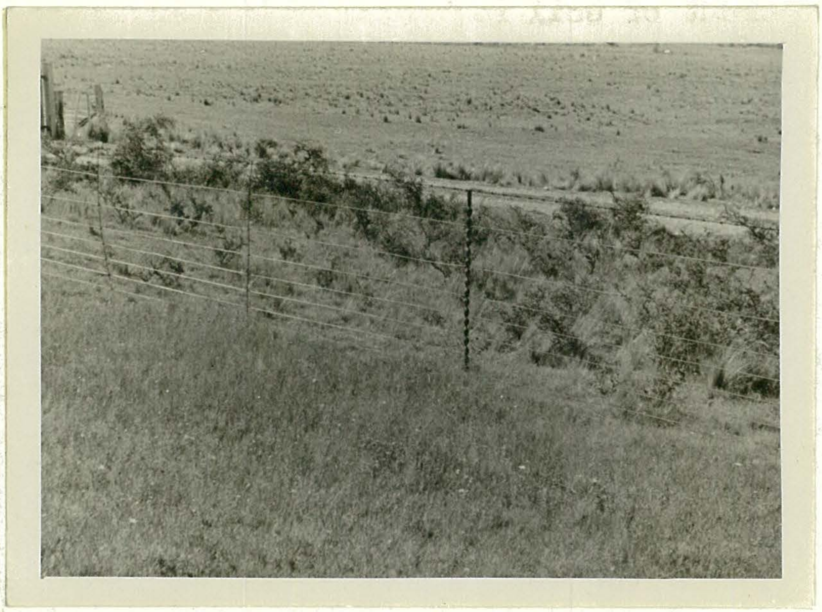


Figure XX. The effect of continuous burning on tussock grassland vegetation.
The sward in the foreground adjoins the railway line near Cass Station, Canterbury, and is burned annually to lessen the fire danger to the surrounding country. It is dominated by browntop, but an occasional blue tussock (Poa Colensoi) is also to be found. Beyond the railway fence the unburned grassland is dominated by hard tussock, and matagouri is much in evidence.

Colorado is a case in point (Hanson, 1929), and the same type of control is noted by Cumberland (1944) in the tussock grasslands of the South Island. Again, as indicated previously, there are differences between species of grasses in their susceptibility to fire. Those species which are less susceptible will be favoured. Provided they are likewise favoured as stock feed, periodical burning may lead to improvement (Figure XX, page 121a).

While forest fires may lead at least to a temporary enhancement of soil fertility by the addition of minerals in the ash and the increased nitrification resulting from the increased pH, it is doubtful - though no figures seem available - if the burning of grassland has any considerable effect in this direction.

Fires of this nature will seldom reach the intense heat necessary to destroy an appreciable amount of the organic matter in, or even on the surface of the soil. The fact remains, however, that continuous and periodic burning will deplete the soil organic matter reserves by depriving them of the replenishment which the burned off, dead leaves and flower stems would normally provide.

Burning off the dead vegetation allows more light and heat energy to reach the ground surface. The light factor alone is important in aiding the germination and subsequent growth of heliophytes. The increased total energy reaching the ground surface enables the soil to heat up more rapidly and to reach higher temperatures than under a close vegetative cover. This may partly explain the earlier spring growth after burning (Aldous, 1934). It will also result in more rapid and complete desiccation of the upper soil layers (Daubenmire, 1947)(ii), a factor which may well be in part responsible for the induced steppe nature of the tussock grasslands of the South Island.

At the other end of the temperature scale, temperatures will tend to fall lower and more rapidly once the soil surface has been partially denuded by fire. The effects of this may not be so damaging as those of increased temperatures, although such things as increased frost heave may be envisaged.

