

Guidelines: land evaluation for extensive grazing

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PREFACE

This publication is the fourth in a series of FAO Guidelines for land evaluation for major land uses. Previous publications have covered Rainfed Agriculture (FAO 1984a), Forestry (FAO 1984b) and Irrigated Agriculture (FAO 1985b). The present Guidelines were produced in response to a recommendation from the International Workshop on Land Evaluation for Extensive Grazing, cosponsored by ISSS, ILCA, FAO and ITC, and held in Addis Ababa, Ethiopia, in November 1983.

It is likely that these Guidelines will be updated after more experience has been gained in applying the FAO Framework for Land Evaluation in extensive grazing areas. A useful follow-up would be the development of a series of Manuals for Land Evaluation for Extensive Grazing, each relating to a specific region (e.g. African Sahel). Comments and suggestions for improvement should be sent to the Chief, AGLS, Land and Water Development Division, FAO, via delle Terme di Caracalla, 00100 Rome, Italy.

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In this Bulletin we would also like to preserve the memory of Jan-Henk Bruin who was working on the draft at the time of his death in December 1987.

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1. INTRODUCTION

1.1 GENERAL

Extensive grazing is the predominant form of land use on at least a quarter of the world's land surface, in which livestock are raised on food that comes mainly from rangelands. The term livestock includes both domesticated animals such as cattle, sheep, goats, camels, horses, llamas and alpacas, and a broad range of wild animals kept for meat or game viewing. It is estimated that tropical grasslands alone cover 18 million square kilometres, where the natural vegetation is used by mobile animals requiring forage and water throughout the year.

Extensive grazing differs from crop or forestry production, in which the produce remains **in situ** whilst growing. Extensive grazing and arable agriculture often either compete for limited land or coexist in symbiosis. Its very size and mobile nature ensure that it is a most variable kind of land use, not conducive to being neatly parcelled into specific units of land occupied by growing crops, or into growing periods.

Evaluation for extensive grazing, unlike that for cropping or forestry, must take into account the production of both grazing forage, termed primary production, and the livestock that feed on this forage, termed secondary production. Extensive grazing also differs from intensive grazing, in which the animal feed comes mainly from artificial, seeded pastures and not from unimproved rangeland.

Rangelands are tracts of land used for grazing by domestic livestock or wildlife, where natural vegetation is the main forage resource (adapted from Gils 1984). They may be used for ranching, where animals graze on private and usually fenced land, or for three other systems of extensive grazing: nomadic pastoralism, transhumance or sedentary pastoralism. In the latter case the rangelands may be part of an agro-pastoral land use system.

i. Nomadic pastoralism. In semi-arid and arid rangelands where the overall vegetation density is low, the forage supply and its quality vary greatly over time. When combined with periodic shortages of drinking water for the livestock, these great fluctuations force the herders to roam continuously with their herds of camels, cattle, donkeys, sheep and goats in a nomadic existence. This diversity of animal species permits maximum exploitation of the sparse vegetation, and limits the risk of herds being decimated by drought, diseases or other circumstances largely beyond the herders' control (Ridder **et al.** 1982).

The life of a nomad is entirely dependent on his livestock. Cows and goats are the most important, principally for their milk. Goats, camels, short-haired sheep, and occasionally cattle, are slaughtered for meat, and long-haired sheep are kept for wool. Camels, horses, donkeys and oxen are used for transport, so essential for nomadic families. On a global basis, nomadic pastoralism is the least common system of extensive grazing.

- ii. Transhumance. Herders take advantage of seasonal vegetation growth by moving their animals between two or more separate areas. Livestock are first grazed in semi-arid or montane areas, which have short growing seasons because of low rainfall or low temperatures, and are then moved to wetter areas or those with milder winters for the remainder of the year.

Transhumance takes advantage of the good-quality herbs and grasses that grow seasonally in drier and cooler locations. At the end of the season, as drinking water diminishes or temperatures fall, the herdsmen are forced to seek other areas where, however, the forage is usually poorer, animal pests and diseases may be more prevalent, and the land is often increasingly used for cropping.

- iii. Sedentary pastoralism. In wetter areas arable farming is more practicable, crop-livestock interactions become more complex and extensive grazing systems become sedentary. In addition to more extensive grazing on rangelands, animals graze around fields where crop residues, stubble and weeds in fallow land are accessible.

Generally, only remote rangelands and arid, montane, periodically flooded land that is unsuitable for more intensive agricultural uses is considered for one of these systems of extensive grazing, or for alternative extensive uses such as wildlife, conservation, water catchment, recreation, or a combination.

However, as seen in transhumant pastoralism, even on rangelands there may be periods when the natural vegetation is inaccessible to animals because it is covered with water or snow, or is nutritionally inadequate or insufficient. Moving them into other areas, which may be more productive under cropping than under extensive grazing, inevitably results in interaction between the farming and the pastoral systems, as land that is periodically suitable for arable cropping is soon cultivated and, at least partially, denied to animals. Thus the livestock, and those who are dependent on them, are increasingly squeezed into smaller areas that remain suitable for their kind of land use. Land evaluation leading to diffusion of technical information about land suitability, could greatly reduce the conflicts that are likely to ensue.

In some areas that are both cropped and grazed, livestock rearing and arable farming have developed a symbiotic relationship, ensuring productivity from both. Livestock supply milk and meat, manure to fertilize fields, animal traction for ploughing and transport, and the means of financing needed cropping inputs through the sale of smallstock, whereas crop residues and fallow fields provide animal feed. In subsistence farming systems livestock often supply the bulk of the protein in the human diet, and the staple crop supplies a major part of the human energy requirement.

This relationship between livestock and arable farming must be considered when evaluating land for improved uses in which livestock play a major part. If one component of the overall land use is developed in isolation from the others, the balance between extensive grazing and arable farming may easily be disturbed.

These Guidelines are intended to assist three groups of users:

- i. land resources surveyors not familiar with rangeland science;
- ii. rangeland experts with limited exposure to the FAO land evaluation methodology;
- iii. land use planners.

A land resources surveyor is often responsible for the subsequent land evaluation, which will usually include cropping as well as grazing land utilization types. The land use planner may have to request or commission a land evaluation for livestock production systems, and will be in a better position to do so if he understands the principles of evaluation for extensive grazing.

To date only a limited number of land evaluations for extensive grazing have followed the FAO Framework: for example, Michieka and Braun 1977; Baig 1977; Voortman 1978; Sow 1981, Rootselaar **et al.** 1982; Ferguson 1983; Kallala 1984; Amuyunzu 1984; Gatahi 1984; Kekem 1984 and 1986; Bouare 1985; Andrade 1985. Although valuable as examples, they do not provide universal factor ratings for this land use, because of the great variety of environments in which extensive grazing may be practised throughout the world, and these Guidelines are only a starting point for national or regional guidelines, from which detailed ratings can be established.

1.2 OBJECTIVES OF LAND EVALUATION

Land evaluation is used to identify alternative land uses or changes in management that will better meet national or local needs, and to estimate the consequences of each feasible change. In terms of extensive grazing, it encourages the promotion of sustainable land uses that integrate land, livestock and people for their mutual benefit.

Answers to the following questions should be provided by a land evaluation (adapted from FAO 1976).

-How is the land currently utilized?

- Are the existing land use practices sustainable, or is there evidence that they will result in degradation?
- Within the present means of using the land, what improvements in management practices are possible?
- Are there alternative uses of the land, which are physically possible and socially and economically preferable?
- Which of these alternative uses offer possibilities of sustained production or other benefits?

- What adverse effects, physical, economic or social, are associated with each alternative use?
- What recurrent inputs are required to minimize any adverse effects of the existing or adopted land use?
- What are the benefits of each form of land use?

In a land evaluation specifically for extensive grazing it will also be necessary to forecast changes in:

- the composition and productivity of the vegetation after the introduction of different grazing practices;
- the existing pattern of mobility by animals, for example through the introduction of cordon fences;
- the traditional local and international movements of herds due to veterinary restrictions being placed on them; and
- the rate of encroachment of arable farms on what traditionally were rangelands.

It will also be important to identify the benefits for the national and local economies, the livestock owners, the herdsmen, and others dependent on the grazing system.

Land evaluation normally requires a comparison between the inputs required and the outputs obtained when each relevant land utilization type is applied to each land unit. In extensive grazing systems in developing countries inputs are largely limited to the work of the herdsman and his family, although the animals may represent a substantial capital asset. Outputs are usually modest, providing only a subsistence diet and some income. In some communities animals are more important for transport, traction and security, while in others meat, wool, hides and skins enter the market economy.

It is normally assumed that capital investments in extensive grazing are restricted to:

- the development of water supplies, dips and crushes;
- a limited amount of fencing;
- shrub clearance and the introduction of improved plants, especially legumes, into the natural vegetation; and
- a limited application of rock phosphate or similar fertilizer, by ground-based or airborne applicators.

If successful implementation of a land evaluation for extensive grazing is conditional on the application of capital investments, it must first be noted that with the land tenure system prevailing in many countries most grazing resources are regarded as communal. Individuals are therefore unlikely to invest their own money in rangeland improvement unless they are assured of the benefits for a certain period, principally through having exclusive grazing rights.

Extensive grazing as a form of land use has low productivity per unit area, causing little attention to be given to its improvement if it involves significant financial outlay; particularly so, if there is no prior evidence that good animal husbandry and land management practices will be applied. It will normally be considered when the evaluations of potentially more profitable land uses are exhausted.

1.3 SCALES OF LAND EVALUATION FOR EXTENSIVE GRAZING

Extensive grazing requires large areas of land, and varying spatial scales are needed for its evaluation at different levels. These may be classed as:

i. Continental or international level

Evaluations at the broadest scale include those of animal production systems involving nomadism and transhumance, and of the need for animal products on a regional basis. Regional planning guidelines will result from studies of these systems.

ii. National level

These are studies of whole countries, or the major regions or administrative divisions of larger countries. They are the basis for decisions on the allocation of major land uses to large areas, in order to meet national needs such as food, fuel, animal transport and recreation. They will also provide guidelines for different types of extensive grazing.

iii. District level

Studies of smaller administrative districts or a single catchment could have as their objectives, improvements in sedentary pastoralism, trekking route alternatives for transhumant herds, the development of ranching, and the allocation of land for nomadic pastoralism and wildlife viewing. Studies at this level will also provide the basis for decisions on the allocation of land for arable farming, plantation crops or woodlots.

iv. Local level

These will usually be studies carried out to promote good management of arable farming land uses with a grazing component. Linkages may be evaluated between crops and livestock in terms of food and domestic fuel supply, draught power, employment and investment.

Synoptic overviews at the international level provide a framework for more detailed plans at national and district level. Priority areas for concentrating future development, and the options open for making improvements are given. Conversely, the evaluation of local areas and subsequent planning within them has a cumulative effect, when many of these small areas are combined to cover a district. Therefore, proposed land use changes at any level of planning should be evaluated for their effects at different levels.

2. PRINCIPLES AND CONCEPTS

2.1 GENERAL PRINCIPLES

Seven basic principles are common to all land evaluations. With illustrations drawn from extensive grazing, they are as follows:

- i. Matching the requirements of the land use against the qualities of the land. This is the fundamental principle of land evaluation, which assesses the suitability of the land for specified kinds of land use. Each land use has different requirements and conditions under which it will perform best; similarly different types of land are best suited to different uses.

This principle applies at all scales of evaluation and at all levels of management. Each major land use, i.e. agriculture, forestry, livestock production, etc., has different requirements. Similarly, each method of livestock production, from extensively grazed livestock production at one end to totally stall-fed livestock at the other, has different land requirements.

- ii. Comparison between alternatives. Land evaluation may only involve a comparison between maintaining the present land use and altering it to another, but an evaluation should present more than one kind of use. They may not differ markedly; differences in management levels or changes in livestock species are sufficient for comparison. If only one land use is considered, and assessed as suitable, then another that is more suitable may be disregarded.
- iii. A multidisciplinary approach. Land evaluation is designed to integrate information from environmental sciences, development studies, the technology of land use, which in this case will be extensive grazing, and from economics and sociology, and to do so through the use of specialists. In the case of extensive grazing they should include a botanist, a livestock specialist, an economist, a sociologist and a soil surveyor. Several skills may be found in one person, so that the size of a team can be kept small, but the multidisciplinary approach to the evaluation must be maintained.
- iv. Evaluation is made in terms relevant to the conditions of the area concerned. The findings of one land evaluation cannot be applied globally, and often not even throughout a region or a country, because of large local variations in land, management skills, standards of living, capital and labour availability, and demand for livestock products.

The principles of evaluation remain the same wherever one is being conducted, but the relevant qualities of the land, and their critical values forming boundaries between classes of land suitability ratings, will vary between countries and regions. What is assessed as suitable land for extensive grazing in one area may be unsuitable in another where the environment is similar.

- v. Land suitability refers to use on a sustained basis. Certain land utilization types may be financially very profitable in the short term, but in the longer term they may result in the soil and natural pasture vegetation being degraded irretrievably. The land must then be classed as unsuitable for those land uses, since they cannot be sustained.

This principle does not require that the environment is maintained in its unaltered state, as all agricultural development involves changing the natural environment to some extent, and it is unrealistic to expect that agricultural development will have no effect on the land. A land evaluation must assess the consequences of applying each proposed land use as accurately as possible, so that only those that can be sustained without long-term degradation of the land may be considered for implementation when determining land suitability.

- vi. A comparison between the inputs required and the outputs obtained. The outputs from an area of land will either be products, such as meat, milk, hides, horns and skins, or will be less directly related, such as draught power, manure and cattle dung made into domestic cooking fuel. Since land hardly ever possesses productive potential without inputs, there will almost always be inputs, such as fencing, watering points, seeds and labour. Even the extensive grazing of natural vegetation by nomads requires the input of livestock supervision. Hence the suitability for each land use is assessed by a comparison of the required inputs with the outputs, which are products or other benefits obtained from the land. Land is only suitable for a given use if the amount of inputs is justified by the returns obtained.
- vii. The intensity of the evaluation varies with the intensity of management. Land usually has low value where it is being used for extensive grazing. Few opportunities exist in such circumstances for increasing output through improved management. A relatively low intensity of evaluation is therefore appropriate for most situations where extensive grazing is being assessed.

When the quality of the land increases on moving from areas of predominant nomadic pastoralism to sedentary pastoralism, where grazing merges with cultivation, then the need also increases for a greater intensity of evaluation.

2.2 TERMS AND CONCEPTS

An introduction to the basic concepts used when describing land, land uses and the relations between the two is necessary in order to understand the principles of land evaluation. The fundamental terms are given here, and others are defined in the sections that follow and in the glossary.

2.2.1 Land use

Since land suitability can only be assessed for specified kinds of land use, the descriptions of the land uses are the distinctive focus of land evaluation. Once they have been fully described, their requirements can be determined. For reconnaissance level

evaluations, it will be sufficient to give the descriptions as summary statements, but full management specifications are required when detailed evaluations at local level are to be undertaken.

At a generalized level an evaluation may be in terms of major land uses, e.g., extensive grazing, rainfed agriculture, irrigated agriculture, and forestry. Major land uses are only used in qualitative evaluation studies, usually when a rapid and synoptic overview is required of the potential of a large area.

Most evaluations are carried out on the basis of land utilization types, which are any uses of the land defined in greater detail than a major land use and described through a set of technical specifications. These specifications are given under a series of headings termed key attributes, which are important features that can affect the requirements or management specifications of the land use. The degree of detail necessary in the description varies with the scale and intensity of the evaluation. Extensive grazing, a major land use, includes land utilization types such as various kinds of nomadic pastoralism, transhumance and sedentary pastoralism.

Although extensive grazing often involves the different use of different areas of land in different seasons, the use of the term “seasonal land utilization types” is not recommended. Extensive grazing encompasses a totality of activities within a production system, within which seasonal land uses are part of wider land utilization types.

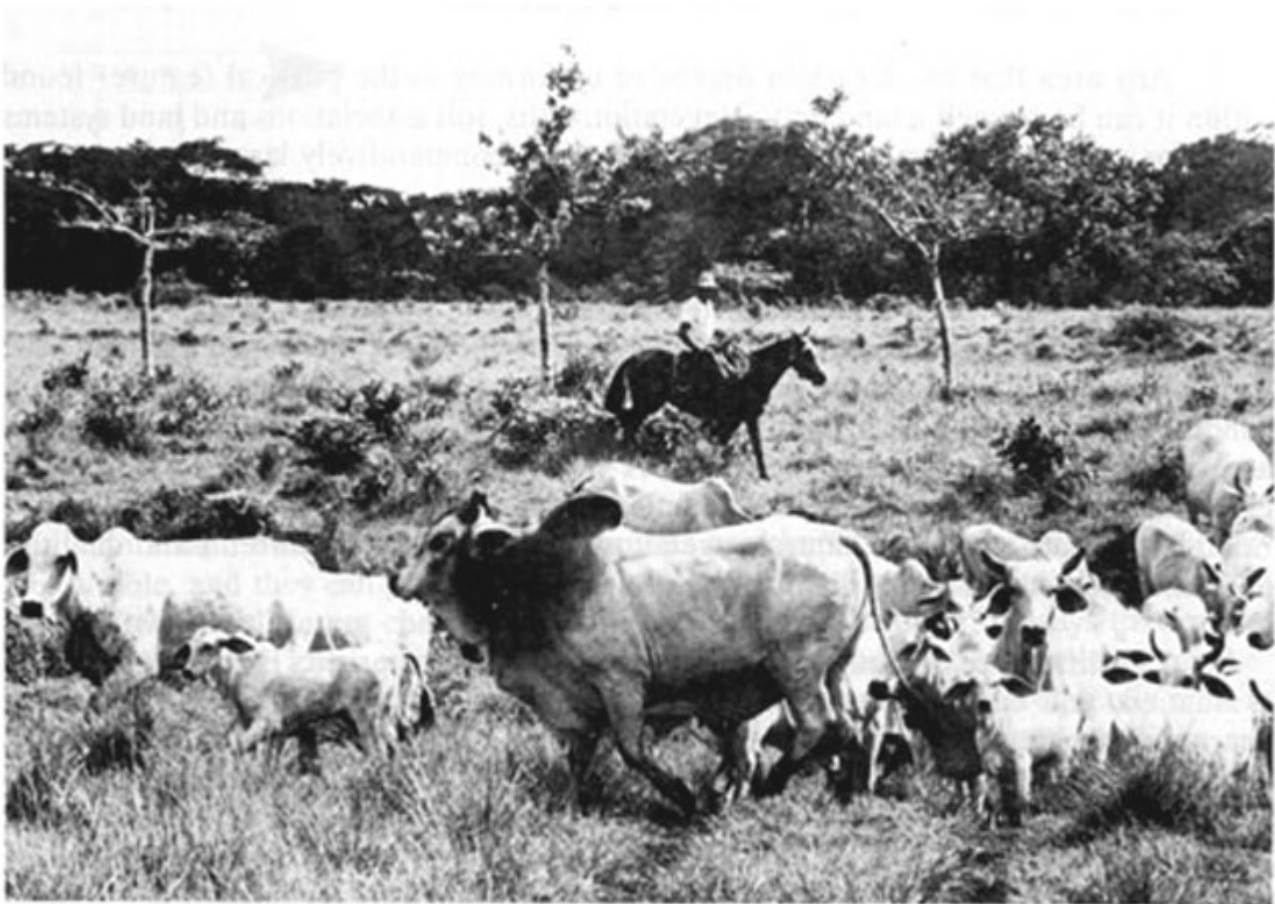


Plate 1 Commercial ranching: an example of a land use type based on extensive grazing in Panama. UN photo.

All major land uses and land utilization types require certain environmental conditions, termed land use requirements, in order to be successfully practised. Adequate forage in the dry season, absence of tsetse flies and access to stock-watering points are examples of land use requirements for extensive grazing in the tropics. Each requirement must relate to a specific land use. For example, the requirement of access to water for camels is quite different to that for sheep, and cattle and goats both have different seasonal feed requirements.

Often two or more land uses are practised in one area. Multiple land use occurs where two or more kinds of land use are practised simultaneously on the same land. Examples are livestock grazing within a forested area, and transhumance in an area of seasonal cultivation. Compound land uses consist of two or more uses taking place sequentially on an area of land. Arable cropping followed by livestock extensively grazing on the crop stubble is an example.

2.2.2 Land

For the purpose of land evaluation, land consists of all the features of the natural environment that have an influence on its potential for land use in the area under study. So, as well as covering rocks, landforms and soils, the term land covers climate, natural vegetation, wild animals, pests and diseases. A land mapping unit, usually shortened to land unit, is an area of land with specified characteristics, mapped and defined by natural resource surveys and forming a basis for land evaluation.

Any area that has a certain degree of uniformity in the physical features found within it can be termed a land unit. Vegetation units, soil associations and land systems all act as examples of land units. Those that cover comparatively large areas, each in terms of tens of square kilometres, will normally be used for extensive grazing.

The properties of the land units are given in terms of land qualities and land characteristics, for which a collective term is diagnostic factors. A land quality is an attribute of land that influences the suitability of the land for a specific land use. Examples of land qualities of importance to extensive grazing include the nutrient conditions of the soil, the hazard of erosion under grazing conditions and the degree of accessibility of the grazing to animals. A land characteristic can be measured or estimated, unlike a land quality. Examples of land characteristics are mean annual rainfall, soil nutrient status, natural vegetation type and topsoil texture. Land qualities and land characteristics are discussed in detail in Section 7.

The difference between land qualities and land characteristics is important in land evaluation, and can be illustrated by an example. Soil nitrogen content is a land characteristic that can be measured in the field as a single property of the land. It affects extensive grazing of natural pastures by altering the level of nitrogen uptake by the forage. Higher nitrogen levels increase the quality of the grazing and hence the productivity of the land unit. Nutrient availability has a distinct effect on the growth of vegetation, and is thus a land quality. It is influenced not only by the nitrogen content of the soil but also by its pH, available phosphorus, organic matter, base saturation and exchangeable potassium, amongst other land characteristics. The quality of nutrient availability results from the interaction of these characteristics.

In extensive grazing there are two distinct levels of production, that of forage, and of livestock reared on that forage. There are therefore land qualities and land characteristics that are specific to one or other of these levels, and others that are common to both. The genetic potential of the natural vegetation is a quality specific to its growth, whereas the availability of drinking water relates solely to livestock production. Flooding hazard will primarily affect forage production, as animals should be able to move away during periods of flood, but this quality therefore also has some effect on livestock production. The full list of land qualities, and their groupings according to production level, are given in Section 7.

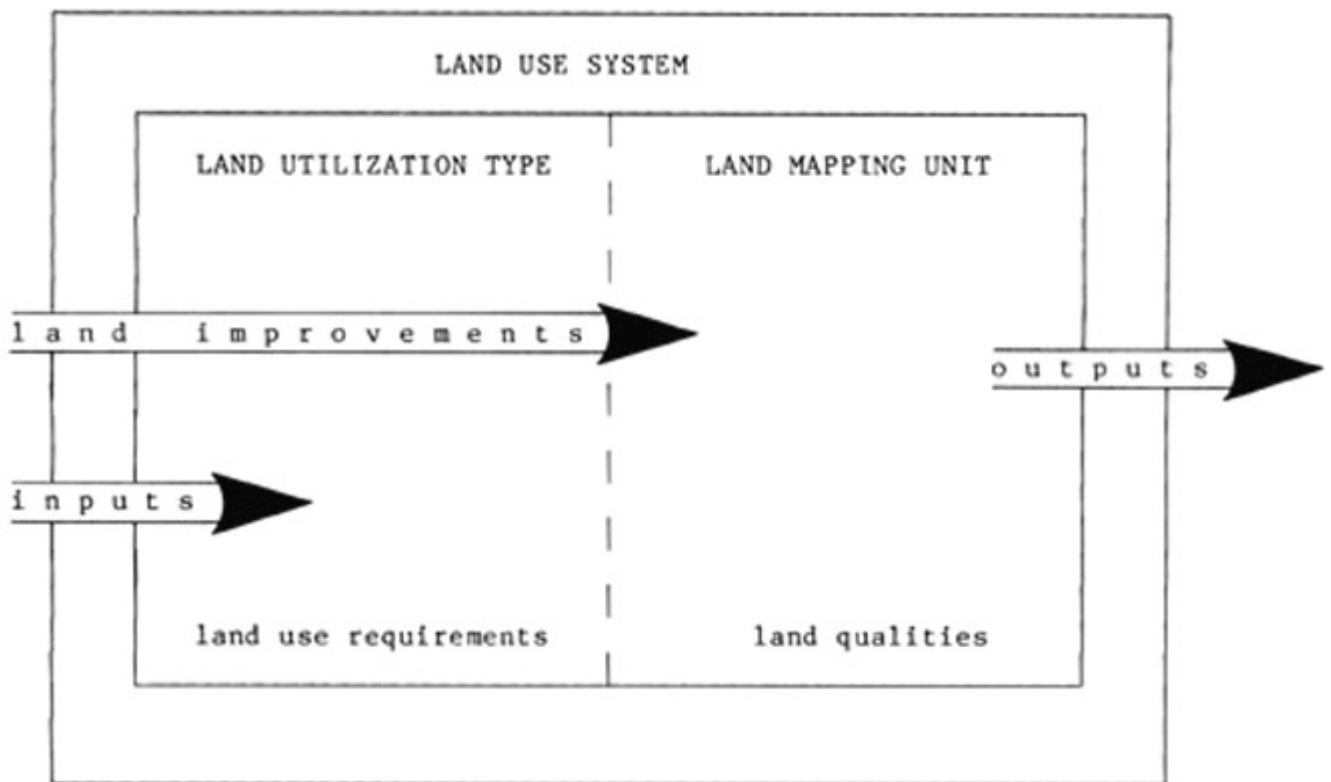


Figure 2.1 Elements of a land use system (from Dent and Young 1981)

In a land evaluation land characteristics are simpler to use as they are directly measurable, and they can provide a valid basis for estimating land suitability in a small area. However, different characteristics interact with one another, in ways that cannot be accounted for if characteristics are used alone. There are also a very large number of land characteristics and, if they are the basis of the evaluation, it is frequently unclear which effect on the land use is being assessed. Only by using land qualities can interactions between characteristics be taken into account, the number of characteristics being employed remain manageable and their effects on the land uses be understood.

Land use requirements and land qualities are usually expressed in the same terms. Rooting requirements is a land use requirement for forage production; rooting conditions is a land quality possessed by land for which forage production may be a suitable land use.

2.2.3 Linking land use and land

Combining land and land use in a land evaluation gives land suitability, defined as the fitness of a land unit for a kind of land use. It is assessed by comparing the land use requirements of the land utilization type with the land qualities of the land unit. The social, economic and environmental factors are also analysed before a final land suitability can be given for a specific land utilization type on a known area of land.

The drawing together of the different components of a land evaluation is well summarized by the concept of the land use system. This is the application of a specified land utilization type on a mapped land unit, and so is a particular combination of land use and land, as shown in Figure 2.1.

In a land evaluation each land utilization type has certain land use requirements, and each land unit has certain land qualities. If inputs are provided through the land utilization type the resulting land use system will yield certain outputs, as products, services and other benefits from the land unit. A land use system therefore describes a specific land use being practised on a certain area of land.

2.3 LAND SUITABILITY CLASSIFICATION

2.3.1 Structure of the classification

The suitability of a land unit refers to its fitness for a defined use. There are four levels of suitability in the classification: land suitability orders, classes, subclasses and units (Figure 2.2). These categories are applied at all degrees of detail of evaluation, and are assessed separately for each land use in every land unit in the study area.

<u>Order</u>	<u>Class</u>	<u>Subclass</u>	<u>Unit</u>
S, Suitable	(S1	(S2m	(S2e-1
	(S2	(S2e	(S2e-2
	(S3	(S2es	etc.
	etc.	etc.	
N, Not suitable	N1	(N1m	
	N2	(N1e	
		etc.	
NR, Not Relevant			

Figure 2.2 Structure of the land suitability classification

2.3.2 Subdivisions of land suitability

- i. Orders : Categorizing kinds of suitability
- ii. Classes : Categorizing degrees of suitability within land suitability orders
- iii. Subclasses : Categorizing kinds of improvement measures required within classes
- iv. Units : Categorizing small differences in production characteristics or management requirements.

i. Land suitability orders separate land units assessed as suitable from those that are not suitable for a given land use. There are two orders:

- S Suitable : Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without damage to land resources
- N Not suitable: Land which has qualities that appear to preclude sustained use of the kind under consideration

There are three main reasons why land may be classed as unsuitable:

- a. The proposed use is technically impracticable. It will not be suitable even for extensive grazing which is frequently undertaken in areas unsuitable for any other significant use, where, for example, the land is too frequently flooded or devoid of natural vegetation.
- b. Application of the use would be environmentally undesirable; e.g., where the introduction of domestic livestock would destroy valuable plant or animal species.
- c. When the intended land use is unprofitable or socially unacceptable. If the benefits from the land use cannot be economically justified or would result in a standard of living which would be socially unacceptable, then the land must be classed as unsuitable.

Subdivision by land suitability orders early on in a land evaluation will eliminate the need to study areas that are clearly unsuitable.

ii. Land suitability classes indicate degrees of suitability. Within the order 'suitable' there are normally three classes: highly, moderately and marginally suitable, indicated by the symbols S1, S2 and S3 respectively. The boundaries between these classes, in terms of lessening degrees of suitability, are not defined in the general case. For evaluations requiring quantitative estimates the boundaries may be decided by yields or economic returns gained from the land; in particular, the boundary between the orders 'suitable' and 'not suitable'.

