ECOLOGICAL AND ECONOMIC CONSIDERATIONS IN LAND USE PLANNING

K. S. MATHUR

ECOLOGICAL AND ECONOMIC CONSIDERATIONS IN LAND USE PLANNING

by

R. S. Mathur, M.Sc., A.I.F.C.

M.Sc. 1967

PREFACE

This thesis is being presented for the degree of M.Sc. in Forestry of the University of Edinburgh, in accordance with the rules.

I wish to acknowledge my thanks to Dr. I. Langdale-Brown for his guidance and supervision of the project, and also to Dr. W.E.S. Mutch for his advice, from time to time, on the economics side of the work.

I also wish to thank the Factor and the staff of the Bowhill Estate, Selkirk, for allowing field work on the Estate premises and access to the office records; in particular, to Mr. J. A. Watson, Head Forester, for his valuable help and co-operation at all stages.

93, Comely Bank Avenue,
Edinburgh, 4
April 24, 1967.

R.S.Mathur

CONTENTS

Appendices

INTRODUCTION

The object of the present study is to demonstrate the co-ordinate roles of ecological and economic considerations in land-use planning by means of classification of land capability. Most of the past studies in this field suffer in varying degrees from a lack of appreciation of the integrated approach to the problem; being either purely ecological investigations ignoring economic significance of land utilization or the other way round. The present study is an attempt to point out this anomaly and illustrate a practical integrated method of classification by its application to a sample area.

The purpose of land-use planning is to promote the optimum management of the available land resources; such a system of management should be suited not only to the economic and social needs of the community or owners of the land, but also to the inherent nature of the land. The basic ecological tasks are to assess the productive capacity of land and to safeguard against any depletion of soil fertility. The social and economic problems are to choose between the various ecological possibilities in order to obtain the maximum profit and well being of the community.

The patterns of land-use in the different parts of the world have been evolved gradually during the course of civilisation. It is paradoxical that this gradual shaping of land-use patterns has not led, in the majority of cases, either to the most appropriate of the land-uses for the site or to the most profitable one for the people themselves. The choice of a land-use is almost everywhere more due to conformity with traditional practices than to considerations of land capability.

In the past few decades, however, the need has been felt for rational land-use policies, based on thorough scientific studies. During the post-war period, these investigations have received much attention. The chief reasons for the increased research activity in this field are connected with the increase of human population and pressure on land resources for:

(i) greater food production,

(ii) urban and industrial expansion, communication and recreation,

(iii) larger quantities of raw material for industries; and

(iv) coupled with the above development is the greater awareness of the need for conservation of resources for prosperity, rather than their exploitation during a limited period, which includes preservation of wild life.

There has been a greater understanding and wider application of ecological methods and principles of economics to these problems in recent years than in the past.

There is a wide range of factors influencing land-use, which can be grouped under five main heads --- ecological, economic social, technological and historical.

Ecological or environmental factors constitute the biggest group and comprise climate, geomorphological and biological factors. It is generally accepted that under natural conditions, the sum total of all the ecological factors, or the ecosystem, is in a dynamic equilibrium and a slight displacement in one factor may cause the movement of the state of equilibrium to a new stable position. The various factors are interdependent and cannot act separately. The use to which man may put his land is severely limited by the combined influence of the total environment. On purely ecological considerations, uses that lead to site deterioration by adversely upsetting the balance are unacceptable.

Economic or financial factors include the economics of production and management of land under existing conditions of demand, wages and costs, in relation with possible future changes. On purely economic grounds the best use is the one that results in maximisation of sustained profits from a piece of land.

Social factors depend on the social needs of the community concerned, or of the nation as a whole. Social factors, which include institutional and legal factors, tend to be more biased than ecological and economic factors but sometimes may override all others.

Under technological factors are included the system and intensity of management and use of different techniques and equipment to improve the site or its utilisation. In the absence of any ameliorative process, many sites have a very limited range of uses. With increasing use of fertilisers and mechanised farming, the productive capacity of agricultural land can be improved considerably.

Historical factors are concerned with the interactions of all the other factors over a period of time. These factors represent the trends which land-use has followed with changes in social conditions and scientific progress. The pattern of land-use at a particular time exerts a considerable influence on development.

It is difficult to establish the superiority of any of the above factors over the others. All are connected and none can be disregarded completely. The relative importance of any factor in a particular study depends on the purpose of that study. Ecological and economic factors are capable of quantification, or at least some values may be assigned to them. On the other hand, the rest of the factors are only qualitative and impossible to measure in numerical terms.

The classification of land into distinct units is a basic requirement of any land-use planning programme. Land has been classified in various ways in the past. Geographers have classified land according to the present land-use. Plant geographers have mapped the distribution of plant communities and individual species. Soil surveyors distinguish areas according to such features as the colour, depth and texture of the soil. Some ecologists have tried to distinguish different areas according to the whole ecological (environmental) complex. These methods of approach are related to visible features of land and its use. The economist's approach is of a different nature inasmuch as economic productivity of land is viewed in relation to alternative investment opportunities in the existing socio-economic pattern.

In the present study, attention has been confined to the ecological and economic factors only. This has been done to achieve useful results, within the available time, on an assessment of land capability. It is stressed, however, that parallel studies of other factors would be essential for development purposes.

In Part I, some of the literature on studies made in the past on land classification and other aspects of land-use in Britain and other countries is reviewed. Part II deals with the investigations carried out in the study area at Bowhill Estate in Selkirkshire, Southern Scotland, and the results achieved therein.

PART I

REVIEW OF LITERATURE AND STATEMENT OF THE PROBLEM

CHAPTER 1

ECOLOGICAL FACTORS AND ENVIRONMENTAL LAND CLASSIFICATION

An assessment of the capacity of land to produce crops useful to man and the subsequent classification of land on this basis necessitates an appraisal of the factors of environment responsible for the variability in productivity. Environmental land classifications try to do this by an evaluation of the inherent site characteristics, in concrete units, and an assessment of their influence on land-use and production. Such classifications aim at a division of land into suitable classes with well defined ranges of chosen factors, considered likely to affect growth and production, and within specified limitations of use. The land is usually graded in terms of some estimate of land-use potential. The grading may be qualitative, such as suitability for a particular land-use, or may be quantitative, based on measurements of a function of productivity.

Environmental factors that affect growth and yield of crops, and therefore land-use, are (i) climate, (ii) geology, (iii) topography or geomorphology, (iv) soil and (v) vegetation. An additional factor is the interference in the natural environment of a locality by man as reflected by the present land-use and system of management, which forms an artificial feature of the environment.

Various studies and surveys made in the past on land capability classifications in different parts of the world use one or the other environmental factors as the starting point for the basic framework - present land-use, climate, soil, vegetation or geomorphology. Many classifications are based on classifications of single factors, for example, on climatic, soil or vegetation types alone, but more comprehensive ones consider every aspect of the environment, with varying degree of emphasis. Referance may also be made to ecological and related surveys, carried out to assess forest, range, or other resources, as distinct from surveys of land potential. These are excluded from the scope of the present study.

CLASSIFICATION OF PRESENT LAND USE

A straight-forward method of classifying land is on the basis of the use to which it is being put at present. Broad features of land-use are normally shown on ordinary geographical maps. These mapping units are usually too generalised to afford a detailed assessment of land capability. Land-use classifications require more elaborate treatment.

The land-use classification of Great Britain by Dudley Stamp (1950) was based on an extensive land utilisation survey carried out from 1930 to 1947. The following land-use classes were recognised and shown on the field sheets :--

1. Forest and woodland.
2. Meadowland and permanent grass, pastures, parks.
3. Arable or tilled land, fallow, rotation grass, market gardens (vegetables).
4. Heathland, moorland, commons and rough hill pastures (rough grazing), rough marsh pasture, abandoned quarries.
5. Gardens, allotments, orchards, nurseries, etc.
6. Agriculturally unproductive e.g. buildings, yards, mines, cemetries, etc.
7. Water, ponds, lakes, reservoirs, ditches, dykes, streams.

On the basis of this land-use survey and taking into consideration the effects of other factors like soils and vegetation, including use of indicator plants, ten major land capability types were finally recognised. Areas were rated according to the best of the existing usage. The final classification is given below :-

Type	Suitability
Major Category I - Good Quality Land	
1. First class land	Agriculture
2. Good general purpose farmland	Agriculture and agriculture with grazing
3. First class land but more moist than type 1.	Grazing
4. Good but heavy land	Grazing and agriculture
Major Category II - Medium Quality Land	
5. Medium quality light land	Agriculture and grazing
6. Medium quality general purpose farmland	Agriculture and grazing
Major Category III - Poor Quality Land	
7. Poor quality heavy land	Grazing
8. Poor quality mountain and moorland	Heathland
9. Poor quality light land	Heathland
10. Poorest quality land	Salt marshes, sand dunes, etc.
Residue - Closely built over	

This classification takes into account soil moisture and textural differences and their influence on agricultural use.

Under a World Land Use Survey programme, initiated by the International Geographical Union, several of whose publications have appeared in recent years (1958 to 1965), the above method is being extended to other countries of the world. This survey recommends a standardised land-use classification, in order to secure uniformity all over the world.

A study of present land-use patterns in the Highlands and Islands of Scotland and their bearing on potential use has been made by the Advisory Panel on the Highlands and Islands (1964), primarily from a social viewpoint. McClellan (1965) has emphasised the role of a basic land-use classification as the starting point in the Canada Land Inventory Project.

The interpretation of existing land-use classification in terms of potential use presents many problems. According to Dudley Stamp (1963), existing land-use studied historically is often a good guide of potential. Variations in yield under present land-use may be due to the level of farming techniques as well as to qualities of land. Such variation forms a good clue to potential.

A severe limitation of basing land classifications on present land-use is the very qualitative and subjective nature of the method. The investigator is easily led to select the best of the existing uses, according to his own experience, as the potential optimal use. He is liable to neglect the ecological needs of the land. Another drawback is that changes in economic conditions may change the potential of a particular type of land under certain existing land-use considerably, thereby rendering the classification ineffective.

CLIMATIC CLASSIFICATION

Climate has a general influence on the broad land-use distribution in different parts of the ~~whole~~ world. Important factors like temperature, rainfall or total precipitation, humidity, length of growing season, drought and frost have been recognised as affecting the growth of vegetation. Attempts have been made to combine individual characteristics of regional climate and microclimate in order to evolve suitable climatic indices related directly to growth. Various such indices have been formulated from time to time. A few of the earlier examples are:

(i) Martonne's humidity quotient - annual precipitation divided by mean annual temperature;

(ii) Angstrom's measure of continentality - the difference between mean temperatures of the warmest and coolest months;

(iii) Köppen's critical rainfall - R = 0.44 X (Mean annual temperature - a constant); if rainfall is greater than R, the area falls in the humid zone;

(iv) Meyer's ratio - precipitation divided by saturation deficit.

None of the above indices have been applied satisfactorily.

Thornthwaite and Hare (1955) attach a great importance to evapotranspiration. Their division of the world into moisture provinces is based on the value of a Moisture Index, derived from the relationship of Moisture surplus(when precipitation exceeds water need), Moisture deficiency(occuring when during the drying season stored soil moisture is steadily diminished due to evapotranspiration and the actual evapotranspiration falls below the potential) and Potential Evapotranspiration.The last is defined as the evapotranspiration that would occur from a vegetation-covered surface if soil moisture conditions were adequate for unrestricted transpiration. Values of Moisture Index of 100 and above indicate perhumid region; 20-100, moist or humid; 0-19.9, moist subhumid;-19.9 to 0, dry subhumid;-39.9 to -20, semi-arid; and -60 to -40, arid zones. A high degree of correlation is found between Moisture Indices and observed distribution of vegetation and soils.

Paterson's(1956) climatic index for potential vegetative productivity, known as CVP index, is probably more useful, as it takes into account a larger number of factors. The index is calculated by the formula;

$$I = \frac{T_v}{T_a} \times \frac{P \times G}{12} \times \frac{R_p}{R_s}$$

, where T_v = mean monthly temperature in °C of the warmest month; T_a = difference in °C between mean monthly temperatures of the warmest and coolest months; P = mean annual precipitation in mm.; G = length of growing season in months and R_p = radiation at the pole and R_s = radiation at the particular site, both measured in thousand gram calories per square cm. per minute. The value of I ranges from zero in polar and desert regions to around 20,000 at the Equator. Forest growth is impossible when I is less than 25 and falls off when it exceeds 30,000.(Rennie,1962).

Paterson (1962) has described the application of CVP index to determine yield potential of individual sites based on climatic and yield data in fully stocked virgin stands of Scotspine, pure or mixed, and aged 80 to 100 years, in Sweden. He found that temperature amplitude had the greatest effect, followed by length of the growing season. Precipitation had comparatively little influence. Estimates of potential total yields based on the climatic index for four Scandinavian countries were comparable with other estimates.

In the modified index, designated CVP_1, precipitation is represented by its square root. CVP and modified CVP_1 indices have also been used in France by Pardé (1959,1964) in Italy by Gambi (1960) and in Canada by Lemieux (1961).

Of regional interest, is a division of Scotland into climatic Sub-regions by Anderson and Fairbairn (1955). The climatic regionalization is on the basis of the two major factors, temperature and precipitation. The former is represented by the length of growing season (instead of the mean temperature of the growing season) adjusted to sea level (by allowing 1°F fall of temperature for every 300' rise in elevation), and the latter by mean rainfall during the growing season, from May to September inclusive. The length of growing season is defined as that period of time, measured in number of days, which lies between the first day in spring, when mean temperature rises to 45°F and the first day in autumn, when mean temperature fails to reach 45°F. On the basis of these two factors, they have formed 4 zones of length of growing season in 5 days intervals starting from below 191 days to over 205 days, and 4 zones of growing season rainfall, having rainfall below 15", 15"-20", 20"-30", and over 30" respectively, giving in all 14 climatic sub-provinces for the whole of Scotland. They range from the cold and dry northeast to warmer and wetter southwest. Apart from temperature measured by length of growing season in interaction with altitude and rainfall, exposure to wind is also seen to have inhibiting effect on tree growth, restricting it to lower protected altitudes even in otherwise favourable localities.

The chief utility of climatic classification or zonation of land on the basis of climate lies in ascertaining a general pattern of growth of crops; but for a detailed investigation of crop responses, interactions with other factors are always more important.

SOIL CLASSIFICATION

The soil reflects the interaction of all factors of the environment. Dokuchaiev(1870) put forward the concept of a soil being developed as a result of a unique combination of the five genetic factors - climate, parent material, relief, living organisms and time. Consequently the soil, like vegetation, can be used as an index of site conditions. A large number of land classifications have been based on soil classifications on this principle.

There are many systems of natural or taxonomic soil classifications based on the morphology of soil profiles. A good historical account of taxonomic soil classifications is given in the U.S. Department of Agriculture, Soil Conservation Service publication on Soil Classification (1960).

Another group of soil classifications is known as interpretative classifications. Vink (1963) and D'Hoore (1965) have listed some of these.

(i) Soil Quality classification, is based on some technical quality of soil important for a certain use or for improvement, such as permeability, ploughability, erosion hazard, etc.

(ii) Soil Crop Response classification, gives the response of a crop on a certain type of soil with a certain management level, for example , fertilizer treatment.

(iii) Soil Use classification, or more appropriately Land Use classification, (discussed earlier)

(iv) Soil suitability classification, indicates the general suitability of soils for a more or less specific use or for soil improvement.

(v) Recommended Use classification; (vi) Advisory land classification; (vii) Adminstrative land classification; and

(viii) Land Capability classification, based on soil in interaction with the other environmental factors.

A taxonomic soil classification, usually termed " Soil Classification", is the grouping of soils according to their inherent properties. D'Hoore(1965) has made comparisons between the four current classification systems with regard to their categorisations. They are Russian, American, French and Belgian systems. All these are pedogenetical soil classifications for a global rather than regional application. In each system, 6-7 category levels are recognised and, thoug-h categories of the same level may be roughly similar in scope they are not so in contents, specially in the case of highest categories. The emphasis in Russian system is more on genetic factors while in the American, more emphasis is given to the morphology of the soil profile.

Of these systems, the American system is more widely known and employed in soil survey. There are six categories in this classification (U.S.D.A.1960), starting from the category of Order, and ending in Soil Series. Families consist of a number of soil series with relatively homogeneous properties, important to growth of plants. A soil series comprises soils which have been derived from the same parent material under the same climate and topography. Variability within a series may occur in slope, stoniness, truncation by erosion, nature of horizons within normal depth of ploughing and depth of bed-rock. Soil series are named after places and Families after main soil series. Soil series is the primary and basic unit in classification and is also the ultimate mapping unit, in general.

In soil surveys in Britain, a simpler genetical classification has been adopted. Two categories are recognised- namely Soil Association and Soil Series. Soil series are named after places or rivers and associations after the main soil series. Soil Association is a grouping of soil series derived from the same geological material and found together in a definable area. A soil series comprises soils belonging to the same major soil type (brown forest soils, podzols, gleys, etc.), with same parent material, climate, topography, drainage conditions and textural differences.

In the Southern Uplands region of Scotland, where soil surveys have been completed, Muir (1956) and Ragg (1960) have classified soils according to the soil profiles and drainage conditions. Gleying developed in various horizons, due to impeded drainage at different depths, forms a distinguishing feature between soil series of the same major types, such as freely drained brown forest soils and brown forest soil with gleyed B and C horizons. There is generally little difference in soil texture within a Soil Association. Soil series is the mapping unit. Variations due to depth of soil, stoniness and soil structure, may occur within soil series. No formal soil suitability classification is attempted in these surveys but general indications regarding suitability of soil series for agriculture are given.

In Ireland, Gardner and Ryan (1964), using approximately the same system of soil classification in the survey of County Wexford, have given more elaborate description. An interesting feature of this survey is a soil suitability classification made on the basis of an evaluation of the significance of the more permanent characteristics of the soil in the lig-ht of existing land-use rather than on any measurement of production. The use range, type of limitations to use and the soil series comprising it are given for each soil suitability class. A high standard of management practices (including the application of lime and fertilizers as required) is assumed. Seven classes are recognised, plus some unclassified soils. Briefly their description is as follows:

Class A- Suitable for cultivated crops, pasture or forestry; wide use range; no serious limitations; includes Brown

Earths, some Grey Brown Podzolics and some Brown Podzolics.

Class B- Moderate suitability for cultivated crops, pastures and forestry; somewhat limited range due to either (i) very coarse texture, or (ii) imperfect natural drainage, or (iii) periodic flooding; includes some Grey Brown Podzolics, some Brown Podzolics and Gleys.

Class C- Moderate to poor suitability for cultivated crops; moderate suitability for pasture or forestry; somewhat limited use range due to poor drainage and weakly developed structure; includes some Gleys.

Class D- Poor suitability for cultivated crops; moderate for pasture or forestry; limited use range due to serious drainage problem, low fertility, heavy texture, weak structure and poor consistence; includes some Gleys.

Class E- Unsuited to cultivated crops or intensive grazing; moderate to poor suitability for extensive grazing or forestry; very limited use range due to shallow soils, rocky out crops, and steep slopes; includes some Brown Podzolics and some Podzols.

Class F- Unsuitable for cultivated crops and intensive grazing; poor suitability for extensive grazing or forestry; extremely limited use range due to very serious drainage problem and adverse soil physical conditions; includes some Gleys.

Unclassified soils include some Grey Brown Podzolics, some Podzols, basin and hill peat, alluvial and aeolian soils.

The soil series have also been classified in to five drainage classes and according to the American nomenclature. It, is seen that soil series belonging to a sub-group formed on the basis of the American classification also fall, in general, into one suitability class.

Soil suitability classifications of similar types, recognising various classes suitable for arable farming or pasture or both, with various kinds of limitations, are also in use in Netherlands and in other countries of Europe (Edelman, 1963).

None of these classifications assess soil potential in quantitative terms. They only give information about the range of uses of different soil types (qualitatively) and the limitations to various uses, if any. Attempts to correlate various soil properties with quantitative measurements of growth and yield of crops are discussed in a later section.

CLASSIFICATION OF VEGETATION TYPES

The study of the floristics of natural vegetation as a guide to productive capacity of land has long been an important branch of ecological investigations, particularly in forest management and silviculture. Clements (1916), working in U.S.A., developed the theory that natural vegetation afforded an index of the sum total of physical factors affecting land fertility and, therefore, that an adequate vegetation survey obviated detailed investigations of soil, climate and drainage.

The nature of climax vegetation in relation to the climate and soil represents an index of site capacity. The mapping of forest types and grassland communities is based on the distribution of tree or plant communities in stable equilibrium with environmental and biological forces. There is an extensive literature on such classification of forest, range and grassland types and only a few instances are given here.

The works of Tansley (1939) in Britain and Champion (1936) in India are important contributions in this field. Stapledon (1936) in Wales recognised chief grassland types as indicating bpth the chacracter of the physical factors and possibilities of improvement. Anderson (1950) has classified wasteland sites in Britain and related them to six soil fertility classes and to three grades of soil moisture availability in summer. The final classification has 20 subclasses of wasteland plant communities (grass herbs). His classification of natural woodlands into 15 forest types is based on an earlier classification by Tansley and others, modified according to his personal observations.

In Canada Linteau (1955), has made a detailed forest site classification based on tree association in Quebec. In Uganda, Langdale Brown et al. (1964) have based their classification on plant communities, which are related to the environment and the current land-use. The land-use potential is assessed by considering the range of uses of each type of land, comparing areas inside and outside Uganda. For Jordon, Poore and Robertson (1964) have given a classification of range types on the basis of distribution of vegetation (plant association) and present land-use. All these workers have made use of aerial photographs to map the distribution of plant cover and environmental types.

Duchaufor (1961) finds a close relationship existing between soil humus type and natural vegetation. He has evolved a method of defining sites based on vegetation-humus-soil correlation and has given a detailed classification of humus into types, varieties and sub-types. According to him, (i) there is a close relationship between the site medium and natural vegetation which characterises it, (ii) soil is the fundamental element of the environment, (iii) in the soil it is the humus type which more closely integrates the locality conditions, and (iv) the vegetation is more closely linked to the humus type. The application of this method is, however, limited in scope due to its reliance on a single factor, which is difficult to evaluate.

Harper(1962) in a study in the Lammermuir Hills in Southern Scotland has demonstrated that the distribution of vegetation types in this area agrees very closely with that of the soils. The latter in turn are also shown to follow the changes in the topography and the parent material.

USE OF INDICATOR PLANTS

The role of ground vegetation as an indicator of site capacity has also been the subject of many ecological studies. The work of Cajander(1909 and later) in Finland on the relation of the productivity of the forest to the ground vegetation showed the usefulness of indicator plants in forest site assessment. Provided forest cover has a certain density, but irrespective of species, increasing productivity is correlated with ground vegetation.

Many studies have been carried out to relate ground vegetation with productivity of forest site. Cajander's classification with some modification,has been used in Sweden by Tamm (1950) on indicator plants in conifer forests. In Canada, Sisam (1938), Linteau(1953) Rowe (1956) and Illingworth and Arlidge(1960) have studied more detailed relationships between forest site and ground vegetation. Daubenmire (1961) found ground vegetation types as indicators of the rate of height growth of Ponderosa pine in Washington and Idaho,U.S.A.

Gilchrist (1872) was one of the first foresters who recognised the importance of ground vegetation and indicator plants(Anderson, 1950). He used his knowledge in the choice of species for planting in waste land and deforested areas. Anderson himself has also dealt with the use of indicator plants in site assessment and also pointed out its limitations, particularly because of two factors. Firstly that wasteland plant communities are greatly affected by human interference, grazing, burning and other agencies; and secondly, that often unsatisfactory indicator plants are widely used for assessment of site that are not indicative of a small range of site conditions. Use of indicator plants for assessment of site before planting seems to be popular with foresters in Australia and New Zealand(van der Voort et al.,1965).

Ure(1965) in New Zealand and Hodgkins(1961) in U.S.A. have tried to establish relationship between forest site and ground vegetation by applying quantitative methods. Ure recognised five site classes for Pinus radiata, differentiated chiefly according to height at 20 years age. The diagnostic ground vegetation of each of five classes was listed in sample areas and the site classes mapped on the basis of their distribution with the help of aerial photographs. This site classification is used for estimating growing stock of forest crops and for preparing long-term cutting and also broad annual plans of operation. This method is found to be useful in planning on a wider scale but not so much on smaller scales. In a check carried out on a number of sample plots, a net average under-estimation by 5.9% of the growing stock volume was found.