The baring of the soil surface has the further detrimental effect of enhancing the chances of erosion during heavy rainfall. This is allied to the terminal velocity of the raindrop which strikes the soil surface without first having its fall broken by vegetation, the compaction of the soil surface so caused, and the concomitant increase in run-off on sloping ground. The point is ably demonstrated by Campbell, (1945) in the following table:

Comparative Trials on the Influence of Burning on Run-off and Soil Loss.
(Rain, 3 inches per hour: Slope 16°)

Soil & Vegetation	Unburned.		Burned.	
	Run-off %	Soil Loss Tons/Acre	Run-off %	Soil Loss Tons/Acre
Matapiro type: Lightly grazed danthonia	32.2	0.01	52.5	0.83
Waiwhare type: Manuka and tutu	-	-	56.0	1.45
Gisborne loam: Danthonia pasture	21.4	0.02	33.2	0.48
Weber loam: Danthonia pasture	34	trace	54.4	1.01
Rondzina soil: Rank pasture	2.5	-	22.4	0.86
Matapiro loam: Manuka scrub	-	-	44.8	1.24

Season of burning also has a profound influence on the effects, deleterious or otherwise, upon the pasture. In Kansas grasslands, Aldous (cit. supra) found late spring burning most detrimental, and early spring burning intermediate in effect. Burning at a time such that the soil was left exposed during periods of heavy rain or intense heat and drying winds would have subsidiary detrimental effects.

It is perhaps because the burning of New Zealand tussock grasslands has exposed them to the full and deleterious effects of these last-mentioned factors that the practice of burning has fallen into disrepute in this country, for until recently there has been no work of a positive nature to demonstrate the effect of fire upon the tussock species. The measurements taken by Sewell (1948) are the first attempt to apply scientific method to the problem, and as such are to be applauded. His nine conclusions are worthy of full quotation:

"1. Burning partly kills the tussocks.

2. It is more severe on fescue tussock (Festuca novae-zealandiae) in dry areas than in damp localities.

3. It is less severe on silver tussock (Poa caespitosa) which usually grows in damp localities.

4. It is least severe on blue tussock.

5. Burning removes the protection of the old leaves and permits stock to graze on the new leaves.

6. It removes from the base of tussocks the dead material which forms humus and protection for the germination of seeds.

7. It reduces the growth of leaves.

8. It reduces the production of seed.

9. It is suggested that it may be two or more years before the microclimate re-develops suitable for the germination of seed. "

Despite any short-term advantages which burning may bring about, for example increasing the palatability of the tussocks (and thereby, incidentally, hastening their destruction) there seems little doubt that the constant burning of New Zealand's tussock grasslands denys that principle of usufruct upon which all good farming should be based.

Nevertheless, as has been demonstrated, mainly by workers in the United States, the effect of burning depends upon the species comprising the sward, the time of year at which the burn is made, the climate of the region, the effect upon the microclimate of the pasture, and many other imponderables, thus ruling out any possibility of generalisation Yet, if nothing more may be said it seems certain that burning is wasteful of the production potential of the pasture. The writer is quite unable to compete with Butler (1863) (ii) in the literary expression of this sentiment. "The day will come when you have no more occasion for burning, when your run will be fully stocked, and the sheep will keep your feed so closely cropped that it will do without it. It is certainly a mortification to see volumes of smoke rising into the air, and to know that all that smoke might have been wool, and might have been sold by you for 2s. a pound in England". How much more mortifying when it might have been sold for 20s. a pound!

The alternative to burning is better utilisation. This will involve the carrying of cattle, and some form of stock control (the subject of a subsequent sub-section). Some runholders on this class of country are already carrying cattle, and find that this allows a reduction in the amount of burning necessary (Cumberland, 1945) - though the writer would dispute Cumberland's suggestion that "the Aberdeen Angus is the Merino of cattle", and would suggest that a search of the world's cattle breeds would provide a better answer.

Outside of the tussock grasslands there should be no need to regard fire as a normal implement in the control of pasture 'per se' provided stock, both sheep and cattle where need be, are controlled in their grazing. In the tussock grasslands fire must become much less regarded as a normal implement for pasture control, indeed the need for its abandonment altogether is more urgent here than elsewhere if the "consumption" and "profligate waste of the earth", so deplored by George Marsh, almost a century ago, is to be halted.