Table 2.1

DEFINITIONS OF LAND SUITABILITY CLASSES

Class S1 Highly Suitable	Land having no significant limitations to sustained application of the given land utilization type, or having only minor limitations that will not significantly reduce productivity or benefits, and will not raise inputs above an acceptable level
Class S2 Moderately Suitable	Land having moderately severe limitations for sustained application of the given land utilization type, thus reducing productivity or benefits and increasing required inputs. Overall benefits will be appreciably inferior to that expected on Class S1 land
Class S3 Marginally Suitable	Land having severe limitations for sustained application of a given land utilization type, and will so reduce productivity or benefits, or increase required inputs, that this expenditure will only marginally be justified
Class N1 Currently not Suitable	Land that has limitations which cannot be overcome at currently acceptable cost
Class N2 Permanently not Suitable	Land in which there are limitations so severe so as to make its use permanently impracticable or uneconomic.

The boundary between the two classes N1 Currently not Suitable and N2 Permanently not Suitable is usually decided by the physical conditions of the land. For extensive grazing, which makes relatively few demands of the land in comparison with more intensive uses, this boundary may not appear in many evaluations. Also, the acceptable cost of upgrading land classed as N1 for extensive grazing will be low. The combination of these two factors requires that land being assessed as unsuitable for this land use is first carefully examined from physical, social and economic aspects.

- iii. Land suitability subclasses reflect the kinds of improvement measures required within classes, such as drinking water availability, rooting conditions for natural forage crops and reduction of undesirable plant species. They are indicated by lower case letters, e.g. Subclasses S2m, S2t. There are no subclasses to class S1 and there is no limit to the number of subclass symbols that can be used in a particular evaluation.
- iv. Land suitability units are subdivisions of a land suitability subclass that differ from each other in detailed aspects of their production characteristics or management requirements. They are numbered successively, e.g. S3r-1, S3r-2, etc., where the lower case letters identify the most important constraints. Being used mainly in surveys at detailed and farm levels, land suitability units will rarely be used in evaluations for

extensive grazing, for which the classification will normally be only down to subclass level.

2.3.3 Types of land suitability classification

The results of land evaluations can be given in qualitative, quantitative or economic terms, and are the means by which the boundaries between the land suitability classes are defined. In a qualitative classification the classes are defined in qualitative terms only, although quantitative procedures are used in the evaluation whenever possible. The terms used are as given in Section 2.3.2, such as highly, moderately or marginally suitable for a specified land use. There are no calculations based on economics, although the boundary between the Marginally Suitable and the Not Suitable classes is normally placed where the land use ceases to be profitable. This type of classification is of use mainly in studies at a reconnaissance level, because it allows the qualitative integration of many aspects of the physical, social and economic environment, and in the evaluation of large areas for extensive grazing, where the potential is required in general terms.

In a quantitative classification the boundaries between suitability classes are defined in terms of quantitative estimates of the production or other benefits to be obtained; e.g., meat or milk production, draught power or pack animals made available. Thus inputs also must be given in quantitative terms; e.g., amount of concentrate feed, mineral supplements and veterinary drugs. A quantitative evaluation is usually the basis for an economic classification, in which the class boundaries are defined in economic terms; hence the suitabilities for each land utilization type on each land unit are given in terms of profit and loss, although the classes Highly Suitable, Moderately Suitable, etc. are still employed. Specific monetary values are assigned to all data from the quantitative evaluation, so that the costs of inputs can be compared with the value of the production.

3. OUTLINE OF PROCEDURES

3.1 INTRODUCTION

The procedures for land evaluation are essentially the same for all types of land use. They have been fully documented by FAO (1976, 1984a, 1984b, 1985b), together with explanations of the terminology used, and they will only be repeated in outline here. Each land use, however, has distinctive features that require modifications to the general procedures. In particular, extensive grazing is distinct in that it is concerned with two interrelated products; a primary one, forage, which is static, and a secondary one, livestock, which are mobile whilst under production.

As with all land uses, the evaluation of land for extensive grazing usually takes place for political, economic or strategic reasons. Frequently an evaluation is requested to assist the resolution of a controversy over land use, as between pastoralism and arable farming or between ranching and wildlife conservation, for which objective recommendations are required. The evaluation must then seek to supply data that are lacking on the existing forms of land use, and provide recommendations on suitable alternatives.

The implementation of any alternative land uses is likely to be constrained by existing land uses and sometimes also by official policies, as well as by the uncontrolled movements of cultivators into rangeland, with the continued threat of their encroaching onto key grazing areas.

Hence a land evaluation for extensive grazing should commence with an awareness of the social needs and limitations of those dependent on this land use, and these are continually changing. For this reason, although set procedures are laid down, they cannot be rigidly adhered to at all times, and flexibility in approach and in proceeding with such an evaluation is necessary. This outline gives some of the essential stages and suggests a sequence that can be followed, and Figure 3.1 gives a diagrammatic view of the procedures.

3.2 STEPS IN A LAND EVALUATION

3.2.1 Step 1: Planning the evaluation

This should be based on discussions between those directly involved: the pastoralists, planning team and decision-makers, who should make it clear:

- i. who the beneficiaries are expected to be;
- ii. what policy issues directly affect its implementation; and
- iii. what land uses are relevant for consideration as options.

The evaluators should familiarize themselves with the social context and study any official plans, even if provisional, of the study area. These may include Five Year

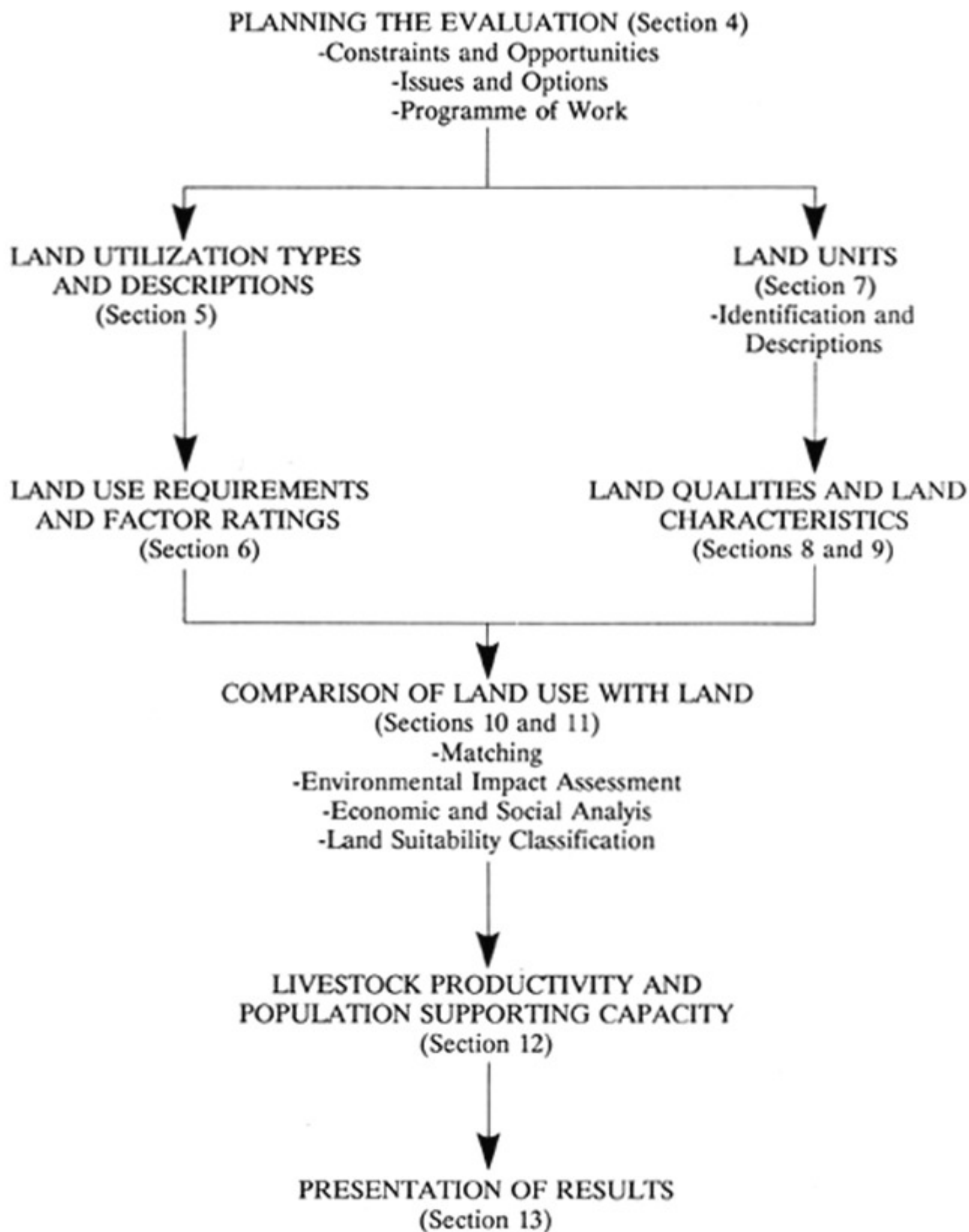


Figure 3.1 Outline of steps in a land evaluation

Development Plans, former project proposals, government livestock production targets and stock-watering improvement schemes.

At the same time any constraints to changes within this major land use should be examined; for example, policies designed to encourage or impose more sedentary forms of grazing on nomadic and transhumant pastoralists. The opportunities open for overcoming these constraints should also be ascertained; e.g., that crop-livestock interactions are being encouraged by improved marketing of livestock products in cropped areas. Overall, as thorough a diagnosis should be undertaken as time permits of the issues and options, constraints and opportunities that the survey team is likely to confront as the evaluation progresses. This will help with the selection of possible future land utilization types and management practices applicable within them.

Members of the survey team should then conduct a rapid review of the physical, grazing, livestock, social and economic context of the study area and of the existing data available, enabling a programme of work to be compiled. It should indicate the results aimed for and new information needed, logistical support requirements, and costs. Three sets of field activities can then commence: examining the land uses, the land, and the social, economic and environmental conditions.

3.2.2 Step 2: Studies of the land utilization types

Land utilization type studies commence with drawing up basic descriptions of each option that has been identified from Step 1. Information about improved grazing land utilization types might be obtained from regional pasture and livestock research stations or demonstration farms. If, however, these do not exist in the area or in a comparable environment, the descriptions will be tentative and general, derived from background literature and field observations.

The data necessary for the key attribute descriptions of the land utilization types are collected by interviewing range and extension staff, veterinary personnel, herders, livestock owners and researchers. Usually the land evaluation will not be considering only the land use of extensive grazing, but also some or all of the following: intensive grazing, wildlife, cropping, forestry, conservation, watershed protection, and recreation.

The products of this Step 2 are a table of land utilization types and their key attributes, and accompanying explanatory text.

3.2.3 Step 3: Determination of the land use requirements

These are the conditions of the land that are necessary for the successful and sustained application of a given type of extensive grazing, such as drinking water availability, the ease with which undesirable plant species used for forage can be controlled, and the conditions necessary to avoid soil erosion under different forms of grazing. The aim here is to provide specific data that can be used later, both in subsequent steps of the evaluation and in the preparation of management specifications if the land use is applied.

These data are the basis for the assignment of factor ratings for each land utilization type. Factor ratings show how well one particular land use requirement is satisfied by a condition of the corresponding land characteristic or land quality. The actual values of the land characteristics are measured in the field in Step 4.

3.2.4 Step 4: Studies of land units

In parallel with the above studies, land units are defined and described. They will have degrees of homogeneity varying with the different levels and scales of survey as given in Section 1.3, and can thus provide information on the land from reconnaissance to detailed levels of precision. The data collected during this step focus on the land characteristics that are of importance in determining land qualities relating to grazing land utilization types, e.g., vegetation composition, vegetation structure, forage production, chemical composition of the forage and watering points.

Many important characteristics of the vegetation can only be measured seasonally, therefore the duration of the land unit survey must be sufficiently long to record seasonal variations. The spatial aspects of the current land use are also part of this survey. The products of this step are a land unit map and accompanying report.

3.2.5 Step 5: Collection of economic and social data

Concurrently with the land use and land surveys, social and economic data required to describe the grazing land utilization types and analyse the alternatives are collected in a parallel approach evaluation (FAO 1976). Alternatively, these data can be collected and analysed after a first approximation of the physical land suitability has been completed, following a two-stage approach to the evaluation (FAO 1976).

The advantages of the two-stage approach are that social and economic data can be collected according to stratified sampling based on the land unit inventory, and in a more problem-oriented manner.

3.2.6 Step 6: Comparison of land use with land

This step and the next form the crux of the land evaluation, for which two sets of data are to hand: the land use requirements with their factor ratings; and the relevant values of the land features that affect how well the land use will perform. These two sets of data are combined by matching them, requirements with qualities. For example, what is required by the land use of the climate is matched with climatic characteristics such as rainfall, temperature and radiation regimes, etc.; requirements in order that erosion is avoided are compared with the susceptibility to erosion of the land; and so on until each land quality is matched with each land use requirement.

This leads to a set of partial suitabilities based on one requirement alone, called land suitability ratings, showing the suitability of a land unit for a specified land use. The separate ratings are then combined to give a first approximation of the land suitability classes for each land use, based only on physical conditions of the land. Thus, for example, matching could show that seven land units in a survey area are unsuitable for sedentary pastoralism because of randomly timed but severe flooding, but that a further twelve units have no physical limitations to their being developed for this land use.

3.2.7 Step 7: Social and economic analysis, and environmental impact assessment

These approximations must now be subjected to social, economic and environmental analysis before being made final. From Step 1 the land evaluation will have been planned around perceived social needs and goals, and these should be analysed in more depth. This is to ensure that the land use changes are acceptable, and that the consequences for the social structure of neighbouring areas are understood when the land use of one area is changed. This is particularly important for extensive grazing, where two quite different types of land users, pastoralists and arable farmers, can easily come into conflict over land use changes that only seek to improve conditions for one.

The depth of economic analyses will vary according to the scale and level of the evaluation. At regional levels strategic reviews of livestock numbers and broad distributions can assist national planners in assessing the priority areas for development. Detailed analyses of economic outputs at the local level will assist in the compilation of management specifications for herders, by giving information about such items as required capital investment, expected economic output, internal rates of return and credit needs. An overall assessment of the environmental impact of the proposed land uses should also form part of this step, supporting the reviews already undertaken in the draughting of the land use requirements and in matching in Steps 3 and 6.

3.2.8 Step 8: Land suitability classification

The final suitability classification of each land unit for each alternative land use is now compiled, as explained in the following sections of this Bulletin, taking account of physical, environmental and socio-economic factors. Provisional suitabilities that were formed in Steps 7 or 8 can be revised, with the one criterion that land can only be classed as suitable for a use if its social consequences can be made acceptable to the land users.

3.2.9 Step 9: Presentation of results

The results of a land evaluation must be presented in formats that are understood by the different interested parties. Varying methods of presentation will usually be required for the wide range of users. These include the pastoralists who may want visual displays and practical instructions on the ground from the extension services, the government policy-makers who require executive summaries of key points of the evaluation, and technical staff of livestock management departments, who need details of the land utilization types, the agricultural practices and inputs required for their implementation, and land suitability maps and tables to link land use recommendations to specific land units.

3.2.10 Step 10: Successful application of the recommended land uses

This final step relates land evaluation to the wider field of land use planning. Thus far one or more land utilization types will have been assessed as being suitable for different land

units, which will now be made into management units by being taken singly or combined. A choice has to be made as to (a) what kind of land use should be practised on which unit, according to the specifications given in their descriptions, and (b) what land use systems will be used, and their yields in terms of outputs, services and other benefits. The chosen alternative use is written into a land use plan, which gives full management details for its implementation. Funds are released as necessary, and implementing agencies or individual herders are coordinated by the evaluators and planners as they apply the results of the evaluation in the study area.

4. PLANNING A LAND EVALUATION

Before a land evaluation can commence a number of preliminary planning tasks must be completed. The issues that necessitated an evaluation must be understood, the knowledge and opinions of interested parties should be taken into account, prior studies should be examined, and the overall objectives that the evaluation aims to achieve should be formulated. Work planning should also be completed, so that responsibilities, schedules and budgets are known in advance.

4.1 INITIAL CONSULTATIONS

At all stages, and particularly at its commencement, land evaluation is facilitated by consultations. It is not a unilateral means for surveyors or governments to tell land users what to do with the land. Technical details in an evaluation will have to be compiled by technically competent field staff, but their work should be closely related to the results of discussions held with those who commission the evaluation and those who are going to be directly involved with its implementation. For a successful evaluation there needs to be a free interchange of ideas between the pastoralists, the surveyors and those in authority who will make the decisions about future land uses. Each group has a specific contribution to make; pastoralists provide local knowledge and experience, the surveyors have the technical skills required, and decision-makers can offer the broad overview of development potentials within a survey area.

Initial consultations between these three groups of people should be held so that the decision-makers and representatives of the land users can brief the surveyors about the area and what they expect to be achieved by a land evaluation. The surveyors in turn must clarify with the other parties how they consider a land evaluation may help them, and what problems will be outside their scope of work. Aspects to be covered during these discussions will include:

- i. objectives of the evaluation and specifications of results required;
- ii. constraints, assumptions, issues and opportunities open for development;
- iii. basic information already available about the area;
- iv. information needed to be obtained from the land evaluation;
- v. technical programme, funding and logistical support.

4.2 OBJECTIVES

Broad objectives will have been outlined at a preliminary stage of discussions, and they should be able to be defined with precision when consultations are completed. The possible objectives of developing extensive grazing are many, but will all be related to the social needs of the pastoralists and to pastoral problems that may be overcome through a land evaluation. At a reconnaissance level an evaluation may assess the suitability of an area

for all relevant forms of use, of which only one is extensive grazing, and a broad physical suitability classification would be a sufficient objective. At more detailed levels the suitability of different forms of extensive grazing may be compared, in order to identify those uses that most closely meet projected national requirements for livestock products.

The objectives must be framed within the principles and concepts of land evaluation as outlined in Section 2. In particular, land suitability is to be assessed for use on a sustained basis, and the evaluation must be relevant to the conditions of the survey area and the needs of the intended beneficiaries. Within this framework, however, stated objectives need not focus on the production of land suitability maps. At a national level the evaluation may be aiming to provide information to guide land use policy or environmental legislation relating to extensive grazing, or to provide data on which national development plans and budgets are to be based. At the other extreme, a detailed survey of a few land units intended for extensive grazing may have the objective of estimating yields and production costs for each unit. In one case, the evaluation will provide an outline of physical suitability, and in the other the results will include a detailed financial analysis.

When formulating objectives at least the following basic information is required:

- i. The location, size, boundaries, accessibility, and centres of population of the survey area.
- ii. Identification of the groups of people that have vested interests in the development of the area - government departments, private companies, international agencies, individuals or groups of pastoralists.
- iii. The intended livestock products from the area, and whether these are the only agricultural products expected.
- iv. Whether there will be conflicts of interest between grazing and non-grazing uses of the land.
- v. The weightings to be assigned to different objectives. For example, is the priority to increase the population supporting capacity, to substitute for livestock imports, to reduce environmental impact, or to maximize return on invested capital.

Objectives for a land evaluation for extensive grazing are as numerous as those for the other major land uses; examples of typical objectives are:

- to provide additional meat and milk products through improved linkages between sedentary pastoralism and cropping practices;
- to promote development of smallstock within a nomadic pastoral system, where natural resources are suitable;
- to design a programme that encourages cooperative holding of livestock and

cooperative management of communal grazing land in highly stocked areas;

- to select potential areas for resettlement of transhumant stock, in which grazing capacity values have been determined for low input levels;
- to assist in the design of a national livestock strategy that aims at import substitution of dairy products;
- to permit grazing access to woodland to the maximum extent compatible with both livestock and forest management.



Plate 2 An example of a specific extensive grazing land use type - karakul sheep production near Kabul, Afghanistan. FAO photo.

4.3 ISSUES AND ASSUMPTIONS

The constraints and assumptions on which the evaluation is to be based must be made clear, in terms of issues and options open for development. An issue may be a limitation to a change of land use, or an opportunity open for its development. Limitations and opportunities will be within contexts that are legal, institutional, environmental, social or economic. For example, extensive grazing may not be feasible because of a political decision to limit growth of this land use in a specific area. Alternatively, an improvement in beef prices on the international markets may motivate a government to invest in extensive grazing in an area that is currently underused. Underlying constraints on a land evaluation proceeding in a certain direction will frequently be set in the first instance by government strategy and legislation.

Assumptions are conditions that also form part of the basis of the land evaluation, such as that transhumant stock routes are to remain intact, that sedentary pastoralism is a preferred option, or that it is socially unacceptable to reject nomadic smallstock herding in an area. A major assumption is that, if land users are cultivators and have no experience of pastoralism, and there is insufficient time or resources for them to gain it during the expected project life, it should be assumed that other types of land use with which they have been involved will need to be assessed instead.

Issues and options are initially determined during the consultation period, through answers to questions that relate to the objectives of the evaluation. These will be as varied as the objectives, with the following as examples:

- Is the extent of the survey area fixed, or only assumed to be as given? If nomadic pastoralism is found to be more wide-ranging than initially considered, the survey area may have to be extended.
- To improve access to a remote area, is road construction a feasible capital investment?
- Can resettlement of existing transhumant pastoralists be considered where dry season grazing is becoming limited by encroaching cultivation?
- Are options open for discussion on modifications of land tenure in an area of communal grazing? If so, what may be the political constraints to such a change?
- What is the length of time over which the results of the evaluation will be in operation? Can implementation be broken down into phases, with periodic monitoring and reviews?

The diagnosis of constraints that will face the surveyors in the evaluation, and the formulation of options open to overcome them, are thus examined in order to improve the evaluation procedures.

4.4 INFORMATION AND DATA REQUIREMENTS

An evaluation must be made in terms relevant to all the physical, economic and social conditions of the survey area. Therefore, ready access to whatever information has already been obtained is a significant aid in planning a land evaluation and in determining the conditions that are present. When a large amount of data is available, skill is required in assessing its quality and relevance, and in filtering out what is unsuitable. Relevant information would cover:

- i. land resources; topographical maps, air photos, satellite images, previous surveys and reports covering any aspect of the physical environment;
- ii. land use and livestock production; livestock censuses and distribution, farming systems, yields and production levels, transport, communications;

- iii. economic context; the present economic structure, including demand for livestock products, labour wage rates, costs and prices, subsidies and taxes, and any published financial or economic analyses;
- iv. social conditions; population totals and distribution, rates of change and movements of people, ethnic groups, class structure, educational levels and attitudes to development, land tenure and rights to livestock, needs and aspirations of the pastoralists;
- v. government involvement; administrative structure and level of authority, veterinary services, provision of subsidies, legislation and directives.

The extent of further data that will have to be collected is then assessed. The technical objectives, issues and assumptions and previous studies in comparable environments or with similar objectives will indicate the types and level of detail required. The final output and quality of the evaluation will also depend on the financial and manpower resources available. Within all these constraints the necessary surveys for the evaluation can be planned.

There are four main aspects to be considered about data collection for a land evaluation, covering land utilization types, resources surveys, economic and social assessment, and presentation of results:

- i. The level of detail to be given in the descriptions of the land utilization types should first be decided, as the remainder of the evaluation depends on this. If a national survey of a number of major land uses is being undertaken, they can be summary descriptions requiring little background research. Where detailed studies are to be conducted, on the other hand, the collection of data will be lengthy, and should follow the full listing in Section 5 of key attributes. Many evaluations will require a level of detail between these extreme examples, with the amount of data collection being more dependent on the number of land uses being considered.
- ii. The level of detail of natural resources data to be collected and analysed varies directly with the level of detail of the land utilization types, and with any existing survey maps and reports. In a reconnaissance survey basic data about the main resources of soils, water, vegetation, etc. will be sufficient for a qualitative evaluation. On the other hand, specialized surveys will be required for livestock management planning, where descriptions give details on production systems such as grazing capacity, water reticulation, stock rotations and crop residue feed supply.
- iii. The amount of economic data to be collected is estimated depending on whether the evaluation is to be a qualitative physical or a quantitative economic assessment. If a broad set of guidelines on the economic potential of an area is sufficient, then adequate economic and social data will cover markets and prices for livestock products, and costs of labour and material inputs. Where economic analyses leading to investment are required as a central part of the evaluation, details of inputs and outputs of all

financial aspects of the proposed land uses are needed, together with a full assessment of the impact on the social structure of the pastoralists.

- iv. Who are expected to be the main users of the evaluation, and hence how the results will be presented, also affects the data collection. For example, if the main users are to be technical field staff, detailed maps, survey reports and analyses can be included; if decision-makers require broad indications of land potential for a strategic initiative, the report could focus on legal and administrative findings; where the pastoralists will themselves play the major role in implementation of a cooperative venture, explicit management data should be prominently collected and reported.

4.5 WORK PLAN

The information obtained from the initial consultations, the objectives of the land evaluation and constraints on it, and the lists of data required have to be transformed into a specific programme of work. A work plan gives details of:

- responsibilities of each team member and the means of coordination of their inputs;
- timing schedules of personnel and activities;
- allocation of logistical support at each step in the evaluation.

The survey team should ideally be able to provide a balanced input of physical, economic and social aspects of the evaluation, with responsibilities directly related to their skills. In practice, a team will range from a well-integrated group of specialists who have experience of working together within a government department or agency, through a collection of individuals rapidly selected for a one-off project, to a single person who has to cover all aspects, drawing assistance and information on an ad hoc basis from any sources available to him. A balanced five-man team for a land evaluation for extensive grazing would be comprised of a livestock production specialist, grassland ecologist, soil surveyor, land evaluator and socio-economist.

Land evaluation covers broad fields of activity and frequently crosses disciplinary boundaries, thus the cooperation of a number of agencies, such as those from government, international and non-governmental organizations, is a valuable means of providing data for the evaluation and assisting with its subsequent implementation.

Coordination is dependent on a systematic schedule of activities being included in the programme of work. The aim is to ensure that all the necessary data from various sources are assembled together at the right time and in the right format for analysis and interpretation. Previous studies and experience will provide the best indications of the time required for each activity and will show, for example, that:

- outline land utilization type descriptions should be written up at an early stage;
- soil surveys are usually the lengthiest of the basic resources surveys to complete;
- matching will invariably depend on land use requirement data and values of land qualities or land characteristics first being assembled together;
- economic data cannot be analysed in the normal two-stage approach before the provisional matching results are available.

With the responsibilities of each team member having been detailed, together with the work plan and scheduling of activities, financial and equipment resources should be allocated for each step in the evaluation. These can include purchases of supplies and materials, the appointment of supporting services for manual labour, transport and printing, and in-service training of inexperienced staff. Logistical planning may be a mundane part of the evaluation, but will help to forestall unexpected problems that inevitably arise, and will reduce needless delays in what is usually a tight time schedule.

From this plan the following working specifications should be included in a land evaluation:

- i. total duration and funds available;
- ii. context of the land evaluation, described by the overall strategy, institutional setting and prior surveys, if any;
- iii. present situation, target beneficiaries, problems to be overcome, project strategy for overcoming these problems;
- iv. objectives, outputs and activities of evaluation;
- v. information to be obtained, linked to the survey activities and specialized studies required;
- vi. plan of work, budget, staffing and logistical inputs and schedules;
- vii. required format and timing of presentation of results.

5. EXTENSIVE GRAZING LAND UTILIZATION TYPES

5.1 INTRODUCTION

This section discusses the first component of the land use system, the land utilization type, as defined in Section 2.2. The second component, the land, is examined in Section 7. Extensive grazing, as a land utilization type, can be subdivided into nomadic pastoralism, transhumance and sedentary pastoralism, as outlined in Section 1. Most evaluations for extensive grazing will be at these levels and be based on the concept of the land utilization type. This can be defined as a set of human activities on the land in a given physical, economic and social setting, in order to produce goods or services from the land.

Land utilization types concerned mainly with extensive grazing differ from those dealing mainly with arable agriculture, and call for modifications to land evaluation procedures, due to three important reasons:

- i. evaluations for extensive grazing must include both primary production of forage and secondary production of livestock;
- ii. planned stocking rate, i.e. the number of livestock per unit area per unit time, can, and is in practice, varied to suit the amount of forage available over space and time;
- iii. unlike plants, livestock are mobile and are often able to find forage over a wide area;
- iv. livestock have continuous and relatively constant nutrient and water requirements throughout the seasons.

In the fourth case above, livestock have some similarity in their requirements to perennial crops although seasonal variations in forage supply demand their constant mobility when grazing extensively.

Animal mobility is a common strategy employed to balance nutrient and water requirements with seasonal supply, and must be considered with those others that grazing and cropping land utilization types have in common. It applies to each of the land utilization types of extensive grazing listed above, because in each case livestock use different parts of the rangeland throughout the year. Animal mobility is approximately the equivalent of shifting cultivation in cropping land utilization types, where it is described as a cropping characteristic.

Mobility causes some of the key attributes of extensive grazing land utilization types to vary over the different grazing seasons, and they must be specified accordingly. For grazing land utilization types with key attributes that diverge greatly according to the season, distinct sub-land utilization types may be present, for which the term “seasonal land utilization types” was proposed by Wijngaarden (1984). Grazing may be seasonally on crop

residues and fallow fields, where it can be classified as a compound land utilization type as described in Section 2.2. It is also common for a grazing land utilization type to be combined seasonally with other kinds of land use, for example with tree crops and firewood collection, forming part of a multiple land utilization type.