Hodgkins on the other hand has estimated site index for Lodgepole pine from quantitative evaluation of associated vegetation. He has related tree site index to mean values of ground site index (average abundance of indicator species measured quantitatively). The latter quantities are also correlated with soil moisture.

COMPREHENSIVE LAND CAPABILITY CLASSIFICATIONS

The Land Capability Classification evolved by the U.S. Department of Agriculture, Soil Conservation Service(1961) is a comprehensive system of classification based principally on soil characteristics modified by climatic limitations and slope (erosion hazard). The soil mapping units form the building stones of the system. A moderately high level of management is assumed. Soil and climatic limitations in relation to the use, management and productivity of soils are the basis for differentiating capability classes.

Among the eight classes formed, classes I to IV are suitable for cultivation and classes V to VIII have limited use range, generally not suited for cultivation. The capability classes are further subdivided into sub-classes corresponding to four kinds of limitations:

Sub-class	Limitations
e	Risk of erosion
w	Wetness, poor soil drainage or overflow due to excess water
s	Limitations within the rooting zone, shallowness, stoniness, low moisture holding capacity, low fertility, salinity or sodium concentration
c	Climatic limitations, temperature or lack of moisture.

The final category in the classification is a capability unit. It is a grouping of one or more soil mapping units that are nearly alike in suitability for plant growth and in responses to the same kind of management.

The elimination of any of the moisture or climatic limitations by improvement of the soil, say, by irrigation or drainage, would place a soil into a higher capability class, consistent with other limitations. The effect of management is thus given due importance.

In Britain, a similar system of physical classification for agricultural use has been evolved by the Study Group on Agricultural Land Classification(1965) for England and Wales. The classification is based on physical characteristics of land influencing crop production and affecting, what are called, long term agricultural values as against short term considerations of social, economic and technological changes.

Five grades of land are recognised according to the degree to which its physical characteristics impose long term limitations on agricultural use, evaluated on the basis of existing usage. Attempt is made to associate various grades with soil properties and therefore with mapped soil series. It is admitted that due to lack of sufficient data on soils, microclimate and productivity, precise definition of grades is not possible. Brief descriptions are as follows:

Grade	Description
I	Land with minor or no physical limitations to agricultural use; deep well drained soils, easy to cultivate; flexible cropping; high yields.
II	Land with minor limitations due to soil (texture, depth or drainage); less flexible cropping; lower yields.
III	Land of average quality; limitations due to soil, relief or climate; restricted cropping, mainly grass and also cereals; reasonable yield with proper management.
IV	Land with severe limitations due to adverse soil,

relief or climate or a combination of these; low-output agriculture, mainly grass.

Grade V   Land of little agricultural value with very severe limitations; mainly under grass or rough grazing.

The grade of a land fixed in accordance with the above classification is further modified considerably by the influence of other factors of climate, soil, and site. For example, steeper slopes result in a lower grade; similarly, shallow soils less than 10" deep or stone content of more than 50% or poor drainage conditions (except in sandy soils) necessitates down-grading.

This classification has been produced for application on a national scale. The economic assessments of various grades are also proposed to be made by the Study Group.

In Canada, Hills (1952, 1960 and other papers) has evolved a theoretical and highly complex method (for particular application to forestry). Site is considered to be an integrated complex of total environment, including forest. The idea is to integrate a very large number of basic factors influencing land capability into a higher category of small number of features and by gradual integration to build up an ultimate whole. Three major groups of integrated features are used in site classification - (a) physiographic, (b) biological, and (c) cultural (i.e. connected with human activity). Because of their stability rather than their importance, physiographic features have been chosen to constitute the frame of reference for total site. They are (a) ecoclimate, (b) soil moisture requirement and (c) nutrient regime. Each contributary factor is ranked on a general site scale from extremely low to extremely high, with eleven classes numbered as Θ, 0, 1 to 9.

In a regional Survey, the area would be classified successively in to the following categories:

1. Forest Association Region, covering a wide range of soil and climatic conditions but with uniform and distinctive vegetation/landform relationships based on temperature and humidity;
2. Site Regions, with relatively uniform effective climate and a narrow range of macroclimate ;
3. Site district, having a characteristic pattern of landform features;
4. Land types, being specific combinations of landform and climate. A land type has a uniform effective climate and a relatively consistent pattern of productivity potential.
5. Physiographic Site types are based on:
   (a) ecoclimate or local climate, dependent on elevation, slope and aspect,
   (b) moisture regime classes characterised by those soil profile features that reflect drainage,
   (c) nutrient regime.

A commendable feature of this classification is its comprehensive approach to include a number of factors. There is greater stress on topographic features and microclimate and less on soils. At all stages of the classification, nevertheless, the technique is subjective and grading of any factors precisely into one of the eleven classes in each case appears to be a formidable task.

The G-lackmeyer Report of Multiple LandUse Plan by Hills and Portelance (1960) is an important account of a land classification system on a physical basis. This report was prepared for a demonstration area in Cochrane Clay Belt of Ontario, Canada, as an exercise into the methods for land-use research, chiefly for agricultural use, other land-usestaking up secondary roles. The essential aim of the project was to prepare a multiple land-use plan with the development of agriculture as the basic objective.

The classification is based on landform characteristics, physiographic features and history of land-use, covering a wide range of factors including climate, soil, geology, land relief and animal and plant communities. Mapping has been done with the help of aerial photographs and ground reconaissance surveys.

The report gives separate land-use plans for agriculture, forestry, wild life, recreation and urban development. In the composite Multiple land-use plan,the different blocks of land are alloted to various suitability classes. The seperate Forest use plan is interesting in itself, because classification of land capability for forestry, which more or less overlaps that for agriculture, has been based on estimated potential yield per acre and quality and production of timber and pulp wood.

Mention may again be made here of the Canada Land Inventory (1961) project which is a programme of a comprehensive survey of land capability and use for various purposes. The method aims at an assessment of land capability for seperate uses like agriculture, forestry, recreation and wild life on the basis of soils, climate, present land-use pattern and productive capacity(in economic terms).

Christian (1952) describes the method of land classification developed in Australia by the Division of Land Research and Regional Survey of C.S.I.R.O. in order to classify and map the lands of large regions and interpret land characteristics in terms of land-use potential. This survey deals chiefly with unsettled areas where little or no indication of potential can be obtained for the present land-use. The classification divided land into natural units differiing in their inherent characteristics; which are taken to be geology, topography, soil and natural vegetation. The survey area is divided into following categories:

(i) Division, having a separate and distinctive drainage system;

(ii) Geomorphological sub-division, with distinctive nature of the land surface-stable, erosional or depositional;

(iii) Geomorphological unit, being broad region of similar soil a-nd topography but varying in parent material and climatic conditions;

(iv) Land System, having similar recurring pattern of topography, soil and vegetation.

(v) Land Unit, being distinctive and recurring units of same topography, associated with equally distinctive grouping of soils and vegetation.

Land System is the major mapping unit, it being difficult to show seperate land units on usual scales. Assessment of land potential is made for each individual land units on the basis of its climatic conditions, water resources, fertility, other soil characteristics, nature of vegetation and pasture and timber resources. An aggregate estimate is prepared for a land system from the values for its component land units. The groups of land systems having somewhat similar potential are called Land-Use Groups.

Surveys employing this method have been carried out in many parts of Australia and New Guinea and through the auspices of F.A.O. in Nicaragua(Whyte and Taylor 1958) and elsewhere, particularly in East Africa.

In the survey of lands of Buna-Kokoda area in Papua and New Guinea by the C.S.I.R.O., Australia (1964), the land classification has been based upon considerations of climate, land form, soils, vegetation (represented by forest types) and present land-use.

The entire area is divided into land systems, according to their geomorphological affinities, and each land system is assigned to a land capability class. For each class the estimated land use potential is indicated. The estimation is essentially subjective. Eight land classes (adapted from U.S. classification) have been recognised; classes I to III being eminently suitable for agriculture; IV, marginally suitable; V to VII, unsuitable for agriculture but useful for forestry and pasture; and VIII, fit only for protection of watershed by maintaining permanent forest. Each land class is further modified by proper subscripts to form sub-classes indicating limitations of erodibility, stoniness, low fertility, impeded drainage, flooding, swampy conditions.

COMPARISON OF DIFFERENT METHODS

The four systems of comprehensive land classifications discussed above have their respective merits. The American system is a practical method dealing with soils and their individual limitations for productive use. The British system is similarly a practical physical classification following the American approach. The Canadian method has a more theoretical approach and places emphasis on detailed evaluation of numerous environmental factors. The Australian method is also dependent on many ecological factors but has less clearly defined and more flexible cate-gories. This classification can be adapted to particular situations by changing the definitions of categories to suit individual requirements.

Methods used in France, Belgium and other countries of Europe place more emphasis on soil properties in their ability to portray the interactions of other environmental factors(Rennie,1963), taking soil mapping units as the starting point.

In all the systems, the ultimate objective is to subdivide the region into uniform areas possessing some distinctive environmental features. The rating of land suitability for particular uses is done on the basis of criteria which imply a certain level of management. Whereas in the American, British and European systems, greater importance is assigned to soil mapping units, in Canadian and Australian systems other environmental features also receive equal attention. The ultimate classification of a certain region arrived at by employing the different techniques is likely to be the same and so also the results and conclusions drawn from them.

It is evident that the comprehensive methods involving a large number of factors would give more detailed and acceptable results than other attempts based on a limited range of factors, like climate, soil or vegetation alone. The latter methods have their useful role in the classification of the factors themselves(climate, soil, present land-use, landform or vegetation types) but in land capability survey the total environment is to be considered.

Even the information provided by the comprehensive methods seems to be inadequate for land-use planning work because of their subjective nature and qualitative assessments of productive capacity. The need is for a more quantitative and mathematical approach giving certain concrete values of land capability.

QUANTITATIVE ASSESSMENTS OF CROP PRODUCTIVITY

Quantitative assessments of productivity are usually based on measurements of some form of growth or yield of crops. In the case of agricultural crops, annual yields of the produce are easily measured and forms a convenient basis. In special cases, yield of the final product, such as sugar or oils, may form the criterion. Dudley Stamp (1963) advocates the adoption of a Standard Nutritional Unit of 1,000,000 calories farm production per annum for comparisons where different crops are concerned. Another such measure is the Kg. Wheat Equivalent or the Grain Equivalent, used by Clark and Haswell (1964). 1 kg. of wheat or similar grain like maize, millet or sorghum, milled down to 900 gms., yields 3150 cals. This is the unit used for conversions of the calorie value of other agricultural produce.

In forest measurements, however, a variety of tree growth and yield characteristics have been used, such as age, diameter at breast height, total height, volume or weight. Generally assessment of site is done in terms of some index that represents its productive capacity and which is evaluated by a few easy determinations of age, height or diameter.

Among those in use, site quality class is determined on the basis of top height at maturity of the crop for the species concerned. The commonly used Site Index is the average height that dominant and codominant trees on an area will attain at key ages such as fifty or hundred years. The key age varies with species.

Yield class is now adopted as the basis for forest site classification by Forestry Commission (1966) in Britain. It is based on actual or potential maximum mean annual volume increment, irrespective of the age at which it culminates. The yields classes are determined from top height/age curves, which divide the range of maximum mean annual volume increment into equal classes. Volume production rather than height is the basis of yield class gradation.The age at which the maximum increment production is attained varies with species.

CORRELATION OF CROP PRODUCTIVITY WITH ENVIRONMENTAL FACTORS

Many studies have been undertaken recently establishing a relationship between some growth characteristics, like height or site index (as the dependent variable), of forest crops and various soil or environmental factors (as the independent variables), usually by multiple regression analysis. The regression equation takes the following form(Husch,1963):

$$\log H = b_0 + b_1(1/A) + b_2(B) + b_3(C) + \dots\dots\dots + b_3(N),$$

where H = Height; A = Age; and B,C,......,N = Soil or other environmental factors. If the site index is used, the component $b_1(1/A)$ disappears and H is replaced by site index. The factors that have been correlated with forest growth include various site characteristics and soil properties, such as aspect, altitude, slope, relative position on the gradient, total soil depth, thickness of horizons available for rooting, soil structure, texture, parent material, available N,K, and Ca, phosphorus status, pH, humus decomposition, C/N ratio and other chemical and physical properties of soil. Some typical studies are described below.

In U.S.A., Trimble and Weitzman(1956) found the following growth equation for red pine in Northern Appalachian mountains:

$$Y = 1.9702 - 0.0618X_1 + 0.0012X_2 - 0.0020X_3 - 0.1509X_4,$$

where Y = site index, X_1 = aspect, X_2 = distance from ridge, X_3 = slope and X_4 = total depth of soil.

Pawluck and Arneman (1961) related site index for growth of Jack pine to external drainage, density, slope, aspect, soil type (brown podzols, podzols and grey wooded soils), soil texture in different horizons, available moisture holding capacity in A_{00}, A_2, B_2 and B_3 horizons and the sum of cation exchange capacities.

Mader and Owen (1961) carried out multiple regression analysis on the growth of Red pine with various soil physical and chemical properties, including total organic matter and total N content. Viro (1961) obtained good correlations between site indices of Scots pine and Norway spruce and a large number of soil properties in a widely distributed area in Europe. In India, Seth and Bhatnagar (1960) have correlated quality class of Sal with total soil nitrogen content.

In Japan, Nishzami et al. (1965) studied correlation of calculated site index with altitude, aspect, slope, parent material, soil texture, structure, depth of bed rock, humus content and thickness of A_1 horizon and got a multiple correlation coeffiecient of 0.96.

Other studies on similar lines include those by Trimble (1964) Gilmore (1963), Van Eck and Whiteside (1963), Eis (1962), Della Binaca and Olson (1961), McGee (1961), Zinke (1961), Row (1960), Tryon et al. (1960) and numerous other earlier works.

All the above studies show that it is possible to estimate site index easily from some carefully chosen soil and topographical site characteristics, without recourse to measurements on the crop itself.

An interesting study by Clarke (1950) on prediction of agricultural yield from a soil profile evaluation formula shows the effect of soil texture and drainage on crop yield. Two prediction formulas for yield of wheat ear weight and straw weight were tested by regression analysis for a few soils found in a large field. The first formula was $P = cV^aG^b$, where P = Yield, c = a constant, V = textural value of the soil profile (sum of textural values of all horizons down to a depth of 30"), G = drainage factor and 'a' and 'b' are the regression coefficients in the equation:

$$\log P = \log c + a \log V + b \log G.$$

In the second formula, $P = kV_G^n$, where k = a constant, V_G^n = the textural value of the profile down to the top of the gleyed horizon, and 'n' is the regression coefficient in the equation:

$$\log P = \log k \quad n \log V_G.$$

Textural value is defined as the product of depth of horizon and the texture rating assigned to the texture grade of the horizon. Drainage factor is a function of the depth at which true gleying starts in 30" deep profile and varies from 0.5 for gleying at 9"-12" to 1.0 when there is no gleying.

The regression coefficients a,b, and n are all found to be nearly equal to unity. Between the two formulas, the first gave more accurate predictions, indicating that wheat roots do make use of gleyed soils. The appropriate formula therefore simplifies to $P = cVG$.

Greig-Smith(1964) describes various ways of statistical treatment of correlating vegetation with habitat factors, when either or both of the dependent and independent variables, namely, vegetation and environmental factors respectively, are measured qualitatively or in quantitative units. He stresses upon the use of quantitative approach in dealing with ecological problems, with judgements based on the methods of statistical analysis, because it allows detection and appreciation of smaller differences and a sounder judgement of the significance of the differences observed. The same remarks can apply equally well to land-use studies in general and land classifications in particular, where a truly quantitative approach is still lacking.

CHAPTER 2

ECONOMICS OF LAND USE

Studies in the economics of land-use cover two kinds of problems- (i) the study of economics of a particular land-use as a business enterprise and (ii) comparisons of two or more land-uses, competing with each other, with a view to determine their relative profitability. These problems involve, besides direct assessments, investigations on economics of management, conservation of resources, marketing of produce, forecasting and related studies. While the first group of studies are essential for improving the efficiency of individual land-use activities in the general economy of a region, those in the second group are directly concerned with land classification and productivity.

In many studies of land-use comparisons, the problem often reduces to a simple proposition of studying the economic viability of competing land-uses on the same site or on comparable sites, given a certain set of management systems, technologies and market demands, either existing or potential. Such studies therefore start with certain basic assumptions regarding external factors and, within the adopted constraints, try to compare the relative merits of alternative land-uses in terms of some quantitative economic criteria. Agriculture and forestry are the two chief rivals for the use of the fertile and agriculturally marginal lands. In the land unsuitable for arable crops, the clash is normally between forestry and rough grazing or pasture management. Wild life management and urban development are other competing uses.

In the economic sense, land-use involves an investment decision, made usually with the objective of maximisation of profit, as in other investment opportunities. Economists usually recognise three factors of production - land, labour and capital. Land plays a uniform part in the alternative uses since its productive capacity is a function of the environment and is not susceptible to change to any great extent. Availability of labour depends on the general economic condition of the local community and rates of wages.

The investment of capital in a land use activity is guided by the timing of the returns. In agricultural crops, the return from the capital invested is obtained within a short period of a few years, even one year in annual crops. On the other hand forestry is a long term activity in which there is a long gap between the initial investment at establishment and the first financial return from thinning. The final major return is obtained after a fairly long period, at the end of the rotation. After the first big investment there is usually recurring annual expenditure and some periodic expenses, for protection and supervision and weeding, brashing and pruning respectively.

Similar situations may also arise in other types of land-use, like arable rotation crops, where the initial investment in fencing, draining, ploughing and manuring is larger than in later years.

Land-use activities thus have two important features - (i) separation in time of investments and returns and their irregular spacing on a time scale, and (ii) variable nature of the time schedules under different land-uses, and, within the same land-use, under different management practices. An investigator in this field is therefore faced with three types of decisions:

(i) Accounting procedure, to prepare correct time schedules of costs and revenues,

(ii) Selection of a suitable rate of discount, to bring down all costs and returns to a specific point on the time scale,

(iii) Choice of suitable economic criteria of profitability for valid application to different activities.

COSTING AND ACCOUNTING

Leslie (1963) considers the problem of costing as one of knowing how to measure costs and returns, which ones to measure and how to project them into the future. The costs of forest plantations are divided into three heads: (i) Land, including the purchase price of land if any, cost of clearing, construction of roads, bridges, etc.; (ii) Establishment, including all operations from burning and planting to brashing and pruning; and (iii) Annual maintenance charges. These are direct costs to which a suitable proportion of overhead costs are added.

Statistics of costs of forestry operations as well as of the revenue and expenditure in private forestry estates in Britain are being collected in surveys conducted by the Universities of Aberdeen (for Scotland) and Oxford (for England and Wales), many of whose reports have been published. MacGregor(1951, 1956), MacGregor and Mutch (1953), MacGregor et al. (1956) and Mutch (1960) have given detailed classification of heads in which forestry accounts may be maintained for proper costing. Notes are given about keeping cash books, wage time sheets, ledgers, compartment books, etc. and the classification of overhead costs and their allocation to various activities in the estate. These surveys suffer from a serious shortcoming in the sampling of estates, which is not random but consists only of estates who have agreed to cooperate. The figures therefore, do not represent average conditions.

Fenton and Brown (1963) have made detailed calculations of costs of tending, thinning, conversion, milling, and other operations of Pinus radiata in Southland, New Zealand, and of the value of thinnings and fellings.Hart (1966) has collected current data regarding forestry costs and timber prices in Britain. A large amount of data regarding economic statistics of farming are compiled by Coppock (1964) for England and Wales.

With regard to assumptions of future prices and wages for evaluating future costs and financial returns, it is necessary to make correct forecasts of supply and demand of the produce by studying general price trends and product to product relationships (possibility of substitution). Many, like Treloar and Morison (1963), have advocated the use of current prices as choice indicators of social benefits and costs. The Land Use Study Group (1965) have also used current market prices of resources and outputs. On the other hand the Forestry Commission (1966) assume a 1½% increase per year in timber prices relative to the prices of other commodities, but no increase in wages and other costs.

Walker (1958), in his study of comparing hill sheep farming and forestry, makes a few assumptions, and uses different combinations of these in his calculations. They are (i) a 30% increase in wages in 50 years' time, (ii) a 25% reduction in timber felling and extraction costs due to increased efficiency after 20 years, (iii) a 1½% per annum increase in the values of net output and the capital and (iv) a 50% increase in the prices of either farm products or timber relative to the other. All the assumed changes are relative to 1953 prices.

The costings in land-use studies are normally based on the assumption of present system of management and technological progress. The majority of the investigators base their calculations on the most efficient of the available management practices on the site concerned. Others, like the Study Group on Agricultural Land

Classification(1965), take average management and fertilizer practice as bases. Treloar and Morison(1963), in studies of economic comparisons between agriculture and forestry in W.Australia, have considered various types of possible activities, including an average farm, with or without bounty, an actual farm, four best farms in the locality, a hypothetical farm, an orchard, hardwood forest and pine plantation, The results demonstrate the effect of variation in management practices on the profitability of a land-use.

RATE OF DISCOUNT

In choosing between alternatives with different time streams and different costs and benefits, it is necessary to make the transactions at different points in time commensurate with each other by assigning to them equivalent present values. This is done by discounting all of them to the present by using compound interest. The rate ~~rate~~ of interest or the discount rate that is used represents the cost of waiting for delayed returns from investments. The lower the discount rate, the higher will be the present worth of future revenue relative to that of immediate gains. A high discount rate will make the long term investment less attractive as the cost of the capital will accumulate over the years considerably when the return is obtained.

The selection of a suitable rate of discount in studies of land-use economics has been the subject of much controversy and discussion. A lower rate favours long term activities like forestry (the maximum at which forestry can compete against agriculture being about 7%). The commonly held view is that it should be equal to the going rate of interest or the market rate, or the current bank rate. The market rate of discount could either be the interest rate at which one could borrow or at which one could lend his liquid assets. Some workers prefer the former alternative, but the latter seems to be more appropriate. It represents an individual's opportunity cost for sacrificing an alternative investment of his resources including the land. This is the rate of interest which an individual could hope to earn by converting his land and capital into liquid fund and lending it to other productive activities.

The choice of a rate of discount depends on the risk involved in the undertaking. With greater risk, a higher speculative rate of discount is necessary. On this ground, taking a forest crop as a very safe investment, many foresters have adopted a rate of interest equal to that of a risk free rate of discount earned in government securities. This is usually about 4%, which for many years has been the standard adopted in forest valuation (Hiley, 1956; Leslie, 1963; Fenton and Brown 1963). The Forestry Commission (1966) have adopted 5% as the standard discount rate in their internal economic calculations. With the assumption that future timber prices are likely to increase by 1½% relative to the prices of other commodities, the effective rate of discount for all future revenues reduces to 3½% at fixed prices. Since the costs are incurred mostly in the beginning of the rotation, the rate of discount does not effect them much, except maintenance and roading costs, which are capitalised at 5%.

In most of the current investigations the difficulty of the choice of discount rates has been overcome by making calculations with a wide range of discount rates between 0 and 10% and some times even higher.

To society as a whole, the discount rate has a slightly different significance. Feldestein (1964) considers two types of discount rates - Social Time Preference (S.T.P.) and Social Opportunity Cost (S.O.C.). The S.T.P. rate, reflecting the government's judgement of the relative social utility of consumption at different points of time, assigns current values to future consumptions. It cannot be derived on the basis of the existing market rates but must be administratively determined as a matter of public policy. The S.T.P. rate may vary through time with changes in consumption level and growth rates. The S.O.C. rate is a measure of the values to society of the next best alternative use to which the funds employed in the public project might otherwise have been put.

Scott (1955) also discusses the role of S.T.P. rate of discount in public investment decisions, particularly with regard to utilisation of natural re-sources. In land-use planning the utility of fixing a S.T.P. rate of discount is apparent, specially where ecological and social exigencies may necessitate a policy of long term conservation.