II. Tree Planting.

Space planting of trees is suggested as a means of erosion control in the hill country of the North Island, and as such is outside the scope of this thesis, but the tree planting herein advocated is primarily for another purpose, though as an erosion abater it would no doubt be of immense value. A plea was made earlier, in the section concerned with the recent ecological history of the tussock hill country, for the wider recognition that the depletion of the tussock grasslands stems, to a large extent, from the modification which farming practices have brought about in the microclimate of these grasslands. Further, the writer has been impressed by the similarity between the climatic regime prevailing over large parts of these grasslands (42° - 46° S. lat.) and that prevailing in the Lombardy Plains of northern Italy, the home of the original föhn winds, where temperatures are high in summer (July 76° avge.) and low in winter (Jan 36° avge.) and the rainfall only moderate (Milan - 45°28' N. lat - avge 40 inches, summer months of July, August and September 2.3, 2.8 and 2.0 respectively). Much of the tussock grasslands lie within the 30-50 inch rainfall belt, January temperatures average 60° - 62° F. and July temperatures 42° - 45° F. Admittedly the Lombardy Plains are formed from rich alluvial soils, but that fact alone would not permit them to become the granary of Italy were they not protected from desiccating winds and temperatures by a 'top storey' of space-planted trees

The writer feels that therein lies a most important lesson for the tussock grassland pastoralist. That trees such as Pinus radiata and species of gum can be established in these grasslands even under most unfavourable conditions was demonstrated by Cockayne thirty years ago (Tennent, 1935). Nor will the fact that they can so alter the microclimate as to permit good grass growth require long years of trial to demonstrate. The tree-sheltered in-bye paddocks and lawns of many a High Country homestead bear witness to the fact. The magnitude of the task may beggar the imagination, but its value may equally be beyond comprehension. It is certainly one which should exercise the minds of runholders, and one whose execution they should begin to undertake with that same annual regularity as they at present undertake dipping or shearing. It should, in fact, become a part of the work of the station to space plant as large an acreage as possible each year with trees.

III. Methods of Stock Control.

In several previous sections of this thesis reference has been made to the necessity for adequate control of stock on the hills if pastures are to be improved, and utilised to the best advantage. If that tenet be accepted, possibilities for achieving it must be studied.

Fencing is the normal method of stock control in New Zealand. On the basis of 1949 costs - an example of which is given in Appendix III - the Committee appointed to report on the sheep industry placed the cost of the normal post and wire fence at £500 per mile, or about £6. 5. - per chain. Any comprehensive subdivision by this means would place a heavy capital burden on an extensive pastoral run. An adaptation of this normal method has been evolved by Hunter (Holden, 1950) in an attempt to reduce costs. The Hunter fence reduces the number of posts from 5 per chain to 2 or 3 and replaces battens by galvanised chains. The cost of materials and erection is computed at £374 per mile (see Appendix III) and the added advantage is claimed that maintenance costs are lowered, and the fence is more durable than the normal 8-wire, post-and-batten fence. The stock holding ability of the fence is claimed to be as great or greater than the conventional type. Even at the price quoted, this fence is still expensive, while both the Hunter and conventional post-and-batten fences suffer from limitations which a difficult terrain necessarily imposes. The chief of these is the difficulty of finding a stable fence line. This difficulty is frequently greatest on that country most requiring stock control, for where, in the past, control has been inadequate, the onset of slipping, slumping and flow erosion may have made a stable fence line impossible to obtain. While these more conventional types of fence should perhaps be an ultimate objective, and investigation into the problems of using cheaper and/or more durable alternative materials, (the use of concrete posts and the like), simplification of erection, simplification of transport of material to the site (perhaps by helicopter) should be pursued, the difficulty of finding a suitable fence line on much hill land, and the capital cost involved must inevitably restrict their use.

A further means of stock control, even under extensive pastoral conditions, is the electric fence. This has been tried out on hill country farms in New Zealand (Elliott, 1940) and the success obtained would seem to merit much further investigation. Several of the farmers whom Elliott quotes found the electric fence extremely satisfactory for controlling both cattle and sheep on hill country. The chief feature leading to success seems to be the use of three strands of barbed wire, and to undertake a certain amount of training of sheep - preferably when they are passing through the yards after shearing - in order to develop the necessary mental reaction to the wire.

Estimates of cost in 1940 showed electric fences to be only 20% of the cost of a conventional 8-wire post-and-batten fence. These fences are used to some extent on the range lands of the United States of America, the cost in that country being less than 1/6th that of a conventional 4-wire barbed fence (Ares, 1939).