Two further issues make for more complexity when extensive grazing land utilization types are being considered. The first, again involving mobility, occurs where two or more livestock species graze either together or sequentially on the same tract of land in at least one grazing season, and graze apart in other seasons. Also, similar use of grazing can be made by animals of different ages and sexes of the same species. Because of this, the terms multiple, compound and seasonal, when applied to extensive grazing land utilization types, should be used carefully, as they are not mutually exclusive in this context.

The second issue is that the genetic potential of indigenous tropical livestock breeds, reared on extensive grazing for the production of milk and meat, is rarely reached because of a lack of adequate feeding (Whiteman 1980; ILCA 1986). Therefore, in extensive grazing land utilization types, the introduction of exotic breeds for replacement or crossbreeding will not usually result in increased livestock production. To do so the correct approach is to commence with increased forage production, and for this a land evaluation with clearly specified land utilization types is a precondition. Only when this production approaches the genetic potential of the livestock, does crossbreeding become a rational means of improving the land utilization types.

Following the second principle of land evaluation given in Section 2, an evaluation of an area for extensive grazing should incorporate at least two kinds of land use. It will include the 'unimproved' type of extensive grazing currently being practised, which itself may include wildlife production, conservation and amenity use. It may also include an improved and more intensive form based on experimental data and recommendations from advisory services and, if applicable, an arable farming land use. However, of the available land evaluation reports for extensive grazing, only two (Baig 1977; Voortman 1978) assess the suitability of even two types of extensive grazing, the current and improved. More commonly either only the current unimproved form has been evaluated (e.g. Sow 1981) or only improved types (e.g. Ferguson 1983; Kallala 1984).

Improvements on presently applied management specifications of land utilization types depends to a large extent on sufficient pasture research results being available about the study area. In Africa Gryseels **et al.** (1986) have observed that 'field experiences have shown that little modern technology was available that had substantial advantages over traditional methods (of extensive grazing), given the economic and ecological conditions facing producers.' This implies that it is premature to propose improved extensive grazing land utilization types for Africa. Other observations support the inclusion of semi-arid and arid Asia in this statement, where little information is available about the indigenous livestock breeds.

However, in Latin America the opportunities for the application of land evaluation for extensive grazing within the concept of land utilization types are more promising. This is because of the prevailing socio-economic conditions, with the dominance of ranching over

extensive pastoralism and the increasing rate of beef consumption per capita, and the environmental setting, with large tracts of rangelands under a humid climate. Here the pasture research undertaken by CIAT (1985) has enabled land evaluations to be carried out for improved, extensively grazed land utilization types (Andrade 1985).

5.2 CHOICE OF LAND UTILIZATION TYPES

There are three important reasons for using land utilization types and for describing them comprehensively in a land evaluation:

- i. Descriptions are used as the basis for subsequent management planning of agricultural operations and activities.
- ii. They are also the basis for the determination of the land use requirements of the land utilization types. Although not all the data supplied in the descriptions are directly applicable for these determinations, many have environmental implications for the land use requirements. This is increasingly so as the descriptions are improved during the course of the evaluation and references are made back to them in an iterative process of refinement.
- iii. The first drafts of the land utilization type descriptions often provide its base data, particularly on the economic and social needs and conditions of the area. These and subsequent improvements ensure that the evaluation remains related to these needs.

The identification of potential land utilization types for the study area is an important early task. Just as the evaluation results in a suitability assessment in physical, economic and social terms, so the land utilization types are also selected on the basis of these criteria. The aim is to select land uses that are feasible in the economic and social situation and that are also physically suitable for the area. To achieve this, their selection is by the process of successive approximation, at first summarily and later in much more detail as the evaluation gets underway. 'Long duration nomadic migrations of camels and smallstock' is an example of an initial summary description, becoming refined to include data on, for example, labour intensity, quantity of livestock products and extension service inputs.

5.3 KEY ATTRIBUTES

5.3.1 General

Land utilization types are described by their main or key attributes, defined as in Section 2 as a set of technical specifications. They can affect the requirements or management specifications of the land use. Most key attributes are common to all land utilization types, but some are related solely to the land use of animal production. Of these the principal one is mobility. The relative importance of each depends more on the level of production employed by the land utilization type, and on the characteristics of the area being evaluated, than on the land use being described.

In a land evaluation, prior to describing the land utilization type by its key attributes, it is informative to provide a summary description and place the land use in its regional setting. The summary may repeat the broad description given at the commencement of the evaluation, e.g. 'sedentary pastoralism with low inputs in an area of shifting cultivation, with short migration in the wet season of the slaughter stock and non-milking sedentary smallstock'; or give an overview, e.g., 'the use is appropriate for large areas of the drier north of the country which have a semi-arid to savanna climate with mean annual rainfall of 400 to 650 mm. The natural vegetation of thorn scrub has been essentially replaced by secondary scrub and cultivated fields, within which short-term transhumance can be practised, making use of crop residues and cereal stubble. There is a wide range of soil types supporting grazing of differing qualities.'

The main groupings of key attributes of extensive grazing land utilization types adapted from Purnell and Leeuw (1984) are as follows:

- i. Livestock:
 - Livestock types and inputs
 - Mobility
 - Outputs
 - Markets
- ii. Rights and tenures:
 - Rights to livestock and outputs
 - Land tenure and land use rights
 - Holding sizes
- iii. Social and economic inputs:
 - Labour
 - Technical knowledge and attitudes
 - Capital
 - Materials
 - Production practices
- iv. Yields and production:

In this list attention will first be directed to the livestock and their outputs, and then to the rights of pastoralists to the above and to the land on which the land use is practised. Social and economic inputs are described next, as also the expected yields and production levels to be achieved by applying the land utilization type in suitable areas.

5.3.2 Livestock types and inputs

Each extensive grazing land utilization type should first specify the livestock being grazed; e.g.:

- i. domesticated stock that includes cattle, sheep, goats, camels and horses;
- ii. semi-domesticated stock such as reindeer, caribou and eland;
- iii. wildlife, such as gazelle, deer, antelope, moose.

Where a particular livestock breed has a significant effect on the productivity or level of management of the land use, this should be specified; e.g., trypano-tolerant N'Dama cattle.

The most important descriptive features about any extensive grazing system are the types and numbers of animals by producer and by given area. Overall approved animal numbers can sometimes be obtained from Veterinary Services, but in nomadic and transhumant systems they are rarely subdivided into seasonal grazing areas, and actual census data can be collected by systematic reconnaissance flight techniques (Gils **et al.** 1985). Herd compositions by different species should be described, as they not only reflect the type and level of production expected but also the feed requirements of the herds and flocks.

5.3.3 Mobility

The form of grazing should be described by the extent of mobility of the livestock within it. As outlined in Section 1, pastoralism is conventionally subdivided on the basis of mobility into nomadism, transhumance and sedentary pastoralism, as follows:

- i. In **nomadism**, pastoralists search for any green vegetation, standing hay and water for their livestock. Although movements are extensive and may appear to be haphazard, they usually observe territorial limits. Old people and children sometimes remain in a semi-permanent camp.
- ii. Pastoralists and their livestock are more regulated in their movements in **transhumance**, migrating seasonally between different grazing areas and often following a circuitous route. They cover long distances to avoid seasonal shortages of food and water, to utilize all available resources, or to avoid unfavourable climatic conditions or disease hazards.
- iii. In **sedentary pastoralism**, otherwise termed local grazing, in at least one season herds are taken out daily from villages or sheds to communal rangeland for extensive grazing.

The duration of grazing seasons in transhumant and nomadic grazing systems are to be given. These occur within different grazing orbits: circles centred on the home of the livestock and grazed by the latter during a season or a year.

Details should be given of variations in mobility by different species within one grazing system, if applicable. For example, the milk cattle in a system may be sedentary, the goats and sheep in transhumance and the camels nomadic. A clear example of such variations in mobility is shown in Table 5.1.

5.3.4 Outputs

Outputs to be described comprise livestock products, e.g., milk, meat, hides and skins, and other benefits, such as draught power and recreational services. A herd often provides several products, amongst which one may dominate. Meat can be live, fresh or

dried, and ghee and sour milk may be important dairy products. Hair, wool and hides are significant both in the subsistence and the cash sectors of the economies of many pastoralists. In exchange for grain or money, herders will kraal their livestock on arable land of their own or others. In some societies manure is the main source of fuel and is an important output from herds. In commercial cattle production systems dependent on extensive grazing, one objective is the production of immature male stock for sale, whereas in some sheep-rearing systems the sale of older breeding females is an important secondary source of income.

Outputs in the form of other benefits are likewise numerous and are to be given. Cattle, buffaloes, yaks and camels are used for transport and draught power. Some pastoralists drink the blood of their cattle as food. Livestock, their numbers, horns and size, can give status and security, and investment opportunities similar to bank accounts open for immediate deposits and withdrawals. Wildlife in game parks provide recreation for the wealthier members of society, and elsewhere are a supply of 'free' food for others.

These are qualitative statements on the types of outputs and other benefits from extensive grazing. Under the key attribute of Yields and Production more detailed descriptions and comparisons between various produce types are given.

Table 5.1 SEASONAL MOBILITY OF FOUR DIFFERENT LIVESTOCK SPECIES BELONGING TO THE SAME PASTORAL SYSTEM IN CYRENAICA, LIBYA. Source: Behnke (1980)

	<u>Cattle</u>	<u>Goats</u>	<u>Sheep</u>	<u>Camels</u>
Winter	Central plateau, crestline	Juniper forest, northern steppe	Leave mtn. and move to steppe	Floodplains south to the Sahara, nomadic
Early Spring	Central plateau, crestline	Juniper forest, northern steppe	Steppe, floodplains	Floodplains south to the Sahara, nomadic
Late Spring	Central plateau, crestline	Juniper forest, crestline	Leave steppe and return to mountain	Steppe, floodplains
Summer	Central plateau	Juniper forest, crestline	Crestline, central plateau	Steppe, floodplains
Autumn	Central plateau, crestline	Juniper forest, crestline	Crestline, central plateau	Steppe, floodplains

5.3.5 Markets

These are described qualitatively in terms of the intended destination of the outputs, ranging from a subsistence economy to conventional commercial operations, with common intermediate stages of subsistence with subsidiary commercial, and commercial with subsidiary subsistence. For example, whilst meeting most of their requirements directly from the produce of their herds, subsistence pastoralists meet the remainder through subsidiary commercial production by selling or bartering milk or manure. They only rarely sell large animals, such as when they have to buy food in times of scarcity, to pay taxes, or to pay for litigation or ceremonies.

Attention may be given in an extensive grazing system that is commercial with subsidiary subsistence to the ratio between participation in the barter economy, functioning primarily for subsistence needs, and the cash economy (Cossins and Mourik 1984). Here any subsistence production for bartering should be converted into a money equivalent, so that it can be compared quantitatively with the extent of market orientation, and the two expressed as relative percentages; e.g., 'the cash economy sector forms 70% of the land utilization type, and 30% is in subsistence production'.

5.3.6 Rights to livestock and their outputs

This is another key attribute that relates specifically to livestock, with the rights of the pastoralists to the livestock they herd showing significant regional variations and requiring description. Livestock can be owned by individuals (e.g., among the Maures in West Africa and many other herders), by households or by extended families (e.g., by the Fulani in West Africa). The determination of ownership rights may be difficult for an outsider to grasp, as herds often include animals belonging to different owners. Complexity of rights is increased by the fact that in the majority of pastoral societies livestock ownership is unevenly distributed, and in some it is extremely so (Livingstone 1985).

The extent of rights to livestock outputs produced by extensive grazing should also be given. Exclusive rights are usually held by livestock herders who also own the animals, unless part of the produce is required by a local authority in lieu of taxes. When animals are herded for their owners, varied and often elaborate rights to the produce and methods of paying for it can ensue. They include all or part of the milk, varying food rations depending on numbers employed, annual or seasonal cash payments and a percentage of the offspring.

For example, among the agro-pastoralists in the Zambezi floodplain in the Western Province of Zambia, four types of ownership rights are distinguished; absentee owner, caretaker owner, caretaker and 'mafisa'. The owner who is absent often has a separate income from urban employment, giving permanent and overall responsibility to a caretaker owner for the whole herd. He in turn has seasonal responsibility for the animals alternating with his caretaker. 'Mafisa' rights are different, being the result of livestock owners mutually exchanging a part of their herd with those of relatives and friends for limited periods, for reasons such as spreading risks and hazards to the livestock and tapping underexploited grazing resources.

The absentee and caretaker system has management and economic implications that should be distinguished and accounted for in the description. For example, an absentee owner may live at a distance from his herds and his caretaker owner, and account must be taken of the resulting delays in crucial decisions such as vaccinating, culling and selling stock, which themselves result in the spread of disease and lowering of market value. Absentee owners may often not be interested in sustained livestock production and rangeland management, instead viewing their herds as a mobile bank or as a means of gaining short-term profits.

5.3.7 Land tenure and land use rights

Land tenure is the legal or customary manner in which ownership of land is held. In extensive grazing land it is closely related to the rights held by pastoralists to use that land, and the two are classified together. A broad distinction should be made in the description between the land tenure and land use rights associated with the two main forms of extensive grazing, ranching and pastoralism.

- i. In **ranching** exclusive grazing rights are held on freehold (private ownership) or leasehold land by an individual or group.
- ii. **Pastoralism** is the use for extensive grazing by a community or group of any land under communal ownership, which is not carrying crops and not subject to legal restrictions, such as those that apply to nature and forestry reserves.

Where it is part of the pastoral system, the formal allocation by one interested party to another of grazing or usufructuary rights on a seasonal or long-term basis should be noted. In particular, users' rights to wells and other stock-watering points are important aspects of this land use that require description. For example, if a pastoralist has himself dug a well, or paid for it to be dug, he has the usufructuary first right to its water supply.

In describing the main features of the land tenure situation in the land utilization type, it should be noted that there is a widely held misconception that communal grazing of rangeland always leads to overgrazing and degradation (Hardin 1968). This view can easily be contradicted, as some communal grazing lands do not show signs of being overgrazed (e.g., the Barotse floodplain in Zambia, and the Sudd floodplain near Kongor, Sudan), whilst some private ranches show severe degradation of the rangeland (e.g. in Botswana and Extremadura, Spain).

5.3.8 Holding sizes

Ideally the sizes of areas of typical grazing orbits within a land use system should be given. However, this is often difficult to define when not dealing with ranches or areas with formally allocated grazing rights. The likely range of sizes is usually the best that can be given.

If there is one grazing orbit within a land utilization type, an approximate holding size may be obtained by subtracting the areas not providing any grazing, such as cropland

and gazetted forest and nature reserves, from the total area. A further approximation may be made by mapping all watering points and adding circles centred on them with radii equal to the known walking distances to water of the livestock. This should be carried out separately for each grazing area and season. However, in the not infrequent cases of floodplains providing water and forage, additional data on the flooding pattern should be obtained in order to establish the grazed area and holding size.

Where there are overlapping grazing orbits, as is common in extensive grazing, the sizes of individual or group holdings should each be given where possible, although they are still more difficult to determine. If there are exclusive rights to a source of water, the holding size may be estimated by using the maximum distances walked to the water by the different species in the herds.

5.3.9 Labour

Pastoralism is often regarded from the outside as an idyllic and leisurely way of life, but it is in fact very demanding. Labour inputs into what may be classed as a 'low input level' of extensive grazing include herding, construction and maintenance of watering points, extraction of water, tethering, kraaling, moving camp, particular care for young and pregnant animals, milking, shearing, and bartering and selling livestock products. The responsibilities for such tasks vary between ethnic groups, but divisions of labour inputs are usually well demarcated by tradition. The description of the land use should include as much information as possible on what tasks are carried out and how much time is spent on each.

Labour intensity is the total amount of human labour inputs provided to the land utilization type, per unit area of land, including family and hired labour. It can be described qualitatively as low, intermediate or high labour intensity, but for management specifications these intensities should be based on estimates of man-months of labour provided per unit area, as for example:

- i. **Low labour intensity:** labour input as is normally found in ranching in developing countries. Less than 0.1 man-month/ha/yr.
- ii. **Medium labour intensity:** labour input between 0.1 and 0.5 man-month/ha/yr.
- iii. **High labour intensity:** labour input as is normally found in pastoralism in developing countries. More than 0.5 man-month/ha/yr.

Note that labour intensity is usually in inverse proportion to the extent of capital investment, as described in Section 5.3.11. A high labour intensity is often required where there is little capital investment, and a lower labour intensity where there are capital intensive operations, though this is not invariably the case.

5.3.10 Technical knowledge and attitudes

These should be described, as the feasibility of introducing improved land utilization types depends significantly on the knowledge of the livestock herders and their attitudes towards changing aspects of their methods of pastoralism. Knowledge and attitudes

vary greatly; pastoralists often exercise great skill in caring for their animals, whereas ranchers may show little knowledge and have attitudes focused on short-term commercial gains. The description should refer to levels of general education, including literacy, levels of agricultural education, and likely receptiveness to innovations and changes, these usually being introduced through the extension services.

5.3.11 Capital

This refers to the levels of capital investment and the recurrent costs. Apart from their livestock, which represent a very substantial asset, most pastoralists can afford few other investments in extensive grazing. Where capital is available to them, boreholes and wells, sheds for protection against a harsh climate and dip tanks are examples of investments that are made. On the other hand, ranching land utilization types require considerably more investments, including fencing the outer boundaries and the paddock subdivisions within them, and machinery for construction of fire breaks. When forage crops are introduced into an extensive grazing system, the related investments are comparable with those made into cropping land utilization types. Annual recurrent costs are calculated from the production practices given in Section 5.3.13.

In a qualitative description levels of capital intensity can be classified as low, medium or high, broadly distinguished as follows:

- i. **Low capital intensity level** is normal in traditional subsistence pastoralism in the tropics.
- ii. **Medium capital intensity levels** are present in more commercially-oriented pastoralism, as in the Middle East and Argentina, and will provide for investments such as motor transport to market, dip tanks and boreholes.
- iii. **High capital intensity levels** are normal in commercial ranching, where fences, machinery, motor transport, roads, water storage tanks and stores are provided.

There are significant regional variations in the meanings of 'high' and 'low' when applied to capital investments and so, wherever possible, quantitative terms should be used for the description of this attribute. These include the value of the capital investment, per hectare, grazing orbit and production unit, and the recurrent costs for the same areas.

5.3.12 Materials

The level of materials in an extensive grazing operation is usually in direct relationship to the levels of capital investment and recurrent costs, as more capital will allow the purchase of more materials. For general descriptions three levels of material inputs are recognised:

- i. **Low inputs:** no significant use of purchase materials such as drugs, lickstones, concentrate feeds; traditional nomadic and sedentary pastoralism and transhumance in developing countries.

- ii. **Intermediate inputs:** materials input by more affluent and commercially-oriented pastoralists, often on the advice of extension and veterinary services; including drugs, mineral supplements, disinfectants, and supplementary feeding in critical seasons and for certain age categories.
- iii. **High inputs:** methods based on advanced technology and high capital resources, and applicable to ranching; includes forage and grass seeds, fertilizer, browse trees, concentrates, silage and hay. Extensively grazed ranches utilizing this level of material inputs merge into intensive grazing systems.

5.3.13 Production practices

The following technical details of how extensive grazing systems are managed in order to produce the desired outputs will enable systems that are presently in operation to be compared with those that are recommended as potential improvements.

For primary production:

- i. grazing management techniques; e.g., time of release from kraal, form of rotational grazing;
- ii. method of control of undesired plants, if any; e.g., by herbicide application, brush crushing, ploughing;
- iii. form of prescribed burning and wildfire prevention; the frequency and season when applied;
- iv. timing of fertilization and mowing;

For secondary production:

- v. frequency of watering, by species and by season;
- vi. supplementary feeding practices, including mineral supplements;
- vii. breeding practices;
- viii. measures taken to control pests and diseases of stock;
- ix. timing of mating, mating control and weaning practices.

If forage crops are to be produced as additional feed in a high input land utilization type, the cultivation practices applied to the land for their production should also be described, approximately as follows:

- i. land preparation, including methods of clearance of natural vegetation;
- ii. planting practices, including timing of planting and timing and methods of fertilizer application;

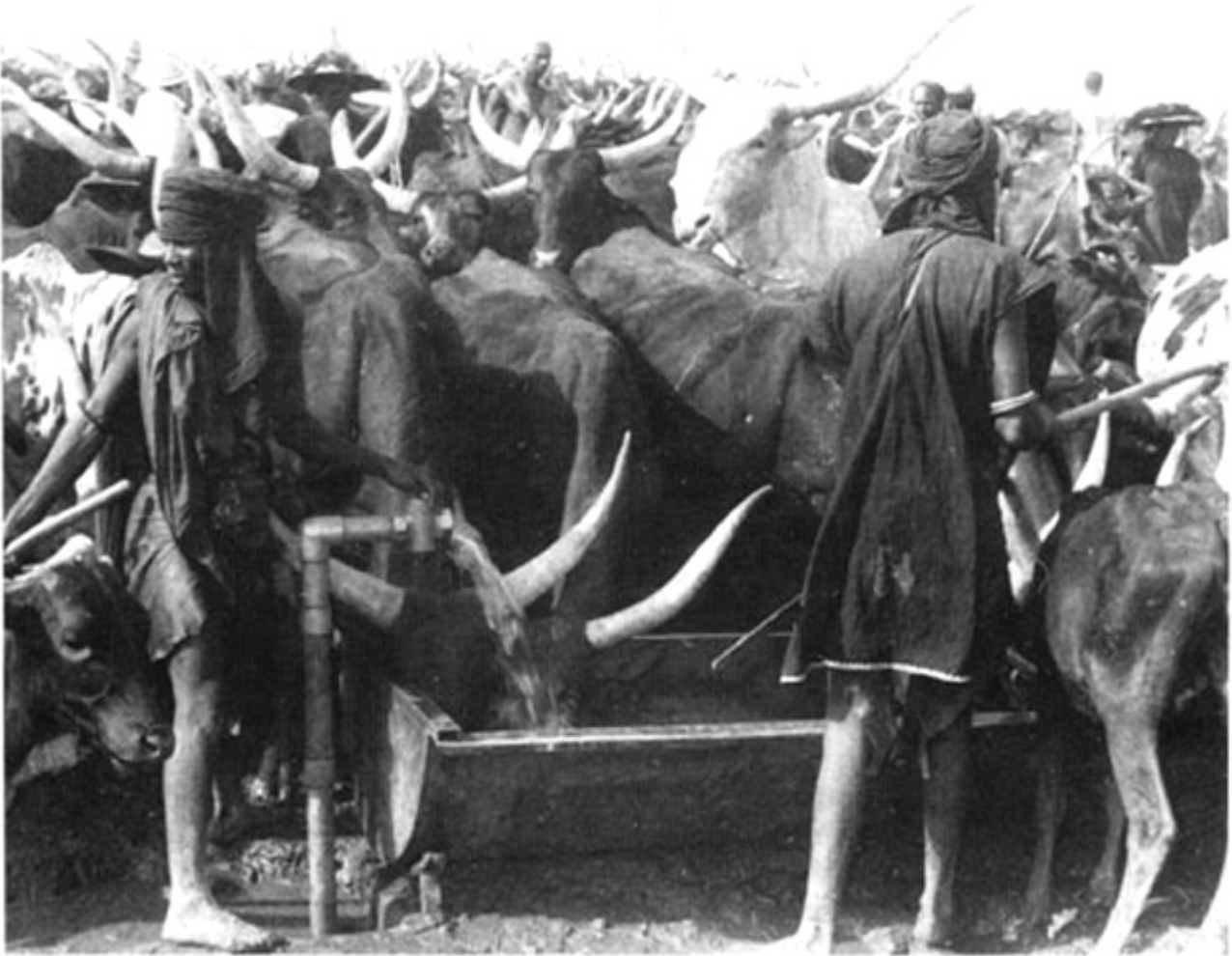


Plate 3 Availability of water is one of the most important factors affecting land suitability for any form of extensive grazing. FAO photo.

- iii. weeding timing and methods;
- iv. harvesting frequency and timing.

5.3.14 Yields and production

The estimated amounts of livestock products or other outputs produced by the extensive grazing land utilization type being described may be expressed by yields and production. **Yield** is the output per unit area and **production** is the output from the whole production unit, which will range from one animal to a whole herd. In subsistence livestock husbandry, animals have both multiple functions and products.

Yield and production estimates form a basis for economic analysis, and they are themselves an important output of the land evaluation, being the final outcome of application of a land utilization type according to the key attributes listed. They will clearly vary greatly with capital and material inputs, production practices and management levels, as well as with the class of suitability of the land for the recommended land use. Thus it is important that

full descriptions of land utilization types accompany statements of expected yields, and that the latter are expressed not as single figures but as ranges that reflect the variability of input levels and management.

Following are some examples of expected values of yields and production at different input levels for different areas. Note that traditional pastoralism achieves relatively low production levels per animal and relatively high yields in comparison with ranching on similar rangelands. The typical milk production per cow for a low input extensive grazing land utilization type in tropical Africa is 250 l/yr. Meat production under similar circumstances is 15-50 kg/yr (Leeuw 1984; Ketelaars 1984), whereas under ranching, where inputs are at a medium level, it is 80-90 kg/yr. In terms of yields the ranching figures correspond to 20-30 l/ha/yr of milk and 3-10 kg/ha/yr of meat. These meat yields are comparable to the 3-15 kg/ha/yr yields typically achieved by extensive grazing and ranching in continental Asia (Ren 1984).

Unimproved Mediterranean shrub range land utilization types typically yield 20-30 kg/ha/yr of meat, but this can be doubled by improvements to the land utilization type (Papanastasis and Liacos 1983). In Latin America alpacas have a yield of wool of 3-4 kg/ha/yr, in addition to a meat yield of 1.2-1.6 kg/ha/yr (Calle 1982). Camels typically produce 1 500-4 000 l/yr of milk, but yields are usually at the lower end of this range, as this animal is grazed very extensively in semi-arid and arid areas where the quantity and quality of browse is usually low (Yagil 1982).

In comparison, more intensive forms of tropical cattle ranching on legume-based pastures have meat yields of 100-500 kg/ha/yr, which can be increased up to 1 000 kg/ha/yr with large applications of superphosphate (Whiteman 1980). Under comparable conditions milk production per cow is about 2 000 l/yr, which is equivalent to a yield of 5 000-10 000 l/ha/yr (Whiteman 1980).

6. LAND USE REQUIREMENTS

6.1 GENERAL

The conditions of the land that are necessary for the successful implementation of land utilization types are known as land use requirements, and are expressed in terms of land qualities or in a negative manner as land use limitations. These are conditions that adversely affect the potential of the land for supporting a certain land utilization type. An example in extensive grazing is the presence of plants that are toxic to livestock. The availability of drinking water for livestock is a land use requirement, whereas pests and diseases of livestock are a limitation. The requirements of a land utilization type, and the limitations to applying that use, are the basis for deciding what data have to be collected during the land unit survey that is described in Section 7.

Often in areas of extensive grazing, as with areas under other land uses, there are factors that limit the suitability of the land and prevent the land use from achieving its maximum potential. Therefore it is insufficient to state only the optimum requirements for a land use, since the subsequent evaluation would be in danger of rejecting all land that did not match up to these requirements. Instead, it is necessary also to give a range of conditions under which they will be met, and to what degree, by determination of:

- i. the conditions that are best for the land use;
- ii. the range of conditions that are below the optimum but are still suitable to some extent;
- iii. the conditions that are unsuitable and unproductive.

These conditions are given quantitatively as critical values of the land use requirements. Presented numerically in this manner, they can be matched with values of land qualities in the subsequent step of the land evaluation. An example of values of the land use requirement that drinking water should be available nearby for cattle in a specific land utilization type could be that, if it is within 2 km, that requirement is fully met, if it is 2-6 km the land is classed as only moderately suitable in terms of drinking water availability, and so on. These are the critical values of the condition of water availability. As critical values that form boundaries between classes of suitability vary so greatly, they must be set independently for each evaluation. Generally, however, when this matching procedure is completed for each condition of the land, the suitability of each land unit can be determined for each land utilization type.

The procedure to arrive at this conclusion is usually one of successive approximation, based largely on studies made in the field. The land use requirements are first determined and outlined, as also the land utilization types. These first approximate descriptions and requirements guide the planning of the land unit surveys, described in Section 7, as to those factors of the land that should be surveyed. However, more detailed descriptions of the land utilization types and their requirements are drawn up at the same time as the land surveys are undertaken.

6.2 REQUIREMENTS FOR EXTENSIVE GRAZING

6.2.1 Introduction

For all extensive grazing land utilization types there are four sets of land use requirements to be given, related to:

- i. the growth and botanical composition of the forage at the primary level of production;
- ii. the requirements of the livestock at the secondary level of production;
- iii. the conditions necessary for both rangeland and livestock to be managed successfully;
- iv. the requirements for conserving the land through maintenance of a sustainable grazing system.

In the subsequent steps of the land evaluation process these sets of land use requirements are used in different combinations as the land utilization types to which they refer are developed.

They are also closely related to the land use requirements of other major land uses, particularly that of rainfed agriculture. The forage for livestock consumption is grown under rainfed conditions and can broadly be classed as a perennial crop producing yields of a certain quality and quantity. The rangeland must be managed and conserved in the manner of rainfed cropland, to ensure sustainable production. What is different is that extensive grazing involves the two successive levels of production; the primary level producing grazing, supporting the secondary level producing livestock and their products. For this reason the land use requirements for extensive grazing must be grouped according to these two production levels, and where applicable under both the requirements for growth, management and conservation should be given.