When the entire invested capital is to be recovered at the end of period out of net current annual income, as in the case of wasting assets, it is usual to create a sinking fund which accumulates at a risk-free rate of interest to an amount equal to the initial investment. The rest of the earning is to be accounted for at a higher risk rate of interest and the present net worth calculated by using the Hoskold's two rate valuation formula (Chapman and Meyer, 1947). If there were no depletion of the stock and therefore no need to replace capital earnings, as in sustained yield operations, only one rate of discount would be required.

CHOICE OF PROFIT CRITERIA

A large number of criteria of profitability have been used in studies on economic comparisons of different timber management systems in forestry alone and of agriculture and forestry as altenatives for the use of the same land. The latter studies are directly related to the problems in land-use planning, but the methods developed in forestry studies are also equally applicable to the wider field of general land-use economics. The choice of a suitable criterion for a specific situation is important.

Grayson(1963) states that the choice of criteria for rational appraisal of investment alternatives can only be made when two conditions are satisfied:

(a) some objective function which we wish to maximise has been defined , and

(b) the constraints limiting our freedom of action have been identified; these constraints are physical(environmental), legal, administrative, social and budgetary(financial).

The nomenclature used by various workers varies and same expression may find different names in the literature. For example, Land or Soil Expectation Value (calculated by the use of the Faustmann formula) is identical with the Net Discounted Revenue (when discounting is done of returns and expenditures in perpetuity) or the Contribution to Present Net Worth. Similarly Internal Rate of Return, Financial Yield and Mean Annual Forest per cent denote the same function.

Fenton and Grainger(1965) of the Forest Research Institute, Rotorua, New Zealand, in a study of the economics of raising a _Pinus radiata_ plantation for eventual comparison with agricultural use of the same area, have calculated Land Expectation Value, with and without social costs, at discount rates ranging from 2 to 7%. The initial cost of land has not been considered and the current controlled timber prices are used in calculations. The Land Expectation Value per acre comes down sharply from £60 at 4% to £8.8s. at 6% in the case excluding social costs (housing, amenities, etc.). The forest per cent or the internal rate of return at which the land expectation value becomes nil is 6.1% and 6.9% with and without social costs respectively.

In a case study in the Burnham/Aylesbury area in New Zealand, on comparison between forestry and agriculture, Ward (1963) employs the same technique. For forestry the land expectation value is calculated by using the Faustmann formula, slightly modified to include expenditure on pruning also:

$$L_f = \frac{Y_r + \sum T_a \times 1.0p^{r-a} - \sum P_b \times 1.0p^{r-b} - c \times 1.0p^{r}}{1.0p^{r} - 1} - \frac{e}{.0p},$$

where r = rotation in years, Y_r = final yield from fellings at the end of rotation and again at years 2r, 3r, etc. in perpituity, T_a = thinning yield at year 'a' in the first rotation and again at years a+r, a+2r, etc. during successive rotations, P_b = cost of pruning at years b, b+r, b+2r, etc., c = cost of formation or establishment at the start of each rotation and e = annual recurring cost of maintenance and protection. p is the rate of discount.

Land expectation value for agriculture is taken simply as the capitalised value of net annual output (gross annual return minus annual costs) using the formula:

$$L_a = \frac{i - c}{.0p},$$ where i = annual gross output and c = annual cost per acre. (This formula fails to take account of the one year's

time lag between investment, c, in any year, and the income, i, from it. The initial investment should therefore be subtracted to get the correct value: $L_a = \frac{i - c}{.0p} - c = \frac{i - c(1.0p)}{.0p}$.

Similar formulae are used by Muir(1964) in Australia. In addition another test of 'percentage return' is also applied. Percentage return is the annual net return per acre expressed as a percentage of total investment per acre but without discounting. In a comparison of returns on three soil types in South Australia from forestry and sheep grazing, the percentage return from forestry is better in each case. Land costs are included in the investment capital, which is 3 to 3½ times higher for forestry than that for grazing. In other studies in N.S.W., for comparasions between forestry and agriculture (sheep farm) and between forestry and apple orchard, both the land expectation values and percentage returns turn out to be substantially lower for forestry.

Chisholm (1963) also uses a land expectation value model in a study of the relatively profitability of sheep/beef farming, dairy farming and forestry on two low productivity soil classes in New Zealand. Leslie (1963) has discussed the application of the Faustmann formula in a variety of calculations on the economics of forest plantations. In a case study he has calculated land expectation values for a 50 years rotation at the discount rates of 2 to 8%. After 6% it becomes negative. The financial yield which is the rate of interest earned by the plantation for any given cost of land can be read directly from the graph of land expectation value against the rate of discount. If financial yields for a number of rotations are calculated, a financial rotation can be selected which gives the greatest financial yield (for a given cost of land). It is further possible to determine the profitability of expenditure on site improvement, where such improvement can lead to higher future money yield. It can also be used to test the merits of different thinning or pruning treatments.

Treloar and Morison (1963) in three studies of economic comparisons of forestry and agriculture in West Australia have used a number of economic criteria :

1. Annual net return per £ of expenditure, expressed as per cent of total cost. This measures economic growth.
2. Discounted net return per acre, discounted over a period equal to a forest rotation.
3. Discounted gross return per acre, discounted over a forest rotation.
4. Internal rate of return determined from the graph when the discounted net return per acre is nil.

Various types of farming and forestry activities have been studied using current costs and prices. With increasing rate of discount the values of the first three criteria drop rapidly in the case of pine plantations but show a gradual decline for farming and orchards. On the basis of the detailed studies of results, the authors have been able to give very definite recommendations about the potential uses in all the three areas.

In Britain, Walker(1958) has assessed the relative productivity of land under forestry and agriculture in the major hill land areas of Scotland and Wales. The comparison is made between the net value added per 100 acres under forestry in 50 years (rotation) and the aggregate of the net annual land products per 100 acres under agriculture, each year's product accruing at interest from the year of origin to the fiftieth year. The effects of changes in wages and extraction costs, timber and farm products prices relative to each other etc. (already discussed), have also been studied. The results of net values added by land is in favour of forest in all cases if the discount rate is 4 percent or less. At higher rates of interest upto 7% the claim of forestry to the hill land depends on factors of wages, prices and housing costs.

The Land-Use Study Group of the Natural Resources (Technical) Committee (1965) have used the following criteria in comparisons between forestry and agriculture in a few selected areas :

1. Net discounted revenue per acre discounted over a period of one forest rotation, at three rates of discounts - 3%, 5%, and 7%.
2. N.D.R. per £100 capital (or discounted investment) - Capital includes initial investment and expenditure up to the point when the under-taking becomes self-financing.
3. Discounted cash flow rate of return, equivalent to financial yield or internal rate of return; the rate of discount at which N.D.R. per acre is nil.

In all calculations current market prices of resources and outputs are used and different levels of investments by a private owner or the state are studied seperately. The choice between the profit criteria depends on which input factors is limiting. Where land is scarce it should be highest profit/unit area (NDR/acre) and when capital is scarce, highest profit/unit of capital (NDR/£100). The cost of land is not taken into account.

For all sites surveyed, the internal rate of return ranges from a negative value to 18% to the nation and from 5 to 20% to a private owner in the case of agriculture and from 3 to $7\frac{1}{4}$% and from $3\frac{3}{4}$% to $8\frac{1}{2}$% respectively in the case of forestry. The decision of the investor would depend on which rate of discount he prefers to choose.

The Forestry Commission(1966) have adopted N.D.R. per acre and N.D.R. per £100 capital, calculated at a 5% rate of interest, in their economic assessment of profitability ~~of profitability~~ of different crops and calculation of the financial rotation as well as the optimum replacement date of a normal or an unsatisfactory crop.

Average Standard Net Output per acre, for agricultural use alone, has also been used as a criterion for economic assessments of physical grades of land by the Study Group on Agricultural Land Classification (1965). Standard Net Output per acre is defined as "yield X price - cost of seed", assuming average management and fertilizer practice. This however, does not appear to be a useful measure for comparing different land-uses with dissimilar management and outputs.

Webster (1963,1965) has made a case study to appraise the practical importances among profit criteria. 23 timber management opportunities were ranked according to four different criteria as follows:

<u>Maximise</u>

1. Internal rate of return
2. Contribution to present net worth, at 3 and 6% discount rates
3. Value response per cost dollar, at 3 and 6% discount rates - relates discounted present worth of benefits and costs as a ratio;

Minimise

4. Pay out period, measuring the number of years required to recover an investment - this criterion is used alone or in combination with site productivity as a secondary criterion,

Rankings by various methods are compared visually and also by correlation analysis for each pair of profit criteria. All the criteria, with the exception of pay out period, gave much the same results in terms of the timber management opportunities examined. This was particularly true of those ranked somewhere near the top of the list (specially first 10 opportunities).

Benefit-Cost Analysis (Sewell et al., 1962) is a simple budget method used in project evaluations which could also be applied in land-use studies. Benefits from output of useful goods and services include primary or direct benefits, secondry or indirect benefits, intangible benefits (not priced in a market but capable of being valued) and unmeasurable benefits. Similarly costs can be classified into tangible and intangible. Net Benefits = Total benefits-Total costs; Benefit-cost ratio = Benefits/Costs. Decision should be based on tangible plus a consideration of intangible benefits. Economic comparisons can be made on the following criteria:

1. A comparision of net benefits;
2. A comparision of Benefit-cost ratio
3. A comparision of ratio of return on investment - annual net benefit expressed as a percentage of capital investment.

Another method developed by forest economists (Duerr et al. 1956; Fedkiw and Yoho, 1956) is Financial Maturity, using the marginal analysis approach (Webster, 1965; Leslie, 1963). Prospective increases in the value of standing timber are expressed as an interest rates based on present values, and are then compared with a minimum acceptable rate, called the alternative rate of return. Timber is judged to be mature when the two rates are equal. At this point the N.D.R. is also maximum. The financial maturity can easily be calculated without discounting when the marginal (current) annual value equals the selected rate of interest (alternative rate of return).

Financial maturity considers only the cost of funds tied in the form of standing timber but if it is modified to include opportunity cost associated with the land it would be equivalent to maximisation of N.D.R.

If the net discounted revenue is converted into a recurring annual rental by multiplying by the rate of discount, this rent is the ceiling rent or, alternatively, land or soil rent. It represents the highest rent that one can expect to get from the land with its existing usage. The net discounted revenue is equivalent to 'Ceiling Price'.

COMPARISON OF DIFFERENT METHODS

The profit criteria described above may be grouped into three classes representing the three ways of comparing alternatives in an economic planning. These are (1) the budget method, (2) the marginal method and (3) the break-even method(Duerr,1960). The budget methods require an accounting of costs and benefits and a comparison of their gross or net values in relation to each other or to similar values of their present worths pertaining to the different alternatives. The marginal analysis approach tries to determine the alternative that equates its marginal costs and returns. The break-even method consists in finding the break-even point at which the two alternatives (or many alternatives considered in pairs) are equally advantageous in respect of the chosen cost of output function, one alternative being better before the break-even point is reached and the other after it.

Out of the several techniques mentioned in the preceding section, the financial maturity method is the only example of using the marginal analysis concept. The methods of pay-out period and net value addition to land(used by Walker) are instances of the break-even technique, but with a difference that the break-even point is taken as the one at which the net capitalised value of an individual activity is either nil (total expenditure equal to total revenue) or equal to an arbitrary value. The rest of the methods all belong to the 'budget' group.

Gaffney (1957) considers the use of the Faustmann formula as the only theoretically correct approach, as it takes into account contribution to present net worth from both the land and its crop. Some general economists favour the present value approach to internal rate of return methods (Turvey,1963;Fleming and Feldstein,1964). The internal rate of return does not correspond to a chosen discount rate and depends on the size of the budget (price of land,initial capital). Webster (1960) also prefers the present net worth methods, but Worrell (1953) however seems to prefer the internal rate of return approach . As demonstrated by Webster, results achieved with present worth and internal rates of return are almost identical. Duerr and others favour the Financial maturity concept for forest crops.

For comparisons between alternative land-uses, the choice of methods is fairly limited. Pay out period considers only one factor of timing of outputs upto the point when the investment is recovered. Net value addition method considers the increase in the value of investment on land in a given time. Both these methods are unsuitable.

Simple budget methods involving annual net benefits or ratio of benefits to cost do not seem to be suitable for long term investment activities met within land-use programmes or for a private owner of land. Marginal analysis methods are also not suitable for such studies because it is difficult to determine marginal costs of inputs and marginal values of returns.

The usual practice in economic investigations for selecting the best land-use for a site is to consider several criteria in combination. The criteria should account for all contigencies, that may be met with; for example, land or capital may be a limiting factor, or the alternative opportunities may be either mutually exclusive (as in the case of agriculture and forestry) or non-exclusive (as when considering different levels of management). In the last case, it is not necessary to specify a discount rate, and internal rate of return is a suitable criterion. The two criteria well suited to all types of land-use studies are (i) N.D.R./acre and (ii) Net Discounted revenue per £100 of total investment, at a specified rate of discount.

CHAPTER 3

DISCUSSION

Looking at the literature reviewed in the last two chapters, the fact emerges that most of the studies in the field of land-use have been carried out in two more or less watertight compartments. Either a physical classification of land is produced based on measurements of soil, vegetation and/or other factors of the environment but with a subjective evaluation of the productivity function which is used to differentiate between the classes. On the other side of the dividing line, precise economic assessments of differences in productivity are made but without a firm quantitative basis for physical comparibility of the sites concerned. In one case the differences in the physical nature of the land are deeply investigated without estimating accurately their influence on the economic performance. In the other case the differences in the physical quality of land are taken for granted on the basis of casual assessments, while economic variations are measured to a high degree of precision. Instances of combination of the two aspects are rare. The nearest attempt to combine an economic grading of land with ecological classification has been made recently by the Study Group on Agricultural Land Classification(1965) in England and Wales and also contemplated by the Canada Land Inventory(1965).

It may be true that in many cases a high degree of correlation would exist between the physical and economic gradings of the same land. Generally a physical higher grade land would be an economic higher grade land too; but sometimes this is not really true. A physically average grade land may be suited to highly economical low cost production, using suitable mechanised methods, thus making it an economically better land. On similar grounds, a better quality land may yet be less productive due to lack of support from capital and labour.

RELATIVE IMPORTANCE OF ECOLOGICAL AND ECONOMIC METHODS

The importance of a primary ecological approach in any land use and conservation programme has been stressed by Julian Huxley (1961). An ecological equilibrium can be upset by climatic changes or human interference - accidentally, as in deforestation or deliberately, as by introduction of new plants. The new equilibrium is too often a poorer one.

Anderson (1950) also very emphatically states that the only safe basis for choice of species (for planting) is the purely ecological one before any economic or social factors can be considered. Lemieux (1965) has stressed the necessity and practicability of the ecosystem approach to forest site classification and considers this to be the only valid approach.

It is apparant that a purely economic classification which completely disregards any ecological considerations would not be valid. Land is the basic natural resource and its natural productive capacity is a function of its inherent environmental characteristics when not interfered with by man. If human interference in the form of land-use and management brings about a deterioration in this natural or minimum capability, it cannot be accepted.

This leads to the question whether a purely ecological approach would be adequate . It is clear that this cannot be the case. No classification can be complete unless the economic significance of environmental variations have been critically examined. Land capability which we seek to estimate is a function of the interaction of environment with management and is thus an economic function.

A recent tendency is to regard productivity dependent more on management and capital and less on physical quality of land. The emphasis is on increasing the economic efficiency of a land-use activity by maintaining the existing level of physical production. Better reorganisation of labour and capital is considered more important in land classification than the inherent productive capacity of the land. This school of thought wants more capital to be invested in a better managed farm rather than on better quality land.

NEED FOR AN INTEGRATED APPROACH

Between the two extremes of views, the need is for an integration of ecological and economic assessments to evolve a fully comprehensive classification that relates land capability in economic terms with a large number of measurable physical features of the land. As stated by Langdale-Brown(1966), if assessments of land capability are to be successfully applied, they must be co-ordinated with sociological and economic studies. In his view, for a pattern of use to be worth introducing it should be ecologically stable, socially desirable, within the cultural abilities of the people and economically gainful.

On the basis of the past experience, one may lay down a set of requirements of a sound land capability classification system :

1. It should be based on as many environmental factors as possible and a variety of land-use and management possibilities.

2. Only measurable or easily quantifiable factors should be taken into consideration. Vague features based on subjective assessments should not be used. The method should be as objective as

possible, avoiding likely personal bias of the investigator but at the same time utilising fully his experience.

3. It should be based on simple observable features for which reliable data is available from maps and reports, aerial photographs and other sources. Stress should be laid on those properties of the environment which can be easily assessed on the ground by field workers rather than on minor properties which can only be determined accurately in elaborate laboratory tests. This is particularly true of soil properties. Soil mapping units like soil series (as used in the American classification) are very useful as a criterion for classification.

4. The economic assessment of the ecological land capability units should be based on sound profit criteria, capable of application to a wide range of alternative forms of usea, in the context of the local socio-economic conditions.

5. The interpretation of results should be based on use of modern techniques of analysis using appropriate statistical methods for significance tests of differences and for regression and correlation analysis. Employment of accurate tests of comparability impart a degree of confidence lacking in qualitative methods.

6. The classification achieved should be capable of application over a fairly wide region, with subsidiary classifications for smaller areas. It should also be adaptable to a wide range of conditions.

7. With the help of the adopted system, it should be possible to evolve a multiple land-use plan, which is not rigid but dynamic in its approach, able to absorb future changes in technological and socio-economic conditions.

Another important concept in land-use planning is of the multiple land-use consisting of integration of several activities.

on the same land with a view to utilise its full capacity for complementary uses. For example, a multiple land-use plan for forest land would comprise management for timber and other forest produce, wild life management, soil and water conservation, grazing by cattle and recreation.

The scale of a system of classification also plays an important part in its utility. The scale is regulated by the heterogeneity or otherwise of the environmental and management conditions as well as the size of the area studied and the scope of the investigation carried out. With a wider scale, smaller differences may be overlooked, necessitating the use of a much finer grouping within factors in complex mosaics or in smaller regions than in broad planning of a general nature.

Sometimes a greater importance placed on variables which occur almost uniformly (between narrow margins) over the entire area may result in a classification in which most of the area falls in one or two classes, usually near the average. Cosequently, other classes cover negligibly small areas. The practical usefulness of such aclassification is thus lost.

OBJECTIVES AND SCOPE OF PRESENT INVESTIGATION

Having stated the problem, it is possible to indicate the objectives and scope of this study. Its purpose is to evolve an integrated ecological and economic land capability classification technique, based on easily available data- in effect a simple practical system of land classification, and to illustrate the method by application to a sample area. Due to the limited extent of the present work and limited availability of time, its scope has been confined to a small scale study of particular applicability to hill areas having fairly uniform climatic conditions and an advanced level of management. The technique evolved could, however, be applied easily to a wider range of climatic, topographical and technological conditions and to larger scale planning.

The object is to determine the economic significance of land classes, grouped independently on the basis of environmental factors that are known to affect plant growth and are easy to define and locate in the field. The method consists of grouping the various units of land first into empirical land capability classes, formed on the basis of selected physical features . Simultaneously, the units involved in the physical grouping are also classified according to their economic productivity in terms of the chosen criteria. Taking the economic value as the dependent variable and the environmental factors as independent variables and assuming a normal sampling distribution, a series of statistical tests are carried out to measure the significance of differences between and within the classes, successively formed from the in-itial grouping until all the interclass differences in the final classification are significant.

To illustrate the methodology, Bowhill Estate in the county of Selkirkshire has been selected as the study area. Its wide range of land-uses and physiographic features, both typical of the Southern Uplands of Scotland in the Border region, and availability of sufficient information on the economics of operations offer an adequate scope for a study of this nature.

TWO VIEWS OF BOWHILL ESTATE FROM WEST PERNASSIE HILL

LOOKING SOUTH

LOOKING WEST

PART II

LAND CAPABILITY CLASSIFICATION OF BOWHILL ESTATE, SELKIRK

CHAPTER 1

DESCRIPTION OF THE STUDY AREA

The area selected for the investigation lies about 4 miles to the west of Selkirk, between latitudes 55°30'N and 55°34'N and longitudes 2°53'W and 3°0'W, and forms part of the Bowhill Estate. The greater part of the area is bounded by the waters of the Ettrick and the Yarrow on the north, east and south and by tenants' farms on the west. It comprises the entire woodland area of the Estate and four farms, namely Carterhaugh, Newarkburn, Fauldshope and Fastheugh. Part of the Carterhaugh farm extends across the Ettrick water towards the south. A number of small woodland blocks are also scattered to the north and east of Yarrow water and south of Ettrick water, mostly along the high banks of the two rivers or along burns. The total study area is 5,139 acres distributed as follows:

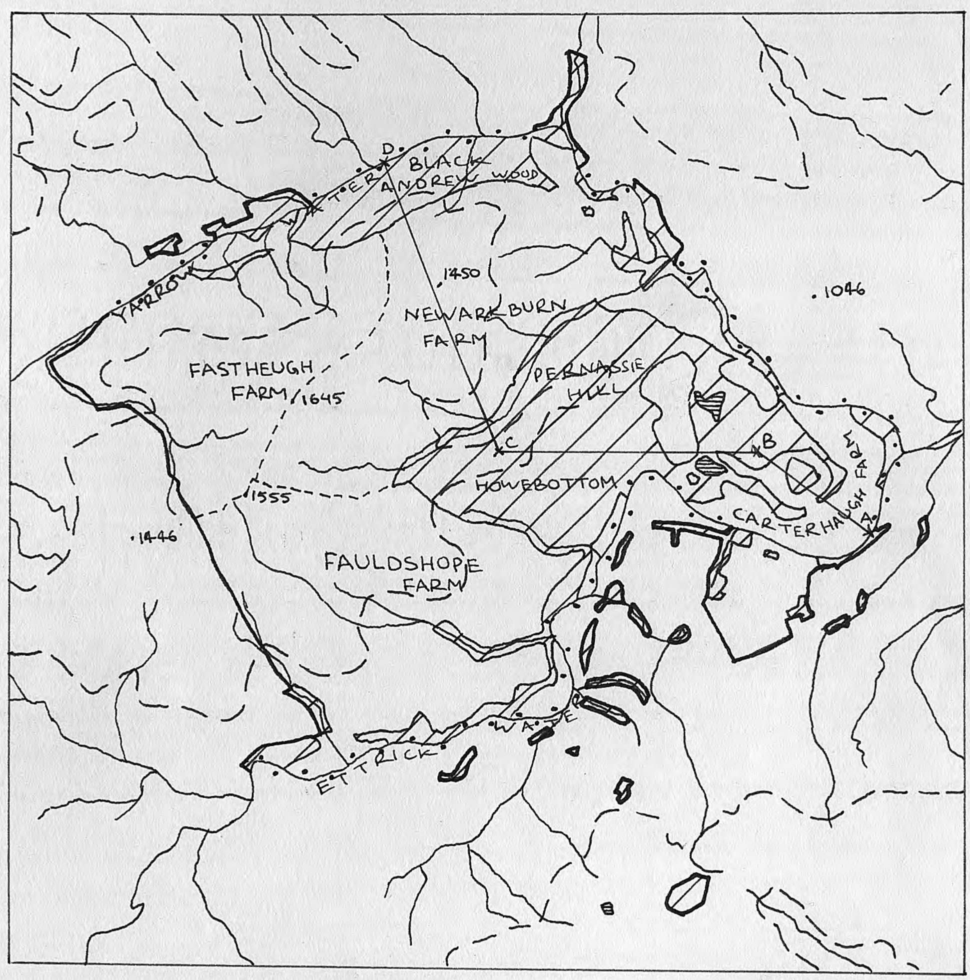
Woodland area	1,453	acres
Carterhaugh farm	605	"
Newarkburn farm	1,002	"
Fauldshope farm	1,181	"
Fastheugh farm	898	"

LANDFORM AND TOPOGRAPHY

The area forms part of the Southern Uplands region of Scotland, the higher ground in the centre and to the west being in the Lammermuir group of hills and the rest of the area in the Gala Uplands

MAP OF THE STUDY AREA

SCALE 1" = 1 MILE



EXTERNAL BOUNDARY

FARM BOUNDARY

WOODLAND AREA

1000' CONTOUR

TRANSECT ABCD

group. The upper part has rounded hills with gentle to steep slopes. Numerous burns flow between these hills through the lower ground down to the two rivers. The lower ground consists of two, sometimes three, successive terraces,,separated by moderate to steep banks. The detailed relief is more or less tied up with the geological formations.