Drawbacks, such as the tendency to short, and replacement cost of insulators, may increase maintenance costs, but even over a long period these should not destroy the economic advantage which this type of fence has over the conventional type. Mechanical defects seem largely to be a matter of faulty construction or erection which experience and technical advance will eliminate (Brooks, 1939).

The American method of controlling grazing by herding may be deemed impossible on account of the expense involved and the difficulty of procuring labour, but another American method of stock control merits mention and might have some applicability in the tussock grasslands of the South Island. This method depends upon the desire of stock for salt "One of the most effective methods of managing range livestock to ensure proper range use and greatest gains is proper salting" Stoddart & Smith, 1949) (v). The method consists of establishing salt feed lots in those areas of the range which it is desired to graze, at the season of the year it is desired that those areas of the range should be grazed. The flock or herd tend to keep in the vicinity of the salt feed until it is consumed. By equating average rate of salt consumption with the amount of feed estimated to be available from the range, both the extremes of overgrazing and under-grazing can be avoided, for if the estimates are reasonably accurate, by the time the salt is finished the range in its vicinity should be moderately well grazed, and if the stock do not move on to the next salting site of their own accord they can be readily mustered and driven there.

It is at best an inaccurate means of stock control and distribution over the range, but it has the advantage of cheapness (part of the small cost may be offset by greater stock thrift), and in the absence of any other method of controlling grazing it might well be worthy of a trial in New Zealand.

IV. The Control of Secondary Growth.

Secondary growth as applied to hill vegetation is an ill-defined term. The writer understands it to be non-pasture vegetation which forms a later stage in the succession towards the forest climax than the pasture species.

With this definition in mind, and bearing in mind the previously defined concept of the ecological survival range of plant species, the principles underlying the control of secondary growth become more apparent. If left undisturbed by anthropogenic influences, the hill pastures over much of the North Island, except perhaps in the drier parts of Hawke's Bay and the Wairarapa, and in the South Island those tussock grasslands, won from forest, abutting on the central dividing range, would revert through a scrubby form of secondary growth to the original type of forest which formed the climatic climax in these regions. The same, however, is true of almost every low ground pasture, at least in the North Island. There, too, the climax vegetation is forest. Yet, while the climatic influences which lead to the regeneration of forest are similar on low country and hill country alike, the former is much less subject to reversion than is the latter. The principles of control of secondary growth must be sought in the non-climatic differences between these two classes of country.

The low ground, being the first settled, has been in grassland for longer than the later settled hill country, and it may be assumed that there are fewer viable seeds of secondary growth species in the soil underlying these swards.

This assumption, however, merits further proof since it is known (Chippendale and Milton, 1934) that seeds may remain viable for very long periods, especially in water-logged soils. These workers found seeds of certain species to be viable after being buried for 68 years. Nevertheless, the foregoing thesis may be accepted since most hill land contains pockets of secondary growth which maintain the supply of second growth seeds and spores to the adjacent country.

The first principle, then, would be to eliminate as many as possible of these sources of infection by mechanical scrub clearing, by biological control as in the case of manuka (Hoy, 1949), or by the use of weed killer sprays (Matthews, 1950). At the same time care must be taken to ensure that the ground is reclothed by desirable species of grass and legumes, otherwise erosion or reinvasion by scrub species will automatically occur. Where pasture species cannot be usefully introduced, or where they cannot be grazed once introduced, there is a strong case for replacing the secondary growth by the final tree stage of the succession. Planted trees will themselves control the scrub, but will not form a menace to grassland, for although they may shed seed, these are unlikely to become established and grow except in the shade of secondary growth species.