Table 6.1 is a summary of the land use requirements for extensive grazing, divided into those for primary and secondary production.

Table 6.1 REQUIREMENTS AND LIMITATIONS OF LAND
UTILIZATION TYPES FOR EXTENSIVE GRAZING

I. **Primary Production Level**

a. Growth requirements

1. Radiation
2. Temperature
3. Moisture
4. Aeration (soil drainage)

5. Nutrients
6. Rooting conditions
7. Salinity/sodicity
8. Soil toxicities
9. Hazards - fire
10. flood
11. frost
12. Genetic potential of vegetation

b. Management requirements

13. Ease of control of undesirable plant species
14. Mechanized operations
15. Size of potential management units

c. Conservation requirements

16. Tolerance to soil erosion
17. Tolerance to vegetation degradation

II. Secondary Production Level

d. Growth requirements

18. Grazing capacity
19. Drinking water availability
20. Biological hazards
21. Climatic limitations
22. Accessibility for animals
23. Conditions for hay and silage

e. Management requirements

24. Ease of fencing or hedging
25. Location

Not all the requirements listed in Table 6.1 will be relevant to a specific evaluation. Those given here cover all conditions of extensive grazing and all environments in which it is found, and only a selection of requirements may be chosen from this table for the assessment of land suitability.

6.2.2 Factor Ratings

For each land use requirement of a land utilization type factor ratings are needed before matching can be undertaken. A factor rating is a set of critical values of land conditions, which shows how well a land use requirement would be satisfied by the corresponding land quality or land characteristic, the diagnostic factor, as defined in Section 2.2. For example, the forage growth requirement of nutrient availability for a transhumant

cattle land utilization type could simply be expressed as the required percentage of nitrogen in the fodder. If the percentage is 1.0 or above, this critical value could be given a high rating; a percentage of below 0.5 could correspond to a low rating, and between these two percentages the rating could be classed as moderate. The set of these values is the factor rating of the nitrogen required in the fodder for the land use of cattle being reared by transhumant pastoralism.

Factor ratings vary between land utilization types, and between forage and livestock species within a land utilization type. Hence any factor rating that is given in an evaluation for extensive grazing must refer to a specific land utilization type, and to the effects on one land utilization type of one diagnostic factor, whether that factor be a land quality, a land characteristic or a function of several land characteristics.

A factor rating is usually given in terms of four classes with critical values attached to each, as for example:

- s1 highly suitable
- s2 moderately suitable
- s3 marginally suitable
- n not suitable

The abbreviations of the classes of a factor rating are given with lower case letters, s1, n, etc., to distinguish them from the upper case letters, S1, N, etc., given for the classes of the final land suitability rating at the completion of the evaluation.

Just as a factor rating shows how well a land use condition is to be satisfied by particular conditions of a diagnostic factor of the land, so the method of its assessment also links land with land use through the assigning of critical values to each class. The choice of what critical values to give to each class in a factor rating may be made by either of the following two methods, which involve the use of inputs and outputs.

- i. It may be in terms of the inputs required to avoid any reduction in yields or products below those that are optimum.
- ii. It may be in terms of the reduction in outputs that will be caused by a deficiency of the requirement that is being considered.

Whichever method is employed, the objective is that the critical values for each factor rating of each land use requirement should indicate comparable reductions in outputs or amounts of inputs needed. For example, consider that a land use requirement of rooting conditions for forage growth is given a factor rating in terms of soil depth with the following critical values for each of four classes:

- s1 = >100 cm
- s2 = 50-100 cm
- s3 = 25-50 cm
- n = <25 cm

Also, that another land use requirement of drinking water availability for smallstock in the same land utilization type has a factor rating in terms of daily intake in litres per hectare, with the following critical values:

- s1 = >5 l
- s2 = 4-5 l
- s3 = 2-4 l
- n = <2 l

Then the critical values given for comparable classes in both of these factor ratings should result in a comparable yield reduction or a comparable amount of required inputs. Similarly, the factor ratings of each land use requirement in a land utilization type should be given critical values that correspond to comparable yield reductions or required inputs. Only by following this procedure can changes in the suitability of different conditions of the land be directly and quantitatively related to one another, in terms of comparable changes in the yields of the land uses. Table 6.2 is a guideline of how critical values of factor ratings should be chosen so that this condition is met.

Table 6.2 GUIDELINES FOR THE DEFINITION OF CLASSES OF A FACTOR RATING IN TERMS OF INPUTS REQUIRED AND OUTPUTS ACHIEVED (applicable to a low input subsistence level extensive grazing system)

Factor rating class	Definition in terms of inputs necessary <u>1/</u>	Definition in terms of outputs expected <u>2/</u>
s1 highly suitable	None	More than 80 percent
s2 moderately suitable	Inputs needed, which are likely to be both practicable and economic	40-80 percent
s3 marginally suitable	Inputs needed, which are practicable but only economic under favourable conditions	20-40 percent
n not suitable	Limitation can rarely or never be overcome by inputs or management practices	Less than 20 percent

1/ In terms of inputs the classes are defined by those inputs or management practices that are necessary to achieve yields of 80 percent of those under optimal conditions, and are specific to the land use requirement being considered.

2/ In terms of yields the classes are defined as a percentage of the yields of livestock products expected under optimal conditions, in the absence of inputs specific to the land use requirement considered.

Table 6.2 illustrates the inputs and yields of an extensive grazing system. However the quality of the grazing is a third and important factor that influences the overall suitability at the primary production level. Poorer quality forage has a significant impact on the output of livestock products, whatever its quantity. The difficulty is that the classes of factor ratings cannot so readily be defined in terms of known changes in overall grazing quality.

Nitrogen and phosphorus contents in the forage give an indication of its quality and may be used as an approximate guide. From field studies and experimental work on N and P contents in plants the critical values of classes for factor ratings of forage quality could be those that result in known reductions in yields from livestock that graze on that forage. As the N and P content is reduced, the forage quality deteriorates and the resulting yields of livestock products fall. This method links quality at the primary production level with yields at the secondary production level.

A suggested format for the layout of factor ratings for different land use requirements is given in Table 6.3. In this example only four land use requirements are given, in terms of four land characteristics.

Table 6.3 SAMPLE FORMAT FOR RATING OF LAND USE REQUIREMENTS

Land utilization type: Sedentary pastoralism with zebu cattle

LAND USE REQUIREMENT	LAND CHARACTERISTIC	FACTOR RATING			
		s1	s2	s3	n
Nutrient availability	%N in fodder	>1	0.8-1	0.5-0.7	<0.7
Drinking water avail.	Distance to water (km)	<2	2-5	6-9	>10
Biological hazards	Tsetse risk	none	slight-moderate	moderate-severe	severe
Climatic limitations	Daytime temperatures (C)	15-20	20-30	30-40	>40

7. LAND

7.1 INTRODUCTION

Land consists of the natural resources of climate, rocks, landforms, soils, plants, water, animals, and the results of land use. It is matched with the latter to obtain ratings of land suitability. Its resources must be rationally surveyed and their characteristics recorded, and the two main functions of natural resources surveys are:

- i. to divide the study area into a number of relatively homogeneous land units, with their boundaries mapped; and
- ii. to provide the necessary information about each of these units so that they can be evaluated for their suitability for the kinds of extensive grazing being considered.

When completed, the basic division of the study area into land units is shown on the main map of the land evaluation, drawn at the largest mapping scale being employed. All the subsequent boundaries between areas with different land suitability classes are derived from this map. The information about the composition of the land units is presented in the form of land qualities, which affect land uses in specific ways. These qualities are described in terms of a large number of land characteristics that can be measured or estimated. For extensive grazing the most important resource to be surveyed and measured is the vegetation that is exploited for livestock and wildlife production.

Land resources surveys should be directed towards obtaining specific information needed to compare the land qualities with the requirements of the land use within the study area, and are not to be undertaken in isolation from the remainder of the land evaluation, but as an integral part of it. This does not preclude information about the land being derived in part from pre-existing surveys or using published data pertinent to the study in hand.

7.2 APPROACHES TO LAND UNIT SURVEYS

At the commencement of the survey the type of land units to be mapped and described must be decided. Whereas the descriptions of land uses are refined as the evaluation progresses, once the decision on the type of land units to be mapped and described has been made it is fixed, because the land qualities and values of land characteristics on which they are based are essentially fixed. What can change is the relative emphasis given to the examination of certain land qualities and characteristics as the land utilization type descriptions and land use requirements are modified.

Extensive grazing covers large areas of land, with low yields per unit area and low financial returns in comparison with most other land uses. With a typical income from extensive grazing being only US \$2.5/ha/yr (Cossins 1985), the high costs of a detailed survey cannot be offset by any subsequent increases in income from improved land uses. The costs per unit area of a land resource survey and land evaluation for extensive grazing

have to be kept much lower than that for surveying an area suitable for rainfed or irrigated cropping.

The scale and intensity of this major land use usually warrant surveys at reconnaissance level only, providing base data on which land units that are broad in scope are mapped. Land systems, which are employed as the basic units in integrated land resources surveys, are often applicable units to use, for reasons of cost and scale. These integrate the three main components of the land; landforms, soils and vegetation, through mapping of areas or systems within which they do not differ by more than specified amounts.

A classical land system survey based on landforms, soils and vegetation is not however the only type of survey that can be used to map land units. Within grazing vegetation there are many variables that can alter the boundaries of land units, and which therefore require to be included in a survey. Burning, for example, can produce very different grasses over many different soil and landform types. Land unit maps may be derived in part from surveys of the extent and frequency of vegetation burning.

The mapping of land systems also requires the collection and analysis of biophysical and socio-economic data, and the collaboration of scientists from a number of disciplines. Well-developed resources surveys require background information, analysis of satellite imagery, interpretation of aerial photography, field work, laboratory analysis of soil and plant samples, and the compilation of maps and reports. Mapping is at a small scale, commonly 1:250 000 to 1:500 000, with satellite imagery interpretation being successfully used, as for example in Botswana (DHV 1980; Gils 1981), in Greece (Vasakis *et al.* 1982), in Zimbabwe (Kappeyne 1985), in Sudan (Yath 1984; Yath and Gils 1986; Bakkit 1986), in Zambia (Mulungushi 1986) and elsewhere (RSC 1983).

Series of resources surveys have been published in Australia by CSIRO (e.g. Christian *et al.* 1952; Perry 1962; Storey *et al.* 1963; Christian and Stewart 1968; Gunn and Nix 1977) and in the U.K. by the Directorate of Overseas Surveys (e.g. Bawden and Tuley 1966; Bawden and Carroll 1968; Astle *et al.* 1969; Verboom and Brunt 1970; Makin *et al.* 1976; Hill 1979a and 1979b). There is, however, no manual on the methods and techniques employed in integrated surveys, although there are textbooks examining the concepts involved (e.g. Zonneveld 1972; Vink 1983).

The scale and intensity of the basic resources survey for extensive grazing controls the degree of detail of the subsequent matching of those resources with land use requirements. There is no practical method of obtaining a high level of precision for small areas of land in the description of soils and vegetation in reconnaissance surveys. What is provided is a synoptic overview of large areas; management units of the order of tens to hundreds of square kilometres in size are commonplace, and the land units should each be of comparable size.

Only when a land evaluation for extensive grazing is commissioned with the objective of changing land use from rangeland to cropland, and the evaluation has to be undertaken for rainfed crops as well as for forage, should the level of detail of the survey be increased. The additional time and costs incurred can be justified by the financial returns that will be gained from cropping.

In this case the survey should be at semi-detailed level, making use of aerial photography at a medium scale of about 1:50 000 and involving more intensive field work. The land units will tend to be smaller and with fewer inclusions, and the mapping legend will be more precise than that prepared at reconnaissance level. These factors, although lengthening the time of the survey and increasing its cost, facilitate quantitative interpretations of the land evaluation. Reconnaissance level surveys require a considerable amount of subjective judgement in the mapping of broad land systems, whereas more objectivity is secured as the mapping scale and level of detail increase in a survey.

7.3 VEGETATION SURVEYS

Whatever the level and scale of the natural resources survey, it must have a specific emphasis on the rangeland and the natural vegetation and the livestock that graze there. As with surveys of land suitable for cropping, the climate, landforms and soils are surveyed for extensive grazing, and land units based on the land system approach are mapped. However, specific natural vegetation surveys are required, as the vegetation and the animals now become the central features of the survey, and different hazards, such as fires and floods, gain increasing prominence (Yath and Gils 1986).

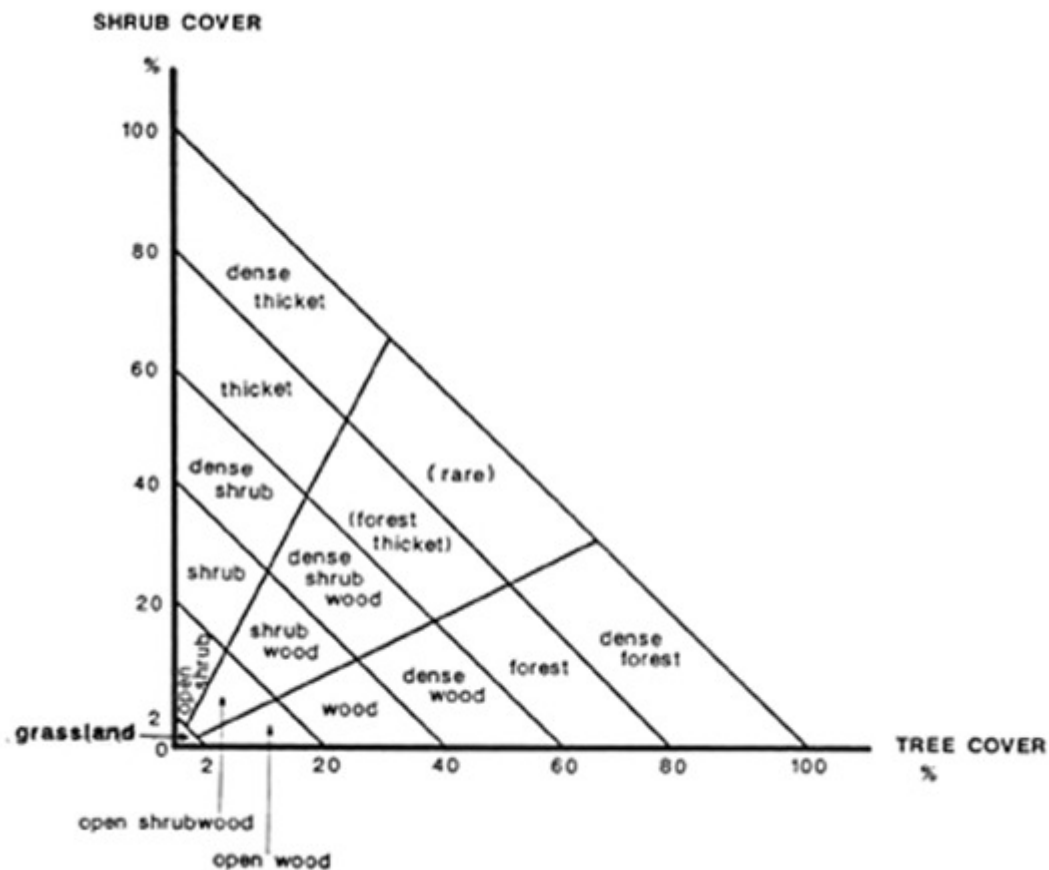


Figure 7.1

Example of classification key for data on vegetation structure (adapted from Gils and Wijngaarden 1984)

The methodology for including vegetation surveys within integrated surveys is outlined by Zonneveld *et al.* (1979) and Gils and Wijngaarden (1984). The vegetation is characterized by its structure as revealed on aerial photographs and from field sampling, and by its botanical composition, also as examined in the field. The vegetation structure includes the height and extent of cover or, if the cover is below about 5 percent, the density. It must be explicitly stated if the cover refers to the aerial or basal cover of the ground by the vegetation, as the latter is the more important parameter used in prediction of soil loss by accelerated erosion caused by rainfall. Figure 7.1 is an illustration of a systematic method of classifying data on vegetation structure by means of its cover.

Vegetation surveys requiring the full botanical composition of each vegetation type are normally too time-consuming in evaluations for extensive grazing. Therefore, only those plant species whose cover or density is above a certain threshold, for example above 5 percent for grass species, should be recorded. This threshold is set for each survey by the local conditions observed, and by those indicated by pastoralists, herders and ranchers as being desirable for livestock.

This data cannot usually be classified taxonomically as soil profile data can. However, to supply lists of plant species on maps and in reports is not an acceptable alternative, as the possible association or mutual exclusiveness of plant species and their relative importance cannot then be derived. Consequently, the surface area of each vegetation type is not known and the grazing capacity of each land unit cannot be calculated correctly.

The vegetation data should, instead, be classified into vegetation types; either by manual means, following the phytosociological approach of Braun-Blanquet (1972), or with automated methods using a computer program such as TABORD or MAINFLEX (Maarel *et al.* 1978) or TWINSPAN (Hill 1979). An example of such a vegetation classification is given in Table 7.1.

As well as assisting with the definition of the land units, surveys of the botanical composition of the vegetation serve to stratify production measurements and to assess important plant characteristics such as the life form (perennial or annual), the carbohydrate assimilation type (C3 or C4), the legume subfamily (nitrogen fixing or not), the grass quality in the dry season (sweet grasses or sour grasses), the growth form and the germination strategy (Gils 1984; Breman *et al.* 1984).

Field measurements of the structure of the forage standing crop should be taken separately for the herbage and the browse at the beginning of the survey. The structure can be estimated subsequently during the evaluation, provided sufficient training in accurate methods of estimation have been obtained during the initial measurements.

Vegetation samples for growth measurements and chemical analysis should also be harvested separately. The height at which herbage is harvested varies with the livestock types that graze it. For example, in ***Lolium perenne*** pastures it is 4-5 cm above ground if grazing is by cattle, and 0-2 cm if by sheep. Browse is harvested by clipping the shoots produced in the current year at the end of the growing season.

Table 7.1

ABUNDANCE OR COVER (PARTS PER TEN) OF SPECIES IN 24 VEGETATION SAMPLE PLOTS FROM SANTO ANTAO (CAPE VERDE), CLASSIFIED INTO FIVE VEGETATION TYPES (Gils 1988)

Sample plot serial number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
Vegetation type	1	1	2	2	2	2	2	2	2	3	3	3	3	3	4	4	4	4	4	5	5	5	5	5	
Lithology ^{1/}	Po	Py	Py	Py	Py	Py	B	Py	B	B	Py	B	Py	Py	Py	B	B	B	Py	Py	B	Py	B	Ph	B
Land use (actual) ^{2/}	p	p	a	a	p	p	a	a	p	p	a	p	p	p	p	p	p	c	c	e	p	p	p	p	
Slope in degrees	10	20	-	30	20	10	20	30	20	45	30	30	45	40	10	10	30	30	7	20	45	45	30	20	
Exposure	N	N	-	SE	SE	SE	S	S	S	SW	SE	W	NE	NE	N	NW	SW	SW	S	NE	SE	W	W	SW	
Altitude in 100 m	16	16	12	12	7	10	11	13	16	13	11	14	14	13	14	13	14	14	12	12	15	14	13	12	
Rockiness + stoniness in 10%	-	4	-	-			1	6	-	6	3	-	8	3	-	2	-	2	1	8	3	-	5	-	8
Plant species names ^{3/}	Abundance or cover ^{4/}																								
<i>Micromeria forbesii</i>				m	p	a		m	m	m	1		m		p	a	p	p							
<i>Trichodesma africana</i>			p	1			2	m	a	m	2	2		p											
<i>Tagetes patula</i>			2	p		a			m				m		a	a	p	p							
<i>Ajuagu iva</i>		p						p						p	p				p	p					
<i>Paronychia illecebroides</i>								r						m	m	m			r						
<i>Diploaxis sp.</i>			m	m				p	p			p	p												
<i>Lavandula stricta</i>				1			r	2		r	2														
<i>Lotus sp.</i>				r				p			p		r	p											
<i>Heliotropium ramosissimum</i>			1		p					p	p														
<i>Sterculiaceae sp.</i>					p										p	p									
<i>Periploca chevalieri</i>													r				r								
<i>Asteriscus vogelii</i>	m	5					r		a	m	(r)	p	p		p					r					
<i>Helianthemum gorgoneum</i>	m	m								m	p	p	p		2										
<i>Conyza feae/varia</i>	1										p	p	p	r								r	m		
<i>Lavandula rotundifolia</i>								p		m				p											
<i>Hyparrhenia hirta</i>	m								p	r		1	p		p	m	m	6	3	p	m	1	a	p	
<i>Heteropogon contortus</i>						r	r			r	r				p	m	5	1	2	1		1			
<i>Cynodon dactylon</i>					r	p		1				1			m		2	2		2	2	1	a	p	
<i>Rhynchelytrum spp.</i>								a			m	p	2						p	p	p	p	a		
<i>Artemisia gorgonum</i>										(r)	a	p	5		(r)	r	r	r		a	p	1			
<i>Euphorbia tuckeyana</i>						(r)								(r)								(r)	m		
<i>Lantana camara</i>						r											p	r	p	r	p	p	p	8	
<i>Echium stenosphon</i>																				p	p		m		
<i>Aristida sp.</i>																				p	p		m		
<i>Sonchus oleraceus</i>																					p	p	p		
<i>Nicotiana glauca</i>								(r)				r			(p)					p					
<i>Conyza bonariensis</i>			p				a			a	a											r	p		

1/ Lithology: Po = pozzolan; Py = pyroclast; B = basalt; Ph = phonolitic basalt.

2/ Land use : P = pastoralism: herding of milch goats; a = agropastoralism: rainfed cultivation rotated with grazing; e = tethered milch goats; c = conservation: tree plantation.

3/ Taxonomy following Rustan and Brochmann (1981).

4/ 1 = 5-15 %; 2 = 15-25 %; etc. For cover less than 5 %: r = rare; p = poor; m = many; a = abundant.

On some woody browse species identification of the current year's shoots is difficult, making browse harvesting lengthier than herbage harvesting. To circumvent this, browse growth need not be measured directly by harvesting. A regression analysis of browse growth versus other woody plant properties (e.g. shrub diameter, height, or crown volume below 1.5 m) can be carried out (Thalen 1979; Houérou 1983). After a regression curve has been produced the more easily measured characteristics, particularly shrub diameter, are sampled systematically.

For land units grazed throughout the growing season data are required on forage production, not on the forage standing crop. Since forage production cannot be measured for all vegetation types during a survey, a relationship between the standing crop growth and forage production should be determined for each land unit.

Herbage and browse samples for chemical analysis should be harvested throughout the grazing season. They are analysed at least for crude protein (CP) and phosphorus content, and preferably also for potassium, sodium, magnesium and other elements. Results of the analyses will permit forage deficiencies to be identified in specific land units, and feed supplements that may be required to be included in the descriptions of the land utilization types, as shown in the example in Table A.1 of Appendix A. Vegetation analyses may also direct attention to deficiencies in soil nutrients that affect forage production, as in Table A.2 of Appendix A.

A note of caution should be sounded about the reliance that can be placed on the correlation of vegetation survey results with livestock yields. The quantity and quality of both herbage and browse always show high spatial and temporal variability (Bille 1977), and samples taken on a specific date or even in a specific year cannot necessarily become reliable data bases for long-term grazing capacity estimations. Changes over seasons and years are especially noticeable in the semi-arid rangelands that form the bulk of the extensively grazed areas of the world. The high spatial variability similarly requires careful analysis, aided by considerable statistical work on sampling designs (Keulen and Wolf 1986).

7.4 LAND QUALITIES AND LAND CHARACTERISTICS

The requirements of specific land uses are compared with the properties of the land units mapped during the resources survey by means of land qualities and land characteristics. **Land qualities** are attributes of the land units that have distinct influences on their suitability for different land uses. They can be divided by their types of influence into three groups, reflecting growth, management and conservation, in a manner similar to the division of land use requirements. These influences affect both primary and secondary production levels of extensive grazing. Examples of land qualities are moisture regime, ease of control of undesirable plant species, erosion hazard under grazing conditions and drinking water availability. There are about 25 land qualities that can influence extensive grazing, though only about ten will significantly affect the land suitability rating.

It is the particular influence of each land quality on a given land use that distinguishes it as a distinct attribute. For example, the moisture regime of the land directly affects forage growth, but forage species have different water requirements, throughout the year and during growing seasons. The rooting conditions of the soil also affect forage growth, but by different means, since different species differ in their rooting depths, their ability to grow in different soil textures and structures, to penetrate self-sealing soil surfaces, etc., all features of the land connected with rooting conditions. However, the land qualities of moisture regime and rooting conditions, like other qualities, cannot directly be measured, as is necessary before they can be matched with land use requirements. They are determined by means of land characteristics.

Land characteristics are attributes of the land that are used in a land evaluation to measure or estimate land qualities. The land quality of moisture regime can, for example, be estimated to varying levels of precision by values of land characteristics including mean annual rainfall, mean rainfall for the growing season, potential evapotranspiration, depth to groundwater, soil effective depth and available soil water capacity. The land quality of rooting conditions can be estimated using land characteristics of soil depth, texture, structure and cementation. There are hundreds of land characteristics that determine how land qualities will influence primary and secondary production for extensive grazing.

7.4.1 Choice between Land Qualities and Land Characteristics

A land evaluation can be based on the use of land qualities, land characteristics or a combination of the two, as:

- i. land qualities measured or estimated by means of land characteristics; or
- ii. land qualities measured by means of land characteristics, mixed with land characteristics used directly; or
- iii. land characteristics used directly on their own.

A land evaluation should be based as much as possible on land qualities:

- i. since there are only about 25 land qualities that influence extensive grazing, it is relatively easy to ensure that all influences are taken into account;
- ii. by definition land qualities also take account of interactions between land characteristics;
- iii. land qualities directly relate to land use requirements, which is an advantage when developing models of the relationships between land use and land;
- iv. land qualities focus on ways by which specific areas of land affect the suitability for given uses;
- v. the same land quality may be estimated by using different land characteristics, depending on what data are collected.

The disadvantages of using land qualities are that they are more complex to handle, and impose an additional step in the land evaluation, as it is not possible to move directly from the measurement of land characteristics to matching of land with land use. If land characteristics are used on their own these disadvantages are overcome and the evaluation is simple and direct. However, there are several limitations, namely:

- i. there are a very large number of land characteristics;
- ii. it is often unclear what effect one land characteristic has on a land use, and therefore how it should be rated;

- iii. interactions between the variable diagnostic factors, that can be land characteristics, land qualities or functions of several land characteristics, are not taken into account.

In practice a land evaluation is often based on a mixture of land qualities, measured by means of land characteristics, and land characteristics used directly in the matching. This is because a number of land qualities can be measured by just one land characteristic, whereas others are complex and require several land characteristics for their measurement. For example, the land quality of flooding hazard in a floodplain that is grazed by transhumant pastoralists may be estimated by the number of days each year when the land is under a certain depth of water. The land quality of rooting conditions in broad reconnaissance surveys of nomadic pastures may be measured by the effective soil depth. Both these land qualities therefore require only one land characteristic by which they are measured or estimated. However, the land quality of erosion hazard under grazing conditions should take account of a number of factors including soil erodibility, rainfall erosivity, slope and present land use, each of which may require several land characteristics for their measurement.

7.4.2 Checklist of Land Qualities

A list of land qualities that may have an effect on the suitability of land for extensive grazing is given in Table 7.2. Land qualities are grouped here into those affecting growth, management and conservation, and are divided into those relating to the primary and the secondary production level. Many land qualities correspond to land use requirements, with corresponding terms used. For example, the land quality of nutrient availability corresponds to the land use requirement for nutrients to be available. Different land utilization types may have different nutrient requirements, and each land unit will possess different levels of nutrients.

In addition to these land qualities there is one other, that of grazing capacity, which is the result of many land qualities and is examined separately in Section 9 because of its importance.

In a land evaluation land qualities should be selected from the checklist in Table 7.2 in relation to:

- i. the land utilization types being considered;
- ii. the type of environment in which some form of extensive grazing is being proposed;
- iii. whether the land qualities have restricting effects on the use of the area.

Only those that are relevant to the land uses should be employed. Climatic limitations on livestock may be rejected as a land quality, for example, where camels are proposed for transhumance in a semi-arid area, or the conditions for hay and silage may not be used where there is no intention to process the forage. Similarly, fire susceptibility and flooding hazards are two land qualities requiring only selective use in humid tropical and arid areas respectively. If it is apparent that poor rooting conditions or an excess of salts are not to be found

in any land unit being surveyed in a region of loess, for instance, then these two land qualities need not be considered.

Table 7.2

LAND QUALITIES FOR EXTENSIVE GRAZING
(adapted from Young and Gils 1984)

I. Primary Production Level

a. Land Qualities affecting Growth

1. Radiation regime
2. Temperature regime
3. Moisture regime
4. Oxygen availability to roots
5. Nutrient availability
6. Rooting conditions
7. Salinity/sodicity
8. Soil toxicities
9. Fire hazard
10. Flood hazard
11. Frost hazard
12. Genetic potential of vegetation

b. Land Qualities affecting Management

13. Ease of control of undesirable plant species
14. Potential for mechanization
15. Size of potential management units

c. Land Qualities affecting Conservation

16. Erosion hazard under grazing conditions
17. Tolerance to vegetation degradation

II. Secondary Production Level

d. Land Qualities affecting Growth

18. Availability of drinking water
19. Biological hazards
20. Climatic limitations
21. Accessibility for animals
22. Conditions for hay and silage

e. Land Qualities affecting Management

23. Ease of fencing or hedging
24. Location

Having rejected those land qualities that are not relevant or significant for the land evaluation, those remaining are measured or estimated by means of land characteristics. Some land qualities will be more relevant than others when matching them with land use requirements. Important qualities and limitations will be those that have a large effect on the land use, such as moisture regime, erosion hazard under grazing conditions and the availability of drinking water; or those for which critical values occur in the survey area, having a substantial effect on the land use. Examples may be nutrient availability in a region of infertile soils, and extreme remoteness and inaccessibility.