Altitude varies from approximately 420' at the meeting point of the two rivers to 1,645' at the top of the Fastheugh Hill. An area of about 1,950 acres or almost 40% of the total area lies above the 1000' contour.

Slope varies from almost ~~almost~~ level in the lower alluvial terraces to steep on the northern and western aspects of higher hills. Generally the slopes are gentle to moderate lower down and at hill tops but moderately steep in the middle. The high banks of the two rivers carry very steep slopes at places.

All aspects are met with in the area but the commonest aspect with comparatively easy slopes, is southe eastern. The direction of the two main ridges is southwest to north east.

CLIMATE

This area falls in the B2f 'Tweeddale' climatic sub-province of Anderson and Fairbairn's(1955) classification. Some of the general characteristics of this sub-province are as follows:

Mean range of temperature (difference between July and January means)	27°F
Mean minimum temperature	33°F
Days of frost	50- 100
June sunshine, Mean hours per day	5.75 hrs.
Annual sunshine	28.0%

Cloud	72%
Humidity (Saturation deficit)	5 mb.
Growing season rainfall	15"-20"
Length of growing season (allowing for altitude; at sea level)	191- 195 days

The local climate of Bowhill Estate fits in the general pattern of the regional climate, modified by the topography. The average annual rainfall is 32" but it increases with altitude to over 45" in the western part. The rainfall is fairly uniformly distributed throughout the year, but there is a tendency to spring drought. Snowfall is normally heavy in winter, falling on 30- 40 days. Frosts can be severe. The growing season lasts from end of May to September.

The prevailing winds are from south or southwest. Strong to severe gale force winds come from the north, northwest and northeast during the period January to May, chiefly in February, and cause forest damage. The most exposed to wind are the northern slopes and also the burn valleys running in roughly North to South direction.

GEOLOGY

The underlying rocks are sedimentary belonging to the Ordovician-Silurian periods of the Older Palaezoic era. The chief rock formations occuring in this area are Queensberry or Buckholm grits, greywackes, flagstones, Birkhill shale(Upper Silurian and Llandovery groups) and Hartfell shale(Ordovician). The rocks are generally tightly folded, highly dipped and shattered due to the Caledonian revolution that took place at the end of the Silurian period. The relief at the top of the hills has a corrugated appearance, caused by the effect of erosion on the alternating hard and soft rocks.

The underlying solid geology has, however, been superposed by fluvio-glacial deposits left during the glacial age in the Quarternary period. These deposits occupy a major part of the area on lower slopes and in valley bottoms. Going up from the riverbbed, there are first two or three successive terraces of recent post-glacial alluvial sand deposits, followed by a zone of fluvio-glacial sand and gravel (derived mainly from shattered greywackes) and higher up boulder clay (till) drift. The boulder clay region is the most extensive. There are a couple of small patches of hill peat deposits on the western boundry.

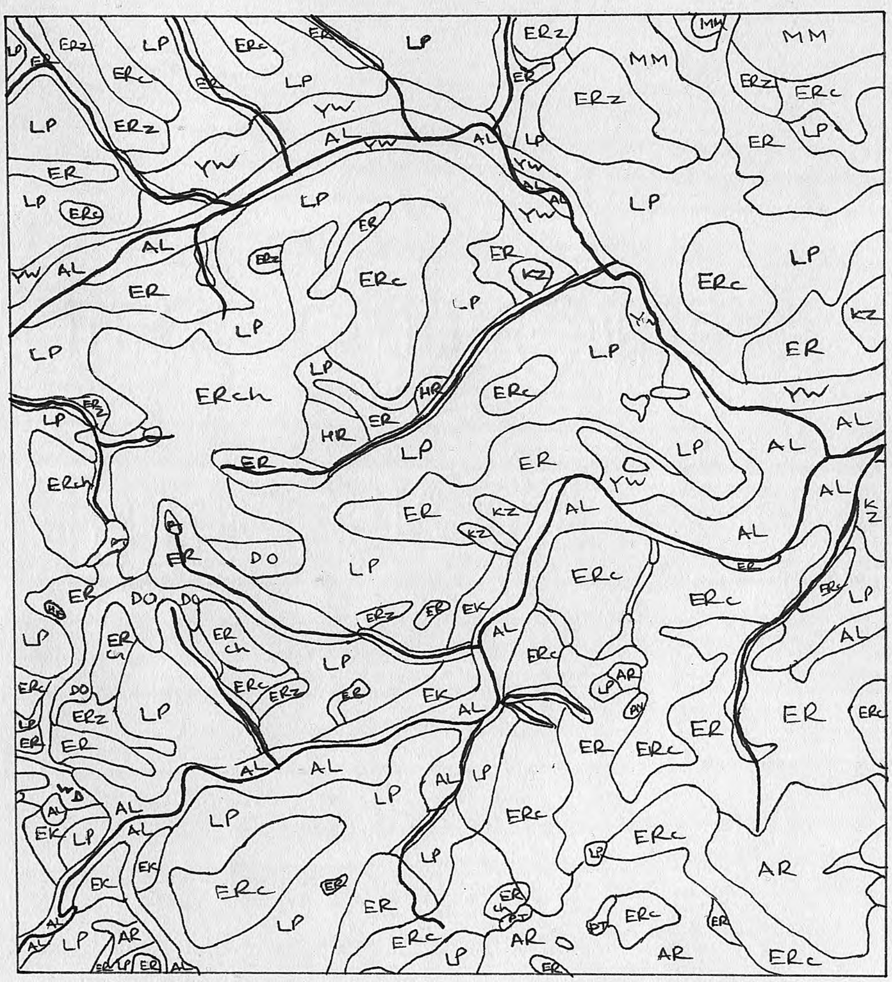
SOIL

A variety of soils are found in this area ranging from deep alluvial soils on recent lower terraces to patches of shallow skeletal soils on higher slopes. Soil texture is generally sandy loam to loam, except in the imperfectly drained soils which are usually clay-loam. Soil structure is variable and is a distinguishing feature of various soil series. Most of the soils particularly Linhope series, are stony and the amount of humus varies from place to place. The development of the soil profile is related chiefly to parent material and relief. Soil depth is also variable within a soil series. Valleys of burns have mostly alluvial deposits with shallow complex soils on banks.

In Linhope series, wherever there is a local intrusion of calcite rock, soil has higher pH and better phosphorus content. Otherwise these soils are deficient in phosphorus but adequate in potash. Soils of Kedslie series are most fertile. The nature of vegetation modifies the composition and nature of humus. There is more windblow (of trees) on water logged and gleyed soils than on brown forest soils.

MAP SHOWING BOUNDARIES OF SOIL SERIES

SCALE 1" = 1 MILE



IN ADDITION TO SOIL SERIES DESCRIBED IN THE TEXT –

MM MINCHMOOR SERIES

PN PEDEN SERIES

WD WOODEND SERIES

An area statement of the various Soil Associations and Soil Series found here is given below (compiled from Soil Survey of Scotland reports). Areas are given correct to nearest 10 acres.

Soil Association	Soil Series	Major Soil Sub-group	Drainage	Area in acres	Symbol used
Ettrick	Linhope	B.F.S.low base status	Free	1,880	LP
	Kedslie	B.F.S.with gleyed B & C horizons	Imperfect	60	KZ
	Ettrick	Non-calcareous gley	Poor	870	ER
	Dod	Peaty podzol	Free below B horizon	80	DO
	Alemoor	Peaty gley	Poor	10	AR
	Hardlee	Peaty gley	Very poor	20	HR
	Complex	-	Free	380	ERc
	Complex (humid)	-	Poor	660	ERch
	Skeletal soils	-	Free	60	ERz
Yarrow	Yarrow	B.F.S.low base status	Free	420	YW
Eckford	Eckford	B.F.S.low base status	Free	140	EK
-	Alluvial	-	Variable	550	AL
-	Hill peat	-	Very poor	10	HPT

The soils of the Ettrick Association are developed from the greywackes, grits and shales of Silurian formation and the till derived from them. The sand and gravel deposits give rise to the soils of Yarrow Association. Soils of the Eckford Association are formed from the sand and gravel deposits derived from sandstones of Upper Red Sandstone formation found west of the area. The alluvial soils are developed on post-glacial alluvium of either intermittent accumulation on the first terraces of streams or stable deposits on higher terraces.

The chief distinguishing character for soil series within an association is the amount of water drained through the soil. Soil series boundaries follow topographical features, such as altitude and change of slope, moisture conditions, changes in ground vegetation and local changes in the character of parent rock.

VEGETATION

The natural vegetation has been modified to a very large extent by human interference. No natural woodland community can be found in this area now and present forests are all planted. Examples of some semi-natural Birch scrub can be seen in some lower level hardwood forests and sandwiched between high level coniferous plantations in Black Andrew wood (compartments 54 b&d). There are also some old oak and Scotspine trees scattered in the lower region.

The ground vegetation inside woodland area and the plant communities in the semi-natural heath and grasslands in the area at present being put under hill grazing follow closely the changes in soils, particularly soil drainage. The common species of ground vegetation in hardwood forests on Brown Forest Soils with low base status are Agrostis tenuis (Bent grass), Dactylis glomerata, Foxglove, Bracken, Brambles, wild Raspberry, Deschampsia species, grasses and Holcus species. On poorer sites of acid podsolic soils and on gleyed soils, Calluna vulgaris (heather), Festuca ovina, Nardus stricta and other grasses are more common. Under coniferous plantations, ground vegetation is sparse in the early years when the canopy is closed but increases in abundance as the canopy opens up in thinnings.

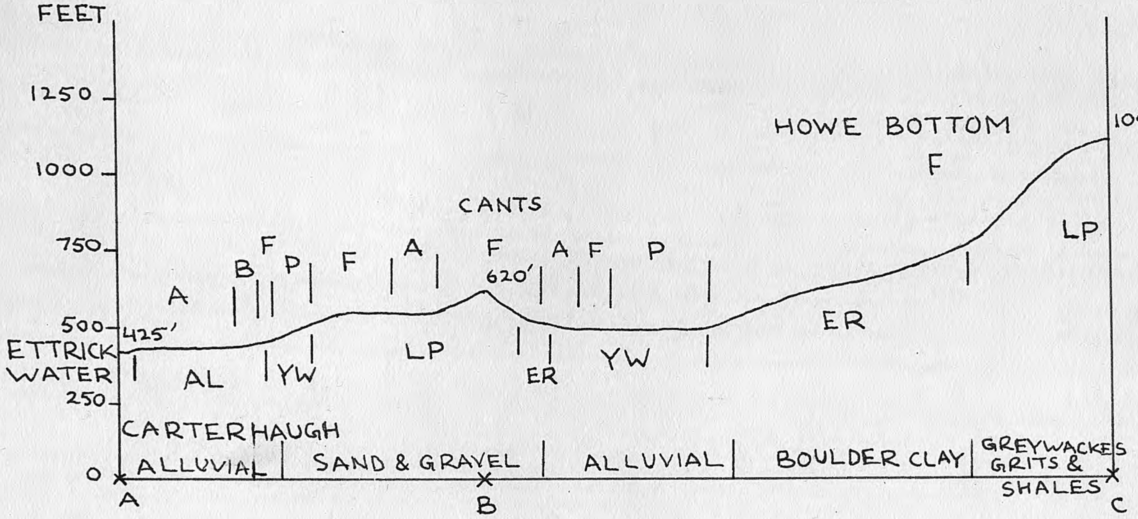
The acidic freely drained Brown Forest Soils are associated with a semi-natural Agrostis-Festuca grassland community with abundant bracken and some heather. Imperfectly drained podsolic soils generally carry a mixed heath and Nardus grassland type of vegetation. The wet gley soils have a greater proportion of Deschampsia caespitosa, Juncus species and Anthoxanthum odoratum.

LAND - USE

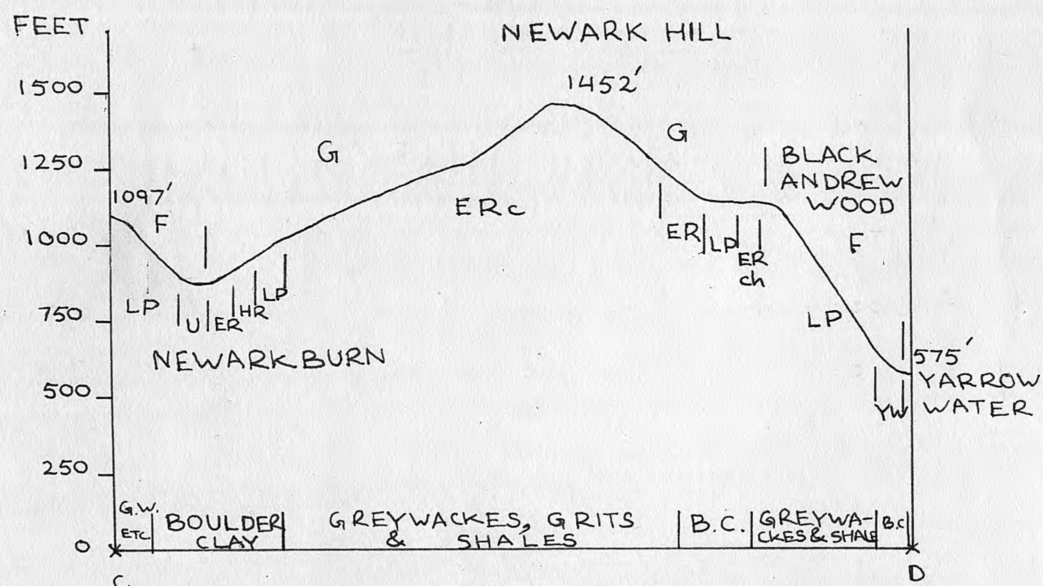
There are two major types of land-uses of almost equal status in the Estate - agriculture and forestry, with hunting being a subsidiary use. The majority of the woodland areas are productive. There are two main woodland blocks occupying the ridge of land between the two rivers. The maximum elevation touched by forests is 1,204'. The soils are mainly of Linhope and Yarrow series but some forests are on Ettrick, Kedslie, Eckford and Alluvial soils also.

Agricultural use can be divided into three types- (i) arable farming comprising tillage crops, usually barley, oats, turnips and kale, and rotation grass (for grazing, hay and silage), (ii) permanent pasture and (iii) hill grazing. Arable farming is confined to the level and gently sloping ground on the alluvial terraces. The soils are mostly alluvial but also of Linhope, Yarrow, Eckford, Ettrick and Kedslie series. Permanent pastures occupy slightly higher ground with less mild slopes and poorer stony Linhope soil. The rest of the area, generally above 800', comes under hill grazing. It has moderate to steep slopes and a variety of soils dominated by the two Ettrick complexes. Soils in the moister upper area in the west are shallow with peaty tops.

The relationship between land-use and environment is illustrated below in a diagram of the section ABCD drawn through the area and shown on the first map.

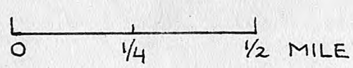


SECTION ABC



SECTION CD

HORIZONTAL SCALE 1:25,000



LAND-USE

A ARABLE FARMING
P PERMANENT PASTURE
G HILL GRAZING
F WOODLAND
B BUILT UP AREA

SOIL SERIES

AL ALLUVIAL
YW YARROW
LP LINHOPE
ER ETTRICK
HR HARDLEE
ERc COMPLEX
ERch COMPLEX (HUMID)
U UNCLASSIFIED

The breakup of farm areas under the land-use activities is given below. Areas are in acres.

Name of farm	Arable farming	Permanent pasture	Hill grazing	Houses, roads, etc.	Total area
Carterhaugh	377	84	139	5	605
Newarkburn	55	6	940	1	1,002
Fauldshope	313	37	824	7	1,181
Fastheugh	61	3	833	1	898
Total	806	130	2,736	14	3,686

WOODLAND MANAGEMENT

The entire woodland area is being managed as a Dedicated forest and is under Schedule B for income tax assessment . A plan of operations is prepared for a 10 year period but revised every five years. The current plan came into operation on 1st. October 1966. The object of management is to manage the woods in accordance with the best modern silvicultural practice, giving due regard to amennity, sporting and any other revelant considerations.

Except for the older hardwood stands of Oak and Beech, with some Scotspine and European Larch, the forests are mostly conifer plantations. In the last two decades, the trend is in favour of raising mixed conifers and broad leaved crops and uneven aged stands, where possible. The policy has been to restock the area by planting all or group planting, after scrub clearance, clear felling or wind - blow, and by underplanting in older open stands. Natural regeneration is utilised where it has appeared.

The main emphasis in the next five years will be on thinnings and cultural operations, particularly in the mixed plantations. At the same time selection fellings in the old hardwood crops and clearance of remaining scrub will continue so that in ten years' time the entire woodland area is fully stocked, and new areas might be brought in for planting.

The following table gives the distribution of area by systems of management, composition and age classes, which indicates the trend in planting and management.

Management System	Composition	Planting years	Area in acres
(i) High Forest (Clearfelling and Selection systems)	Broadleaved and Mixed	Pre 1901	127
		1901 - 30	54
		1931 - 50	5
		1951 - 60	142
		1961 - 70	56
		Total BL & mxd.	384
	Conifers	Pre 1901	3
		1901 - 30	305
		1931 - 50	187
		1951 - 60	359
		1961 - 70	127
		Total cfs.	981
	Total H.F.		1,365
(ii) Other plantable land to planted within 10 years	Scrub and felled	-	37
	Bare land	-	25
(iii) Land to be planted later	Scrub and felled	-	19
	Bare land	-	2
(iv) Unplantable land	-	-	5
Total			1,453

The woodland area is divided into a large number of compartments and sub-compartments. The total number of compartments is 69, and of sub-compartments 329. The area of a sub-compartment varies from 0.1 acre to 28.1 acres, average 4.4 acres.

The planting stock is raised in the nursery. Normally 2 + 2 year old nursary plants are planted out in the field. At the time of planting, the soil is worked deep with tractors and artificially drained where necessary. Planting is done in crowbar holes at a spacing of 4' X 4' or 5' X 5' or sometimes 6'X 6' during the period October to February. The plantations are tended for some years by weeding, clearing of bushes round plants and high pruning.

The principal species being planted at present are Sitka Spruce, Norway Spruce, Grand Fir, Japanese Larch, Scotspine, Beech, and Sycamore. Grand Fir is the main species used in under-plantings in old Beech and Larch stands. Sitka Spruce has the best growth in the region. Scotspine has slower growth but is favoured due to its adaptability to a wide range of conditions.

The timings of thinning and fellings are decided on considerations of age and condition of crop, market requirements, windblow and other factors. Thinnings are heavy and frequent, often every alternate year.

Portable chain saws are used for felling. Pulpwood billets are removed with bark, and debarking is done at road-side depots by a special machine. Large logs are removed by portable crane to the sawmill for conversion. The sawmill is an integral part of the woodland estate and produces pit props, fence posts, chipwood, boards, etc. Most of the hardwood timber production, some conifer sawlogs and all pulpwood are sold to outside buyers, and the remaining timber goes to the sawmill for processing.

Adequate protective measures are taken against fire, vermin, fungi and insects. A fairly extensive network of roads is maintained to facilitate transport, logging and supervision. Most of the work is done by the estate staff, supplemented, as required, by skilled contract labour.

Forestry Commission and other Government grants are recieved by the estate on management of dedicated woodlands (1,427 acres) and on areas of scrub clearance and planting.

FARM MANAGEMENT

Of the four farms in the study area, Carterhaugh farm is an Upland farm and Fastheugh a Hill farm, while the greater parts of the two remaining farms are under hill farming type. Carterhaugh farm (along with the Chesterhall farm near Melrose, not included in this study) is the oldest member of the Estate; Newarkburn farm was added in 1955, Fauldshope in 1961 and Fastheugh in 1964. All the farms are managed for breeding and rearing of sheep and cattle, and arable crops are chiefly grown for winter feeding of the stock and for grazing. About 80% of the total farm receipts are accounted for by sheep and cattle farming, 10% by direct sale of arable produce (barley, oats, straw, hay etc.) and 10% by poultry keeping.

Arable farming is confined to the deep, well drained soils of all the farms. There is more area under rotation grass than under tillage crops. In Carterhaugh and Newarkburn farms, considered together, the percentage of tillage crops has gradually diminished from 42% in 1957 to 27% in 1965, while in Fauldshope it has remained stationary, around 23%. Grass is usually retained for 4 to 8 years. Barley, oats, turnips, swedes, kale, arable silage and grass silage are the other crops. Hay is cut from two years grass crops. Typical crop rotations are - 4 to 8 years grass, followed by barley or oats; turnips, kale or grass silage; oats or barley. Arable silage is some times substituted as the first crop after grass, followed by either oats or barley, or as the last crop before grass.

The arable fields on higher ground have grass for longer rotation periods of upto 16 years.

A large amount of fertilisers is applied regularly to arable fields and periodically also to permanent pastures and parts of hill grazing land. In the arable fields phosphate deficiency is overcome by application of basic slag at the rate of 7 to 10 cwt. per acre at least once in a crop rotation. Concentrated complete fertilisers are applied to root and grain crops and nitro chalk to grass. Liming of the arable fields is not done now, but on acidic soils in hill grazing area magnesium limestone is spread locally.

Sheep farming is the principal activity. Carterhaugh and Fauldshope farms carry park sheep stocks of North Country Cheviot ewes; bringing up Half-bred lambs in Carterhaugh farm and breeding pure in Fauldshope farm. In the hill farm areas of Newarkburn, Fauldshope and Fastheugh farms the sheep stock is of Black face breed. The concentration is about 2.4 acres of hill land per ewe (hill sheep) in all the three farms. The average lambing percentage of different varieties of sheep are as follows :

Farm	Kind of sheep	Average lambing percentage
Carterhaugh	H.B. lambs (Border Leicester rams x N.C. Cheviot ewes)	150%
Newarkburn	B.F. lambs	90%
Fauldshope	N.C. Cheviot lambs	134%
	B.F. lambs	73%
Fastheugh	B.F. lambs	82%

The annual death rate is about 2½% in park sheep and 4 to 6% in hill sheep stock.

There is a ready market for H.B. lambs and N.C. Cheviot lambs and ewes; they fetch 2 to 3 times the prices of B.F. variety. Wool clips also show a wide difference in the two kinds of sheep. While the average price per lb. of wool (including brokes anddags) is comparable in all cases, the average weight per fleece is about 5.3 lbs. for park sheep and 3.0 to 4.4 lbs. for hill sheep.

In both types of farm areas, cattle follow sheep on grazing ground. This helps in the rough grasses and herbage being grazed off by cattle, encouraging finer and thicker grass to grow for grazing by sheep. The breed of beef cattle is Blue-Grey Cow, obtained by crossing Galloway cows with Shorthorned Bulls in the hill farm area. On lower farm area, B.G. cows are also crossed with Aberdeen Angus and Hereford bulls. Carterhaugh farm also has a stock of Ayrshire dairy cattle. The average length of lactation (1965 figures) is 275 days and average milk yield per lactation 9054 lbs.

Feeding stuff for sheep and cattle are provided from farm crops but some quantity of concentrates is also purchased. These include ground nut cakes, bran, beet pulp, turnips, oats, salts and minerals, etc.

The farm subsidies and grants received from government include those on Home Grown Cereals, Calf rearing, Marginal Land improvement, Grassland ploughing, Hill Cattle, Fatstock marketing, Bracken destruction, Hill Sheep farming, and Fertilisers and account for about 20% of the total receipts.

CHAPTER 2

METHODS OF ASSESSMENT AND ANALYSIS

The outline of the method adopted in this study has already been explained in Chapter 3 of Part I. The computation of data involves the following process:

1. Selection of units to serve as sampling units.
2. Selection of environmental variables and their evaluation and classification of units.
3. Assessment of economic productivity, costing, selection of rates of discounts and calculations of economic values to be used as dependent variables in analysis.
4. Statistical analysis and tests of significance for each land-use/crop group.
5. Interpretation of results and formulation of capability classes for the whole area.

A large amount of information concerning Bowhill Estate, collected from all available sources, has been utilized in the computations that follow.