There are other fundamental differences between hill and low country such as slope, elevation, differing rigour of climate, varying soil type, which may broadly be said to add up to a different fertility. These factors allow the low ground to grow a denser and more productive sward than hill country. Levy (1933) believes this fact of sward density to be important in secondary growth control. His contention is that a weak, open sward, by allowing light to reach the soil surface, encourages the growth of secondary growth species. Shade inhibits this process. Again, Levy (1948) believes the productivity of the sward to be important insofar as it permits heavier stocking per acre, and claims that until hill land can be made to carry 3 to 4 sheep per acre there will be a constant struggle against secondary growth. Whether Levy regards this carrying capacity to be important 'per se', i.e. from the point of view of the mechanical damage which will, with this intensity of stocking, be done to young, establishing secondary growth species, or simply believes that a sward of this carrying capacity will provide sufficient ground shade to inhibit scrub growth is not clear. The latter is probably more true, though sheep do a considerable amount of mechanical damage to certain scrub growths, notably gorse.

The second principle would seem to be to enhance hill soil fertility to such an extent that, despite adverse climate, slope, and elevation, which are unalterable, a dense sward of productive grass and legume species can be maintained. On much hill country this may, however, be a distant if not impossible objective. The alternative is to grow a dense sward of less productive species, for where fertility is too low, or other conditions adverse for, say, perennial ryegrass and white clover to form a dense sward, a sufficient density of cover may be produced by lower fertility demanding species, such as browntop, sweet vernal, and Danthonia - though these may not form a sward capable of carrying 3 to 4 sheep per acre.

A further difference between hill and low country is in the type of stock carried, and the system of graze management used. On low ground sheep farms the sheep which utilise the sward directly are, normally, mature ewes, except on stud stock farms where all classes of sheep are run. In the earlier section concerned with kind, class, and breed of stock carried it was stated that there was no evidence of differential grazing between classes of stock. It is conceivable, however, that older, broken-mouth ewes will have grazing habits more after the nature of cattle. While there is no evidence that old ewes, cast-for-age from the hill, will eat ranker herbage and so control a pasture better than younger stock, the converse fact is recognised, that broken-mouth ewes require longer herbage in order to maintain condition than full mouth sheep, and the former, if run on close grazed pastures, will starve. It is possible, then, that ewes cast-for-age from the hill, may, like cattle, equate appetite with availability and palatability of herbage, and so control pastures better than younger sheep.

Grazing management on well subdivided low ground is commonly better controlled than on hill country. Systems of spelling and rotational grazing are simpler and more common.

These aspects of pasture growth control doubtless play a part in limiting reversion to secondary growth on low ground, and their adaptation to hill conditions would partially assist in limiting secondary growth there. The possibility of doing this has been discussed earlier.

The aim in secondary growth control must be to drive the secondary growth species beyond the limits of their ecological survival range, by increasing the intensity of the anthropogenic interference in the sere which has forest as its climatic climax, so bringing the ecological conditions within the survival range of desirable grass and legume species, and encouraging them to become the dominant species of the plagioclimax.

K. CONCLUSION.

It has been claimed that the improvement of under-developed land is internationally important, because this seems to offer a more certain and rapid means of increasing world food output, to assuage the appetite of the increasing world population, than could any attempt to increase the production of the already intensively farmed agricultural regions of the world.

In any such scheme the hill lands of New Zealand must, logically, take their place. New Zealand's hill land is already productive, and important in the national economy. But with mounting local population, an increasing proportion of which is finding its way into those servicing industries which are unproductive of real wealth, and the demand for an ever increasing standard of living, the hill land of New Zealand, far from being exploited and allowed to deteriorate, must be carefully husbanded and its productive capacity improved.

It may be reiterated that the achievement of this ideal is a problem of applied ecology in the widest sense of that term, for a solution of the problems of agricultural ecology must be made within a favourable economic and social framework.

The problem most fully treated in this dissertation is but a small part of the whole. The improvement of hill pastures is but one aspect of the phenomenon of animal - pasture interaction. It considers the influence which climate, man and animals have upon the pasture, and how these elements of the habitat react to the detriment or benefit of the sward. This aspect of the interaction is considered more fundamental than the influence of the pasture upon the animal, since the grazing animal is dependent upon a healthy and productive sward for its very existence. However, these two facets of the one problem cannot be readily divorced one from another, for they are indeed an interaction - the influence of animal upon plant conditioning the influence the plant will have upon the animal as the plant - animal community lives out its dynamic existence.

For these reasons the management of stock on the pasture, and the effect which different kinds, classes and breeds of stock have on the pasture are important. These influences react on the pasture to produce an effect which, in turn, is the cause of a further effect, all culminating in deterioration or improvement of the pasture, in the declination or enhancement of its productive capacity, of the national wealth, and, ultimately, of international wellbeing.