Land evaluations so far have used land qualities mostly at the secondary production level. Michieka and Braun (1977) and Amuyunzu (1984) have also used land qualities at the primary production level. Details are given in Section 8 of the nature and effects of land qualities used in evaluations for extensive grazing, and methods of their assessment.

7.4.3 Checklist of Land Characteristics

Table 7.3 is a list of land characteristics that could affect the suitability of the land for extensive grazing growth, management or conservation. They are grouped according to major divisions of the land. Some characteristics will provide for only indirect estimates of land qualities to which they relate, as they themselves represent compilations of numerous characteristics; e.g., climatic class, landform class, soil type. The list is not exhaustive, but should provide an adequate check when lists are being drawn up in an evaluation.

Table 7.3 **LAND CHARACTERISTICS THAT MAY BE USED
TO ASSESS LAND QUALITIES**

a. Characteristics of Climate

Total radiation, day length, sunshine hours. Mean annual temperature, mean temperature in growing season, temperatures of hottest and coldest months, extreme temperatures, frost incidence, frost-free period. Mean annual rainfall, mean rainfall in growing season, rainfall variability, rainfall intensity, relative humidity, moisture surplus or deficit. Length of growing season(s), length of dry season, incidence of dry periods. Evaporation, actual and potential evapotranspiration. Relative humidity. Wind speeds. Climatic class.

b. Characteristics of Landforms

Altitude, aspect, slope angle, slope length, relative relief, stream frequency. Rock outcrops, landslide occurrence. Landform class.

c. Characteristics of Soils

Effective soil depth, depth to impermeable layer. Texture, structure, consistence. Occurrences of crusting, pans, laterite horizon. Soil drainage, colour, depth to

mottling, permeability, infiltration rate, available water capacity. Nutrient content, organic matter content, pH, base saturation, nitrogen, 'available' phosphorus, total nutrients, electrical conductivity of saturation extract, total soluble salts, exchangeable sodium percentage, sodium absorption ratio, presence of toxic substances. Soil temperature regime, soil moisture regime, diagnostic horizons, soil type.

d. Characteristics of Vegetation

Vegetation communities, species. Structure, plant aerial cover, basal cover, diameter, height, crown volume, density. Botanical composition, life form, carbohydrate assimilation type, palatability, legume subfamily, growth form, germination strategy, crude protein content, phosphorus content. Combustibility of ground vegetation. Floristic type, genetic diversity.

e. Characteristics of Hydrology

River flow regime, flood frequency, periods of waterlogging, periods of inundation. Groundwater hydrology, groundwater depth, water quality, presence of aquifers.

f. Characteristics of Fauna and Disease

Wild animals. Insect pests, plant diseases.

g. Characteristic of Location

Accessibility.

Table 7.4 combines the land qualities affecting growth, management and conservation, and the land characteristics. It is also a checklist of those characteristics that may be used to measure or estimate each of the land qualities in turn. Which characteristics are used will depend on which can practicably be measured or estimated, and which best represent the land quality to which they refer. When they are costly, time-consuming or difficult to measure, particularly if laboratory analyses of soil or plant samples are required, it may be more practicable to obtain values of different characteristics that are easily measured in the field, although they relate less precisely to a land quality.

For example, a full assessment of drinking water availability will examine all possible sources, present and future, above and below ground, measuring quantities and qualities and calculating required yields under different stocking rates at different seasons for different species, whose watering requirements all differ. On the other hand, a rapid assessment for reconnaissance surveys of areas where groundwater is used may take the water abstraction rates from boreholes to provide an estimate of available water.

Table 7.4 **LAND QUALITIES AND LAND CHARACTERISTICS
BY WHICH THEY ARE MEASURED OR ESTIMATED**

I. Primary Production Level

<u>Land Qualities affecting Growth</u>	<u>Land Characteristics</u>
1. Radiation regime	Total radiation, sunshine hours, slope angle, aspect, climatic class.
2. Temperature regime	Mean annual temperature, mean temperature in growing season, temperatures of hottest and coldest month, extreme temperatures, soil temperature, climatic class, altitude.
3. Moisture regime	Actual and potential evapotranspiration, mean annual rainfall, mean rainfall in growing season, moisture surplus or deficit, soil moisture regime.
4. Oxygen availability to roots	Soil drainage class, depth to mottling, permeability, infiltration rate, vegetation indicators (by communities and species), periods of waterlogging, periods of inundation.
5. Nutrient availability	Soil pH, total exchangeable bases, base saturation, nitrogen, 'available' phosphorus, exchangeable potassium, other nutrients, total nutrients, topsoil thickness, diagnostic horizons, soil type.
6. Rooting conditions	Soil texture, structure, consistence, effective depth, stones and gravel, rock outcrops, crusting, pans, surface sealing, diagnostic horizons, soil type, vegetation indicators.
7. Salinity/sodicity	Electrical conductivity of saturation extract, total soluble salts, exchangeable sodium percentage, soil type, vegetation indicators.
8. Soil toxicities	Presence of excess aluminium, calcium carbonate, gypsum, other observed toxic substances, acid sulphate hazard, soil pH, soil type.
9. Fire hazard	Observed frequency and severity, length of dry season, rainfall, combustibility of ground vegetation, vegetation indicators.
10. Flood hazard	Flood frequency, discharge, topographical location.

- | | |
|---|---|
| 11. Frost hazard | Frost incidence, length of frost period, altitude, aspect. |
| 12. Genetic potential of vegetation | 'Available' phosphorus, vegetation indicators, leaf/stem ratio, stoloniferous growth form, palatability. |
| b. <u>Land Qualities affecting Management</u> | <u>Land Characteristics</u> |
| 13. Ease of control of undesirable plants | Vegetation indicators of unpalatable and poisonous plants; their percentage cover, type of dispersal, speed of dispersal. |
| 14. Potential for mechanization | Slope angle, slope length, rock outcrops and boulders, drainage density, landform class. |
| 15. Size of potential land management units | Sizes of blocks suitable for extensive grazing. |

c. Land Qualities affecting Conservation

Land Characteristics

- | | |
|---|---|
| 16. Erosion hazard | Rainfall intensity, erosivity, slope angle, slope length, soil texture, permeability, erodibility, vegetation cover, indices of water erosion, landslide occurrence, soil type, estimated soil loss, t/ha/yr. |
| 17. Tolerance to vegetation degradation | Present condition of vegetation, vegetation type, observed or estimated vegetation. |

II. Secondary Production Level

d. Land Qualities affecting Growth

Land Characteristics

- | | |
|------------------------------------|---|
| 18. Availability of drinking water | Moisture surplus or deficit, rainfall variability, presence of surface water sources, stream frequency, river flow regime, groundwater hydrology, ground-water depth, presence of aquifers, available drinking water quality. |
| 19. Biological hazards | Observed incidence of harmful plants, diseases and disease vectors, ticks, tsetse flies, competing herbivorous wildlife, predators. |
| 20. Climatic limitations | Total radiation, solar radiation, sunshine hours, extreme high and low temperatures, frost incidence, relative humidity, wind speed. |

21. Accessibility to animals Altitude, slope angle, stones and rock outcrops, vegetation density, presence of thickets, flooding frequency, severity, landform class.
22. Conditions for hay or silage Rainfall variability, moisture surplus, relative humidity, wind speed, botanical composition, carbohydrate assimilation type, floristic type of vegetation.

e. Land Qualities affecting Management

Land Characteristics

23. Ease of fencing and hedging Soil depth, surface stones and rock outcrops, flooding frequency, presence of termites, large game species.
24. Location Existing and potential accessibility, slope angle, drainage density, relative relief, distances from roads, presence of markets and distances to population centres.

8. LAND QUALITIES AND THEIR ASSESSMENT

8.1 INTRODUCTION

This Section provides details of the nature and effects of the land qualities listed in Section 7, and the methods used in their assessment. The land qualities are grouped according to production levels (Young and Gils 1984; Wijngaarden 1984; Zonneveld 1984), as shown in the summary list in Table 7.4. Forage production is the first, or primary production level, which groups land qualities affecting the growth, management and conservation of forage. The secondary production level groups land qualities relating to forage and water availability, and hazards faced by livestock.

The nature and effect of each land quality discusses the conditions of the land that contribute to it, and its effects on extensive grazing land utilization types. The land characteristics used in the measurement or estimation are then examined, as the means of assessing the land quality. This thorough review facilitates matching of the land with land use, as described in Section 10. The assessment of each land quality should be read in conjunction with Table 7.4, which relates land qualities with land characteristics by which they can be measured.

The physical characteristics of the land, however important, can be and often are secondary to the effect of management practices. Well-managed but poor-quality land may carry more stock on a sustainable basis than poorly-managed but better-quality land. The influence of management on extensive grazing systems, through social and economic inputs as detailed in Section 5, must be considered in parallel with those of the physical environment.

The grazing capacity of extensively grazed land is a result of many of the land qualities listed in Section 7. On account of its overriding importance in land evaluation for extensive grazing, it is listed and discussed separately in Section 9, after the remaining qualities have been examined.

8.2 LAND QUALITIES AT THE PRIMARY PRODUCTION LEVEL

8.2.1 Land Qualities affecting Growth

1. Radiation Regime

Nature and Effects

There is a direct relationship between the amount of solar radiation and the growth response by forage plants, up to a certain limit. A higher limit to the rate of growth in response to solar radiation is reached by C4 than by C3 plants, but below the natural limits for plants all are affected by a deficiency in radiation. C3 plants are so named because a compound containing three atoms of carbon is the first product of carbon dioxide fixation as these plants photosynthesize. In C4 plants a 4-carbon compound is produced at this stage instead (Raven, Evert and Eichhorn 1986).

Radiation deficiency is caused by cloudiness, slope aspect and, for grazing species, by density of overcover of browse species.

Assessment

The easiest method of assessing total radiation is by the land characteristic of the average number of hours per day of sunshine during the growing season. The suitability of areas which receive little sunshine due to slope aspect and steepness or vegetation cover, should be downgraded. Radiation received at ground level is the total received at the top of the earth's atmosphere, which is obtainable from meteorological tables for any latitude, reduced by the number of daylight hours when the sky is cloud-covered.

2. Temperature Regime

Nature and Effects

There is a minimum temperature for plants, for many about 6.5°C, below which they will not grow, and an optimum temperature for photosynthesis. Between these two temperatures their rates of growth rise as the temperature rises. Very high temperatures, typically above 30-35°C, adversely effect growth. Maximum growth occurs when the temperature is optimum and there is a high amount of radiation.

In temperate climates the temperature regime is an important land quality affecting forage species. During the winter, spring and autumn, temperatures are below either those required for any growth or for optimum growth. During these seasons slope aspect can also considerably affect temperature and growth rates.

Forage species are divided into four adaptability groups on the basis of:

- i. their photosynthetic response to radiation and temperature; and
- ii. their photosynthetic carbon assimilation pathway (C3 or C4).

Table 8.1 provides a list of the photosynthetic pathways and adaptability groups of a some common forage species. The ranges of mean annual temperatures that are optimum for photosynthesis for extensive grazing species are approximately:

Adaptability Group I	15-20°C
Adaptability Group II	25-30°C
Adaptability Group III	30-35°C
Adaptability Group IV	20-30°C

Table 8.1 PHOTOSYNTHETIC PATHWAYS AND ADAPTABILITY GROUPS OF COMMON FORAGE SPECIES (after Kassam **et al.** 1989)

Photosynthetic Pathway C3: Adaptability Group I

Medicago sativa (lucerne or alfalfa), **Trifolium spp.** (clover).

Photosynthetic Pathway C3: Adaptability Group II

Centrosema pubescens, **Desmodium spp.** (tick clover), **Lablab purpureus** (hyacinth bean), **Macroptilium atropurpureum** (siratiro), **Stylosanthes spp.** (Stylo), **Vigna spp.**

Photosynthetic Pathway C4: Adaptability Group III

Aristida spp., **Cenchrus ciliaris** (buffel grass), **Chloris gayana** (Rhodes grass), **Cymbopogon spp.**, **Cynodon dactylon** (star grass), **Digitaria spp.**, **Eragrostis superba**, **Hyparrhenia spp.** (zebra grass), **Panicum coloratum** (coloured Guinea grass), **Panicum maximum** (Guinea grass), **Pennisetum purpureum** (Napier grass), **Setaria splendida** (giant setaria), **Sorghum arundinaceum** (Sudan grass), **Sporobolus helvolus**, **Tripsacum laxum** (Guatemala grass).

Photosynthetic Pathway C4: Adaptability Group IV

Dactylis glomerata (cocksfoot), **Eleusine jaegeri**, **Exotheca abyssinica**, **Festuca spp.** (fescue grass), **Lolium spp.** (rye grass), **Pennisetum catabasis**, **Pennisetum clandestinum** (Kikuyu grass), **Pennisetum schimperi**, **Themeda triandra** (red oat grass).

Assessment

The most suitable land characteristics are the mean of the average monthly soil temperatures, and those for the coldest and hottest months during the growing season, or the equivalent air temperatures. Approximate mean temperatures can be calculated from altitude. If the mean monthly temperature is above or below the optimum temperatures given in Table 8.1, the suitability rating should be lowered.

3. Moisture Regime

Nature and Effects

This is one of the most important land qualities, as all plants are affected by moisture availability. Plants become stressed when soil water in the rooting zone falls well below field capacity and towards wilting point. The amounts of moisture that should be available for good growth and development of plants are however very different between natural vegetation for extensive grazing and crops. Whereas for planted crops the effects of moisture stress during growth can lead to their death through drought, natural pasture is better adapted to variable rainfall, surviving longer drought periods and making more efficient use of whatever moisture is available. Moisture stress may in fact be desirable during ripening of grass seeds, to improve their nutrient content. Hence a more accurate estimate of the effect of this land quality will be obtained from measurements taken throughout the growth cycle of forage grazing and browse crops, in order to focus attention on the varying moisture requirements during the cycle.

Assessment

Extensive grazing involves both grazing and browsing, and there are large differences in the abilities of different species to utilize available moisture. The total

moisture can be readily assessed using mean annual rainfall, mean rainfall during the growing season, or moisture surplus, which is the excess of rainfall over potential evapotranspiration. Drought hazard is common in extensive grazing, and should preferably be assessed separately for each species that has a separate rooting depth. A simple method of assessing drought hazard is taken from FAO 1984a, which estimates the amount of water available, the amount lost to extensive grazing, and the amount required before drought ensues:

- i. For each soil type present estimate the total available soil moisture storage within the rooting zone.
- ii. Estimate the rate of potential evapotranspiration, as the rate of soil moisture depletion in the absence of rainfall.
- iii. For each grazing species, or groups of grazing species where approximate estimates are adequate in a reconnaissance survey, estimate:
 - a. the rooting depth;
 - b. length of time it can survive without moisture.
- iv. By combining steps i and ii, followed by step iii, obtain the period without rainfall after which a drought hazard will occur to the grazing species.

4. Oxygen Availability to Roots

Nature and Effects

Since oxygen is practically unavailable in soil that is waterlogged for lengthy periods, poor soil drainage has the greatest single effect on oxygen availability to plant roots. The effects on growth retardation due to a low oxygen content in the soil are more damaging the longer the soil is saturated, with most species surviving short periods of flooding but few where stagnant water lies for any length of time. Hence this land quality must be considered wherever there are poorly drained valley floors or other areas of impermeable soil.

Assessment

This quality is expressed through measurements or estimates of rainfall totals, landforms, hydrological conditions, soil and vegetation indicators. Inferences of poor drainage can be obtained by remote sensing in areas of natural vegetation, by mapping from satellite images, or aerial photographs of those vegetation associations that are more tolerant of poorly drained soils. Assessment is most readily carried out in the field by studying soil drainage classes in conjunction with vegetation surveys. Drainage classes are assessed by measuring soil colour, soil mottling, periods of water saturation and groundwater levels over different periods of the year and, preferably, over different years.

5. Nutrient Availability

Nature and Effects

Since extensive grazing utilizes rangelands that are normally unimproved by fertilizers, the availability of nutrients in the soil is of great importance in assessing forage growth. Nitrogen and 'available' phosphorus are the most significant nutrients required by forage species and livestock grazing them. Low inherent nutrient availability may not have serious effects on the quantity of growth of forage, but on the quality available for secondary production.

The nutrients that are available for plant growth depend on the total amounts that are available and are not fixed within the soil, and on the capacity of the soil and the vegetation to restore nutrients removed through grazing.

Assessment

Measurement of the soil nutrient content is the simplest and most usual method of assessing nutrient availability. Major N, P and K nutrient contents are usually included in routine soil analyses in resources surveys, and information can be abstracted directly from them. In reconnaissance surveys of rangelands, vegetation indicators as mapped by remote sensing can provide a rapid method of assessing nutrient availability. Once the relationships between species composition and vegetation patterns have been established, use can be made of the fact that there is often a close correlation between vegetation patterns and nutrient availability in areas that are not overgrazed.

6. Rooting Conditions

Nature and Effects

The roots of a plant extract moisture and nutrients from the soil, ensure the plant is retained in the soil under grazing pressure, and encourage adequate above-ground growth when the volume of root development is sufficient. Inadequate rooting conditions occur when the soil is too shallow, stoney, coarse-structured or with a very firm consistence that hinders root penetration.

Assessment

Effective soil depth is the most important, and often the only land characteristic used in assessing this land quality. The presence of a hardpan, surface sealing or cementation in the profile, which limit but do not prevent root growth, can also be used to assess less suitable soils. A measured or estimated percentage content of stones and gravel above a minimum will also downgrade the soil suitability for root penetration.

7. Salinity and sodicity

Nature and Effects

This land quality can limit growth when there is an excess of free salts in the soil or the exchange complex is saturated with sodium ions. It is relatively common where

extensive grazing occurs, especially in depressions under a semi-arid climate, where water, which has run off higher ground and contains dissolved salts, collects, evaporates and leaves increasingly saline or sodic soils. It is also found in all climates where there is brackish water, which does not permit the land to be used for cropping but is adequate for some forms of grazing.

Assessment

There is a considerable range of tolerance by different species to this limitation of the land, and for an accurate assessment the tolerance of each main grazing species should be determined. Salinity may be assessed by measuring the electrical conductivity in mS/cm of a saturation extract, or the total soluble salts from soil samples taken within the rooting depth. Sodicity is assessed by measuring the exchangeable sodium percentage or the sodium absorption ratio.

8. Soil Toxicities

Nature and Effects

A wide variety of toxic substances may be present in the soil, though rarely will more than one be found at a site. They include gypsum, calcium carbonate, manganese, aluminium and acid sulphate, which reduce yields and leave toxicities in the plants to be grazed by the livestock. Very small amounts of some substances that are normally toxic are essential for good plant growth, but excesses can cause poisoning to livestock, as discussed under land quality 20.

Assessment

Each kind of toxicity has to be assessed by separate analytical methods, and when soil toxicity is suspected the appropriate soil and plant analyses should be undertaken as described by Young (1976) and Dent (1985).

One of the more common toxicities found in poorly drained areas which may be otherwise suitable for extensive grazing, is linked with potentially acid sulphate soils. These are assessed by soil colour, smell of hydrogen sulphide, organic matter content, and a pH that is low and falls to below 3.0 if the land is drained. Such a low pH effectively kills many forage species, and the condition is not readily reversed merely by flooding the land once more.

9. Fire hazard

Nature and Effects

Fires in rangelands may be started accidentally by lightning, especially in the tropics at the beginning of a rainy season. Many, however, are started deliberately by pastoralists, in order to burn large amounts of low-quality dry matter and encourage the growth of new, green and highly digestible grasses. Burning may also be used to control tsetse and ticks, to drive game animals into the open and to clear bush prior to cultivation. In order for a fire to

spread there should be a low relative humidity, steady wind blowing and an adequate supply, about 1 000 kg/dry matter/ha, of dry, combustible material.

According to DHV (1980) the effect fires will have on rangeland depends on the season, the fire-grazing interaction, the structure of the vegetation, the frequency of occurrence of fires, and whether they are back or head fires, burning at low or high intensity. Fire is a hazard when it burns sweet or dry C3 grasses that contain sufficient crude protein to be digestible forage. Repeated burning followed by overgrazing also reduces the vigour of perennial grasses and causes major nitrogen losses from the plant-soil system. Only in some floodplains do fires appear to have no degrading effects on the rangeland.

Fire often has a complex effect on the vegetation, influencing the balance between grasses and woody plants. For example, fires in Spanish rangelands bordering the Mediterranean result in woody **Cistus spp.** increasing at the expense of grasses, because of differences in their susceptibility to fires at different seasons. In savanna areas early dry season fires burn the grasses but less so the trees, and regular late dry season burning at the time of tree bud flush leads to a decrease in the woody component and an increase in the grasses.

Assessment

This quality is expressed by vegetation indicators, observed by remote sensing or field work. On air photos, and satellite imagery if the fires were extensive, areas of burned vegetation are recognised by their characteristic shapes and patterns. Image tones and colours should not be used as they give unreliable assessments of fire hazards. Burned vegetation leaves ash of varying colours and reveals bare soil beneath, which together effectively control tones and colours observed.

Regularly burned vegetation can be recognised and assessed in the field by its species composition, since burning eliminates fire-sensitive species and favours those adapted to fire.

10. Flood Hazard

Nature and Effects

Flooding is not as serious a hazard to primary production on rangelands as it may be to standing crops. If deep and fast enough, moving water can flatten or uproot browse species and cover the land with silt, and repeated salt water flooding will increase the salt content in a soil. Areas of extensive grazing are often on floodplains that are too frequently inundated to be cultivable, although not to an extent that grasses are unable to survive; but livestock have to be moved away when floods occur, depriving them periodically of grazing.

Assessment

The two land characteristics of flood frequency and periods of inundation are used to estimate this limitation. Inundation periods are those when the land is under water, given

in days per year, and measured or estimated from records. Flood frequency is given according to the occurrence of damaging floods, and the extent of actual or estimated damage to the rangelands.

11. Frost Hazard

Nature and Effects

Evaluations of rangelands in temperate climates or at high altitudes in the tropics may have to take account of frost hazard. Different plant species are affected by varying severities of frost which damages, and usually kills, the more tropical species. Others may be adapted to slight ground frost but die when the air temperature falls below about -3°C . The frost tolerance of new species should always be determined before their introduction into a temperate rangeland.

Assessment

This land quality is assessed by the characteristics of frost incidence, frost-free period, altitude and aspect as they affect plant species. Any likely occurrence of a damaging frost is measured or estimated from climatic records, modified if necessary for a prevailing aspect of the landforms that encourages frost pockets to form. If damaging frosts are rare, e.g. less than one a year, the suitability of the area will be downgraded less.

12. Genetic Potential of Vegetation

Nature and Effects

Extending from major biogeographical realms to individual plant species there are marked differences in the genetic potential of plants to support livestock production under extensive grazing. For example, in South America where nutrient availability is low, introduced African grasses (e.g. **Hyparrhenia sp.**, **Brachiaria spp.**, **Andropogon gayanus**, **Panicum spp.**) are genetically superior to indigenous species (CIAT 1986). On the other hand, legumes have been introduced from tropical America into African and Australian savannas (e.g. **Stylosanthes spp.**, **Pueraria phaseoloides**, **Centrosema spp.**, **Desmodium spp.**) to counter the apparent lack of legumes there. This shortage, however, is probably due more to a low phosphorus content in the soil that limits leguminous growth, than to differences in genetic development.

Another example is the almost complete lack of widely distributed leguminous browse trees in the Mediterranean area. These species are abundant in Africa and Australia, and an Australian legume tree **Acacia saligna** has been introduced into the Mediterranean for browse. By contrast the Mediterranean area is the centre of origin for several herbaceous pasture legumes (e.g. **Trifolium spp.**, **Medicago spp.**), and pasture grasses such as **Dactylis glomerata**.

At the other extreme, characteristics that are important for livestock production, such as the ability to resist disease, the leaf/stem ratio, the stoloniferous growth form and the palatability can vary significantly within one plant species.

Assessment

This complex land quality is to be assessed experimentally, by comparing livestock production from grazing of different species including those found within the survey area, and any exotic species intended for introduction. The botanical composition, phosphorus content and crude protein content should be measured and compared between species, grown under comparable and suitable conditions.

8.2.2 Land Qualities affecting Management

13. Ease of Control of Undesirable Plant Species

Nature and Effects

Overgrazing in extensively grazed rangelands encourages the spread of less desirable plants, which compete for light, water and nutrients with desirable plants, and reduce the yield of the land. Several methods can be used to control them, including the:

- i. application of suitably formulated herbicides in liquid or granular form where the general level of inputs and expected returns are high;
- ii. mechanical control of woody species by uprooting, where equipment is available at high input levels;
- iii. selective control by burning at appropriate seasons;
- iv. introduction of goats that will graze specific unwanted plants.

A reduction in the grazing pressure will eventually lead to the re-establishment of more desirable species.

Assessment

The extent of undesirable plant species in a rangeland will be revealed during the resources survey. This is assessed by the land characteristics of their percentage cover, and type and speed of dispersal; by stolons, seeds blown by wind, carried on animals' skins or dropped in dung. If the species are found to be extensive then the practicalities and economics of their control must be assessed before they are reduced.

14. Potential for Mechanization

Nature and Effects

This land quality only affects areas being evaluated for ranching, where high inputs include mechanized operations of transport. The conditions of land that limit mechanized ranching are slope angle, rock outcrops, stoniness and plastic heavy clays.

Assessment

This quality is assessed by measuring or estimating the characteristics that can hinder the movement of vehicles, with approximate classes of suitability for each characteristic to be given as follows:

Table 8.2 CLASSES FOR ASSESSING THE POTENTIAL FOR MECHANIZATION (after FAO 1984a)

<u>Land characteristic</u>	<u>Assessment Class</u>			
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
Slope angle, percent	10	20	30	any
Rock outcrops, percent	1	4	10	any
Stoniness in topsoil, percent	1	5	15	any
Plastic heavy clay	absent	absent	present	present

15. Size of Potential Management Units

Nature and Effects

Extensive grazing requires large areas of land. There are minimum effective sizes for different types of extensive grazing, below which they cannot be viably managed. As the pressures mount on this land use, from encroaching cultivation and population increases, extensively grazed areas become increasingly smaller and less viable. This is particularly the case when economic returns are required.

Assessment

This land quality must be assessed with that of location, and after all the others. Areas of land that are otherwise suitable for extensive grazing may be insufficient in size for this land use. It is assessed by the land characteristic of minimum size required for viability, which is derived from the description of the land utilization type.

c. Land Qualities affecting Conservation

16. Erosion Hazard under Grazing Conditions

Nature and Effects

Removal of vegetation cover by overgrazing, trampling and the uprooting of plants will result in soil erosion. The rate of erosion and its effects vary with the rate and time of removal of vegetation, the species removed, the soil types being exposed, and the landforms

and the climate under which overgrazing is occurring. As a more extreme example, in arid and semi-arid rangelands with a long history of overgrazing, soils have often been almost completely eroded where they are within the reach of watering points by livestock. What is particularly disturbing is that, wherever erosion occurs, the soil removed contains higher proportions of fine soil fractions, organic matter and plant nutrients than that remaining (Wischmeier and Smith 1978; Elwell 1980; Elwell and Stocking 1982).

Differences in the rate of soil loss between vegetation-covered land and bare ground for a range of climatic types are available for the West African Sahel (Kessler and Ohler 1983). Long-term measurements of rates of soil erosion in pastures under different grazing pressures are also available (e.g., Plessis and Mostert 1965; Haylett 1960; Barnes and Franklin 1970).



Plate 4 Erosion caused by overgrazing on steep slopes.
 An example from Ethiopia. FAO photo.

The most effective method of limiting soil erosion by water is through maintenance of a ground and basal cover of herbaceous perennials. In tropical climates subject to intensive rainfall this is particularly important. At the beginning of the wet season the aerial cover of perennial species has often been much reduced by fire, grazing or natural decomposition, and cannot therefore act as an erosion control measure, especially on steeper

slopes where erosion is more prevalent. If a vegetative cover of the order of 5 tons/ha can be maintained in this period, soil losses become small except on the steepest slopes (Young 1989). Once re-established in the wet season however, the aerial cover of herbs and grasses provides as effective a control on erosion as the basal cover. By contrast only negligible control is provided by tree and shrub cover that is greater than 3 m above ground level.

It is more difficult to measure the nature and effects of erosion caused by wind (FAO 1984a). Methods applicable to rangelands are not available, though the wind erosion equation of Woodruff and Siddoway (1965) may be able to be adapted to extensive grazing lands.

Soil erosion can also occur as a result of poaching, which is the destruction of the physical structure of wet soils due to prolonged trampling by livestock. The effects of poaching are most commonly found in tropical floodplains that are poorly drained and have high amounts of organic matter in their topsoils.