SOURCES OF DATA

Information about land and topography has been compiled from Ordinance Survey maps on 6" = 1 mile, $2\frac{1}{2}$" = 1 mile and 1" = 1 mile scales and from interpretation of aerial photographs. Unfortunately the only aerial photographs of the area, available from the Scottish Development Department, were taken 20 years back, in the year 1947 at scales of 1/10,000 and 1/25,000 by using split photography taking two near-verticals on the same flight. The aerial photographs were used in differentiating land form characteristics, slopes, aspects, etc.

Drift Geological boundaries have been taken from geological maps, on 6" = 1 mile scale, of the Geological Survey of Great Britain. Information about soils has been compiled from two Soil Survey Reports (Muir 1956; Ragg 1960) of the Soil Survey of Scotland and the 1" = 1 mile scale soil maps attached with these reports.

Preliminary data about the age, composition, growth, yield and management of woodland units have been compiled from the compartment books, Annual returns of income and expenditure up to 1964-65, and other records maintained by the Head Forester of the Estate, and supplemented by height measurements in the field. For determinations of yield, classes, rotations and productions, use has been made of the Management Tables of the Forestry Commission (1966).

Farming data has been collected from the Annual Farm Reports of the Estate for various years upto 1964-65 and other records in the office.

MANAGEMENT UNITS

The primary unit of classification is the smallest management unit for which separate statistics of cost, growth and productivity can be assessed. These are (i) compartments and sub-compartments in woodland area, (ii) fields of arable farming (iii) permanent pastures and (iv) hill grazing areas. The fourth type are managed for grazing as single units separately for each farm. Each management unit is treated as a sampling unit and only those units are considered for which reliable data exists. Other units have been excluded.

A further reduction in the available number of sampling units is necessitated by omitting those which overlap two or more of the classes formed of individual environmental factors. Exceptions are made in the cases of (i) the four very large units of hill grazing land which covers fairly wide range of soils and other environmental conditions and (ii) those units where less than 20% part extends beyond the boundaries of one class.

ENVIRONMENTAL FACTORS AND CLASSIFICATION OF UNITS

Each unit is classified according to each of the environmental factors included in the investigation. The total number of such factors which could be considered in an investigation of this type is virtually unlimited. In the present study, the guiding principle was to select important, easily definable and mapped features only. The regional climate is assumed to be uniform over the whole area. Any variations in the local climate are caused by topographical, and, to some extent, soil and vegetational differences. Hence no specific climatic factor has been included.

Five factors are selected for this study, which are known to account for most of the inherent site characteristics. They are Altitude, Aspect, Slope, Geological formation and Soil.

The three topographical factors of altitude, aspect and slope among themselves form a combined index of temperature, amount of solar radiation received, small variation in total precipitation, length of growing season, occurence of frost, drainage, and exposure. The effect of any single factor on crop growth is not so important as that of interaction among all three of them.

The fourth factor is drift geology, which indirectly influences growth of crops through the effect on soil formation in general and on soil fertility, drainage, structure, texture, depth and stone content. The geological zones determine the land form and micro-relief in the area, which along with topographical features, govern the degree of exposure (particularly to wind).

The fifth factor is soil, represented by soil series. Soil series constitute the mapping units in most soil surveys and form a useful index for representing most of the physical and chemical soil properties as well as the associated vegetation. A soil series possesses more or less uniform characteristics, but variation within a soil series may occur in depth, stoniness and minor differences in drainage. These variations are direct results of topographical and geological differences. Soil series, therefore, form the most practical way of grading of soil and have been preferred to any other type of soil classification.

Altitude, aspect, and slope are continuous variables, and have to be grouped into suitable classes for convenience. The chief consideration in alloting class intervals is to have as fine a grouping as possible, but coarse enough to include a maximum number of units within single classes. Drift geology and soil series are discontinuous variables. The groupings adopted are as follows:

1. Altitude: 6 classes at 200' height intervals; class (i) 400'-600', (ii) 600'-800', (iii) 800'-1,000', (iv) 1,000'-1,200', (v) 1,200'-1,400' and (vi) over 1,400";
2. Aspect: 4 aspects; N, E, S and W;
3. Slope: The standard single slope classes of the U.S. Soil Survey -

Slope Class	Lower and upper limits of slope Degrees	 Slope Class
A Level	0° to $\frac{1}{2}^\circ - 1\frac{1}{2}^\circ$	0 to 1 - 3%
B Gentle	$\frac{1}{2}^\circ-1\frac{1}{2}^\circ$ to $3^\circ-4\frac{1}{2}^\circ$	1-3 to 5-8%
C Moderate	$3^\circ-4\frac{1}{2}^\circ$ to $6^\circ-9^\circ$	5-8 to 10-16%
D Moderately Steep	$6^\circ-9^\circ$ to $12^\circ-17^\circ$	10-16 to 20-30%
E Steep	$12^\circ-17^\circ$ to $24^\circ-33^\circ$	20-30 to 45-65%
F Very Steep	$24^\circ-33^\circ$ to 90°	45-65% to no limit.

4. Geology: 4 zones of geological formation-

a Recent post glacial alluvial deposits on lower and higher terraces,

g Fluvio-glacial sand and gravel deposits,

bc Boulder clay deposits, and

s Silurian rocks.

5. Soil: Soil Series, as described in the Soil Survey of Scotland reports, details given in Chapter 1, p.66.

A complete list of forest compartments and sub-compartments classified according to the environmental factors and grouped by species is given in Appendix I. The list includes only those units which have been included in the analyses that follow.

A similar list in respect of agricultural fields ~~and grazing grounds~~ is given in Appendix II.

ASSESSMENT OF ECONOMIC PRODUCTIVITY

The two economic criteria that have been used to evaluate economic productivity of units are Net Discounted Revenue per acre, or simply NDR/acre, and N.D.R. per £100 of discounted expenditure, or NDR/£100, calculated at rates of discount from 2 to 8%. If V = total discounted revenue per acre and C = total discounted expenditure per acre, then NDR/acre = V - C ; and NDR/£100 = $\frac{V - C}{C} \times 100$.

The formulae for calculation of values of V and C are:

1. For forest crops- (p = rate of discount)

$$V = \frac{Y_r + \Sigma T_a X 1.0p^{r-a}}{1.0p^r - 1}; \qquad C = \frac{cX1.0p^r}{1.0p^r - 1} + \frac{e}{.0p},$$

where Y_r = final yield from fellings at rotation age in each successive rotation, T_a = thinning yield in year 'a' in each successive rotation; c = cost of establishment at the start of the rotation; and e = annual recurring expenditure on protection and supervision.

2. For arable rotations -

$$V = \frac{\Sigma i_a X 1.0p^{r-a}}{1.0p^r - 1}; \qquad C = \frac{\Sigma c_b X 1.0p^{r-b}}{1.0p^r - 1};$$

where i_a = income in year 'a' in each successive rotation and c_b = expediture in year 'b' in each successive rotation.

3. For grazing area with uniform pattern of annual income and expenditure -

Substituting r = 1, a = 1 and b = 0 in formulae in (2),

$$V = \frac{i}{.0p}; \qquad C = \frac{c X 1.0p}{.0p},$$

where i = annual income, accruing at the end of the year, and c = annual expenditure incurred at the beginning of the year.

In the calculations of the above economic values, a few assumptions have been made. The present (1965) pattern of land-use and management has been assumed as the standard. It is assumed that the present management practices are the optimum ones for the area. The 1965 level of government subsidies and grants are also assumed. These grants and subsidies are now an integral part of the farm economy. Cost of land is not considered.

Secondly, present costs and prices have been assumed in all calculations. It is presumed that any change in any one of them would be compensated by corresponding changes in the others and that the relative differences between them in future would be of the same magnitude as at present. The 1965 level of prices and costs have been used.

The values of actual or anticipated yield is calculated at prices obtainable as near to the land as possible. For example, in the case of forest crops, prices of standing timber are used to calculate the value of both thinnings and fellings. For arable crops, prices at the farm gate are taken. It is assumed that the price obtainable near the land adjusts itself in a perfect competitive market to the prevailing market price, making due allowances for costs of conversion, storage, transport and handling.

The actual computation techniques involved in the two main land-use types - Forestry and Agriculture are dissimilar and are treated separately.

ACCOUNTING PROCEDURE FOR WOODLAND AREAS

For woodland areas, values of timber production from thinnings and final fellings are obtained by reference to the Management Tables of the Forestry Commission (1966). For this it is necessary first to determine the Yield Class (Y.C.) related to the tree species planted in the unit and the production class of the area.

The species planted and the years of planting are known for all the compartments and sub-compartments from compartment books, excepting for some of the pre-1900 plantations. The latter plantations, chiefly of hardwoods, were left out, and so also were stands of species other than six principal species, because of inadequacy of number of units in them. The six species included in the investigation are Sitka Spruce (SS), Norway Spruce (NS), Japanese Larch (JL), including Hybrid Larch (HL), European Larch (EL) and Douglas Fir (DF). For the first five species the sample sizes were quite adequate but for Douglas Fir, only just large enough.

Due to limitation of time, it was not possible to carry out extensive tree height measurements in order to find out top heights for Y.C. determination. Recourse was therefore made to utilizing all relevent statistics available at hand. The Y.C. was first determined by reading from the Age/Top Height graphs against the height measurements of September, 1966; supplemented by record of heights taken in Sept. 1957 as recorded in the compartment books. The Y.C. so obtained was checked by reference to toQuality Class/Yield Class conversion tables, converting quality classes recorded in 1957. Another checking was done by comparing the totals of actual thinning yields recorded in compartment books with the aggregate thinning yields given in the Thinning Control Tables for the same period of time. The agreement between yield class determinations from these four sources was fairly good. A table showing assessed Y.C. of compartments and sub-compartments is given in Appendix I.

The production class for this area is found to be 'b' class, by reference to the Production Class curves showing relationship between top height and total volume production. The local Y.C. is therefore the same as the general Y.C.

Though rotations have not been fixed for any species in the Estate, it is presumed that eventually they would be same as those adopted by the Forestry Commission, being the rotations yielding maximum NDR/acre under Forestry Commission management. These rotations have therefore been adopted for calculations in this study. They are:

Species Y.C.-	40	60	80	100	120	140	160	180	200	220	240	260	280
SS				60	60	55	55	55	55	50	50	50	50
NS				70	65	65	65	65	60	60	60		
JL & HL		50	50	45	45	45	40						
EL	60	55	55	50	50	45							
SP		75	70	70	65	65	60						
DF					55	55	55	55	50	50	50	50	

(Rotation in years)

The standing timber prices for thinnings and fellings have been adapted from the actual sale prices of 1965 in the Estate.

Species	Nature of felling	Price per hoppus foot (Volume over bark to 3" top diameter o.b.)			
		Breast height quarter girth class			
		Under 6"	6"- 7¾"	8"- 11¾"	12" and over
SS,NS,DF	Fellings	1/6	2/4	2/9	3/3
	Thinnings	1/1½	1/8	2/3	2/9
JL,HL,EL	Fellings	1/9	2/6	3/-	3/6
	Thinnings	1/4	2/-	2/6	3/-
SP	Fellings	1/3	1/9	2/3	2/9
	Thinnings	-/10½	1/3	1/9	2/3

The above prices are used, corresponding to the mean B.H.Q.G. of the crop at the time of thinnings and fallings, to find the value of the yields given in the Production Forecast tables. These values are substituted in the formula to calculate the value of discounted revenue,V.

For calculation of the value of total discounted expenditure, the following average figures of costs of establishment of plantations and annual maintenance have been used:

Cost of establishment,c.

Item	Expenditure per acre £	
Draining	5	
Fencing	6	
Site preparation(ploughing,etc.)	7	
Planting -		
Cost of plants(5'X5'spacing)	15	
Labour	7	
Transport of plants and labour	3	
Weeding	5)	include expenditure in the first 4years after planting.
Beating up	3)	
Initial roading	6	
Total Direct Costs	57	
Overheads(supervision,staff,etc.)	30	
Total expenditure	87	
Less government subsidy	22	
Net establishment cost	65	

Annual cost of maintenance, e.

	£/acre
Cost of protection, supervision and annual maintenance of roads	2
Less subsidy	1
Net annual cost	1

The direct costs of establishment are based on a few available figures of actual expenditure incurred on plantings in years 1963 - 66. The total overhead costs under establishment and annual cost of maintenance are assumed to be about 25% of the total annual expenditure on management and miscellaneous items. The remaining 75% of this expenditure is alloted to logging, sawmill, and marketing. Out of the 25% alloted to establishment and annual maintenance, which comes to about £4000 in a year, ¼th goes to the former activity and the remaining ¾th to the latter, which gives the figures of £30/acre and £2/acre, respectively.

The cost figures given above represent an approximation to average conditions in the Estate. For example, expenditure in drainage may be larger on imperfectly drained soils of Kedslie and Ettrick series as compared to the well drained Linhope series. But this is likely to be compensated by increased expenditure on soil workings on the latter soils due to their thin stony nature. In all calculations, therefore, these average cost figures are taken, considering them to be reasonable estimates.

Tables of Discounted Revenue, Discounted Expenditure, NDR/acre and NDR/£100 for various species, Y.C.s and p% are given in appendix III. All the values in these tables have been rounded off to the nearest £5. An example is given below :

Species - Sitka Spruce Y.C. = 240
Rotation = r Rate of discount, p = 6%

Discounted Revenue/acre = V = £100
Discounted Expenditure/acre = C = £85
Net Discounted Revenue = V-C = £15

$$\text{NDR}/\ £100 = \frac{V-C}{C} \times 100 = £20$$

The Internal Rate of Return when NDR/acre is 0 is 6.6% in this case.

ACCOUNTING PROCEDURE FOR FARMLAND

The accounting in farming areas is very much complicated due to presence of a large number of diverse factors. Since the mainstay of farming activities in the Estate is sheep farming, the position is everchanging due to frequent movement of sheep (and cattle) from field to field, and carry over of produce of one year to next year for feeding of stock or for sale. Changes are made in cropping areas of different arable crops from year to year, depending on the requirement of feeding stuffs and area for grazing. The patterns of crop rotations are not fixed, so also the application of fertilisers to individual fields. No value is normally attached to the arable produce fed to stock. The figures that are derived here are therefore more in the nature of indication of the real values rather than the estimates of averages.

For purposes of analysis, the lower arable farming area of Newarkburn farm is included with Carterhaugh farm. The livestock population figures are given in terms of average population for the year 1964-65.

Some farm indices for the Estate as a whole and for individual farm enterprises (including poultry keeping but excluding Chesterhall farm) are given below :

(Livestock Units and annual Starch Equivalent requirements calculated according to conversion tables in Blagburn, 1961.)

Type of Livestock	Livestock Units	Distribution in Farms			
		C'haugh	F'hope	N'burn	F'heugh
Park Sheep	168	96	72	-	-
Hill Sheep	331	-	93	134	104
Dairy Cattle	48	48	-	-	-
Beef Cattle	192	8	57	66	61
Poultry	75	75	-	-	-
Total	814	227	222	200	165

Total area of farmland = 3686 acres

Av. No. of Livestock Units per 100 acres of farm = 22.1

Total Forage Acreage
(area under grass & other bulky forage crops, like Kale) = 3,434 acre

Av. forage acreage per grazing L.U. = 4.65 acres

The figures for individual farms as follows :

Farm	Forage Acreage	Forage Acreage per grazing L.U.
C'haugh	521	3.43 acres
F'hope	1090	4.91 acres
N'burn	940	4.70 acres
F'heugh	883	5.35 acres

Including Chesterhall farm also (L.U. = 71), the total S.E. requirements of all livestock = 30,100 cwt., of which 3,640 cwt. is provided by 130 tons of purchased concentrateds, and 140 tons of homegrown cereals fed to stock, leaving 26,360 cwt. The total area of forage crops is 3,768 acres

Av. yield of food output (S.E.) = 7.0 cwt. per forage acre.

Total feed acreage = 4,040 acres

Feed acreage per L.U. = 4.56 acres

The total income from sale of livestock during 1964-65 was £29,100, which gives an average livestock output of £7. 4s. per acre of feed.

The sale values of different kinds of arable produce (except grazing) at farm gate are taken as follows (Average 1965 prices):

Barley	£1. 2s.	per cwt.
Oats	£1. 0s.	per cwt.
Hay	£10.	per ton
Turnips and Swedes	£18.	per acre
Kale	£16.	per acre
Arable Silage	£10.	per acre
Grass Silage	£8.	per acre

The average yield of Hay from 2nd year grass is about 35 cwt. in C'haugh farm and 32cwt. in F'hope and N'burn farms. Some of the recorded yields of Barley and Oats from various fields during the years 1962 to 1965 are given in Appendix V.

In order to estimate the annual costs and returns per acre from different types of land-uses, the following procedure is adopted:

1. Direct costs and receipts are attributed to the activity concerned and distributed both on the basis of area (per acre) and effective livestock population (per ewe or per cow), as applicable. Grants and subsidies are subtracted from the related expenditure and not added to the reciepts.

2. The distribution of overhead costs is made by using two criteria - (i) allocation of the same proportion to the individual enterprise as its share in the total reciepts, assuming that a higher yielding activity would recieve more attention. The reciepts from arable farming include the value of produce fed to stock; and (ii) within an enterprise the cost is distributed as in item 1 on area or population basis.

3. In the case of rotation grass and permanent grazing land, the total costs and receipts per acre are made up of (i) those calculated for the land on area basis and (ii) those attributable to the livestock population it carries, calculated on the basis of average stock density, in terms of acres per ewe or per cow.

The average stock densities calculated for various farms and kinds of livestock are as follows :

Average Stock Density - Acres per ewe or cow

Crop	C'haugh		F'hope		N'burn		F'heugh	
	Sheep	Cattle	Sheep	Cattle	Sheep	Cattle	Sheep	Cattle
Young grass	$\frac{3}{4}$	7	$\frac{3}{4}$	8	$\frac{3}{4}$	7	-	-
2nd year grass (hay)	$2\frac{1}{2}$	25	$2\frac{1}{2}$	25	$2\frac{1}{2}$	25	-	-
Grass upto 4 year old	$1\frac{1}{2}$	20	$1\frac{1}{2}$	20	$1\frac{1}{2}$	20	-	--
Older grass	2	15	2	20	2	15	2	20
Permanent pasture	2	15	2	20	2	15	2	20
Hill grazing	$2\frac{1}{2}$	20	3	20	$2\frac{1}{4}$	19	3	20

The following statement gives the actual distribution of costs and receipts of the year 1965 arrived at by using the principles enunciated above.

Expenditure

A. Costs directly connected with land, per acre.

Item	Tillage crops	Young grass	Hay	Older grass	Permanent pasture	Hill grazing
1. Fencing and draining	£10	-	-	-	-	-
2. Ploughing	£8	£8	-	-	-	-
3. Cost of seed	£4	£4	-	-	-	-
4. Cost of fertilisers(less subsidy)	£7	£1.10s.	£1.10s	-	-	-
5. Harvesting	£2	-	£2	-	-	-
6. Transport and haulage	5s.	5s.	5s.	-	-	-
7. Overheads	£5	£5	£5	£3	£1	10s.
Less total subsidies(except fertiliser)	£7	£3	-	-	-	15s.

B. Costs directly connected with livestock, per ewe or per cow.

Item	Park sheep	Hill sheep	Dairy cattle	Hill cattle
1. Purchase of livestock-				
Carterhaugh farm	£3.15s.	-	-	£9.10s.
Fauldshope farm	5s.	5s.	-	£9.10s.
Newarkburn farm	-	5s.	-	£9.10s.
Fastheugh farm	-	5s.	-	£9.10s.
2. Cost of feeding stuff (including home grown)	£1.10s.	£1.0s.	£50	£9.0s.
3. Herd depreciation				
Carterhaugh farm	15s.	-	£1.10s.	10s.
Fauldshope farm	10s.	5s.	-	10s.
Newarkburn farm	-	10s.	-	10s.
Fastheugh farm	-	5s.	-	10s.
4. Veterinary fees, medicines, etc.	10s.	10s.	£1	10s.
5. Transport and haulage	5s.	5s.	5s.	5s.
6. Overheads	£4	£1	£37	£12
Less subsidies	£1	£1.5s.	-	£17.10s.

In calculating average costs of ploughing and harvesting, the cost of machinery is taken as the value of annual depreciation and added to costs of repairs, maintenance and running expenses. The fertiliser treatment involves the following costs:

Tillage crops- Basic slag £3.10s.
Grain or turnip manure £3.10s.
Rotation grass- Nitro-chalk £1.10s., usually twice during a rotation
Other grazing areas- Liming done as necessary.

Subsidy on tillage crops applies to cereals only.

Herd depreciation accounts for natural mortality.

Receipts

A. Direct receipts from sale and disposal of arable produce-

Actual or average outturn taken, as applicable.

B. Receipts from sale of livestock and livestock produce,

per ewe or per cow in the livestock population.

Item	Park sheep	Hill sheep	Dairy cattle	Hill cattle
1. Sale of livestock-				
Carterhaugh	£14.15s.	-	£6.5s.	£42.10s.
Fauldshope	£8.5s.	£2	-	£42.10s.
Newarkburn	-	£2.10s.	-	£42.10s.
Fastheugh	-	£1.10s.	-	£42.10s.
2. Sale of wool-				
Carterhaugh	£1.15s.	-	-	-
Fauldshope	£2	£1.5s.	-	-
Newarkburn	-	£1.5s.	-	-
Fastheugh	-	£1	-	-
3. Sale of milk, etc.				
Carterhaugh	-	-	£130.10s.	-

The average cost and receipt figures shown against beef (hill) cattle are combined averages for the whole Estate, as farm-wise records are not kept.

On the basis of the average figures of costs and revenues and of stock density carried by different forage crops, values of NDR/acre and NDR/£100 at rates of discount from 2 to 8% have been calculated for ~~for~~ some of the units and are tabulated in Appendix IV. The current arable rotations have been assumed for each field. Only those units could be included for which some actual outturn figures were available and the rotations were definitely known.

METHOD OF ANALYSIS

Mathematically, the relationship between the productivity of land, as measured by an economic value and various environmental factors, may be expressed as

$I_j = f_j(A, B, C, \text{etc.})$, where I_j is an index representing economic productivity, pertaining to land-use/crop combination, j, calculated at a certain rate of discount, and A, B, C, etc. are the values of various environmental factors. The function f_j would not be the same for each crop, because of the widely varying requirements of individual crops.

A number of statistical techniques may be used with advantage to test the correlation of productivity with environmental factors. In the present study the choice of methods has been fairly restricted owing to the non-quantifiable nature of two of the factors, soil and geology. The method of analysis of variance is used to test the significance of differences in economic productivity between various environmental groups. If the inter-group differences are found to be significant at 5% level, a series of 't' tests are carried out to find out the significance of differences among individual pairs of the groups. Groups not showing any significant differences between them are amalgamated, so that finally a revised classification is achieved in which all inter-class differences are significant.

Analysis has been done for the values of N.D.R./acre and N.D.R./£100 at 4% and 6%, giving in all 4 sets of analysis. Separate analysis has been carried out for the 6 woodland species and a combined analysis for all the farming areas.

The complete analysis for the case of Sitka Spruce is given below to illustrate the technique used, but in all other cases only the final stage in operations is giben.

For Sitka Spruce, the frequency distribution of units under various environmental groups is as follows:

Soil	Geology	Altitude	Aspect	Slope	Yield Class	No. of units	Total
AL	a	i	W	D	280	1	1
LP	g	i	E	B	240	1	
					260	1	2
"	"	"	S	B	240	1	1
"	bc	"	N	D	220	1	
					280	1	2
"	"	"	"	E	220	1	1
"	"	ii	"	C	220	1	1
"	"	"	"	D	200	2	
					220	1	
					260	1	
					280	1	5
"	"	"	"	E	180	1	
					220	3	4
"	"	"	E	D	260	1	1
"	"	iii	N	D	220	1	1
"	s	ii	"	D	180	1	
					200	1	2
"	"	"	W	E	140	1	
					160	1	2
"	"	iii	N	D	180	1	
					200	1	2
"	"	"	"	E	160	1	1
"	"	iv	"	C	140	1	
					180	1	2
"	"	"	"	D	140	1	
					180	1	2
"	"	"	"	E	140	1	1
"	"	"	S	B	180	1	1
"	"	"	W	E	140	1	1
YW	a	i	S	B	200	1	1
ER	bc	"	E	C	240	1	1
"	"	ii	S	C	200	1	
					220	1	2
KZ	"	"	E	C	220	1	1
ERc	s	iii	N	D	260	1	1
"	"	"	S	D	240	1	1

The above table indicates some affinities among environmental factors. For example, environmental groups in the middle of the table have lower Y.C.'s than those at either end.