But animals and plants are mere pawns in the conflict between climate and man. "Climate is the fundamental dynamic force shaping the pattern of vegetation and the pattern of soils". Man cannot radically alter the effects of climate. He may modify them to some extent by such devices as irrigation and drainage. He may mitigate the effects of climate by partial control of the microclimate of the plant habitat. This he may do by such devices as lenient grazing and tree planting, which have been discussed herein. Conversely he may enhance the harmful effects of climate by overgrazing or burning of the pasture. Or he may attempt to breed, or introduce from other regions of the world, plant strains and species capable of withstanding the rigours of the existing climate and the new microclimate which he, by his use of the pasture, has brought into being. Further, he may attempt to alter soil fertility by the addition of fertilisers, and so overcome, to some extent, one of the influences of climate upon soil. These endeavours form the basis of much that is discussed in this dissertation.

To date agricultural research has been largely concerned with the modification and better adaptation of man's farming techniques to a lowland environment. Their further adaptation to hill conditions necessitates taking into consideration those elements of slope, elevation, and extensive utilisation, with all the influences and effects arising therefrom, which differentiate hill land from low land. These elements of the hill habitat and their effects on plants and animals under different climatic and anthropogenic regimes have been insufficiently studied, as the deficiencies of this dissertation will partly indicate. In New Zealand, where hill farming forms such an important proportion of the total agricultural enterprise, and is such a valuable national asset, it seems imperative that a more intensive study of the agricultural ecology of this class of land be made in the future.

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APPENDICES.

APPENDIX I.

WETHER LAMBS & THEIR DISPOSAL.

BREED	SEASON	TOTAL WEANED	DISPOSAL AS FATS AND STORES															DEATHS	
			OFF MOTHERS			OFF GRASS - IMPROVED PASTURES ON THE FLATS													
			1ST DRAFT			2ND DRAFT			3RD DRAFT			4TH DRAFT			STORES			
			No. Drafted.	% total lambs weaned	Aver. Wgt. in lbs.	No. Drafted.	% total lambs weaned	Aver. Wgt. in lbs.	No. Drafted.	% total lambs weaned	Aver. Wgt. in lbs.	No. Drafted.	% total lambs weaned	Aver. Wgt. in lbs.	No.	% total lambs weaned	No.	% total lambs weaned
ROMNEY	1949/50	63	7	11.1	30.42	8	12	31.50	22	34.9	32.50	5	7.9	32.80	20	31.8	1	1.6
	1948/49	43	3	7.0	33.33	nil	nil	nil	16	37.2	35.75	20	46.5	34.40	4	9.3	nil	nil
	1947/48	65	3	4.6	31.66	nil	nil	nil	3	4.6	35.66	nil	nil	nil	58	89.3	1	1.5
	1946/47	68	11	16.2	34.45	5	7.4	32.2	11	16.2	32.54	7	10.2	32.42	33	48.5	1	1.5
	1945/46	66	23	34.9	30.6	nil	nil	nil	19	28.8	31.9	2	3.0	31.0	20	30.3	2	3.0
	1944/45	118	22	18.6	34.1	17	14.4	35.9	28	23.7	34.5	20	17.0	33.7	29	24.6	2	1.7
TOTALS AND AVERAGES six SEASONS		423	69	16.3	33.9	30	7.1	34.1	99	23.4	33.6	54	12.7	33.6	164	38.7	7	1.7

APPENDIX I. (contd).

WETHER LAMBS & THEIR DISPOSAL.