Throughout rangelands special care is necessary to site all infrastructure so that concentrations of livestock numbers are minimized. Otherwise excessive trampling and grazing around these facilities will lead to accelerated erosion.

Assessment

There are a number of alternative methods of assessing erosion hazard. They aim to predict soil losses using the land characteristics of climate, landforms, soils and vegetation. One suitable for the large areas covered by extensive grazing systems is the FAO Soil Degradation Assessment methodology, of which full details are given in FAO (1979). In it the factors of rainfall intensity, soil erodibility, slope, vegetation, land use and management are rated into tabulated classes and combined by multiplication. The subsequent values of predicted soil loss are more nearly relative indices of erosion than precise amounts. However, the methodology is simple to use, it has the units of the FAO Soil Map of the World as its framework, and takes advantage of the considerable quantity of available small-scale data for all areas of the world.

17. Tolerance to vegetation degradation

Nature and Effects

The extents to which different species will tolerate grazing pressure vary with their location, season of the year and levels of past management. In most situations of overgrazing there is a decrease in desirable forage plants and an associated increase of undesirable species. The quality of the vegetation becomes degraded, leading to widespread bush encroachment and lower productivity.

Assessment

This land quality is usually assessed in conjunction with that of erosion hazard, as soil and vegetation degradation are normally associated signs of overgrazing. If the total

quantity and quality of ground cover is reduced by grazing on erodible soils, accelerated soil erosion is almost inevitable. The quality may be expressed by the characteristics of the vegetation type and the measured or estimated condition of the vegetation. The observed extent of degradation of species composition is also valuable to obtain, as part of the overall vegetation survey described in Section 7.3.

8.3 LAND QUALITIES AT THE SECONDARY PRODUCTION LEVEL

d. Land Qualities affecting Growth

18. Availability of Drinking Water

Nature and Effects

All animals require drinking water to be available at some time. However the frequency of drinking, and the quantity and quality of water they will consume, vary greatly between the species, within breeds, with different seasons of the year and with different amounts of forage consumed. At one extreme some species of wild animals, such as the Arabian oryx, are able to survive without drinking water for long periods. At the other a pedigree lactating cow requires large quantities of good quality water to be available on a daily basis for maximum productivity.

Animals obtain water directly from their food, and indirectly by metabolic processes. The need to drink additional water depends particularly on the air temperature, with high temperatures increasing the need to replace water lost from the body, and on the class of animal, with lactating and young animals requiring more water more frequently. As an example of drinking water amounts that should be made available, the approximate requirements for indigenous breeds of livestock being raised in semi-arid conditions are:

cattle:	watering every 1-3 days, at a rate of 25-45 l/day
sheep :	watering every 2-7 days, at a rate of 3-6 l/day
camels:	watering every 10-20 days, at rates of from 4-13 l/day up to 30 l/day on salty pastures.

In order that these requirements for cattle and sheep are met, it should not involve their walking more than 8-10 km to water. By contrast, temperate zone cattle introduced into tropical conditions require 60-90 l/day.

Tables and formulae for calculating more precise water requirements of cattle and sheep are given in the NRC Standards (NRC 1978; 1984; 1985). In general, mature and dry cattle should be restricted to watering every second or third day, to improve the digestibility and nitrogen retention of their forage, to reduce the amount of energy expended in walking to water, and to increase the grazing time. In the south of Ethiopia, for example, watering dry cattle every three days rather than daily has been shown to have little effect on their productivity (ILCA 1986). However, the reduction in the frequency of watering has meant that grazing does not have to take place as close as before to the water supply, with a consequent reduction in rangeland degradation.

Detailed standards of drinking water quality for the major types of livestock are given in NRC (1972, 1974) and FAO (1985a). An increased salt content has the direct and usually deleterious effect of increasing the water requirements of all animals; the limiting quality for stock watering is normally in the range of 3 000 to 10 000 mg of total dissolved salts (TDS) per litre, although more saline water may be used in some seasons.

Well and borehole water frequently contain minerals, of which the commonest are carbonates, bicarbonates, sulphates, chlorides and fluorides of magnesium, calcium and sodium. The levels of magnesium, sulphate and fluoride are of special significance, as water containing these minerals may not be potable even though the TDS level is not high. A high concentration of magnesium sulphate affects potability more adversely than a high concentration of sodium chloride. Water containing up to 10 000 mg TDS/l is not harmful, provided the proportion of bivalent cations and anions, notably magnesium sulphate and magnesium carbonate, is low.

Assessment

Each actual or potential source of available water must be assessed separately in order to estimate this land quality. This involves measuring the quantity, quality and reliability of surface water in streams and rivers, estimating the opportunities for increasing supplies by surface water storage, and measuring or estimating the groundwater availability. Land characteristics providing direct measurements are river flow regimes, groundwater hydrology and depth, and water quality in terms of TDS/l. Indirect estimates can be obtained from rainfall totals, observed moisture surpluses or deficits, rainfall variability, and the presence of aquifers. Since extensive grazing frequently utilizes fossil groundwater stored in underlying aquifers from earlier pluvial periods, a careful assessment should be made before committing a rangeland to a groundwater regime that is not recharged.

19. Biological Hazards

The land quality of biological hazards to livestock is subdivided into harmful plants, diseases and disease vectors, and wildlife.

i. Harmful Plants

Nature and Effects

Plants can absorb certain soil toxicities without ill effect, and only become harmful to livestock when excesses are absorbed. Potentially toxic substances in soils may be essential to livestock, provided they are available in the forage in minute quantities, for example selenium, copper and molybdenum.

Some plants are also poisonous and harmful by their chemical composition. Naturally toxic substances in plants however should preferably not be present if they are to be grazed or browsed. Examples of these toxicities are nitrates and phyto-oestrogens in temperate pasture legumes. Apart from certain amino acids that cause adverse effects on livestock, plant poisons belong to a relatively small number of compounds. These include fluoro-acetate, oxalates, cyanogenic glycosides and alkaloids. Poisoning can sometimes be

treated simply, for example by withholding water from a case of fluoro-acetate poisoning.

Plant poisoning is most common when food is scarce and not selected, such as during droughts and when nomadic and transhumant animals are being moved to new grazing. Otherwise it is not usually a serious problem, either because most poisonous plants are unpalatable and stock learn to avoid them, or because poisonous plant material only forms a small part of their diet and is within the tolerance level. Different livestock species, however, differ widely in their susceptibility to plant poisons. Other localized sources of harm from plants are that:

- a. the awns of some grass seeds may injure stock;
- b. in humid areas grasses can carry a toxic fungus **Pithomyces chartarum**, that causes mortality in sheep (Kellerman and Coetzer 1984; Garcia **et al.** 1982); and
- c. hooked seeds can damage or be undesirable in wool and pelts.

Assessment

This limitation of the land will be assessed during the vegetation survey by the observed incidence of poisonous and harmful plants. Land units found to contain such plants may not have to be classed as unsuitable for extensive grazing on account of this quality alone. It may not be physically or economically feasible to eradicate the plants, but the area may be used with caution, provided the pastoralists are aware of the dangers, and of the methods they can adopt of minimizing the risk of poisoning their livestock.

ii. Diseases and Disease Vectors

Nature and Effects

Many diseases related to specific areas or environmental conditions affect domestic and wild animals, and are transmitted by various means, killing or seriously reducing the productivity of the livestock. Some diseases are confined to wildlife, whilst others were introduced by domestic animals and transmitted to wildlife, of which rinderpest in Africa is a good example. Others, such as contagious bovine pleuropneumonia and babesiosis, are confined to domestic stock. There are also indigenous diseases that affect domestic animals much more severely than wildlife. These include theileriosis, foot-and-mouth disease, East Coast fever, malignant catarrhal fever and trypanosomiasis. Of these, foot-and-mouth disease occurs in wild buffalo, although its transmission to domestic livestock has not been conclusively proved; malignant catarrhal fever is only transmitted by wildebeest calves aged up to three months; and the most serious, trypanosomiasis, is transmitted from a variety of wild animals to domestic stock by tsetse flies (**Glossina spp.**).

Domestic animals are also susceptible to many viral, bacterial and protozoan diseases, and are debilitated by external and internal parasites. Some protozoan diseases are

transmitted by internal parasites, or have in them an alternative host in their life cycles. Even if the animals survive infection and the presence of parasites, their production is reduced and morbidity increased. Resistance is improved if the level of nutrition gained from the forage can be improved. Animals can also be moved between seasons to reduce certain risks, as parasites, alternative hosts and disease vectors may favour certain environmental conditions throughout the year. Whole herds of livestock may be condemned by a disease even when single animals are uninfected. For example, an outbreak of foot-and-mouth disease in a country usually ensures that animal and meat products from it are unacceptable to importing countries.

Assessment

Veterinary records and observations will provide means of assessing the extent of this limitation. However, the variety is so great and levels of incidence so varied that sample surveys at one time may only yield information of marginal value for future development of improved land uses. It is important to be aware of the diseases and disease vectors likely to be present, and of possible means of controlling them so that the area retains at least partial suitability for extensive grazing.

In a new area proposed for livestock, harmful organisms, their vectors and alternative hosts, including ticks, snails, insects and wildlife may already be present. The extent of diseases and their vectors will have to be assessed before proceeding further. It may be possible to utilize some areas seasonally when the extent of disease vectors is slight. In other areas it will be necessary first to eradicate or control vectors before any livestock can be safely introduced.

The level of inputs being envisaged to combat diseases may determine whether or not an area is suitable for livestock. For example, prophylactic chemotherapy with Samorin and Berenil against African trypanosomiasis will allow livestock production to proceed under high input conditions associated with ranching in tsetse-infested areas (Stewart 1985). This chemotherapy treatment is however unlikely to be economic under pastoral conditions, in which the introduction of trypano-tolerant N'Dama cattle would be a more viable alternative. Again, effective dipping and spraying facilities are required for the control of ticks and tick-borne diseases. These are efficient but expensive, and pastoralists will often diligently remove ticks by hand as the only method of control available to them.

The diseases present should also be assessed in terms of protection of animals by vaccination and the financial outlay thus incurred, as treatment may need to be repeated regularly even after the disease appears to have been eradicated. Alternatives to vaccines may also be available. In Latin America trypanosomiasis, locally termed Chagas disease, is transferred by the insect **Triatom infestans**. It can be controlled relatively simply by maintenance of hygienic housing practices and prohibition of livestock from dwelling areas. Here the social conditions allowing these practices to become widespread will need to be assessed.

The ability to move animals regularly should be assessed, as a means of lessening the prevalence of many diseases. For example, grassland that is already heavily soiled

should be examined for worm burdens, which most seriously affect young animals. Livestock should be tested for fascioliasis if they graze snail-infested wet grasslands, as this disease causes liver damage. Where movement is not frequent a high level of stock management is the best preventive measure for disease control.

iii. Wildlife

Nature and Effects

Wildlife are a source of meat and potential revenue from tourism, but a limitation when considered as herbivores competing for grazing with associated predators, and pastoralists practise herding and kraaling to protect their livestock, though this may now be more frequently because of rustling and livestock theft.

The effect of competition between animals for limited grazing is more serious. Different species have different grazing and browsing preferences, but not all are complementary. Wildlife is better adapted than domestic livestock to utilize forage, especially during periods of limited growth. During these times their more efficient cropping may deny areas to the livestock.

Assessment

A survey of competing herbivorous wildlife and predators, their numbers, species and movements, is required. This can be undertaken by aerial counting methods with sample field checks. If found to be a serious limitation in an otherwise suitable area, the opportunities for establishing game reserves and migration corridors should be assessed. These should preferably be separated from the rangelands by zones of controlled hunting of wildlife and movement of domestic animals.

20. Climatic Limitations

Nature and Effects

Extreme climatic conditions including very high and low temperatures, intense solar radiation, prolonged rainfall, high relative humidities and strong winds can cause undue hardship to livestock. Animals are variously adapted to withstand them, and so the effects of these conditions are different for different species, breeds and animals within breeds, and differ with their general condition. Following are examples of the effects of high and low temperatures.

In domestic animals body temperature cannot fluctuate significantly, with the one exception of the camel. If the air temperature falls animals achieve thermoregulation by diversion of additional energy to maintain their body temperature; if air temperature rises they disperse body heat by sweating and panting, though less effectively when the relative humidity is also high. This increased rate of metabolism involves the use of additional energy and water, and reduces food intake and overall productivity. The body temperature of the camel uniquely fluctuates, rising by day and falling by night, so that the animal copes more efficiently with wide diurnal temperature ranges and conserves body water.

Aside from the camel, different species and breeds within them exhibit different levels of adaptation to heat stress. **Bos indicus** has a lower metabolic rate than **Bos taurus**, and is adapted to a higher range of ambient temperatures. Above 22°C mean temperature European cattle breeds and their crossbreeds suffer heat stress and are insufficiently productive for use in extensive grazing. Where the mean temperature is between 18.5 and 22°C heat stress can be reduced by careful crossbreeding of indigenous and European breeds selected for stress resilience. It can also generally be reduced by feeding forage with a lower crude fibre content, as this raises body temperature, and by protection from high levels of solar radiation associated with high temperatures.

Little is known about the effect of low mean temperatures on grazing cattle, though forage growth itself will probably cease (Arnold 1987). Low night temperatures, down to -9°C, have no ill effects on sheep. Llama, alpaca and vicuna are adapted to the extreme cold of the high Andes, and have specialized red blood corpuscles that absorb more oxygen from the rarified air. Provision of shelter from strong winds blowing cold air will reduce the wind chill effect on animals.

Overall, the effect of any climatic limitation on livestock will be to produce stressed animals, which are unable to move far from water, so causing greater range deterioration around watering points, resulting in lower productivity and yields per area.

Assessment

It will be necessary to take account of individual limits to optimum growth of the different livestock species as a result of this limitation. Land characteristics used to assess the effect of heat stress are total radiation, solar radiation, relative humidity, high mean and extreme temperatures. The limitation due to cold is assessed by low mean and extreme temperatures, frost incidence and wind speed. Young animals face a hazard of prolonged wetting where rainfall and relative humidity are high.

The extent by which the suitability of an area for a specific kind of extensive grazing will be reduced due to a climatic limitation will probably have to be determined by experimentation. Where such a hazard is known to exist it would be preferable to modify the recommendations and stock the area with breeds that have known levels of tolerance to the hazard.

21. Accessibility for Animals

Nature and Effects

Gaining access to forage can be limited by steep slopes, stones and rock outcrops, dense vegetation, flooding and other land uses blocking the migration routes. A common hazard, especially to the larger types of herbivore, is particularly thick stands of thorny scrub through which they cannot force a path. Tall woody vegetation often has edible parts growing beyond the reach of livestock, and is featured by distinct browse lines, above which the vegetation is untouched by the tallest browsing animal; goats, cattle, camels or giraffe. Livestock movements are impeded by many land uses or management practices including arable cultivation, overground pipelines, fenced ranches, international boundaries, and veterinary cordon fences or other measures erected for disease control.

Table 8.3, after Kekem (1984), gives slope classes and their suitabilities in terms of a factor rating for three categories of stock. It illustrates the variations in degrees of limitation presented by one hazard, that of steep slopes, to different species trying to gain access to an area.

Table 8.3 FACTOR RATING OF SLOPE CLASSES (IN PERCENT) RELATED TO ACCESSIBILITY FOR THREE CATEGORIES OF STOCK (after Kekem 1984)

Factor rating	Slope classes for		
	camels	cattle	sheep/goats
s1	0-8	0-16	0-16
s2	8-16	16-30	16-30
s3	16-30	30-40	30-50

Similar tables may be compiled for the degrees of access provided to different species by ranges of stoniness, boulder cover, severity of flooding and vegetation density.

Assessment

Accessibility can be estimated by measurements of the land characteristics of slope angle, percentage stones and rock outcrops, vegetation density and presence of thickets, and flooding severity. From these suitability tables may be compiled, similar to that given in Table 8.3, or generalized statements can be made about how different degrees of severity will lower the suitability of an area. Assessment will be assisted by local experience with different types of stock at different seasons.

22. Conditions for Hay and Silage

Nature and Effects

Fodder conserved as hay or silage is important where winter or dry season feed must be provided to replace grazing and maintain livestock productivity, and to build up strategic feed reserves against periods of drought. However, conditions frequently militate against making hay or silage.

In many regions the terrain is too rough for even hand-operated scythes to cut the grasses. Hay should be cut and cured at the pre-flowering stage, when its crude protein content and dry matter yield of forage are optimal. But in wet climates cut hay that is left on the land to cure becomes mouldy. Where it is possible in drier climates, sweet grasses and C3 grasses should be left uncut to cure naturally and become standing hay. Now though, the hazards become unexpected late season rains and dry season fires. To supplement the natural vegetation, an introduced herbaceous legume may provide a nutritious crop of standing hay in ranches, but only where the owner is assured of exclusive grazing rights. When grasses are ensiled this operation should be carried out at the flowering stage, when they have a 30-35 percent dry matter content.

Assessment

Suitable conditions for making hay and silage in most extensive grazing systems will depend on the vegetation types and the climate. The quality is best measured or observed by characteristics of the vegetation of the carbohydrate assimilation type and the floristic type, and of climate of the mean rainfall, moisture surplus, relative humidity and wind speed. Measurements or observations should be concentrated on conditions at the pre-flowering and flowering stages of grasses, to ensure that hay curing is possible and to determine the effects on the suitability of less than optimal conditions at this period in the growing season.

e. Land Qualities affecting Management

23. Ease of fencing or hedging

Nature and Effects

Improved extensive grazing includes some form of enclosing paddocks and holdings, either by fencing, drift fencing, hedging or walling, in order to control livestock movements. The ease of building enclosures will vary; shallow soils will restrict the digging of fence posts, a lack of stones will limit the use of stone walls, flooding and termite attacks can damage wooden fence posts and hedges, and large wildlife can destroy a variety of fencing material. The effects of a limitation to building enclosures may be to downgrade the suitability of an area, or to restrict its use to less improved types of grazing.

Assessment

The positioning of enclosures and the materials to be used may be decided by the absence of limiting conditions of the land. These can be estimated from observations of soil depth, surface stones and rock outcrops, frequency and severity of flooding, and the presence of termites and large game species. These land characteristics will normally have been measured during the course of the resources survey. Their assessment will depend considerably on the input and management levels being planned for each area. For example, with a high level of inputs and mechanization, fence posts can be treated and pile driven into otherwise unsuitable ground, and herds of elephants can be excluded by tall electrified wire fences.

24. Location

Nature and Effects

This land quality is considered in relation to inputs and outputs of an extensive grazing system; to centres of supply for the pastoralists and their animals, and to markets for livestock and livestock products. Constraints of location arise because of the remoteness of many grazing areas, the difficulty of the terrain and the absence of roads and transport infrastructure. Livestock have traditionally been trekked long distances to market, though they are now increasingly being trucked. For this reason the existing accessibility to grazing is often similar to its potential, and a poor location increases the cost of its development.

Assessment

Assessment is usually based on the expense of transport, with otherwise suitable areas being excluded because of the high cost of transport of goods to and from a local centre. A centre is a town from which supplies can be obtained and at which livestock and their products can be marketed. In the absence of markets it may be necessary to develop them at strategic centres. For example, collecting centres for milk and butterfat have been established in remote locations in some developing countries, where the costs of transport have been met by the high value of the products. Distances to centres and the roughness of the terrain are therefore the main characteristics by which this quality is measured, and suitability is determined by the cost of providing transport over those distances.

Location also has a social aspect requiring a qualitative assessment. Pastoralists are often located in remote areas, and the provision of basic amenities to them, such as health care and education, severely taxes the limited resources of poor countries; more so when nomadic pastoralism is being practised. Remote areas have been shown to remain viable for this land use when peripatetic teachers and medical and veterinary assistants have been recruited from amongst the pastoralists themselves. However, they must be well trained and kept motivated to provide a high standard of service to their community.

9. GRAZING CAPACITY

9.1 NATURE AND EFFECTS

The methods of assessment examined in Section 8 cover the full range of land qualities that can influence the suitability of land for extensive grazing, and hence for livestock production. There is, however, the need to provide a link between these qualities and the two levels of production, because of the inherent dual nature of this form of land use.

This link is undertaken by means of the concept of grazing capacity which, while not a land quality in itself, is a result of all the land qualities examined in Section 8. Through its assessment, details can be given about the overall productivity and yield of land when it is used for extensive grazing. It is the link between the land qualities affecting both forage and livestock production, leading directly to the matching of grazing land uses with grazing land.

Grazing capacity can be defined as: the maximum stocking rate of an animal type with a specific production objective that a certain land unit can support on a sustainable basis during a defined grazing season. Animal types are related to tropical livestock units (TLUs), as described in Appendix A. Stocking rate is the actual number of livestock on a specific area at a specific time, usually described in terms of TLUs/ha.

In this definition grazing, livestock, land and time are brought together. Grazing capacity should not be confused with **carrying capacity**, which is the maximum capacity of a land unit for supporting animals during the time of greatest stress to them in the year. This definition does not refer to land use on a sustained basis, and has no place in land evaluation.

Grazing capacity is a major problem, and its assessment is the single most important reason for devising the procedures that are given here. At the outset it needs to be understood that it is almost never possible to give a single value of the grazing capacity of a land unit. There are a number of reasons for this:

- i. As with other kinds of land use the capacity for production that exists at the time of the survey may well be below the potential. Many factors taken into account during assessment of the other land qualities determine the gap between actual and potential grazing capacity; for example the availability of drinking water, the amount of depletion of nutrients from the soil, the extent of bush encroachment, the frequency of fire hazard and the control of animal diseases. In this respect potential grazing capacity has also been referred to as the capability of the land for grazing (Hacker 1984).
- ii. The overall objectives of production and yield differ widely between land uses and between animals. For example, if two or more land uses that include extensive grazing are combined in a single area of land, then the grazing capacity will be below the maximum stocking rate that would be achieved under extensive grazing

alone. Here, however, the aim is not to achieve the highest stocking rate. The objectives of raising animals within such a combination would include milk and beef production, draught power and dung for domestic fuel, wool and hides. Each objective is best achieved at a different grazing capacity.

- iii. The grazing capacity differs between animal species. For example, sheep graze more grass stubble than cattle, and goats more commonly browse. Different mixtures of species and breeds in herds and flocks make varying demands of the grazing. Within the descriptions of the land utilization types are the animals to be reared and their mixtures; hence estimations of the grazing capacity must be directly related to these details in the descriptions of the uses.
- iv. There are marked variations in the quality of the land for grazing at different seasons of the year, as illustrated in Figure 9.1. Animals to some extent accommodate their requirements to the changing quantity and quality of grazing available to them over time, and are assisted in this by nomadic and transhumant practices. Hence, for a given rangeland, grazing capacity will vary according to whether the grazing occurs during a growing season, throughout the year regardless of growth, or for an intermediate period.

Grazing capacity must therefore be assessed by measurements or estimations of a wide range of land characteristics for each grazing orbit of each type of livestock. Overall grazing capacity is set as the grazing orbit with the lowest grazing capacity, so ensuring that there is no deterioration to the rangeland and that the land use can be sustained.

A deteriorating range can be assessed as one in which there is:

- desertification or a dramatic decrease in plant cover;
- replacement of existing vegetation by undesirable vegetation, e.g. bush encroaching into grassland, perennials being replaced by annuals;
- accelerated soil erosion, resulting from desertification or replacement of vegetation, or both combined;
- depletion of nutrients, mainly N and P, from the plant/soil system.

In many cases deterioration of rangeland does not result primarily from grazing, but from associated practices such as burning, fuelwood collection and seasonal cropping. Thus the grazing capacity of an area is not just determined by the number of animals that can be carried, but by the intensity of land uses with a predominance of extensive grazing practices that can be sustained.

9.2 ASSESSMENT

There are three main methods of assessing grazing capacity, ranging from the most accurate quantitative estimates, which are lengthy and costly to obtain and hence

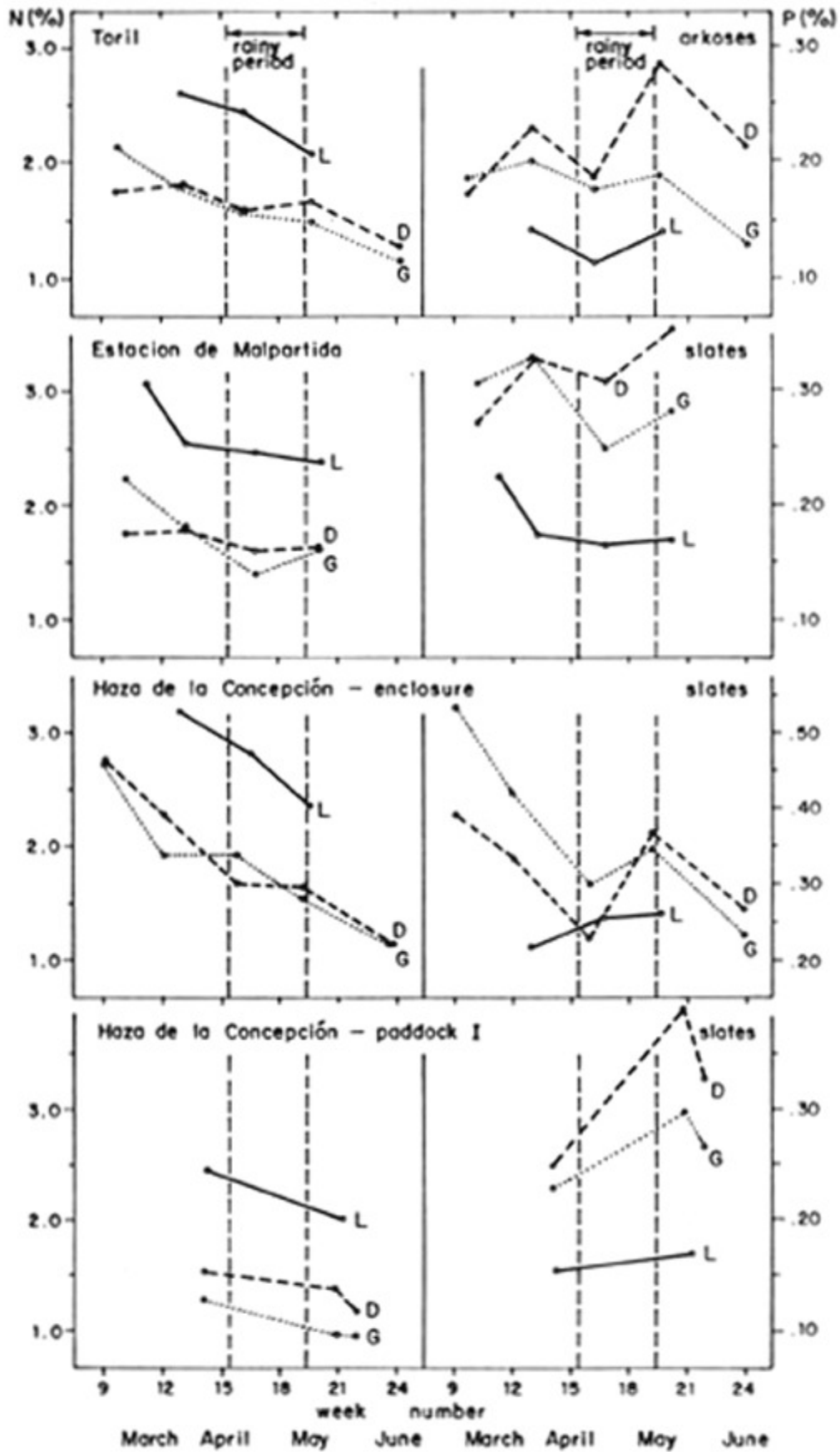


Figure 9.1 Nitrogen and phosphorus contents of four sites for three components of the herbage (L = Legumes, G = Grasses, D = Dicotyledons excluding legumes) during the growing season of 1983. Source: Esselink *et al.* (1988).

rarely an integral part of a land evaluation, to those that are derived qualitatively and are indicative of this land quality. The methods are based on:

- i. **experiments** with stocking rates, in which forage and livestock production are monitored;
- ii. **calculations and models** that assume a balance between animal dry matter (DM) requirement and DM supplied by the rangeland;
- iii. **inferences** made from recorded or estimated stocking rates and related rangeland conditions.

9.2.1 Experiments

Experimentation with stocking rates is expensive and time-consuming and can be undertaken at best for a few areas and selected land units. Nevertheless, a land evaluation for extensive grazing will always be lacking if it has no baseline data on experimental stocking rates for a representative sample of the land units.

9.2.2 Calculations and Models

The calculation of grazing capacity is undertaken by a comparison of stocking rates with forage dry matter produced during the growing season. This assumes that the crude protein, and hence energy, obtained by livestock from the dry matter is the main influence on livestock maintenance and production.

There are significant differences in annual amounts of dry matter production by annuals and perennials, and in the relative proportions of the total production that are usable. The forage dry matter production of annuals may be 150-200 percent higher than the dry matter in the standing crop at any one time, as much of their production decomposes or is consumed by insects and wildlife without becoming forage for domestic livestock (Esselink *et al.* 1988). Alternatively, the standing crop of perennials is up to 200 percent higher than the annual dry matter production, because that crop represents production over several years (DHV 1980).

Therefore, in the calculation of grazing capacity for a specific area, the main variable to be measured or estimated is the standing crop available for forage. It can be measured by direct sampling of the crop using harvesting techniques, although these can be time-consuming and expensive. The 'difference method' is used routinely. In it forage weight in a grazed area (A) is measured. Simultaneously, grazing exclosures are constructed and after a set period of days or weeks the herbage weight inside the exclosures (C) is determined. Forage production is C-A. The exclusion period varies with the productivity of the vegetation: 5-7 days where it is highly productive, and 4-6 weeks where production is low. The experiment can be repeated throughout a season or a year, to obtain standing crop production values over a longer period.