In order to make the data fit for analysing, a re-grouping is done by combining those groups which posess a fair amount of uniformity in Y.C. pattern. This device increases the number of sampling units in individual groups. The revised table is given below. Description of the groups follows the table.

Yield Class	NDR/acre 4%	NDR/acre 6%	NDR/£100 4%	NDR/£100 6%	Environmental Groups 1	2	3	4	5	6	7	Total
140	15	-45	15	-50	-	-	-	-	-	1	4	5
160	35	-35	40	-40	-	-	-	-	-	2	-	2
180	60	-25	65	-25	-	-	-	-	1	2	3	6
200	80	-15	90	-10	-	1	2	1	-	2	-	6
220	110	0	110	0	-	-	4	2	4	-	-	10
240	150	15	155	20	1	2	-	1	-	-	-	4
260	185	30	185	40	1	1	2	-	-	-	-	4
280	215	45	215	55	-	1	2	-	-	-	-	3
				Total	2	5	10	4	5	7	7	40

Group	Soil	Geology	Altitude	Aspect	Slope
1	ERc	s	iii	N,E	D
2	AL,LP,YW	a,g	i	E,S,W	B,D
3	LP	bc	i -iii	N, E	C,D
4	ER,KZ	bc	i, ii	E,S	C
5	LP	bc	i, ii	N	E
6	LP	s	ii,iii	N,W	D,E
7	LP	s	iv	N,S,W	C,D,E

For analysis of variance the standard model for partition of degrees of freedom and sum of squares of differences is used.

	Degrees of freedom	Sum of squares
Between arrays	m - 1	$\Sigma\{n_p(\bar{y}_p - \bar{y})^2\}$
Within arrays	n - m	by subtraction
Total	n - 1	$\Sigma(y - \bar{y})^2$

where n is the total number of observations, m the number of arrays, n_p the number of observations in the pth array, $\bar{y}_p$ the mean of observations in pth array and $\bar{y}$ the mean of all observations.

For 't' test the value of the statistic 't' is calculated by the standard formula but if the difference in the variances of the two groups is too large the modified formula is used.

The level of significance at 5%, 1% and 0.1% is denoted by the the symbols x , xx , xxx respectively.

The results of analysis of variance of the differences among the seven groups using the four variable functions are given below.

NDR/acre at 4% rate of discount

	d.f.	S.S.	Mean S.S.	F
Between groups	6	83,912	13,985	9.5 xxx
Within groups	33	48,478	1,470	
Total	39	132,390		

NDR/£100 at 4% rate of discount

	d.f.	S.S.	M.S.S.	F
Between groups	6	89,969	14,995	11.7 xxx
Within groups	33	42,281	1,281	
Total	39	132,250		

NDR/acre at 6% rate of discount

	d.f.	S.S.	M.S.S.	F
Between groups	6	17,513	2,919	10.1 xxx
Within groups	33	9,527	288	
Total	39	27,040		

NDR/£100 at 6% rate of discount

	D.F.	S.S.	M.S.S.	F
Between groups	6	22,097	3,683	8.3 xxx
Within groups	33	14,558	441	
Total	39	36,655		

With all the four criteria the differences of means are highly significant. In a series of t tests carried out in each case to test the significance of differences of the means between individual pairs of groups, the values of t and the levels of significance are found to be of the same order. These levels of significance are given below in the form of a chart.

Groups	2	3	4	5	6	7
1	n.s.	n.s.	n.s.	x	xxx	xxx
2		n.s.	n.s.	n.s.	xxx	xxx
3			n.s.	n.s.	xxx	xxx
4				n.s.	xx	xx
5					xx	xx
6						n.s.

A scrutiny of the results shows that there are no significant differences among groups 1 to 5 and again between groups 6 and 7. These are therefore merged to form only 2 groups and a new classification table prepared of new groups designated groups I and II.

Yield Class	NDR/acre 4%	6%	NDR/£100 4%	6%	Environmental groups I	II	Total
140	15	-45	15	-50	-	5	5
160	35	-35	40	-40	-	2	2
180	60	-25	65	-25	1	5	6
200	80	-15	90	-10	4	2	6
220	110	0	110	0	10	-	10
240	150	15	155	20	4	-	4
260	185	30	185	40	4	-	4
280	215	45	215	55	3	-	3
Total	-	-	-	-	26	14	40

Description of groups

Group	Soil	Geology	Altitude	Aspect	Slope
I	AL	a	i	W	D
	LP	g, bc	i to iii	N,E,S	B to E
	YW	a	i	S	B
	ER,KZ	bc	i, ii	E,S	C
	ERc	s	iii	N,E	D
II	LP	s	ii to iv	N,S,W	C to E

These two groups show highly significant differences between them using 't' test with all the four criteria :

Criteria	Value of 't'	
NDR/acre,4%	6.72	xxx
6%	7.06	xxx
NDR/£100,4%	6.83	xxx
6%	7.52	xxx

This therefore is the final classification in the case of Sitka Spruce. The better quality land consists of all types of soils, geological formation and topography, except for the shallower dry soils of Linhope series formed on shattered Silurian rocks.

In the analysis for Sitka Spruce, it is seen that identical results of significance tests are obtained by using any of the four economic criteria. The same pattern is revealed in other cases also.

The tables of final groupings for the remaining five species are given below. To show the significance of differences of the means of groups among themselves, the results of t test for the case of NDR/acre at 4% only are discussed.

For Norway Spruce, the final grouping is as follows :

Yield Class	NDR/acre 4%	6%	NDR/£100 4%	6%	Environmental groups I	II	III	Total
100	-40	-65	-40	-80			8	8
120	-20	-60	-20	-70		2	3	5
140	0	-50	0	-60		4	1	5
160	25	-40	20	-50		9		9
180	50	-30	50	-35	1			1
200	80	-20	80	-20	2			2
220	105	-10	105	-5	1			1
240	130	5	135	5	4			4
Total					8	15	12	35

Description of the groups

Group	Soil	Geology	Altitude	Aspect	Slope
I	AL	a	i	E,S	A,E
	LP	bc	i	N	C
	ER,KZ	bc	i,ii	S	C
II	LP	bc,s	ii,iii	N,E,S	CtoD
III	AL	a,bc	i,ii	W	BtoD
	LP	s	iv	N	BtoE
	ERc	bc	iii	N	D

These groups also show a high level of significance of inter-group differences as given in the table below of 't' values for NDR/acre at 4%

Group	II	III
I	12.51 xxx	14.08 xxx
II		7.32 xxx

In theecase of Japanese and Hybrid Larches, the final grouping is as follows :

Yield Class	NDR/acre 4%	NDR/acre 6%	NDR/£100 4%	NDR/£100 6%	Environmental groups I	II	III	IV	Total
80									
80	-25	-55	-25	-65				2	2
100	--5	-40	5	-45		1	6		7
120	35	-25	35	-30	7	3	4		14
140	70	-10	70	-5	8	7	3		18
160	115	10	105	15	21	1			22
Total					36	12	13	2	63

The significance level of interclass differences is given below :

Description of groups

Group	Soil	Geology	Altitude	Aspect	Slope
I	LP	bc	i,ii	N,E,S	C,DE
	YW	a	i	S	B
	ER,KZ	bc	i,ii	E,S	C
	ERc	s	iii	N,S	D
II	AL	g	i	E	B
	LP	g	i	N, E,S	D
	EK	g	i	S	D
	YW	a,g	i	N,E	A,B,C,D
III	AL	a	i	N,E	A,F
	LP	s	i, ii to iv	N,W	B,D,E,F
	ERc	bc	i	N	F
IV	LP	bc	i	W	D

NDR/acre at 4%

Group	II	III	IV
I	3.09 xx	6.56 xxx	5.48 xxx
II		9.01 xxx	4.25 xx
III			2.25 x

In the case of European Larch again, only two significantly differing groups are obtained.

Yield Class	NDR/acre 4%	NDR/acre 6%	NDR/£100 4%	NDR/£100 6%	Environmental groups I	II	Total
66	-55	-70	-55	-85	-	1	1
80	-30	-60	-25	-70	-	6	6
100	5	-50	5	-55	4	4	8
120	30	-30	35	-35	4	-	4
140	65	-10	65	-15	6	1	7
Total					14	12	26

Description of groups

Group	Soil	Geology	Altitude	Aspect	Slope
I	LP	g,s	i to iii	N,E	B,D,E,F
	EK	g	i	E	D,E
	YW	a	i	E,S	B,C
	ER	bc	i	E	C
	KZ	bc	i	E	C
	ERc	bc	i	N	F
IIa	AL	a	i	E,S	A,C
	LP	bc	ii,iii	N	D,E,F
IIb	LP	s	iv	N,S	C,D,E

NDR/acre at 4%   t = 5.02 xxx

For Scotspine, the position is as follows:

Yield Class	NDR/acre 4%	NDR/acre 6%	NDR/£100 4%	NDR/£100 6%	Environmental groups I	II	III	Total
80	-60	-70	-60	-85		1	6	7
100	-45	-65	-45	-80		2	2	4
120	-25	-60	-30	-70	9	2	2	11
140	0	-50	0	-60	6	1		7
160	20	-40	25	-45	4			4
Total					19	6	8	33

Description of groups

Group	Soil	Geology	Altitude	Aspect	Slope
I	AL	a,bc	i,ii	E,W	D
	LP	g,bc	ii,iii	N,E,S	B,C,D
	EK	g	i	S	A,E
	ER	bc	i,ii	E,S	C,E
	ERc	s	iv	N,S	C,D
II	LP	bc,s	ii,iii	N	E
III	LP	s	iv	N	B,D
	AL	a,bc	i,ii	W	B,C

Significance of't'for NDR/acre at 4%

Group	II	III
I	2.52 x	5.58 xxx
II		2.43 x

Lastly in the case of Douglas Fir also only two groups are formed. The frequency table, description of groups and the result of't' test for NDR/acre at 4% are given below.

Yield Class	NDR/acre 4%	NDR/acre 6%	NDR/£100 4%	NDR/£100 6%	Environmental groups I	Environmental groups II	Total
120	-5	-50	-5	-60		3	3
160	50	-25	50	-30	2		2
200	125	5	125	5	1		1
220	165	20	165	25	1		1
240	210	40	205	45	1		1
Total					5	3	8

Group	Soil	Geology	Altitude	Aspect	Slopes
I	LP	bc	ii	E	C
	YW	a,g	i	N,E,S	B,C,D
	ER	bc	i	E	C
II	AL	a,bc	i	N,W	A,C,D

NDR/acre 4%, 't' = 4.27 x

In the case of agriculture, there are in all 30 units, 27 fields of arable farming and 3 large hill grazing units, for which values of NDR/acre and NDR/£100 have been calculated. The tables below give the final environmental grouping in terms of NDR/acre 4% and 6% respectively. The frequency distribution in the two cases is not the same, as in the case of forestry where Y.C. was the deciding factor; but the environmental classes obtained, which show significant differences amongst themselves, are the same.

NDR/acre at 4%	I	II	III	IV	Total
25				3	3
55			1		1
60			3		3
65			7		7
70		2	4		6
75		3			3
80		4			4
90	2				2
105	1				1
Total	3	9	15	3	30

NDR/acre at 6%	I	II	III	IV	Total
15				3	3
25			6		6
30			5		5
35		1	3		4

NDR/acre at 6%	I	II	III	IV	Total
40		4	1		5
45		4			4
50	2				2
60	1				1
Total	3	9	15	3	30

NDR/acre at 4%

Group	II	III	IV
I	5.27xxx	9.20xxx	14.00xxx
II		5.12xxx	20.40xxx
III			15.18xxx

NDR/acre at 6%

Group	II	III	IV
I	3.89xx	7.24xxx	10.92xxx
II		5.66xxx	10.40xxx
III			5.26xxx

The results indicate that in arable farming productivity varies with the soil. Best soils are of Ettrick and Kedslie series, followed by the Alluvial soils, while all the freely drained brown forest soils are next.

Using NDR/£100 at both rates of discount, no significant differences are obtained, because the values of this function are almost the same for each field. This contingency arises because in the calculations no restriction was placed on the amount of capital that could be invested on farming. The capital being unlimited, the NDR/£100 of expenditure reflects a situation in which as much money goes into the land as needed. The return per unit of investment, therefore, becomes constant.

CHAPTER 3

DISCUSSION OF RESULTS

The results of analysis show that though the productivity of land is largely overshadowed by the systems of management, some significant differences, nevertheless, emerge due to its physical characteristics. It is seen that the soils of Kedslie and Ettrick series get the highest ranking in almost all of the seven alternatives. Similarly soils formed on Sand and gravel deposits get higher ranking, except in arable farming, where they are placed only in the third group. Lowest ranks are also accorded to altitudes above 1000' and to western aspects, almost in all cases. Other single factors show a wider range of rankings.

FORMATION OF LAND CAPABILITY CLASSES

The relative rankings received by various major environmental groups under the seven activities are shown below in a tabulated form. The total number of ranks of each activity are given under it. The ranking for farming are based on NDR/acre only and not on NDR/£100. The twelve groups shown exhaust all the types of situations met with in woodland and lower farming area.

The visible correlation between rankings is not very marked but shows a general pattern of correspondence. There are two anomalies which can be explained. Group no.3, with Ettrick complex soils at a height level 800' - 1000' and placed comparatively higher than its counter-part on no. 10, contains a few exceptionally good forest crops in continuation of forests on lower area of Linhope series. The better quality of land is perhaps due to locally good soil in the Complex. Group at 12 contains some exceptionally poor quality JL stands, separating from the main group at no. 6. The variation in the performance of Linhope soils with altitude and underlying geology is caused by differences in soil depth and local drainage conditions.

S/No.	Soil	Geology	Altitude	Aspect	Slope	A 3	SS 2	NS 3	JL 4	EL 2	SP 3	DF 2
	Environmental groups					Ranks						
1	KZ	bc	i,ii	E,S	A to C	1	1		1	1	1	1
2	ER	bc	i	E,S	A to C	1	1		1	1	1	1
3	ERc	s	iii	N,E	D		1		1		1	
4	AL	a,g	i	E,S,W	A to D	2	1	1,3	2,3	2	1,3	2
5	ER	bc	ii	E,S	B,C	3	1		1		1	
6	LP,YW	a,g	i	N,E,S	A to C	3	1	1	1,2	1	1	1
7	EK	a,g	i,ii	E,S	B to D	3			2	1	1	
8	LP	g,bc	ii,iii	N,E,S	B to F	3	1	1,2	1	2	1,2	1
9	LP	s	i to iii	all	B to E		2	2	3	1	2	
10	ERc	bc	i to iii	N	D to F			3	3	1		
11	LP	s	iv	all	C to E		2	3		2	3	
12	LP	bc	i	W	D				4			

A = Arable Farming.

Giving due weightage to Arable farming and Sitka Spruce, which is likely to be the main species for planting for sometime to come, a formal land classification may be attempted now. The twelve groups can be merged to form 5 classes including respectively (i) groups nos.1, 2 and 5; (ii) 4; (iii) 6,7,and8; (iv) 9; and (v) 11.Groups placed at nos. 3 and 10 would be treated separately; group no. 12 neglected. The Hill grazing area,outside the boundaries of the above classified tract, have been lumped into one class of land. This has to be done because of lack of detailed information about this area.

The description of the suggested 6 classes is given below:

Class I Imperfectly drained fertile soils of Kedslie and Ettrick series, found on boulder clay, at altitude below 800'. Present use mainly forestry, with some arable farming on easier slopes.

easier slopes; suitable for arable farming; or for plantations of SS, DF, and NS.

Class II Alluvial soils, on lower terraces, formed on recent alluvium and sand and gravel; below 600'. Present use mainly arable farming. Flatter ground suitable for arable farming but high banks may be planted with SS, NS and JL.

Class III Well drained brown forest soils of Yarrow, Eckford and Linhope series formed on alluvium sand and gravel, the last soil series also on boulder clay, giving deep fertile soils. Present use forestry and permanent pasture on higher sloping ground and arable farming on gentler slopes lower down.

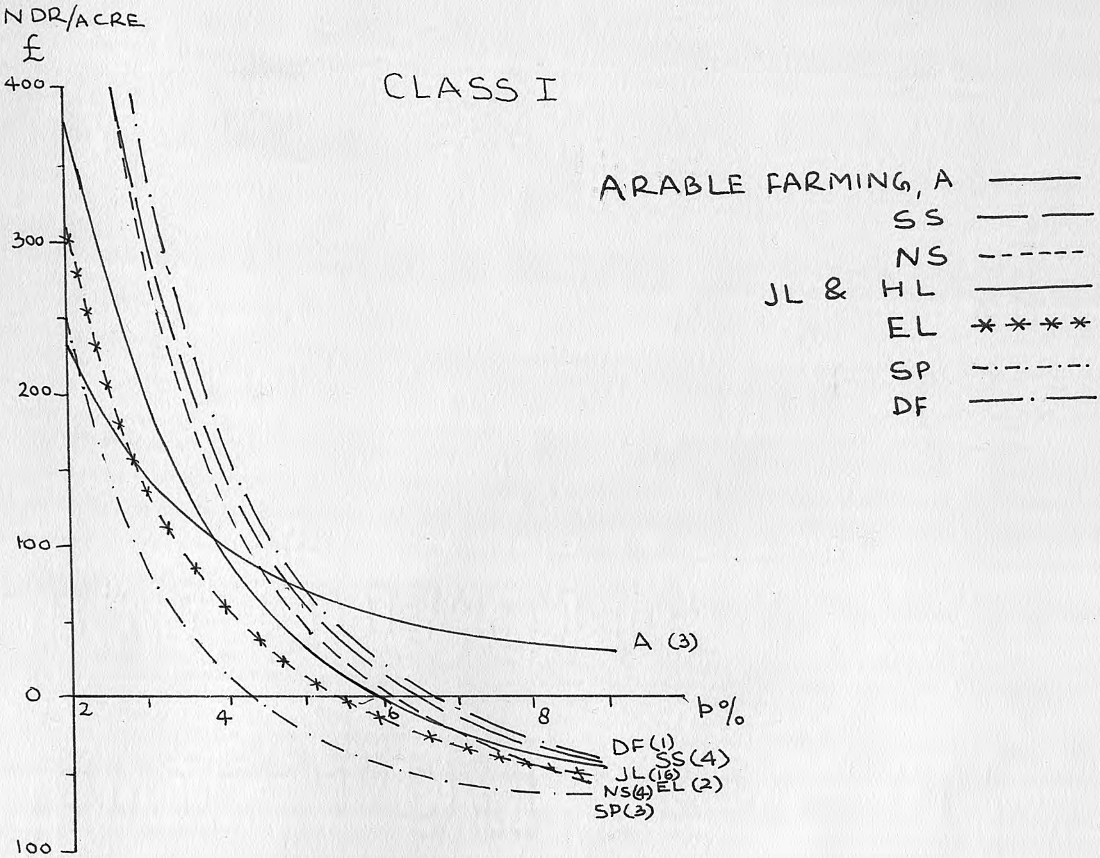
Class IV Shallower soils of Linhope series formed on shattered greywacks, and grits upto 1000'. Present use forestry, permanent pastures and hill grazing.

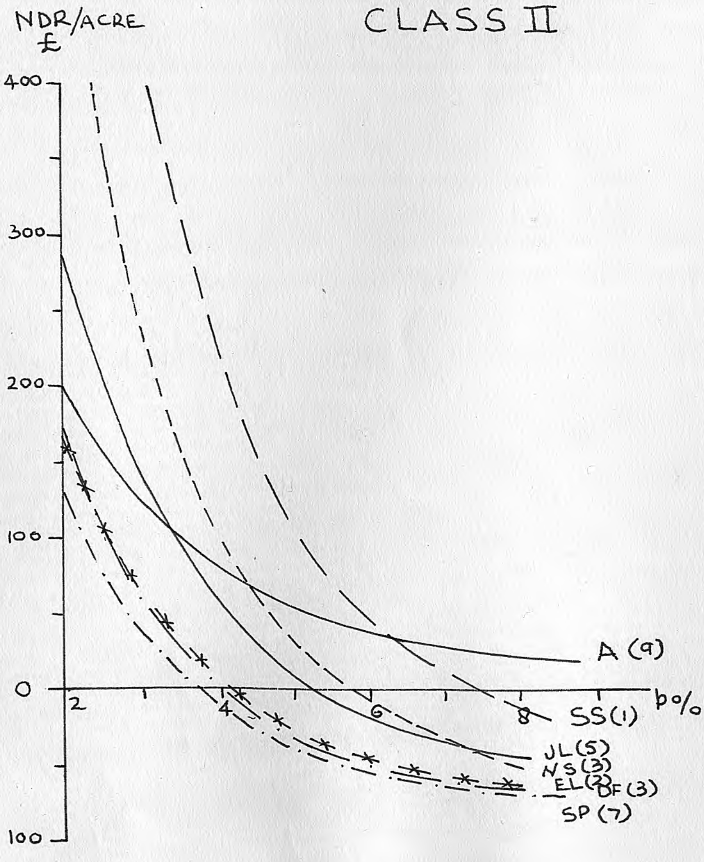
Class V Land above an altitude of 1000' on Linhope series. Low productivity. Present use forestry and hill grazing.

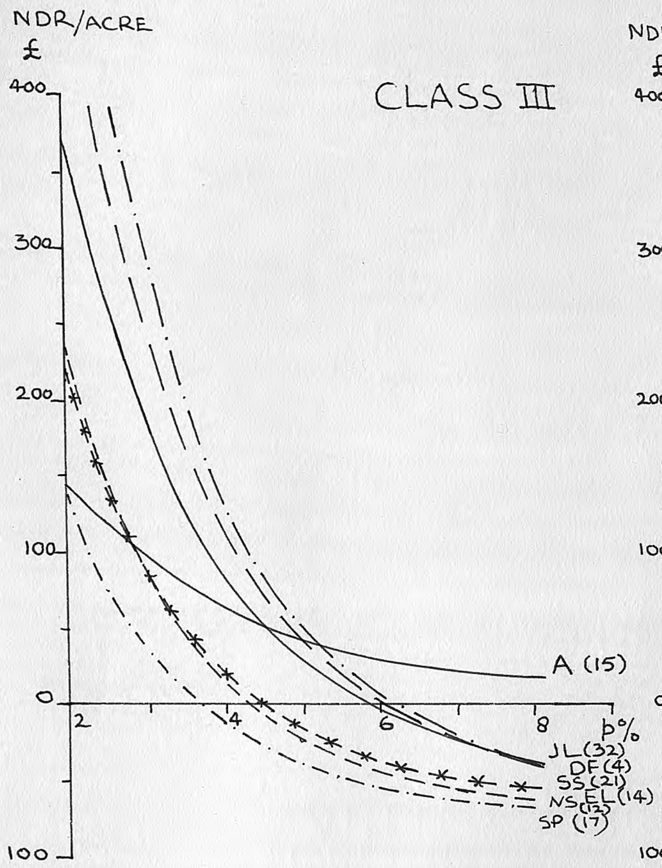
Class VI Hill grazing land on different soils, namely, the Linhope, Dod and Hardlees series, and the two complexes. Present use hill grazing.

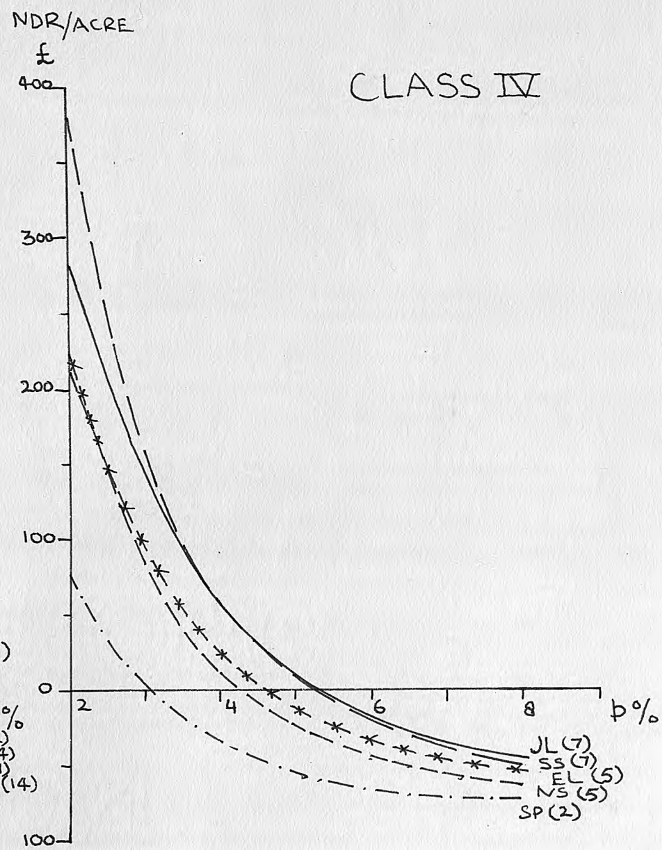
Soils of the Ettrick complex carrying woodland area, have not been included in any of the above classes. They are deemed to be allocated to the class of the adjoining soils.