BREED	SEASON	TOTAL WEANED	DISPOSAL AS FATS AND STORES															DEATHS	
			OFF MOTHERS			OFF GRASS - IMPROVED PASTURES ON THE FLATS													
			1ST DRAFT			2ND DRAFT			3RD DRAFT			4TH DRAFT			STORES				
			No. Drafted.	% total lambs weaned	Aver. Wgt. in lbs.	No. Drafted.	% total lambs weaned	Aver. Wgt. in lbs.	No. Drafted.	% total lambs weaned	Aver. Wgt. in lbs.	No. Drafted.	% total lambs weaned	Aver. Wgt. in lbs.	No.	% total lambs weaned		No.	% total lambs weaned
HALF BRED	1949/50	88	29	33.0	30.6	20	22.7	30.90	26	29.5	33.11	2	2.3	30.0	7	8.0		4	4.5
	1948/49	84	29	34.5	37.06	19	22.6	34.21	32	38.1	36.78	2	2.4	32.50	nil	nil		2	2.4
	1947/48	92	29	31.5	34.10	28	30.43	32.07	17	18.5	30.70	nil	nil	nil	18	19.6		nil	nil
	1946/47	68	30	44.1	33.46	8	11.8	30.12	26	38.2	32.34	4	5.9	30.25	nil	nil		nil	nil
	1945/46	187	29	15.5	30.9	17	9.2	32.0	100	53.4	32.1	39	20.8	30.4	2	1.1		nil	nil
	1944/45	200	102	51.0	33.7	62	31.0	32.9	24	12.0	33.3	9	4.5	33.9	2	1.0		1	0.5
TOTALS and AVERAGES six SEASONS		719	248	34.4	33.4	154	21.4	32.4	225	31.3	32.9	56	7.8	31.0	29	4.0		7	1.0

APPENDIX II.

AVERAGE GROSS MONETARY RETURNS PER EWE FOR WOOL AND LAMB.

(Note: The ewe lambs have been valued at the average price received for wether lambs.)

YEAR	ROMNEY				HALF-BRED				DIFF. IN FAVOUR OF HALF-BRED
	% lambs weaned	Av. Return per Ewe Fleece Wool	Av. Return per Ewe Lamb	Total Return per ewe for Wool and Lamb	% lambs weaned	Av. Return per Ewe Fleece Wool	Av. Return per Ewe Lamb	Total Return per ewe for wool and lamb.	
1949	97	39/3	33/8	3.12.11	115.1	31/1	37/6	3. 8. 7	- 4/4d
1948	81.7	17/3	27/10	2. 5. 1	112.2	15/9	38/2	2.13.11	+ 8/10d
1947	79.3	23/4½	18/5	2. 1. 9½	118.8	17/6½	33/2	2.10. 8½	+ 8/11d
1946	79.5	17/10	19/9	1.17. 7	110.3	14/2	29/7	2. 3. 9	+ 6/2d
1945	92.7	12/2	18/5	1.10. 7	114.5	9/1	26/10	1.15.11	+ 5/4d
1944	82.6	12/6	18/3	1.10. 9	119.6	10/6	27/3	1.17. 9	+ 7/-

APPENDIX III.

COSTS FOR POST AND BATTEN FENCE.

	1930		1949
Posts: Splitting @ £3/100 and 500/mile	£15	(@ £40)	£200
Battens: Splitting @ 12/-/100 and 1500/mile	9	(@ £2.10.)	37.10.-
Strainers: Splitting @ 3/- each and 9/mile	1.7.-	(@ 22/6d)	3. 7.6
Wire: 23 cwt. No.8 @ £20.10.-/ton	23.1.6	(@ 73/- cwt.)	83.19.-
Staples: 1 cwt. Post 28/-	1.8.-	(@ 99/-)	4.19.-
1 cwt. Batten 30/-	1.10.-	(@ 100/6)	5.-.6
Packing: 2 men, 8 horses (10 days) @ £2.10.-/week & £1 keep	10.10.-	(@ £5/week & £1 Keep)	18.-.-
Erecting: 14/-d/chain	56	(@ 27/-d/ chain)	108.-.-
Wear & tear on Saddlery & Horseshoes @ 2/-/horse/day	8	(@ 4/0)	16.-.-
Cost per mile	£132.6.6		£497.11.-
Cost per chain	33/-d		124/4d

COSTS FOR 'HUNTER' FENCE (per mile).

Totara posts @ 2 per chain	£72
Chains, dips and clips	60
6 wires No.8 plain, and 2 barbed	94
8 anchors and stays @ £1	8
4 gates @ £5	20
Erecting @ 30/- per chain	120
Cost per mile	£374.-.-
Cost per chain	93/6d