An alternative method that provides an estimate of the standing crop and that covers a large area more rapidly is by use of remote sensing techniques. The levels of red and

infrared reflectance from the main species of herbage are measured on the ground and calibrated against the quantity of standing crop that each represents. These ground truth measurements are then extrapolated by aerial and satellite remote sensing data, also obtained in the red and infrared bands, to provide estimates of standing crop quantities throughout the survey area.

Since remote sensing provides only estimates of the standing crop there are uncertainties attached to this method. The ground measurements correlate tolerably well with the standing crop quantities (Thalen **et al.** 1980; Jensen 1980; Grouzis and Methy 1983; Tucker **et al.** 1983), but only when:

- i. reflectance values are calibrated with the standing crop separately for each vegetation type and for each crop growth stage;
- ii. reflectance values are measured at the same time of day or are corrected for varying sun angles.

When satellite data are used, reliable correlations between vegetation reflectance and standing crop measurements are difficult to obtain. The best estimates appear to be made through the use of a composite parameter of red and infrared band reflectance values, combined by the formula:

$$\frac{\text{infrared} - \text{red}}{\text{infrared} + \text{red}}$$

and termed the Normalized Difference Vegetation Index (NDVI).

Values obtained from this formula broadly indicate the amount of vegetation being sensed, in that vegetation reflects better than bare soil in the infrared spectral band. Correlations using the NDVI have been significant in flat areas, within a certain vegetation type in the same growing phase (Prince and Tucker 1986; Prince and Astle 1986). Elsewhere, in more complex environments, they have been difficult to establish, for both practical and theoretical reasons. A pragmatic approach when using the NDVI is to stratify the grazing land into a small number of classes of herbage that are relatively homogenous. Reflectance measurements are then taken of each of them, NDVI values are produced and these are related to the standing crop production.

Models can also be used to estimate the dry matter standing crop available for forage at the end of the growing season. The simplest model is correlative, linking mean annual rainfall with dry matter production, and has been used by Houerou and Hoste (1977), Walter (1973), Deshmukh and Baig (1983) and Wijngaarden (1985). The equation used in the model is:

$$y = a + bx$$

where y = dry matter production in kg/ha/yr
 x = mean annual rainfall in mm/yr
 a = constant (given in Table 9.1)
 b = constant (given in Table 9.1).

Values of the constants a and b in Table 9.1 are as given by Gils **et al.** (1985).

Table 9.1 MEAN ANNUAL RAINFALL AND CONSTANTS USED IN FORMULA (1) FOR ARID AND SEMI-ARID ZONES

Region	Type of forage		Rainfall range mm/yr	Constants		Source
	herbage only	herbage + browse		a	b	
Mediterranean		+	20- 900	-200	4.4	Houérou and Host 1977
Sahelo-Sudanian	+		200-1400	100	2.6	Houérou and Host 1977
Semi-arid Kenya	+		50- 400	-180	6.3	Wijngaarden 1985
Semi-arid Kenya		+	50- 400	-400	10.0	Wijngaarden 1985
Sudano-Zambeziian	+		200- 800	0	2.0	Rutherford 1978
Karoo-Namib	+		50- 500	-100	4.8	Walter 1973 as adapted by Rutherford 1978
East+South Africa	+	+	500- 800	-200	8.5	Deshmukh and Baig 1983
Northern China	+		?	-530	6.5	Ting-Cheng 1983

Since it does not take account of other environmental factors than rainfall, notably soils and temperatures, this model is only applicable where the soils and temperatures are relatively uniform. Elsewhere predictions of dry matter have been overestimations and are often unreliable when made for one particular year. Dry matter production in unusually dry and wet years should also be predicted separately, by appropriate modification of the rainfall values in the equation (Gils 1977).

More elaborate models attempt to simulate the environment more precisely, for example by using:

- the availability of water and nutrients (Penning de Vries and Djiteye 1982; Lek and Keulen 1986; Keulen **et al.** 1986);
- actual evapotranspiration, mean annual precipitation and temperature (Lieth and Whittaker 1975);
- length of growing season (FAO 1978);
- soil, crop and weather characteristics in the SOW model (Keulen and Wolf 1986).

However, none of these models includes such essential environmental factors as vegetation composition, competition between grasses and woody species, and between annuals and perennials, rangeland condition, interactions between rangeland and herbivores, or the effects of fire or flooding. Thus, for predicting forage production, results obtained from them should be subject to field verification.

By whatever method forage production figures are obtained, they can be used to calculate approximate grazing capacities in the formula adapted from Thalen (1979) and Esselink **et al.** (1988), which balances forage dry matter production with animal dry matter requirements:

$G = F/R$ multiplied by the lowest of the following:

g , or $(1-l)$ or p ,

where G is the grazing capacity in Tropical Livestock Units (TLUs) per unit area for a specified grazing season, given as ha/TLU, with useful categories being >2, 2-5, 5-10, 10-20 and >20 ha/TLU;

- F is the weight of dry matter (DM) production per unit area during the grazing season (kg DM/ha), obtained by experiment or modelling;
- R is the animal requirement of DM, per TLU during a grazing season (kg DM/TLU);
- g is the grazing efficiency; the proportion of forage that is ingested by the grazing animal;
- l is the forage loss factor; the proportion of the forage lost to grazing by being trampled, fouled by excreta or decomposed;
- p is the proper use multiplier, or the proper use factor, indicating the maximum proportion of the forage that may be grazed without causing rangeland deterioration through accelerated erosion, nutrient depletion, physical soil degradation or undesired vegetation changes.

The grazing efficiency (g) varies considerably throughout rangelands. Pastoralism with cattle and sheep at low inputs typically has a grazing efficiency of 10-25 percent (Kaplan 1984). Here goats may achieve a higher efficiency, but verifiable data are lacking. Well-stocked Sahelian pastures with annual grasses attain 35 percent, and temperate pastures of **Lolium perenne** in the Netherlands are reported as having 40 percent grazing efficiency. In Australia it can rise to about 50 percent under improved Mediterranean annual grasses (Rossiter 1966).

Limited evidence suggests that the forage loss factor (l) is two to three times the grazing efficiency in areas of medium to dense vegetation cover (Esselink **et al.** 1988). In sparse vegetation the loss due to trampling and fouling is lower, and vegetation that remains ungrazed provides protection as a mulch against erosion.

The grazing efficiency and the forage loss factor are often combined into a utilization factor in calculations of grazing capacity (Mannetje 1978). The utilization factor of sparse vegetation is reported as being 60-100 percent (Kessler 1987), although data permitting the breakdown of the utilization into grazing efficiency and forage loss are limited.

The proper use multiplier (p) is lowered as the vegetation cover is reduced below its potential, and as undesirable vegetation encroaches. Assessments of the amounts of reduction by long-term observations of vegetation and stocking rates are preferable. Where time is not available, estimates can be obtained by comparison of similar rangeland environments and conditions, as discussed in Section 9.2.4.

In relation to this equation, some general features of animal nutrition are given in Appendix A. Animal dry matter requirements (R) are given for conditions in the USA by the National Research Council (NRC), for stallfed sheep, beef cattle, dairy cattle and goats. These, however, are above those required for subsistence pastoralism in the tropics. Here an approximate value of 1.5-2.0 percent of body weight can be taken as the daily animal dry matter required by cattle and sheep for maintenance only. However, the maintenance requirements of animals cannot be met throughout the year under conditions of subsistence grazing, and in certain seasons low feed intake results in weight losses, to compensate for which, weight must be gained during the rest of the year.

The NRC figures above do not take account of the mobile animal grazing extensively and requiring extra energy, for which extra dry matter above maintenance is required. The NRC (1978) indicates that an extra 3 percent of dry matter is required by dairy cows above their normal daily intake for each kilometre walked. Approximate additional requirements for grazing goats (NRC 1981) above that required for stallfed animals are:

- i. 75 percent for grazing of sparsely vegetated land, mountains and areas used for transhumant pastoralism;
- ii. 50 percent for grazing of semi-arid pastures and undulating terrain;
- iii. 25 percent for grazing on intensively managed pastures.

The above calculations assume that grazing capacity is determined for livestock maintained on the rangelands throughout the seasons. In some instances grazing capacity will have to be calculated for livestock grazing only after the end of the vegetative growing season, in which case only the standing crop is utilized. A modified equation is used in this case, in which:

$G = SC/R$ multiplied by the lowest of the following:

g , or $(1-l)$, or p ,

- where
- | | |
|----|---|
| G | is the grazing capacity in TLUs per unit area for the non-growing season; |
| SC | is the weight of standing crop dry matter (DM) per unit area at the end of the growing season, in kg DM/ha; |
| R | is the animal requirement of DM, per TLU during the non-growing season, in kg DM/TLU; |

g , l and p are as already given.

9.2.3 Discussion on Methods of Calculating Grazing Capacity

The calculation of grazing capacities, by the use of formulae that balance energy supply and demand, is only valid if values of digestibilities in the supply and demand terms, as described in Appendix A, are similar. The digestibility of forage in tropical rangelands varies between 30 and 70 percent. Between 55 and 70 percent of growing green herbage is digestible, with annual plants remaining green only during the rains and perennials continuing to be green for three to six weeks after the cessation of the rains. Thereafter the digestibility of mature herbage falls to 30-60 percent. Green browse is also less digestible than green herbage, at about 40-50 percent digestibility.

If greater accuracies are required in calculating grazing capacities, they can be achieved theoretically by using values of animal energy requirements and forage energy content, subdivided into digestible, metabolizable and net energy as described in Appendix A. It is however unlikely that a land evaluation for extensive grazing will warrant examination of energy to this degree of detail.

If livestock are stocked at rates determined with the assistance of grazing capacity calculations, then clearly there are interactions between the livestock and the grazing, leading to changes in the vegetation and the demands made of it. If the stocking rate is high, forage production is lowered (CIAF 1985; Whiteman 1980). However it is also lowered if the stocking rate is below that estimated by calculation. This occurs in both rangelands (McNaughton 1979) and in seeded pastures (Morley 1981). The reasons are that, where stocking rates are low, insufficient vegetation is removed to discourage mutual leaf shading, leading to decreases in grass tillering and leaf senescence.

The quality of the vegetation will also determine the quantity of feed intake, whether above or below the theoretical requirement. Feed quality is expressed in terms of the nitrogen or crude protein content, where approximately:

$$\text{crude protein} = \text{nitrogen} \times 6.25$$

Where the proportion of crude protein in dry matter is below about 7 percent, voluntary intake of grass by beef cattle and sheep is reduced, and where it is below about 12 percent feed intake by dairy cattle is reduced. Grazing capacities for different species are therefore to be calculated on the basis that crude protein will at least be at these levels.

Nutrient depletion, to the extent that feed intake is reduced significantly, is assessed by an input/output budget for the nutrients in the plant/soil system, and particularly for nitrogen and phosphorus. Examples of budgets are given in Gils (1985) and Esselink **et al.** (1988). A positive budget balance results in a proper use multiplier (p) of 1.0, in terms of nutrients, and a negative budget balance results in p being below 1.0.

The major nitrogen inputs into unimproved rangelands in developing countries are through rain, providing about 5 kg N/ha/yr. In improved rangelands the largest potential contributors of nitrogen are the legumes, and in a savanna dominated by nitrogen-fixing trees

up to 90 kg N/ha/yr can be provided. Nitrogen will also accumulate as a result of supplementary feeding, and of residual added fertilizer in an extensive grazing system being included within an area of shifting cultivation.

Most of the nitrogen lost directly through livestock from a rangeland is realized by volatilization from animal urine. Nitrogen losses from rangeland by the removal of meat, milk and hides are minimal, in the order of 0.5-1.0 kg N/ha/yr, in comparison with the nitrogen losses by burning, cropping and fuelwood harvesting, which are typically 2-5 kg N/ha/yr for each activity. Another way in which nitrogen is lost is through denitrification in flooded rangelands and volcanic landscapes. Soil erosion and soil leaching are processes which remove the whole range of soil nutrients.

Although grazing by itself removes insignificant amounts of nutrients, it is efficient at redistributing them within a rangeland. The carrying of manure and dung to cultivated areas for fertilizer and fuel, and to watering points by the animals themselves, depletes the remaining rangeland of significant quantities of phosphorus, magnesium, potassium and other minerals. Long continued practising of these land uses results in the actual grazing capacity falling well below its potential.

Thus far the methods for calculating grazing capacities have assumed that adequate soil nutrients are available for forage growth, as assessed in Section 8.2 under land quality 5. If there are mineral deficiencies in the forage, either the calculated grazing capacities must be reduced to take these into account, or mineral supplements should be provided in an improved land utilization type. The extent of deficiencies can be measured by laboratory analyses of plant samples, taken throughout the grazing area at different seasons.

A common example of grazing capacity values being lowered by mineral deficiencies is the case of phosphorus. In many rangelands there is insufficient phosphorus in the forage even for animal maintenance requirements. Stated amounts required for maintenance vary from 0.12 percent (Little 1980), 0.14 percent (Underwood 1981), to 0.2 percent (NRC 1978, 1981, 1984, 1985), whereas requirements are approximately 0.05-0.15 percent (Margaris *et al.* 1984; DHV 1980). The effect of insufficient phosphorus on the grazing capacity is difficult to assess, but it is estimated to be lowered by approximately one third.

In addition, the calculations given so far refer only to grazing capacities derived from herbage. Browse is also included in forage, and this supplies a considerable part of the energy, crude protein and mineral requirements for typical browsers, and seasonally for grazers also. For any grazing land utilization types that have a significant proportion of browse supplied in the forage, this should also be taken into account in calculations of the grazing capacity, through the use of different proper use multipliers (p). The browsing efficiency for trees is low because many leaves are inaccessible, but a higher proportion of leaves can be consumed without decreasing browse production. Browse is a richer source of protein and phosphorus than herbage during the non-growing season, but its digestibility is usually lower. It may be lowered further if the browse contains secondary plant compounds, such as tannins, polyphenolics and related phytochemicals, that deter the browsers from feeding on the trees and shrubs.

9.2.4 Rangeland conditions

Approximations of the grazing capacity of a rangeland, varying in accuracy with the time and data available, and the skill and knowledge of the evaluator, can be made from observations of the range condition and inspection of recorded or estimated stocking rates.

Assessment of the rangeland condition involves two components: the condition of the pasture and the extent of soil erosion under grazing conditions. Methods of assessing the soil erosion component are given in Section 8.2 under land quality 16. The pasture condition is assessed from the relative proportions of desirable and undesirable plants, by estimations of their cover, or density and vigour, and of their relative amounts in comparison with those that are optimal for the environmental conditions prevalent in the area. Desirable species in this context will include grasses, perennials and sweet grasses, and undesirables will be shrubs, annuals and sour grasses.

In measuring the relative cover of different plants, it is preferable to take the basal cover of herbs and the crown cover of woody species. From these measurements the range condition is then commonly given as being in one of the following four classes, devised by Humphrey (1962, 1966), which is the production of forage as a percentage of that which should be able to be produced under good practical management:

Excellent condition:	more than 75 percent
Good condition:	50-75 percent
Fair condition:	25-50 percent
Poor condition:	less than 25 percent.

If the range condition is to be assessed of grassland that is dominated by a single species, the vigour and reproductivity of this species is rated. For example, if the species is a tufted grass, it will show expanding, stationary or retreating tufts and corresponding increasing or decreasing extents of cover. Such an assessment will provide a basic pasture condition standard.

Having assessed the condition of a rangeland, qualitative statements can be made about its likely grazing capacity. These can be through the use of the range condition as a multiplier for a reference grazing capacity (Condon *et al.* 1969). Alternatively, it can be assumed that the range condition classes correspond to stocking rates, such as:

Excellent condition:	Correct stocking rate or understocking
Good to fair condition:	Stocking rate slightly above the grazing capacity
Poor condition:	Overstocked or grossly overstocked rangeland.

If the actual stocking rates of a rangeland are known, the potential grazing capacity can be inferred as being in correspondence with the stocking rate at the pasture condition classes of good and excellent. However, if the rangeland is in a poor condition, and stocking rates too high, then the actual grazing capacity will be lower, its estimation is more difficult, and it should be calculated using methods given in Section 9.2.2.

10. MATCHING LAND USE WITH LAND

10.1 INTRODUCTION

The next stage is the crux of the land evaluation, in which land uses are brought together with the land.

The following information is now available:

- i. constraints and opportunities to development;
- ii. land utilization type descriptions;
- iii. land use requirements and limitations for each land utilization type;
- iv. factor ratings of the land utilization types;
- v. land unit boundaries surveyed by land resources surveys;
- vi. values of land qualities, and diagnostic factors by which they are measured or estimated, for each land unit.

This information concentrates on the physical factors of the land uses and the land. The social and economic aspects of the land utilization types are either examined concurrently with the physical aspects or, as is described in Section 11, the analysis of these aspects follows the physical surveys. Also dependent on the physical evaluation, and analysed in Section 11, is an assessment of the impact on the environment of practising the various land uses.

With this information suitability assessments are made, by comparison of the requirements of each land utilization type with the land qualities of each land unit. The four stages in this process are:

matching
economic and social analysis
environmental impact assessment
final land suitability classification.

In this section the procedure of matching of the land uses with the land is examined, and the remaining three stages are described in Section 11.

10.2 LAND SUITABILITY RATINGS

The first step in matching is to compare:

- i. the factor ratings for each land use requirement of all the land utilization types in turn with

- ii. the corresponding conditions of each land unit as given by the diagnostic factors, which may be land qualities, land characteristics or functions of several land characteristics.

For every land use requirement of each land utilization type there is a corresponding land quality of each land unit, and for each factor rating of these requirements there are values of diagnostic factors by which these qualities are measured. The matching of factor ratings with values of diagnostic factors of each land quality by this means results in sets of land suitability ratings being obtained.

A **land suitability rating** is a suitability of a land unit for a land utilization type. It is based on the factor ratings of one land use requirement being matched with one land quality, and it shows the suitability of that land unit for a land use in terms of one requirement. Land suitability rating classes are given, as factor ratings, in terms of the four classes s1, s2, s3 and n.

Where a land quality is measured or estimated by means of one land characteristic, the value of that characteristic can be directly matched with the critical values in the factor rating of the corresponding land use requirement. Taking the example in Section 6.2.2 of drinking water availability, suppose the land quality of availability of drinking water has been assessed in a survey by the one characteristic of borehole supply, measured as 300 l/day, and that 100 head of smallstock are to comprise the livestock in the proposed land utilization type. This rate of supply is within the critical values 2-4 l/day per animal in the factor rating given in the example, and corresponds to a land suitability rating of s3.

If, however, a land quality is measured by means of a diagnostic factor that is a function of several land characteristics, as is commonly the case in land evaluations, then the value of each land characteristic must be taken into account. As a simple example, take again the requirement of drinking water availability. This quality is now assessed by two characteristics; the quantity available, as given above, and the distance livestock must walk to a watering point. In a survey of a land unit average distance to water has been measured as 4 km. Using the critical values in the example of Table 6.3, a 4 km walk to water results in a partial land suitability rating of s2. The resulting land suitability rating of the land unit, based on quantity of drinking water available, is s3, and on distance to water is s2. These two partial ratings are combined into one land suitability rating.

The methods of combining partial land suitability ratings, based on two or more land characteristic being used to measure a land quality, are similar to those used in the second step in the matching process. This is the combination of the range of land suitability ratings derived from matching each land quality with each land use requirement, and results in provisional land suitability classifications.

10.3 COMBINATION OF LAND SUITABILITY RATINGS

There are three different methods of combining land suitability ratings, based on:

- i. limiting conditions;

- ii. arithmetic procedures;
- iii. subjective assessment.

i. **Limiting conditions.** The simplest method and often the most appropriate is to take the least favourable assessment as limiting and the one that determines the provisional classification. In the above example the land quality of availability of drinking water will be given a partial land suitability rating of s3, because the quantity available is less suitable, rated at s3, than the distance to water, rated at s2. Similarly, other land suitability ratings of land qualities will have been determined, and these are combined in the same manner, by taking the least suitable rating as limiting. Assume, for example, that there are six land qualities considered as important and rated as s1, s3, s2, s2, s1 and s2; then the overall land suitability rating is taken as s3. There is little point in rating a land unit as moderately suitable on all accounts, but neglecting the fact that there is a risk of disease from tsetse flies, which is a seriously limiting condition within the survey area.

This method of limiting conditions should always be followed where there is an n - not suitable assessment of a land quality, and this will be the final suitability classification. In such a case no further time need be spent on economic or social analysis of the land unit. The advantages of the method are its undoubted simplicity, and the fact that the resulting land suitability ratings will err on the conservative side, so that the land suitability will never be overrated. Less advantageous is the fact that the method does not take account of possible interactions between land qualities, such as the control of undesirable plant species resulting also in the removal of trees that harbour tsetse flies, so lessening a biological hazard.

ii. **Arithmetic procedures.** The individual land suitability ratings can be combined by arithmetic means, using multiplication, to obtain one provisional suitability classification. The ratings are first assigned numerical values, which will vary from one land evaluation and one area to another. As an indication of values that can be used, the following are generally applicable:

$$s1 = 1.0 \qquad s2 = 0.8 \qquad s3 = 0.5 \qquad n = 0$$

Note that by assigning a value of 0.0 to n and multiplying it with other values, this suitability rating automatically becomes limiting.

The product of multiplying together the separate values is converted into a land suitability classification by means of a second scale, for example as follows. This must be different from the first, as otherwise there would be too high a proportion of s3 classifications.

$$s1 = 0.8-1.0 \qquad s2 = 0.4-0.8 \qquad s3 = 0.2-0.4 \qquad n = 0-0.2$$

Taking the same six land suitability ratings as were used in the example of the method of limiting conditions, and combining them by multiplication gives:

$$s1 \quad s3 \quad s2 \quad s2 \quad s1 \quad s2 \\ 1.0 \quad x \quad 0.5 \quad x \quad 0.8 \quad x \quad 0.8 \quad x \quad 1.0 \quad x \quad 0.8 = 0.26$$

The product of 0.26 falls between 0.2 and 0.4, giving a provisional suitability classification of s3.

Two problems with this method are, first, that the greater the number of land qualities used the smaller will be the product. To take account of this, the same number of land qualities is required in all calculations that are to be compared. If some qualities are not considered important they are still included if needed to meet this condition, and are given an s1 assessment, which will not adversely influence the result. Secondly, when the assigned numerical values of a rating in one area are applied arbitrarily in another, they tend to give poor results. Each area should be given values that are only applicable within defined limits.

An advantage of this method is that it is amenable to use with computerized land evaluation procedures. Many provisional classifications can then be quickly obtained, but care should be taken to examine the results and ensure they are substantiated by field data and experience.

- iii. **Subjective combination.** When there is extensive knowledge available about the land uses, provisional land suitability classifications may be made by the method of subjective combination. Here the basis remains the individual land suitability ratings of each land quality in every land unit, derived by matching land use with land. However, now they are combined subjectively by using detailed knowledge of the ecology and technology of the land utilization types. It is important that a thorough description is given in the land evaluation of the principles of any subjective means used, so that they can be reproduced elsewhere if necessary, as illustrated in the examples given in Tables 10.1-10.4.

10.4 MATCHING IN A MORE GENERAL SENSE

The stages of matching examined so far describe a process that can be undertaken almost automatically, as indeed it is in many land evaluations for which computers are available to process the land use and land data. If the land utilization types as already described are unchangeable, and if the possibility of land improvements is not envisaged, then the provisional land suitability classifications that have been obtained are ready to be considered for their economic and social acceptability.

However, matching should involve more than this. Land evaluation is essentially an interactive process, continually calling for modifications to be made to the proposed land uses, so that at the completion they most suitably fit the conditions of the land. Where matching has indicated that a land utilization type is unsuitable or only marginally suitable, then reference should be made back to its description and associated land use requirements. Modifications, in order that the land use more closely matches with the land, may be found to be acceptable.

Table 10.1 EXAMPLE OF CONVERSION TABLE: FACTOR RATINGS FOR TRANSHUMANCE GRAZING PER ANIMAL TYPE AND WILDLIFE IN BALUCHISTAN, PAKISTAN (adapted from Baig 1977)

Suitability of LUT	Land qualities	Forage (standing) crop	Distribution of watering points	Quality of water	Accessibility	Erosion hazard	Climatic harshness	Shelter and protection for wildlife only
Sheep	S1	1,2	1,2	1,2	1,2,3	1	1	N.R.
	S2	3	3	3	4	2	2	
	S3	4	4,5	4	-	3,4	-	
	N	5	-	5	-	-	3,4	
Goats	S1	1,2	1,2	1,2	1,2,3	1	1	N.R.
	S2	3	3	3	4	2	2	
	S3	4	4,5	4	-	3,4	-	
	N	5	-	5	-	-	3,4	
Camels	S1	1,2	N.R.	1,2	1	1	1	N.R.
	S2	3		3	2	2	2	
	S3	4		4	3	3	-	
	N	5		5	4	4	4	
Cattle	S1	1,2	1	1	1	1	1	N.R.
	S2	3	2	2	2	2	2	
	S3	4	3	3	-	3	-	
	N	5	4,5	4,5	-	-	-	
Ibex	S1	1,2	N.R.	N.R.	1	N.R.	N.R.	1
	S2	3			-			2
	S3	4			-			3
	N	-			2			4
Gazelle	S1	1,2	N.R.	N.R.	1	N.R.	N.R.	1
	S2	-			2			
	S3	-			3			
	N	2			4			
Birds	S1	N.R.	1	N.R.	N.R.	N.R.	N.R.	N.R.
	S2		2					
	S3		3,4,5					
	N		-					

N.R. = not relevant

Table 10.2

CONVERSION TABLE FOR THE LAND UTILIZATION TYPE
'CATTLE' IN KIBOKO AREA, KENYA (adapted from Michieka
and Braun 1977, as cited by Gatahi 1984)

Overall land suitability	Land quality	Climate	Soil moisture storage	Availability of soil nutrients	Resistance to erosion	Hindrance by vegetation	Availability of oxygen	Nutritive value of vegetation	Present state of overgrazing
S 1 Highly Suitable		IVb-V	s1	s2	s1	s1	s2	s1	s1
S 2 Moderately Suitable		IVb-V	s2	s3	s2	s2	s3	s2	s2
S 3 Marginally Suitable		IVb-V	s3	s4	s3	s3	s4	s3	s3

In the example of Table 10.2, soil moisture storage capacity is used within the climatic zone (IVb-V) as a diagnostic characteristic for grazing capacity. The individual land quality rating for the availability of soil nutrients and the availability of oxygen obviously do not degrade the overall land suitability rating; moreover these qualities seem more related to crop production.

Not all possible combinations of individual land qualities occur in this conversion table. It is easy to construct a realistic combination of land qualities such as high soil moisture storage capacity (s1), high nutritive value of vegetation (s1) and a severe state of overgrazing (s4) for which the conversion table does not supply an overall suitability rating. Decision rules (see Table 10.3) should be supplied to cover all possible combinations of individual land quality ratings.

In Table 10.3 each of the three land units provides fodder seasonally, but together they provide year-round support. Herdsmen in West Africa use these kinds of land units in a number of different systems: there is transhumance, with movement from Land Unit A to Land Unit C to Land Unit B to Land Unit A; in other regions, Land Unit A will gradually be complemented by some grazing of Land Unit B on a daily basis and later the animals graze Land Unit B and Land Unit C before moving back to grazing Land Unit A.

A further modification in West Africa is transhumance involving seasonal north-south movements between climatic zones; the longer growing season of the subhumid zone provides more acceptable dry season fodder if burning is applied; in the past its year-round use has often been prevented by tsetse.

From experience it is known that transhumance systems are often complex and that movements are fairly precise. The transhumance system can be geared to plant phenology, animal adaptability and social factors, e.g. avoidance of conflict, in addition to the more obvious factors mentioned above.

Table 10.3 CONVERSION TABLE SHOWING LAND SUITABILITY RATING BY MONTH FOR TRADITIONAL CATTLE TRANSHUMANCE USING THREE LAND UNITS IN WEST AFRICA
(adapted from Sow - personal communication)

<u>Land Unit A: Upland, open savana</u>												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Quality												
Grazing capacity	n	n	n	n	s3	s2	s1	s1	s1	s2	s3	s3
Distance to water	s3	s3	s3	s3	s2	s2	s1	s1	s1	s2	s2	s2
Tsetse risk	s1	s1	s1	s1	s1	s2	s3	s3	s2	s2	s1	s1
Daytime temperature	s1	s1	s3	s3	s3	s2	s1	s1	s2	s1	s1	s1
Overall land suitability	N	N	N	N	S3	S2	S2	S2	S2	S2	S2	S2

<u>Land Unit B: Grassy floodplain of Central Niger Delta in Mali</u>												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Quality												
Flooding	s1	s1	s1	s1	s2	s2	s3	n	n	n	s2	s2
Grazing capacity	s1	s1	s2	s3	s2	s1	s1	s1	s1	s1	s1	s1
Overall land suitability	S1	S1	S2	S3	S2	S2	N	N	N	N	S2	S2

<u>Land Unit C: Arable farms cultivating cereals and grain legumes</u>												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Quality												
Grazing capacity stubbles and crop residues	s3	s3	n	n	n	n	n	n	n	s1	s1	s2
Overall land suitability	S3	S3	N	N	N	N	N	N	N	S1	S1	S2

Land Unit A:

Grazing capacity: the rains start mid to end of April, consequently the first green herbage appears in May (s3). Full development of green herbage is during July to September (s1) in the peak rainy season. In October, rains have stopped and herbage starts drying (s2). In November, there is still some green herbage growing on residual moisture (s3). Green herbs occur locally in December (s3). From January to April there is no green herbage in the upland.