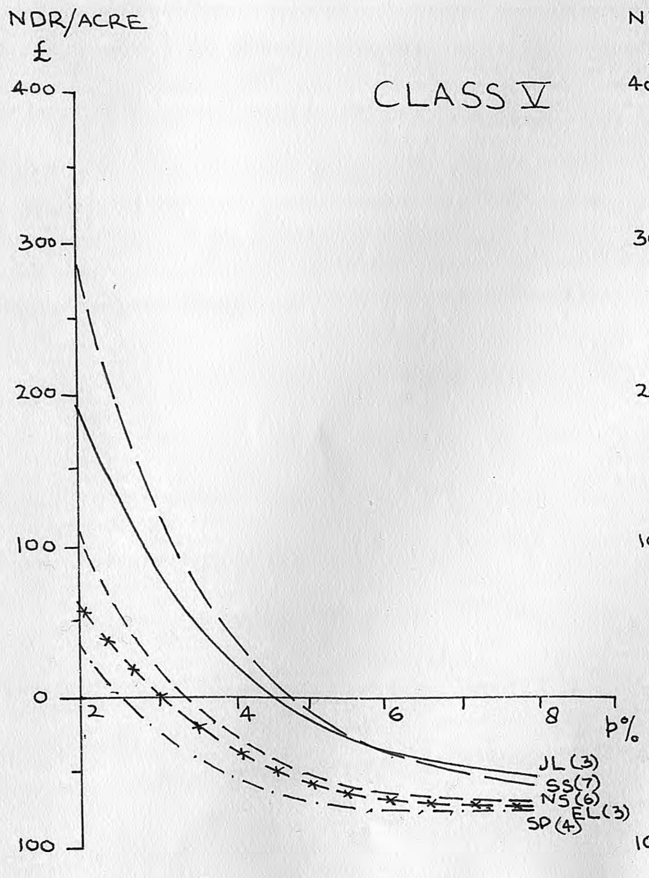
Curves of mean NDR/acre against rate of discount are given in the diagrams that follow. The number of observations (units) on which a curve represents is shown against it in brackets.

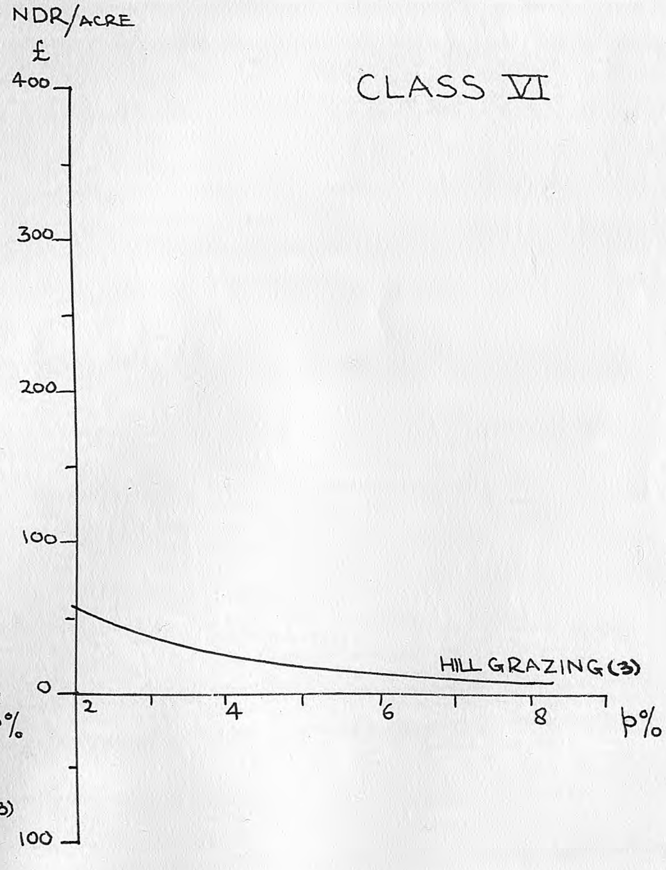

NDR/ACRE
£
CLASS I
400
300
200
100
0
100
2
4
6
8
p%
ARABLE FARMING, A
SS
NS
JL & HL
EL
SP
DF
A (3)
DF(1)
SS(4)
JL(16)
NS(4)
EL (2)
SP(3)


NDR/ACRE
£
CLASS II
400
300
200
100
0
100
2
4
6
8
p%
A (9)
SS(1)
JL(5)
NS(3)
EL(2)
DF (3)
SP (7)


NDR/ACRE
£
CLASS III
400
300
200
100
0
100
2
4
6
8
p%
A (15)
JL (32)
DF (4)
SS (21)
NS (13)
EL (14)
SP (17)


NDR/ACRE
£
CLASS IV
400
300
200
100
0
100
2
4
6
8
p%
JL (7)
SS (7)
EL (5)
NS (5)
SP (2)


NDR/ACRE
£
CLASS V
400
300
200
100
0
100
2
4
6
8
p%
JL (3)
SS (7)
NS (6)
EL (3)
SP (4)


NDR/ACRE
£
CLASS VI
400
300
200
100
0
100
2
4
6
8
p%
HILL GRAZING (3)

From the above graphs, it may be seen that the curves for arable farming and hill grazing have flatter gradients of fall of NDR/acre with increasing rate of discount than those for the six forest species. The point of intersection of two curves indicates the relative superiority of one of the alternative uses over the other above the corresponding rate of discount or below it.

In classes I to III, arable farming turns out to be the most profitable alternative above $5\frac{1}{4}\%$ rate of discount. In class II, the very high values of NDR/acre for SS are due to there being only one unit in this class. If more than one units were there, the NDR/acre curve would perhaps be closer to that of NS than now, crossing the arable farming curve nearer to 5%, than now. $5\frac{1}{4}\%$ may therefore be taken as the critical value of the discount rate for choosing between forestry and agriculture.

Among forest species, SS is the most profitable in classes I to IV, followed closely by JL. The least remunerative are EL and SP. These four species show a fairly consistent pattern. Above 8% in classes I to III and 6% in classes III and IV, JL turns out to be the best forest crop, because of its faster growth and consequently shorter rotations.

The gradual decline in productivity of the successive grades of land can be judged by the decreasing internal rates of return for each alternative, being the rate of discount at which the curves cuts the x-axis.

This classification is strictly applicable to the particular conditions in the Estate. It is, however, capable of a wider application to other similar areas, provided same costs and prices, stock densities and levels of management are met with.

CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

The results of this study indicate that it is possible to classify land according to environmental features on the basis of economic productivity, giving due regard to the management alternatives provided. Though the effect of management apparently masks out the influence of the inherent land characteristics, its interaction with the environment provides the real index to land capability. Unless the economic considerations justify, it is not advantageous to differentiate land capability on environmental factors alone.

In this study, almost identical results are obtained by using any of the four economic criteria, namely NDR/acre and NDR/£100 at 4% and 6% rates of discounts, in the case of forestry. In the case of agriculture, the criterion NDR/£100 has failed to show any significant results, as discussed in last chapter.

The results for the woodland and arable farming areas show that soil is the chief distinguishing factor for land classification in this area, followed by altitude and parent material. The effects of aspect and slope are not significant, except for some differences locally attributable to aspect. Though the role of slope is not manifest directly, it has an indirect influence, for a particular soil series generally forms on certain slopes. Therefore the effect of slope is largely accounted for by soil differences.

The final land capability classification obtained in this study would perhaps not be different from similar classifications attempted by considering environmental factors alone, using qualitative or quantitative physical criteria. Nevertheless the method adopted in this study treats the entire process of land classification with a high degree of objectivity and makes it possible to justify on economic grounds the observed differences of productivity of land.

Because of the inherent limitations of time, scope, and availability of adequate data in this study, the results obtained are not very conclusive. But they have demonstrated that an integration of physical and economic aspects of land-use study is a practical proposition. It has been shown that economic assessments of productivity can be related to the physical nature of land. The objectives with which this study was initiated have therefore been achieved.

During the work on this project it was felt that it might be worthwhile to investigate the utility of this method on a much wider area with more complex conditions of soil, climate, etc. In a larger study of this nature the work should be spread up over a number of years, and accurate records of actual yields, costs, stock density and other economic statistics should be kept.

APPENDIX I

Area Statement Of Woodlands

Statement showing Environmental Classification and Yield Classes of forest compartments and sub-compartments, arranged by species. (Explanation of symbols as in the text.) pp. 66, 79 & 80.

Compartment or sub-compartment No.	Soil	Geology	Environmental Factors Altitude	Aspect	Slope	Yield class
1.	2.	3.	4.	5.	6.	7.
Sitka Spruce						
1d	LP	g	i	S	B	240
9f	KZ	bc	ii	E	C	220
12c	ER	bc	i	E	C	240
14a	YW	a	i	S	B	200
21e	LP	g	i	E	B	240
23d	LP	g	i	E	B	260
26c	AL	a	i	W	D	280
28a	LP	s	ii	N	D	200
28b	LP	bc	ii	N	D	280
28c	LP	bc	ii	N	D	200
30c	LP	bc	i	N	D	280
30e	LP	bc	ii	N	D	260
31b	LP	bc	ii	E	D	160
31e	LP	bc	ii	N	D	200
32c	LP	s	ii	N	D	180
33c	LP	s	iii	N	D	180
33d	LP	s	iii	N	D	200
33f	ERc	s	iii	N	D	260
35g	LP	bc	ii	N	E	180
39a	LP	s	iv	N	D	180
39b	LP	s	iv	N	C	140
40a	LP	s	iv	S	B	180
40b	LP	s	iv	N	C	180
48b	ERc	s	iii	S	D	240
51b	ER	bc	ii	S	C	220
51c	ER	bc	ii	S	C	200
52a	LP	bc	i	N	D	220
53a	LP	bc	ii	N	E	220
53c	LP	bc	ii	N	E	220
54a	LP	bc	iii	N	D	220
54c	LP	bc	ii	N	D	220
54e	LP	bc	ii	N	E	220
55a	LP	s	iii	N	E	160
56d	LP	bc	i	N	E	220
56f	LP	bc	ii	N	C	220
57a	LP	s	iv	N	E	140
57b	LP	s	iv	N	D	140
59a	LP	s	iv	W	E	140
60a	LP	s	ii	W	E	140
60c	LP	s	ii	W	E	260

1.	2.	3.	4.	5.	6.	7.
			Norway Spruce			
4h	AL	g	i	S	E	200
7a	KZ	bc	i	E	C	200
10b	ER	bc	ii	E	C	240
11d	ER	BC	ii	E	C	240
11e	ER	bc	ii	E	C	240
18a	AL	a	i	E	A	240
31g	LP	bc	ii	N	D	140
32a	LP	bc	iii	N	D	140
32b	LP	bc	iii	N	D	140
33a	LP	s	iii	N	D	160
33b	LP	s	iii	N	D	160
34	LP	bc	ii	E	C	160
35a	LP	bc	ii	N	D	140
35c	LP	bc	ii	N	D	120
35d	LP	s	iii	N	E	120
35e	LP	bc	iii	N	E	160
35f	LP	bc	iii	N	E	160
35g	LP	bc	ii	N	E	160
36b	LP	s	iii	N	D	160
36h	LP	s	iv	N	B	100
37b	LP	s	iv	N	D	120
38a	LP	s	iv	N	E	120
40d	LP	s	iv	N	D	100
49d	LP	s	iii	S	D	160
51d	AL	a	i	N	A	220
52c	YW	a	i	N	C	180
56e	LP	bc	ii	N	D	160
57a	LP	s	iv	N	E	100
71a	AL	bc	i	W	D	120
72a	AL	bc	ii	W	C	100
72b	AL	bc	ii	W	C	100
72c	AL	bc	i	W	D	140
73b	AL	bc	i	W	B	100
73d	AL	a	i	W	B	100
74a	ERc	bc	iii	N	D	100
			JapaneseLarch and Hybrid Larch			
1c	LP	g	i	S	D	120
4d	EK	g	i	S	D	120
4j	EK	g	i	S	D	120
7b	AL	g	i	E	B	160
7g	ER	bc	i	S	E	160
8a	ER	bc	i	E	C	140
9a	KZ	bc	ii	E	C	140
9b	ER	bc	ii	E	C	140
9c	KZ	bc	ii	E	C	140
9d	KZ	bc	ii	E	C	140
9g	KZ	bc	ii	E	C	120
9h	ER	bc	ii	E	C	140
10a	ER	bc	ii	E	C	160

1.	2.	3.	4.	5.	6.	7.
11c	ER	bc	i	E	C	120
12d	ER	bc	i	E	C	140
14a	YW	a	i	S	B	160
14c	YW	a	i	S	B	140
15a	YW	a	i	S	B	160
15b	YW	a	i	S	B	120
15d	YW	a	i	S	B	160
15e	YW	a	i	S	B	160
15g	YW	a	i	S	B	160
17a	ERc	bc	i	N	F	120
18b	AL	a	i	E	A	100
18d	AL	a	i	E	A	100
20a	YW	a	i	E	B	160
20b	YW	a	i	E	B	140
20c	YW	a	i	E	C	140
21a	LP	g	i	E	C	140
23c	LP	g	i	E	B	160
23e	YW	g	i	E	B	120
25d	AL	a	i	E	F	120
26a	LP	bc	i	W	D	80
26b	LP	bc	i	W	D	80
27c	YW	g	i	E	A	120
27e	LP	g	i	N	B	120
27f	YW	g	i	E	B	100
28b	LP	s	ii	N	D	140
29a	LP	s	ii	E	D	160
30d	LP	bc	ii	N	D	160
33e	LP	s	iv	N	D	120
33f	ERc	s	iii	N	D	160
36c	LP	s	iii	N	D	140
36d	LP	s	iii	N	D	100
36e	LP	s	i	N	F	100
36h	LP	s	iv	N	B	100
46c	ER	bc	ii	S	C	160
47a	ER	bc	ii	S	C	160
47b	ER	bc	ii	S	C	160
47e	ER	bc	ii	S	C	160
48b	ERc	s	iii	S	D	160
49a	LP	bc	ii	S	E	160
49b	LP	bc	ii	S	C	160
50b	LP	bc	ii	S	C	160
50d	ER	bc	ii	S	C	120
51d	AL	a	i	N	A	140
52b	YW	a	i	N	D	140
52d	YW	a	i	N	B	140
53b	LP	bc	ii	N	E	160
55b	LP	bc	ii	N	E	140
58d	LP	bc	i	N	E	140
58h	LP	s	ii	N	E	120
59a	LP	s	iv	W	E	100

European Larch

6d	EK	g	i	E	E	100
6e	EK	a	i	E	D	140
8b	KZ	bc	i	E	C	140

1.	2.	3.	4.	5.	6.	7.
11d	ER	bc	i	E	C	120
15c	YW	a	i	S	B	140
15g	YW	a	i	S	B	140
16a	AL	a	i	S	C	100
17a	ERc	bc	i	N	F	120
18e	AL	a	i	E	A	100
20d	YW	a	i	E	C	140
23b	LP	g	i	E	B	100
26b	LP	bc	i	W	D	80
27e	LP	g	i	N	B	120
30b	LP	bc	ii	N	D	140
33b	LP	s	iii	N	D	140
35e	LP	bc	iii	N	E	80
35f	LP	bc	iii	N	E	80
36d	LP	s	iii	N	D	100
36g	LP	s	iii	N	F	100
37b	LP	s	iv	N	D	80
37c	LP	bc	iii	N	E	80
37d	LP	s	iv	N	E	80
37e	LP	bc	iii	N	E	100
41c	LP	s	iv	S	C	60
58d	LP	bc	i	N	E	100
58f	LP	s	ii	N	E	120

<u>Scotspine</u>

1a	LP	g	ii	S	C	140
3b	EK	g	i	S	E	140
4k	EK	g	i	S	A	120
5a	LP	bc	ii	S	C	120
5b	LP	bc	ii	E	C	140
9e	ER	bc	ii	E	C	160
11d	ER	bc	i	E	C	160
18e	AL	a	i	E	A	140
28b	LP	bc	ii	N	D	140
29d	LP	s	ii	E	D	120
32a	LP	bc	iii	N	D	120
35a	LP	bc	ii	N	D	120
35e	LP	bc	iii	N	E	120
35f	LP	bc	iii	N	E	120
35h	LP	bc	ii	N	E	80
36a	ERc	s	iv	N	C	140
36h	LP	s	iv	N	B	100
37b	LP	s	iv	N	D	100
37c	LP	bc	iii	N	E	100
37e	LP	Bc	iii	N	E	140
40d	LP	s	iv	N	D	80
48b	ERc	s	iii	S	D	160
49a	LP	bc	ii	S	E	160
51a	ER	bc	i	S	E	120
57b	LP	s	iv	N	D	80
57c	LP	bc	iii	N	D	120

1.	2.	3.	4.	5.	6.	7.
58e	LP	s	ii	N	E	100
71a	AL	bc	i	W	D	120
72a	AL	bc	i	W	C	80
72b	AL	bc	ii	W	C	80
72c	AL	bc	ii	W	D	120
73b	AL	bc	i	W	B	80
73d	AL	a	i	W	B	80
		Douglas Fir				
5b	LP	bc	ii	E	C	160
12b	ER	bc	i	E	C	220
15a	YW	a	i	S	B	240
18c	AL	a	i	N	A	120
20d	YW	g	i	E	C	160
52a	YW	a	i	N	D	200
71d	AL	bc	i	W	C	120
71f	AL	bc	i	W	D	120

APPENDIX II

Area Statement of Arable Fields

Statement showing Environmental classification of arable fields and the present crop rotations. (Explamation of symbols as in the text) pp. 66, 79 & 80.

Name of field	Soil	Geology	Altitude	Aspect	Slope	Crop Rotation
		Environmental factors				
Carterhaugh farm						
Weatherhouse Haugh	AL	a	i	S	A	7a
Experimental Haugh	AL	a	i	S	A	7a
Big Haugh West	AL	a	i	S	A	6a
" " East	AL	a	i	S	A	7a
House Park	AL	a	i	E	A	7a
North Gilkeket	AL	a	i	E	A	6a
Back Haugh	AL	a	i	E	A	6a
Yarrow Haugh	AL	a	i	E	A	7a
Cants Plot 1	LP	g	i	E	B	9a
" " 2	YW	g	i	E	B	7d
Little Cants	ER	a	i	S	A	8a
Newarkburn farm						
Auld Wark South End	LP,YW	g	i	E	B	7b
" " School End	LP,YW	g	i	N	B	7d
Castle Park	YW	g	i	S	A	7a
Wester Park	YW	a	i	N	B	7c
Nursery Field	LP	g	i	N	B	7b
Brickfield Park	KZ,ER	bc	i	E	B	8a
Steel Syke	KZ	bc	i	E	B	6b
Fauldshope farm						
Upper Park	LP	bc	ii	E	B	11a
Cottages Field	LP	bc	ii	E	B	6a
Toories Field	LP	bc	ii	E	B	11a
The Clints	LP,EK	g	ii	E	B	11a
Front Field	EK	g	i	E	B	8a
Big Haugh	AL	a	i	S	A	8a
Bonnyrig	LP,EK	g	ii	S	B	11a
Big Field	LP,ER	bc	ii	S	C	11a
Franks Field	LP	bc	ii	S	C	11a

Explanation of crop rotation symbols:

6 year rotations-	6a	Turnips-kale; Barley; Grass for 4 years
	6b	Barley; Turnips; Barley; Grass for 3 years
7 year rotations-	7a	Barley or oats; Grass silage; Arable silage-barley; followed by grass for 4 years
	7b	Oats; Turnips; Oats or barley; Grass for 4 years
	7c	Turnips; Oats; Barley; Grass for 4 years
	7d	Turnips; Barley; Grass for 5 years
8 year rotations-	8a	Barley; Turnips-kale, grass or arable silage; Oats; Grass for 5 years
9 year rotations-	9a	Turnips-kale; Barley; Arable silage; Grass 6 yrs.
11 year rotations-	11a	Barley or oats; Turnips-kale, grass or arable silage; Oats or Barley; Grass for 8 years.

Note: Only those fi-elds are included in this list which are analysed.

Appendix III

Table 1

Discounted Revenue per acre, rounded off to the nearest £5

Species	Yield Class Y.C.	Rotation in years r	Rate of discount p%						
			2	3	4	5	6	7	8
SS	100	60	230	110	60	40	25	15	10
	120	60	315	155	85	50	30	20	15
	140	55	385	195	115	65	40	25	20
	160	55	445	230	135	80	50	30	25
	180	55	540	270	160	95	60	40	30
	200	55	590	305	180	110	70	50	35
	220	50	670	360	210	130	85	60	45
	240	50	780	435	250	160	100	70	50
	260	50	905	485	285	180	115	80	60
	280	50	985	550	315	200	130	90	65
NS	100	70	225	105	55	30	25	10	10
	120	65	285	140	75	45	25	15	10
	140	65	350	175	95	55	35	20	15
	160	65	410	210	120	70	45	25	20
	180	65	525	265	145	85	55	35	25
	200	60	615	310	175	105	65	40	30
	220	60	700	350	200	120	75	50	35
	240	60	780	395	225	140	90	60	40
JL & HL	60	50	165	95	50	30	20	10	10
	80	50	235	125	75	45	30	20	15
	100	45	335	100	120	70	45	30	25
	120	45	420	330	140	90	60	45	30
	140	45	510	285	175	110	75	55	40
	160	40	600	335	225	130	100	75	50
EL	40	60	75	35	20	15	10	5	5
	60	55	155	80	45	25	15	10	10
	80	55	250	130	70	45	25	15	15
	100	50	335	180	105	60	35	25	20
	120	50	400	225	130	85	65	40	30
	140	45	510	275	170	115	75	50	40
SP	60	75	90	35	20	10	10	5	5
	80	70	145	70	35	15	15	5	5
	100	70	190	95	50	25	20	10	10
	120	65	245	125	70	40	25	15	10
	140	65	340	170	95	55	35	20	15
	160	60	415	225	115	70	45	30	20
DF	120	55	325	160	95	55	25	20	15
	140	55	400	225	120	75	45	30	20
	160	55	485	270	150	95	60	40	25
	180	55	605	350	185	115	70	45	30
	200	50	690	415	225	135	90	60	40
	220	50	790	475	265	160	105	75	50
	240	50	890	555	310	180	125	85	60
	260	50	985	635	365	210	140	100	70

Table 2.

Total Discounted Expenditure per acre, rounded off to nearest £5
(c=£65 per acre; e=£1.0 per acre)

Rotation in years	Rate of discount						
	2	3	4	5	6	7	8
40	170	125	110	95	90	85	80
45	160	120	105	95	85	80	80
50	155	120	100	90	85	80	80
55	150	115	100	90	85	80	80
60	145	110	95	90	85	80	80
65	140	110	95	90	85	80	80
70	135	110	95	85	85	80	80
75	135	105	95	85	85	80	80

Table 3.

Net Discounted Revenue per acre, rounded off to the nearest £5.
The last column shows the financial yield, the rate at which NDR/acre=0

Species	Yield Class	Rate of discount, p%							Financial yield %
		2	3	4	5	6	7	8	
SS	100	85	0	-35	-50	-60	-65	-70	3.0
	120	170	45	-10	-40	-55	-60	-65	3.8
	140	235	80	15	-25	-45	-55	-60	4.3
	160	295	115	35	-10	-35	-50	-55	4.8
	180	390	155	60	5	-25	-40	-50	5.1
	200	440	190	80	20	-15	-30	-45	5.5
	220	515	240	110	40	0	-20	-35	6.0
	240	625	315	150	70	15	-10	-30	6.6
	260	750	365	185	90	30	0	-20	7.0
	280	830	430	215	110	45	10	-15	7.4
NS	100	90	0	-40	-55	-65	-70	-70	3.0
	120	145	30	-20	-45	-60	-65	-70	3.5
	140	210	65	0	-35	-50	-60	-65	4.0
	160	270	100	25	-20	-40	-55	-60	4.5
	180	385	155	50	-5	-30	-45	-55	4.9
	200	470	200	80	15	-20	-40	-50	5.4
	220	555	240	105	30	-10	-30	-45	5.8
	240	635	285	130	50	5	-20	-40	6.2
JL & HL	60	10	-25	-50	-60	-65	-70	-70	2.3
	80	80	5	-25	-45	-55	-60	-65	3.2
	100	175	60	5	-25	-40	-50	-55	4.1
	120	260	110	35	-5	-25	-35	-50	4.8
	140	350	165	70	15	-10	-25	-40	5.6
	160	430	210	115	45	10	-10	-30	6.5
EL	40	-70	-75	-75	-75	-75	-75	-75	0.5
	60	5	-30	-55	-65	-70	-70	-70	2.1
	80	100	15	-30	-45	-60	-65	-65	3.2
	100	180	60	5	-30	-50	-55	-60	4.1
	120	245	105	30	-5	-30	-40	-50	4.8
	140	350	155	65	20	-10	-30	-40	5.6
SP	60	-45	-70	-75	-75	-75	-75	-75	1.0
	80	10	-40	-60	-70	-70	-75	-75	2.2
	100	55	-15	-45	-60	-65	-70	-70	2.8
	120	105	15	-25	-50	-60	-65	-70	3.3
	140	200	60	0	-35	-50	-60	-65	4.0
	160	270	115	20	-20	-40	-50	-60	4.5
DF	120	175	45	-5	-35	-50	-60	-65	3.9
	140	250	105	20	-15	-40	-50	-60	4.5
	160	335	155	50	5	-25	-40	-55	5.1
	180	455	235	85	25	-15	-35	-50	5.6
	200	535	295	125	45	5	-20	-40	6.2
	220	635	355	165	70	20	-5	-30	6.8
	240	735	435	210	90	40	5	-20	7.2
	260	830	515	265	120	55	20	-10	7.6

Table 4.

Net Discounted Revenue per £100 of expenditure, rounded off to the nearest £5.

Species	Yield Class Y.C.	Rate of discount p% 2	3	4	5	6	7	8
SS	100	60	0	-35	-60	-75	-85	-90
	120	115	45	-10	-45	-65	-75	-85
	140	155	70	15	-25	-50	-65	-75
	160	195	105	40	-10	-40	-60	-70
	180	260	145	65	10	-25	-50	-65
	200	295	170	90	25	-10	-40	-55
	220	335	210	110	45	0	-25	-45
	240	405	265	155	75	20	-10	-35
	260	490	310	185	100	40	0	-25
	280	540	365	215	120	55	10	-20
NS	100	65	0	-40	-65	-80	-85	-90
	120	105	25	-20	-50	-70	-80	-85
	140	150	55	0	-35	-60	-75	-80
	160	190	90	20	-20	-50	-65	-75
	180	275	140	50	-5	-35	-55	-70
	200	325	175	80	15	-20	-45	-65
	220	380	215	105	35	-5	-40	-60
	240	435	255	135	55	5	-30	-50
JL & HL	60	10	-20	-50	-65	-75	-85	-90
	80	55	5	-25	-50	-65	-75	-80
	100	110	50	5	-25	-45	-60	-70
	120	165	90	35	-5	-30	-45	-60
	140	220	135	70	20	-5	-30	-50
	160	260	170	105	50	15	-20	-40
EL	40	-50	-65	-80	-90	-90	-95	-95
	60	5	-25	-55	-70	-85	-90	-80
	80	65	10	-25	-50	-70	-80	-85
	100	115	50	5	-35	-55	-70	-75
	120	160	90	35	-5	-35	-55	-65
	140	220	125	65	20	-15	-40	-55
SP	60	-35	-65	-80	-85	-90	-95	-95
	80	5	-35	-60	-75	-85	-90	-95
	100	40	-15	-45	-65	-80	-85	-90
	120	75	15	-30	-55	-70	-80	-85
	140	145	55	0	-35	-60	-70	-80
	160	190	90	25	-15	-45	-65	-75
DF	120	115	40	-5	-35	-60	-75	-80
	140	165	85	20	-15	-45	-65	-75
	160	240	130	50	5	-30	-50	-70
	180	315	190	85	25	-15	-40	-60
	200	385	250	125	50	5	-25	-50
	220	480	300	165	75	25	-10	-35
	240	545	370	205	100	45	10	-25
	260	615	435	250	135	65	20	-15

APPENDIX IV

Table showing values of Discounted Revenue, Discounted Expenditure, NDR/acre and NDR/£100 for various arable fields with certain crop rotations as given in Appendix II. All figures rounded off to the nearest £5.

Names of fields	r	Function	Rate of discount, p% 2	3	4	5	6	7	8
Steel Syke	6	V	1395	925	665	525	440	380	325
		C	1170	770	560	445	380	330	285
		NDR/acre	225	155	105	80	60	50	40
		NDR/£100	20	20	20	20	15	15	15
Brickfield, Little Cants	8	V	1330	855	660	530	440	385	335
		C	1115	725	570	460	390	345	305
		NDR/acre	215	130	90	70	50	40	30
		NDR/£100	20	20	15	15	15	10	10
Weatherhouse Haugh, Experimental Haugh, Big Haugh East, Yarrow Haugh	7	V	1380	915	685	530	455	395	335
		C	1175	800	605	475	410	360	310
		NDR/acre	205	155	80	55	45	35	25
		NDR/£100	20	15	15	10	10	10	10
Big Haugh, Front Field	8	V	975	630	485	385	325	280	250
		C	790	525	415	335	285	250	225
		NDR/acre	180	105	70	50	40	30	25
		NDR/£100	20	20	20	15	15	10	10
North Gilkeeket, Back Haugh, Big Haugh West	6	V	1455	950	705	570	480	415	360
		C	1265	840	630	515	440	380	335
		NDR/acre	190	110	75	55	40	35	25
		NDR/£100	20	15	10	10	10	10	10
Castle Park, Wester Park, Nursery Field, House Park	7	V	1335	895	675	515	440	380	330
		C	1170	800	605	465	405	355	310
		NDR/acre	165	95	70	50	35	25	20
		NDR/£100	15	10	10	10	10	10	5
Cants Plot 1	9	V	1295	880	675	535	440	370	325
		C	1150	790	610	490	410	350	310
		NDR/acre	145	90	65	45	30	20	15
		NDR/£100	15	10	10	10	10	5	5
Cants Plot 2, Auld Wark School End, Auld Wark South End	7	V	1315	885	660	510	435	380	325
		C	1170	795	600	470	405	355	305
		NDR/acre	145	90	60	40	30	25	20
		NDR/£100	10	10	10	10	10	5	5
Cottages Field	6	V	1010	660	490	395	335	290	255
		C	865	575	435	355	305	265	235
		NDR/acre	145	85	55	40	30	25	20
		NDR/£100	15	15	15	10	10	10	10
Upper Park, Toories Field, The Clints, Bonnyrig, Big Field, Franks Field	11	V	810	580	425	335	280	245	210
		C	680	490	360	295	255	225	195
		NDR/acre	130	90	65	40	25	20	15
		NDR/£100	20	20	20	15	10	10	10

APPENDIX V

Yield of barley and oats during the years 1962 to 1965.

Farm	Name of field	Crop	Year	Yield/acre cwt.
Carterhaugh	Shielshaugh East	Barley	1962	32
	Weatherhouse Haugh	"	1962	34
	Experiment Haugh	"	1962	32
	Big haugh West	"	1963	23 x
	Big haugh East	"	1964	29
	House Park	Oats	1965	21
	North Gilkeeket	Barley	1964	33
	Black Haugh	"	1962	23
	Yarrow Haugh	"	1963	23 x
	Cants Plot 2	Oats	1965	21
Newarkburn	Auldwark South End	"	1965	21
	Auldwark School End	Barley	1964	32
	Auldwark Road Road	"	1961	29
	Castle Park	"	1963	21 x
	Western Park	"	1961	22
	Nursery Field	Oats	1965	21
	Brick Field	Barley	1963	21 x
		Oats	1965	21
	Steel Syke	Barley	1962	30
		"	1964	30
Fauldshope	Cottages Field	"	1963	23 x
	Toorie Field	"	1962	25
	The Clints	Barley	1962	26
	Front Field	"	1963	24 x
		Oats	1965	21
	Big Haugh	Barley	1963	20 x
		Oats	1965	21
	Bonnyrig	Barley	1963	21 x
	Franks Field	Oats	1964	24
	Brockhill Field	Oats	1964	24

x Yields in 1963 were considerably lower than in a normal year due to a cold wet summer.

BIBLIOGRAPHY

ADVISORY PANEL ON THE HIGHLANDS AND ISLANDS(1964).Land Use in the Highlands and Islands,Dep.Agric.& Fish. Scot.

ANDERSON,M.L.(1950).The Selection of Trees Species,Oliver & Boyd,Edin.

_____________ & FAIRBAIRN,W.A.(1955).Division of Scotland into climatic sub-regions as an aid to silviculture,Bull.No.1, Edin. Univ., For.Dep.

BLAGBURN,C.H.(1961).Farm Planning and Management, Longmans, London.

CAJANDER,A.K.(1909)Ueber Waldtypen.(Later work Studien uber die Moore Finnlands.)

CANADA LAND INVENTORY(1965).Objectives,Scope and Organization,Rep. No.1,ARDA,Dep. For.Pub.No. 1088.

CARMEAN,W.H.(1954).Site quality for Douglas Fir in South Western Washington and its relationship to precipitation, elevation and physical soil properties, Proc.Soil Sci. Soc. Amer.,18,330-334.

CHAMPION,H.G.(1936).A preliminary survey of the forest types of India and Burma,Ind.For.Rec.(N.S.) Silviculture No. 1.

CHAPMAN,H.H.& MEYER,W.H.(1947).Forest Valuation,McGrawHill BookCo. New York.

CHISHOLM,A.H.(1963).An economic comparison of forestry and agriculture,Disc.pap.No.30,Dep.Agric.Econ.& Farm Management, Massey Univ. Manawatu, N.Z.

CHRISTIAN,C.S.(1952).Regional landSurveys, J.Austr.Inst.Agric.Sci., 18(3).

CLARK,C. & HASWELL,M.(1964).The economics of subsistence agriculture.

CLARKE,G .R.(1950).The evaluation of soils and the definition of quality class from studies of physical properties of the soil profile in the field, J.Soil Sci.,II(1).

CLEMENTS,F.E.(1916).Plant succession,Carnegie Inst. Washington.

____________(1928).Plant sucession,and plant indicators,CarnegieInst. Washington.

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION,AUSTRALIA (1964).General reports on Lands of Buna-Kokoda Area, Territory of Papua and NewGuinea,Land Res. Series No.10.

COPPOCK,J.T.(1964).<u>An Agricultural Atlas of England and Wales</u>, Faber & Faber,London.

D'HOORE,J.L.(1965).The classification used in the CCTA soil maps of Africa,Symposium on Soil Resources of Tropical Africa, African Studies Assoc.U.K.

DAUBENMIRE,R.(1961).Vegetative indications of rate of height growth in Pondrosa pine, For.Sci.,7,24-34.

DELLA-BINACA,L.& OLSON,D.F.(1961).Soil-site studies in Piedmont hardwood and Pine-hardwood upland forests,For.Sci.,74, 320-329.

DUCHAUFOR, Ph.(1961).Site,humus typeand ecological grouping,Scot.For. 15,53-62.(Trans. by M.L.Anderson).

DUDLEY STAMP,L.(1950).<u>The Land of Britain,its use and misuse</u>,Longmans, London.

______________(1963).Surveys of Resources andPPotentialities,Rep. on Land Use Course for Forestry and Agriculture,Comm.For. Inst.,Oxford.

______________(1965).Land Use statistics of the countries of Europe, TheWorld Land Use Survey,Int.Union,Occasional Papers No.3.

DUERR,W.A.(1960).Fundamentals of Forestry Economics,McGraw-Hill Book Co. New York.

_________, FEDKIW,J.& GUTTENBERG,S.(1956).Financial Maturity, a guide to profitable timber growing,U.S.D.A.Tech. Bull No.1146.

EDELMAN,C.H.(1963).Application of Soil Survey in land development in Europe, with special reference to experience in the Netherlands,Int.Inst.Land Rec. &nImp. Pub. 12.

EIS,S.(1962).Statistical analysis of several methods for estimation of forest habits and tree growth near Vancouver,B.C., For. Bull.,Fac. For. Univ.B.C.,No. 24.

FEDKIW,J.& YOHO,J.G.(1956).Financial Maturity:what is it good for?, J.For.,54,587-590.

FELDESTEIN,M.S.(1964a).Net Social Benefit calculation and the public investment decision,Oxford Econ. Papers,16.

______________(1964b).The Social Time Preference Discount rate in Cost Benefit analysis, Econ. J., 74(294), 360-379.

FENTON,R.& BROWN,C.H.(1963).An economic analysis of tending <u>Pinus radiata</u> in South Land, N.Z.J. For. 8(5).

_________& GRAINGER,M.B.(1965).Economic results for afforestation of the Maraetai Blocks, N.Z.For.Res.Ins.,Rotorua,Silv. Br.Rep.No.31.

FORESTRY COMMISSION(1962).The plan of operations,a guide to the preparation of the plan of operations for dedicated and approved woodlands, Booklet No. 7.

___________________(1964).Income Tax and Estate Duty on Woodlands, Leaflet No.12.

___________________(1965). Working Plans Code.

___________________(1966).Forest Management Tables, Booklet No.16.

GAFFNEY,M.M.(1957).Concepts of financial maturity of timber and other assets,Agric. Econ.Infor.Series No.62,N.Carolina State Coll.,Raleigh, N.C.

GAMBI,G.(1960). Monte e Boschi, 11, 78-83.

GARDNER,M.J.& RYAN,P.(1964).Soils of County Wexford,Soil Survey Bull No.1, National Soil Survey of Ireland,An Faras Taluntais.

GILCHRIST,W.(1872).On the soils best suited for the different kinds of forest trees as indicated by the plants that grow naturally upon them,Trans.Scottish Arbor.Soc.,VI.(cited by M.L.Anderson,1950)

GILMORE,A.R.(1963).Predicting yields of Loblolly pine plantations in Southern Illinois from soil characteristics,For. Note, Ill. Agric. Exp. Sta., No. 101.

GRAYSON,A.J.(1963).Economic and social considerations in forestry, Rep.Land Use Course for For.& Agric.,Comm.For.Inst.,Oxford

GREIG-SMITH,P.(1964).Quantitative Plant Ecology,Butterworths,London.

HARPER,P.C.(1962).The soils and vegetation of Lammermuir,J.Ecol., 50(1), 35-51.

HART,C.E.(1964).Taxation of woodlands, 6th ed.

________(1966).A guide to home grown timber prices and forestry costings, 1966-67.

HILEY,W.E.(1956).Economics of plantations.

HILLS,G.A.(1952).The classification and evaluation of site for forestry,Res.Rep.No.24,Ont.Dep.Lands and For.

________(1960).Regional site research, For.Chron.,36(4).

________(1961).The ecological basis for land use planning,Res. Rep.No.46, Ont.Dep. Lands and For.

________ & PORTELANCE,R.(1960).The Glackmeyer Report of Multiple Land Use planning,Ont.Dep.Lands and For.

HODGKINS,E.J.(1961).Estimating site index for Longleaf pine through quantitative evaluation of associated vegetation, Proc. Soc. Amer. For. 1960, 28-32.

HUSCH,B.(1963).Forest Mensuration and Statistics.

HUXLEY,J.(1961).The conservation of wild life and natural habitats in Central and East Africa, UNESCO.

ILLINGWORTH,K. & ARLIDGE,J.W.C.(1960).Interim report on some forest site types in Lodgepole pine and Spruce-Alpine Fir stands,B.C.For.Service Res.Note No. 35.

LAND USE STUDY GROUP(1965).Land use for forestry and agriculture, Rep.Natural Resources(Tech.)Committee,Comm. on Agric.

LANGDALE-BROWN, I. (1966). Some aspects of land capability assessment in Africa, African Affairs.

_______________, OSMASTON, H.A. & WILSON, J.G. (1964). The vegetation of Uganda and its bearing on land use, Govt. Printer, Entebbe

LEMIEUX, G.J. (1965). Soil-vegetation relationship in the northern hardwoods of Quebec, "nd N.Amer.For.Soils Conf., Oregon State Univ., Cornvallis.

LESLIE, A.J. (1963). Seminar on Economics of Forestry, For.Comm. of N.S.W., Tech.Paper No.3.

LINNARTZ, N.E. (1963). Relation of soil and topographic characteristics to site quality for Southern pine in the Florida parish of Luisiana, J.For., 61(6).

LINTEAU, A. (1955). Forest site classification of the North Eastern Coniferous sector, Boreal Forest region, Quebec, Bull. 118, Canada Dep.Northern Affairs & Natural Resources, For. Br.

MADER, D.L. & OWEN, D.F. (1961). Relationships between soil properties and Red pine growth in Massachusetts, Proc. Soil Sci. Soc. Amer., 25(1).

McCLENNAN, J.B. (1965). The land-use sector of the Canada Land Inventory, Geog.Bull., 7(2), 73-78.

McGEE, C.E. (1961). Soil site index for Georgian Slash pine, Sta. Paper, S.E.For.Exp. Sta., No. 119.

McGREGOR, J.J. (1951). Estate accounting and forestry costs, Quart.J. For., Oct.1951.

_____________ (1956). Forestry costs on private estates, IUFRO, 12th Cong.

_____________ & MUTCH, W.E.S. (1953). An introduction to the survey of private forestry costs in England and Wales, Imp. For. Inst., Oxford.

MUIR, J.W. (1956). The soils of the country round Jedburgh and Morebattle, Mem. Soil Survey Scot., H.M.S.O., Edin.

MUIR, W.D. (1964). Forestry as an economic form of land use, Aust. Timb. J., 30(2).

MUTCH, W.E.S. (1960). Financial and cost accounting for forest enterprises, Bull. No. 7, For. Dep. Univ. Edin.

NELSON, A.W. (1961). How forest industries judje investment opportunities, Soc. Amer. For., Proc. 1960, 85-88.

NISHZAMI, M., MASHIMO, Y. & KAWABATA, K. (1965). Estimation method for site index by quantification, Bull. For. Exp. Sta. Meguro, Tokyo, No. 176, 1-54.

PARDÉ, J. (1959). More about Paterson's CVP index, Rev. For. Franç., 11(1).

________ (1964). Climatic index and productivity of wood, C.R. Acad. Agric. France, 50(6).

PATERSON, S.S. (1956). The forest area of the World and its potential productivity, Medd. Goteborgs Univ. Geog. Inst. Gotenberg, 51.

____________ (1962). Introduction to phycochorology of Norden (Scandinavia), Medd. Skogsforsken Inst., Stockholm, 50(5).

PAWLUCK, S. & ARNEMAN, H.F. (1961). Some forest soil characteristics and their relationship to Jackpine growth, For. Sci., 7(2).

POORE, M.E.D. & ROBERTSON, V.C. (1964). An approach to the rapid description and mapping of biological habitats, International Biological Programme, London.

RAGG, J.M. (1960). The soils of the country round Kelso and Lauder, Mem. Soil Susvey Scot., H.M.S.O., Edin.

RENNIE, P.J. (1963). Methods of assessing site capacity, Comm. For. Rev., 42(4).

ROW, C. (1960). Soil site relations of old-field Slash pine plantations in Carolina Sandhills, J. For., 58(9).

SCOTT, A. (1955). Natural Resources: Thé economics of Conservation, Canadian Studies in Economics,No.3,Univ.of Toronto Press.

SETH,S.K.& BHATNAGAR,H.P.(1960).Interrelations between minerals constituents of foliage,Soil properties,site quality and regeneration status in some Shorea robusta forests, Ind.For. 86,590-601.

SEWELL,W.R.D.,DAVIS,J.,SCOTT,A.D.& ROSS,D.W.(1962).Resources for Tomorrow-A guide to Benefit Cost Analysis,Readings in Resource Management and Conservation,Queens Printer, Ottawa.

SISAM,J.W.B.(1938).Site as a factor in silviculture,its determination with special reference to indicator plants,Canada Silv . Res. Note No.54.

STAPLEDON(1936). A survey of the agricultural and waste lands of Wales. (cited by Tansley,1939)

STUDY GROUP ON AGRICULTURAL LAND CLASSIFICATION(1966).First progress Rep.,Ministry of Agric.,Fisheries and Food.

TAMM,O.(1950).Northern Coniferous forest soils,Camb.Univ.Press. (Trans. by M.L.Anderson)

TANSLEY,A.(1939).The British Isles and their vegetation,Camb.Univ.Pres

TRELOAR,D.W.G.,C.W.& MORISON,I.G.(1963).Economic comparisons of forestry and agriculture, three studies in the Hardwood/Butter fat region of Western Australia,Agric.Econ.Res.Rep.No.3, Inst.Agric.Univ.W.Australia.

THORNTHWAITE,C.W.& HARE,F.K.(1955).Climatic classification in forestry Unasylva, 9,51-59.

TRIMBLE,G.R.(1964).An equation for predicting Oak site index without measuring soil depth, J. For.,58(2).

__________ & WEITZMAN,S.(1956).Site index studies of uplands Oaks in the Northern Appalachians,For.Sci.,2,162-173.

TRYON,C.P.,BEERS,T.W.& MERRITT,C.(1960).The measurement of site quality for Yellow Poplar, J.For.,58(2).

TURVEY,R.(1963).Present values versus Internal rate of return:an essay in the theory of the Third Best,Econ.J.,LXXIII,93-98

U.S.D.A.SOIL CONSERVATION SERVICE(1951).Soil Survey Manual,Handbook No.18.

________________(1960).Soil Classification,a comprehensive system, 7th. Approximation.

________________(1961).Land capability classification Agric. Handbook No.210.

URE,J.(1965).Experience with vegetational indicators in Rotorua Conservancy,Assessments methods in New Zealand and Australia, N.Z. For.Service, For.Res.Inst.

van der VOORT,C.R.,WARDROP,T.N.,BEEKHUS,J.& DUFF,G.(1965).Assessment methods in NewZealand and Australia,N.Z. For. Service, For. Res. Inst. (Compilation)

van ECK,W.A.& WHITESIDE,E.P.(1963).Site evaluation studies in Redpine plantations in Michigan,Proc.Soil.Sci.Soc.Amer.27(6).

VINK,A.P.A.(1960).Quantitative aspects of land classification,Trans. VII Int.Congress Soil Sci.,IV,371-378.

________(1963).Planning of soil surveys in land development,Int. Inst. Land Development andIImprovement,publication 10.

VIRO,P.J.(1961).Evaluation of Site Fertility, Unasylva,15,91-97.

WALKER,K.R.(1958).Forestry Commission and the use of Hill Land,Scot. J.Political Economy,VII,14-35

WARD,J.T.(1963).Economic principles of land use,a comparison of agriculture and forestry,N.Z.J. For.,8(5).

WEBSTER,H.H.(1960).Timber management opportunities in Pennsylvania, U.S.For.Service, N.E.For. Exp. Sta. Paper No. 137.

________(1963).Timber management and economic analysis:a case study,U.S.For.Service,N.E.For.Exp.Sta.Res.Paper NE-14.

________(1965).Profit criteria and timber management,J.For.,63(4).

WORRELL,A.C.(1953).Financial maturity:a questionable concept,J.For. 51, 711-714.

WHYTE,R.O.& TAYLOR,B.W.(1958).A comprehensive approach to land classification, Int.Seminar on Land Development for agricultural uses, Int. Agric. Centre,Wageningen,The Netherlands.

ZINKE,P.J.(1961).Forest site quality as related to soil nitrogen content, Trans. 7th. Int. Congress Soil Sci., Madson,Vol.3