Distance to water: during the peak rainy season (July-September) surface water is available within a short distance for livestock (s1). From October to December surface water points disappear one by one (s2), and from January to April livestock have to walk long distances to permanent water supplies (s3).

Tsetse risk (suitabilities refer to cattle): in June moisture conditions are favourable for the fly, so reproduction and dissemination start (s2). July and August are very favourable for the tsetse fly (s3). September and October still have favourable air moisture for tsetse (s2). From November to April tsetse is not found (s1).

Daytime temperatures: March to May is very hot (s3). July to August is the peak rainy season, clouds and rain make the temperature favourable for livestock. June is the start and September the end of the rainy season, temperatures are acceptable (s2). October to February, winter temperatures are favourable for livestock (s1).

Decision rule for overall land suitability rating: The lowest rating for the individual land quality is also the overall suitability, if it occurs twice or is n. If the lowest land quality rating occurs only once, then the overall suitability rating is one class higher than the lowest individual land quality rating.

Land Unit B:

Flooding: August to October, the plain is completely flooded and inaccessible for cattle (n). November to December, flood waters have receded, but soils are very muddy, hindering livestock movements (s2). January to April, floodplains are completely accessible (s1). May to June, the rains start and soils start becoming muddy (s2). July, inundation starts, soils are muddy (s3).

Grazing capacity: May, green herbage appears (s2). June-February, green herbage is fully developed (s1). March, herbage is drying out except locally in swamps (s2). April, herbage is completely dry (s3).

Decision rule for overall land suitability: the lowest individual land quality is also the overall suitability.

Frequently an alteration in the intended stocking rate, or of the species or breeds stocked, will improve the land suitability ratings. The animals may then be considered more mobile, or less demanding of drinking water or of supplementary feed, or more able to thrive on steep terrain. An improvement in the technical knowledge and attitudes

Table 10.4

LAND SUITABILITY CLASSIFICATION PER LAND UTILIZATION TYPE (COLUMNS) AND LAND UNIT (ROWS) (from Ferguson 1983)

Map symbol	Land Units		Improved extensive grazing - cattle & sheep (sedentary) final rating				Improved extensive grazing - goats (sedentary) final rating				Improved extensive grazing - red deer & wild boar final rating				Unimproved extensive grazing - red deer & wild boar final rating				Rainfed annual crops	Irrigated pastures												
	Vegetation	In combination	Sp	Su	Au	Wl	Sp	Su	Au	Wl	Sp	Su	Au	Wl	Sp	Su	Au	Wl														
	<u>Units with a single vegetation type:</u>																															
9/10	<i>Quercus ilex</i> woodland with shrubs with <i>Securinega</i> valleys	without arable cropping with rainfed annual crops for stubble grazing or with irrigated pastures	S3	S3	N1	S3	N1(fpa)	S2	S2	S3	S2	S3(fp)	S2	S3	N1	S2	N	(fp)	S2	S3	N1	S2	N	(fp)	S2/S3	S2/S3						
8/11	<i>Quercus</i> woodland with shrubs with <i>Asphodelus</i> or <i>Scirpus</i> valleys	without arable cropping with rainfed annual crops for stubble grazing or with irrigated pastures	S2	S2	N1	S2	N1(fpa)	S2	S3	S3	S2	S3(p)	S2	S2	N1	S1	N	(fp)	S2	S2	N1	S1	N	(fp)	S2/S3	S2/S3						
4/12/13/14/15	<i>Quercus</i> woodland	without arable cropping with rainfed annual crops for stubble grazing or with irrigated pastures	S1	S2	N1	S1	N1(fp)	S2	S3	N1	S2	N	(fe)	S2	S2	N1	S1	N	(fp)	S2	S3	N1	S2	N	(fe)	S2/S3	S2/S3					
17/18	<i>Quercus ilex</i> shrubland with <i>Securinega</i> valleys	without arable cropping with rainfed annual crops for stubble grazing or with irrigated pastures	S3	S3	N1	S3	N1(fpas)	S2	S3	S3	S2	S3(fp)	S3	S3	N1	S3	N	(fp)	S3	S3	S3	S3	S3(fp)	S3	S3	S3	S3(fp)	S2/S3	S2/S3			
19/20/21/22/23	<i>Quercus ilex</i> grasslands	without arable cropping with rainfed annual crops for stubble grazing or with irrigated pastures	S2	S2	N1	S2	N1(fp)	S2	N1	N1	S2	N	(fp)	S2	S3	N1	S2	N	(fpa)	S3	S3	N1	S3	N	(fpa)	S2/S3	S2/S3					
24/25	<i>Cistus ladanifer</i> shrubland		N	N	N	N	N1(fpa)	S1	S2	S3	S1	S2(fp)	S2	S3	N1	S3	N	(fp)	S2	S3	N1	S3	N	(fp)	N	N						
30	<i>Arbutus/Pistacia</i> shrubland		N	N	N	N	N (faw)	S1	S2	S3	S1	S2(fp)	S2	S2	S3	S2	S3(fp)	S2	S2	S3	S2	S2(fp)	S2	S2	S3	S2(fp)	N	N				
27	<i>Pinus</i> plantation		N	N	N	N	N (fpa)	S2	S3	S3	S2	S3(fp)	S3	S3	S3	S3	S3(fp)	S3	S3	S3	S3	S3(fp)	S3	S3	S3	S3(fp)	N	N				
29	<i>Eucalyptus</i> plantation		N	N	N	N	N (fpa)	N1	N1	N1	N1	N1(fp)	N1	N1	N1	N1	N1(fpa)	N1	N1	N1	N1	N1(fpa)	N1	N1	N1	N1(fpa)	N	N				
	<u>Units with a complex vegetation structure:</u>																															
51/52	<i>Quercus ilex</i> woodland with shrubs, woodland 50/50	without arable cropping with rainfed annual crops with irrigated pastures	S2	S3	N1	S2	N1(fpa)	S2	S3	N1	S1	N1(fp)	S2	S2	N1	S1	N1(fp)	S2	S2	N1	S1	N1(fp)	S2	S2	N1	S1	N1(fp)	S2/S3	S2/S3			
53/54	<i>Quercus ilex</i> woodland with shrubs, grassland 50/50	without arable cropping with rainfed annual crops with irrigated pastures	S2	S3	N1	S2	N1(fpa)	S2	S3	N1	S2	N1(fp)	S1	S3	N1	S1	N1(fp)	S1	S3	N1	S1	N1(fp)	S1	S3	N1	S1	N1(fp)	S2/S3	S2/S3			
55	<i>Quercus ilex</i> woodland, grassland 50/50	without arable cropping with rainfed crops with irrigated pastures	S1	S3	N1	S2	N1(fp)	S2	N1	N1	S2	N1(fp)	S1	S3	N1	S1	N1(fpa)	S1	S3	N1	S1	N1(fpa)	S1	S3	N1	S1	N1(fpa)	S2/S3	S2/S3			
56	<i>Quercus ilex</i> woodland, grassland 50/50	without arable cropping with rainfed crops with irrigated pastures	S1	S3	N1	S1	N(fpa)	S3	S3	N	S3	S3(fp)	S2	S2	N1	S2	N	(fp)	S2	S2	N1	S2	N	(fp)	S2	S2	N1	S2	N	(fp)	S2/S3	S2/S3

S1 = highly suitable
S2 = moderately suitable
S3 = marginally suitable
N1 = currently not suitable
N = not suitable

Sp = March 1 - June 15
Su = June 16 - July 31
Au = August 1 - October 31
Wl = November 1 - February 28/29

The current classification is carried out with and without the possibility of arable cropping. In general, the classification with arable cropping may be considered as a potential suitability (see text).
The major constraints mentioned are: f = amount of usable forage is not sufficient (energy deficiency)
p = protein deficiency
a = accessibility
s = shelter and/or cover not available

of the pastoralists, through an extension programme that focuses on management training being made an integral part of the implementation, may permit new species to be introduced that are better adapted to the prevailing environmental conditions.

Whatever modifications are proposed to the land utilization types, they will in turn modify the land use requirements. The adapted requirements are then matched with the land qualities and, if found appropriate, improved land suitability classifications are derived.

If there is still no change in the classification a more radical option can be taken, of considering improvements to the land. This may involve more initial expense well above the recurrent costs of animal production, but could result in more suitable land uses, both in terms of the environment and the profitability of the land use. Common land improvements that are applicable to extensive grazing are the provision of additional watering points to increase the availability of drinking water, the control of undesirable forage plant species, the reduction of tsetse fly hazard, the improvement of plant nutrient status by the application of a phosphorus fertilizer, and the construction of trekking routes to improve accessibility to markets.

The values of the land characteristics that have been measured or estimated are then modified according to the land improvements that are proposed. The adapted conditions of the land units are then again matched with the land use requirements, aiming once more at raising the suitability classification. The overall outcome of matching is a set of land utilization types of varying degrees of suitability, about which the social and economic consequences are now required.

10.5 PROVISIONAL LAND SUITABILITY CLASSIFICATION

This step is the last in a physical land evaluation, when all the land suitability ratings have been produced. The output is provisional land suitability classes, which may be presented as focusing either on the land use or on the land, or by emphasizing both aspects. The classes are divided into subclasses, that are indicated by lower case letters and reflect the kinds of improvement measures required within the classes.

Table 10.5 SUMMARY TABLE PRESENTING RESULTS OF A PROVISIONAL LAND SUITABILITY CLASSIFICATION BY LAND UTILIZATION TYPE

Land utilization type: transhumant cattle and smallstock, low inputs

Land use requirements for:	Land units				
	1	2	3	4	etc.
<hr/>					
<u>Primary Production Level:</u>					
Growth requirements	s2	s1	n	s2	
Management requirements	s2	s2	s3	s3	
Conservation requirements	s1	s1	s3	s2	

Secondary Production Level:

Growth requirements	s2	s1	n	s3
Management requirements	s2	s2	s3	s3

Provisional land suitability	S2m	s2l	N2n	s3p
------------------------------	-----	-----	-----	-----

- i. Where the requirement of the land evaluation is to identify in which areas specific land utilization types of extensive grazing are best suited, the summary results of land suitability classes should focus on the land use, as in the example in Table 10.5.
- ii. The second method of summarizing provisional land suitabilities is by identifying the suitability of each land utilization type for the specific area of land covered by each land unit. The example in Table 10.6 illustrates that here land is the focus of the results.

Table 10.6 SUMMARY TABLE PRESENTING RESULTS OF A PROVISIONAL LAND SUITABILITY CLASSIFICATION BY LAND UNIT

Land unit: Thumrait Land System

Land use requirements for:	Land utilization type				
	A	B	C	D	etc.

Primary Production Level:

Growth requirements	n	s3	s2	s1
Management requirements	s3	s3	s1	s1
Conservation requirements	s3	s2	s1	s1

Secondary Production Level:

Growth requirements	n	s3	s2	s1
Management requirements	s2	s2	s2	s1

Provisional land suitability	N2m	S3n	s2l	S1
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- iii. A combined table, with both land utilization types and land units, provides the information on the land suitability classes in two ways. In Table 10.7, details of the suitability of one land unit for the range of land utilization types is given along the rows, and down the columns is the range of suitabilities of one land utilization type within the different land units. The interim stage is now omitted, of giving the partial land suitability ratings for both production levels.

Table 10.7

COMBINED TABLE OF LAND UTILIZATION
TYPES COMPARED WITH LAND UNITS

Land unit	Land utilization type				
	A	B	C	D	etc.
1	N2m	S3n	S2l	S1	
2	S3n	S2e	S2b	S2e	
3	S3l	S2m	S1	S2p	
4	N2n	S3r	S3m	S1	



Plate 5

An example from Jordan showing integration of extensive grazing practices with settled farming, in this case based on cereal production

11. ENVIRONMENTAL IMPACT ASSESSMENT AND ECONOMIC AND SOCIAL ANALYSIS

11.1 ENVIRONMENTAL IMPACT ASSESSMENT

The stages of land evaluation carried out so far have classified land on the basis of environmental characteristics, and have identified land that is suitable for certain uses on a sustained basis. The key land use requirements of tolerance to soil erosion and vegetation degradation will already have been taken into account. An assessment of any significant adverse effects resulting from extensive grazing, and the further analysis of the requirements of conservation of the environment should now be made, to gain an overall view of potential impacts on it.

The impact of land use changes on the environment affects both the area in which the changes take place and surrounding areas. A few examples relating to extensive grazing follow:

The erection of veterinary cordon fences within extensively grazed ranches influence the migration routes of wildlife;

prescribed burning during the dry season can alter those woody perennial plant species that have a beneficial effect on soil conservation, irrespective of their value for browse;

the pumping from additional boreholes may lower the watertable over significant distances;

the provision of new surface watering points may act as sources of waterborne diseases;

increased grazing pressure may encourage soil degradation, leading to erosion and downstream silting of rivers;

as they colonize and spread, new herbage material and livestock breeds can have significant impacts on existing plants and animals outside the grazing area;

where grazing is abandoned the effect can be detrimental, by increasing the woody component of the vegetation, the fire risk, the tsetse hazard and the predators on livestock grazing elsewhere;

ground applications or aerial spraying of phosphates and nitrogen can pollute the downstream drinking water sources;

the construction of new roads can provide access for developers other than those involved in grazing.

If one or more of these environmental impacts are likely to occur then they require to be quantified and assessed. For some impacts specific data by land units will have to be collected during the resources survey. They may include such features as the prevalence of tsetse in neighbouring areas, the natural rate of replenishment of groundwater supplies over a wide area, botanical compositions of all main plant species, or regional migration routes that impinge on newly proposed ranches. They are assessed for likely adverse effects due to changes in extensive grazing practices.

If it is found that effects will result in unsustainable land uses and environmental degradation, then alterations to the land utilization types must be made before they can be applied. These will be in line with, and extensions of, changes made during the broad matching process described in Section 10.4. If a negative impact of a land use cannot be counteracted and remains unacceptable, however much the land use is modified, then it should be abandoned, even if the land is otherwise suitable, at least until new technology becomes available to overcome the impact.

Examples of how land uses may be adapted to limit potentially adverse environmental impacts are:

rotational grazing around watering points, to limit degradation of the natural pasture by trampling and overgrazing;

the gazettement of particular areas as National Parks, Game Management Areas, etc., in order to protect identified flora and fauna of special interest;

the spraying of vegetation around newly constructed watering points, to limit tsetse fly hazard;

the provision of migration routes for wildlife between fenced ranches;

the limited construction of roads to control access to a fragile environment;

the control of stock movements to watering points, to limit the spread of infectious and contagious diseases.

The methodology of environmental impact assessment should be rigorously followed in any land evaluation of significant size. To assist in this, the International Union for the Conservation of Nature and Natural Resources (IUCN) has developed a comprehensive system for designating areas subject to adverse environmental impacts, and has drafted management specifications to alleviate specific impacts in these areas. Where the physical scale or the intensity of potential impacts are large, the assessment should be developed into an environmental impact statement. This contains an analysis of the costs and benefits of the proposed alternative methods of overcoming adverse impacts, and can be taken further to hold legal authority, to ensure that the methods are applied during plan implementation. If required, Munn (1975) provides full details of the specialized aspects of statements on environmental impact.

11.2 FINANCIAL AND ECONOMIC ANALYSIS

The tangible costs and benefits of extensive grazing will have been identified when describing the key attributes of the land utilization types, as given in Section 5. There, markets, labour, capital, materials, and yields and production are listed and examined. If physical evaluations are being undertaken, these descriptions are sufficient, but if an economic analysis is required then the costs and benefits of these attributes must be assessed in financial terms.

In a land evaluation there are two methods of combining the results of physical and economic assessments:

- i. In the two-stage approach, the first stage is mainly concerned with evaluation of an area in physical terms, and the second stage with subjecting the results of the physical evaluation to economic analysis.
- ii. In the parallel approach, the analysis of the relationships between land and land use proceed concurrently with economic and social analysis.

The two-stage approach is more commonly used, as it is more straightforward and can follow established procedures of economic assessment. It is valuable in broad evaluations for extensive grazing of large regions. In this approach only those land utilization types assessed as being physically suitable within specified land units are then analysed for their economic suitability, so that all have initially to be surveyed and matched with the land. The parallel approach is excellent when used by a well-trained and experienced team, as it leads to a concentration of field work in only those areas that are assessed as being economically viable, so saving time and energy during the physical evaluation.

Few examples of land evaluations for extensive grazing include any economic assessment; most end with a physical suitability classification. An exception is Ferguson (1983), who gives a financial cost-benefit analysis for a specific land unit, and compares physical land suitabilities with land suitabilities based on the results of cost-benefit analysis at current prices.

There are probably several reasons for this absence of economic analyses from land evaluations for extensive grazing. Given the same physical conditions, the results of economic analyses vary considerably with time, with changing prices of inputs and outputs, and with the manner in which costs and benefits are taken into account. There are also considerable differences in the details of financial and economic analyses, as described below. Also, in economic analyses, the percentage rate assumed for discounting has a significant effect on the outcome of the evaluation. However, economic evaluations are to be encouraged, as they force the land evaluation team to be precise about inputs required by suitable land utilization types and outputs to be expected in terms of yields and production.

The two main types of economic evaluation are termed financial and economic analyses. The aim of a financial analysis is to ensure that the livestock owner receives adequate income

from his enterprise, season by season and year by year. Where the economic viability of a whole community involvement with extensive grazing is to be evaluated, rather than that of an individual, then an economic analysis is required. It takes account of factors that can less readily be given in cash terms, such as subsidies and the effect on employment of land development. In short, where capital investment is not being considered, gross margin analysis is applied; where there is major capital investment, a discounted cash flow analysis is required.

An example will help to illustrate the difference between the more precise but narrow financial analysis and the broader economic analysis. If feed supplements are provided seasonally to livestock at a subsidized price, the price of the feed is used in a financial analysis of an enterprise. However, in an economic analysis, the cost to the community of the subsidized price must also be taken into account, as the subsidy has to be paid for by some means. Financial analyses give precise results which, however, are strictly limited in their usage, about tightly defined enterprises. Economic analyses are broader in scope and more generally applicable, but provide results that lack the precision of financial analyses.

In simple terms, a financial analysis in land evaluation is comparable to gross margin analysis, and economic analysis to gross margin analysis followed by discounted cash flow analysis. The procedures followed in both these types of analysis are in reality no different from those used in any financial or economic analyses. However, when used in extensive grazing, they are specifically applied to a comparison of different areas of land and of different types of extensive grazing that may profitably be practised on those areas. Where capital investment in an enterprise is relatively insignificant, then economic assessment can be based on gross margins. Where substantial capital investment is to be made, this investment must be analysed by setting the cost of the initial investment against the increased production in future years. In this context an example of a large investment is the purchase of cattle in an area recently cleared of tsetse fly and opened up for extensive grazing. Here gross margin analysis should be followed by discounted cash flow analysis, to provide a full economic evaluation of the recommended land uses.

The basic principles of gross margin and discounted cash flow analysis need to be grasped, in order that the economics of land evaluation can be understood. They are given in Price Gittinger (1982), and in Dent and Young (1981) and FAO (1984a), where they are specifically related to land evaluation. They are described here within the context of the more commonly used two-stage approach to economic assessment, which follows a well-defined sequence of activities.

11.2.1 Gross Margin Analysis

The analysis of gross margins allows for the determination of the profitability of a grazing enterprise for a livestock owner. For each land utilization type assessed as suitable, and for each land suitability class, the recurrent inputs are first estimated. Material inputs for extensive grazing can include groundwater watering points, drugs, mineral supplements, disinfectants and forage seeds, and non-material inputs include labour requirements for herding and veterinary services. The level of inputs required for a land utilization type to function

profitably will usually be higher on land that has been classified as being physically less suitable than on more suitable land.

Next comes the most difficult step; the estimation of production from each land use system that is being considered in the financial analysis. For each land utilization type/land unit combination, estimates must be given of the output of livestock products in quantitative physical terms. This may be relatively straightforward in the case of material products such as milk, meat, hides and skins, and dung for fuel, but will be more complicated when estimations are required of draught power and tourist revenues from game viewing.

Having estimated the amounts of inputs and outputs, their prices are next found. It will often be necessary to estimate future trends in prices, from which relative differences between those of products and inputs can be found.

As well as the variable costs of inputs and outputs, the fixed costs of production are also required in gross margin analysis. Fixed costs are all those that cannot be attributed to a specific grazing enterprise, or do not vary in proportion to the size of the enterprise. Examples of costs are for the maintenance of fences on ranches, cattle shed construction, drilling for water and for pumping groundwater.

In order to determine the gross margins, the information obtained so far is combined in two steps:

- i. Multiply inputs by their costs, to obtain variable costs, and yields by their prices, to obtain output. The gross margin of an enterprise is then the output minus the variable costs.
- ii. Combine the gross margins of each enterprise in proportion to the area of land occupied, and subtract the fixed costs, to give the net income. This is the profit or loss that the livestock owner will make.

The boundary between a land utilization type being suitable and not suitable, on economic criteria, is the point at which it achieves an assumed target income that will give a profit.

11.2.2 Discounted Cash Flow Analysis

Discounted cash flow, alternatively termed cost-benefit, analysis is required where substantial initial capital expenditure must be set against the profits derived from it at some future date. In this procedure first the output minus the variable costs of the extensive grazing production unit are calculated in a gross margin analysis. Then the anticipated initial capital expenditure is determined. This will frequently include the purchase of stock, the development of watering points and the construction of required veterinary facilities. Major land improvements will probably be met by the community in developing countries, and by bank loans to the livestock owners in developed countries. Economic and financial assumptions made at this point, about who pays for what and at what rates, can make as much difference to the outcome of a land suitability classification as can variations in land qualities.

Where an international bank or agency, or the national government, is responsible for funding major land improvements, economic calculations are based on social cost-benefit analysis. Here certain assumptions must be made about the overall costs of the improvements and the benefits that the community receives from their use. Real or shadow prices must be taken, reflecting the costs to the community, and it should be decided whether to cost the labour of the livestock owner and his family. A social discount rate should also be fixed, which will be lower than the current commercial rate for the long-term interests of the grazing community. A project life must also be assumed, which is an arbitrary cut-off date beyond which benefits received and costs incurred are excluded from the analysis.

The cash flows of inputs and production are next allocated by year, with substantial capital improvements being spread over several years. Benefits will generally build up as productivity of the extensive grazing system is developed. After a number of years it is assumed that capital expenditure is completed, recurrent costs and production are both steady, and net annual excess of benefits over costs is near constant.

The estimated costs and benefits over this period are then discounted and their present values calculated, to give the results of the discounted cash flow analysis as net present value, benefit-cost ratio and internal rate of return, defined as:

- i. Net present value is the present value of benefits minus the present value of costs.
- ii. Benefit-cost ratio is the present value of benefits divided by the present value of costs.
- iii. Internal rate of return is the rate of discounting at which the present value of benefits becomes equal to the present value of costs.

11.2.3 Results of Economic Evaluations

In economic evaluations the boundaries between land suitability classes are defined in economic terms, for example in gross margins per hectare as:

<u>Land suitability class</u>	<u>Gross margin per hectare (in \$)</u>
S1 highly suitable	Over 100
S2 moderately suitable	50-100
S3 marginally suitable	25-50
N1 currently not suitable	less than 25
N2 permanently not suitable	-

The marginally suitable/not suitable (S3/N) boundary can only be defined in economic terms, as there is no abrupt change at this boundary in the values of the physical land characteristics. It is rather the point at which it becomes unprofitable to practise a land utilization type, and making a profit changes to incurring a loss. Care should be taken in interpreting the results of economic evaluations that are provided in these terms, as their figures can give the air of precision to an otherwise qualitative evaluation of a land use system that cannot be justified.

Three features of an economic evaluation should be borne in mind when financial and economic analyses are being incorporated with a physical evaluation:

- i. It is time-dependent, in that the results vary over time with changes in relative costs and prices. In the short term this will not adversely influence the analysis, but longer-term trends over periods of years are harder to predict. Hence the reason for having a cut-off date and an arbitrary project life.
- ii. Gross margin analyses have very varying results where different major land uses are evaluated. This variation has important consequences where extensive grazing is being compared with other land uses.
- iii. Whereas financial evaluations involving gross margin analysis are relatively precise, economic evaluations that include discount cash flow analysis are of necessity based on a number of assumptions. The social discount rate and the project life-span are two values that are difficult to define precisely, but have a significant effect on an overall economic suitability rating.

In a survey area the results of economic evaluation need to be combined with those from physical evaluation, to produce an overall land suitability classification for each land unit. Economic criteria derived from financial or economic analyses that are available are:

- i. Income per capita at full production of the extensive grazing system, obtained from gross margin analysis.
- ii. Income per land unit, also obtained from gross margin analysis.
- iii. Measures of return on capital invested, per capita or per land unit, obtained from discount cash flow analysis, expressed in terms of net present values, benefit-cost ratios and internal rates of return.

From a spatial viewpoint the more useful combination of physical and economic evaluations is the one that provides a suitability classification by land units. The physical suitability of each land utilization type and the income derived from its application are taken as being applied uniformly over each land unit of known area. The overall suitability of the unit could then provisionally be taken as the lower of the two suitability classes derived from the physical and economic evaluations.

11.3 SOCIAL ANALYSIS

The descriptions of the key attributes of land utilization types that are proposed for an area are the basis of social analyses. The key attributes that are concerned with social issues and that may positively affect the suitability rating should now be reconsidered. These include markets, labour, land tenure and land use rights, and technical knowledge and attitudes. Changes in land uses based on findings of the physical and economic evaluations may have specific effects on their social attributes, which in turn may influence the final suitability ratings.

Common social influences on the suitability for extensive grazing involve:

- i. legislation covering land tenure, land use rights to communal grazing, and rights to livestock and their output, which can be major constraints to successful implementation of land use plans;
- ii. locations and sizes of necessary infrastructure, including markets, abattoirs, and milk collection centres;
- iii. support services that can be provided to livestock owners and herders, particularly veterinary care, extension and training;
- iv. labour constraints, which may require modifications to the land utilization types where they are otherwise suitable and profitable, but where insufficient manpower is available for them to be practised;
- v. possible population displacement, and population supporting capacities under different types of extensive grazing in comparison with other major land uses.

12. LIVESTOCK PRODUCTIVITY AND POPULATION SUPPORTING CAPACITY

12.1 LIVESTOCK PRODUCTIVITY

The livestock productivity model considered here includes five steps:

1. estimation of primary productivity;
2. characterization of livestock systems;
3. determination of herd performance;
4. estimation of feed requirements;
5. quantification of secondary productivity.

The model is framed by a land resources database which contains several layers of information on the physical resources of climate, landforms and soils. These are combined to produce agro-ecological land units, termed cells, within which there is a degree of homogeneity of climatic, landform and soil qualities. In their application to extensive grazing, these cells are comparable to the land systems described in Section 7, but they pay more attention to climatic controls on the environment. They are also made up of combinations of square grid cells, so that information about them can be readily stored in computers. The land qualities of the climate, landforms and soils resources are similar to those given in Section 8.

Feed supplies available to livestock in each agro-ecological cell are estimated from these resources data in part 1 of the livestock productivity model. Part 2 is comparable to a quantitative description of land utilization types, in that the livestock systems to be considered are characterized in terms of livestock types, input levels, production systems and herd structures. In part 3, the potential productivity of different types of livestock are quantified, according to different climatic zones and input levels in which they are reared.

Part 4 formulates the livestock feed requirements, taking into account maintenance as well as production needs. These are comparable to land use requirements in land evaluation, with critical values of the factor ratings of each land utilization type being quantified from data available in parts 2 and 3 of the model.

Finally, in part 5, the feed requirements of livestock systems as given in part 4 are matched with the feed supplies as given in part 1, resulting in quantified statements about the livestock productivity of each agro-ecological cell, given in terms of suitability classes S1, S2, etc. Where output is liable to be affected by constraints such as high temperature stress, shortage of drinking water or tsetse flies, these are taken into account in assessing productivity and the suitability classes are downgraded accordingly. To assist land use planning, the assessments of each agro-ecological cell are usually grouped by administrative

divisions, as these provide a common spatial framework for plans. Kassam **et al.** (1989) have taken these procedures a step further.



Plate 6 Brahman cows provided through a technical assistance programme in the Philippines. The animals were sent to communities where training courses on improved livestock husbandry had been held, and were crossed with local cattle. FAO photo by F. Mattioli.

12.2 POPULATION SUPPORTING CAPACITY

Having produced quantitative values of the productivity of extensively grazed land, the livestock model formulated by Kassam **et al.** (1989) has been developed to determine how many people can subsist on this type of land use, practised on a given land unit. This is termed the population supporting capacity of a land use system. It is a particularly valuable technique for assessing large areas of land, as pastoral production systems are the dominant type of land use in at least one quarter of the world, and where they occur they are essentially subsistence systems.

An estimate of the capacity of an area of land to support people whose total nutritional requirements are derived from extensively grazed livestock is however

impractical when taken in isolation. Few livestock herders have no access to other food sources, made available, for example, by the sale of livestock products or during periods of sedentary pastoralism. However, it is important that base values are determined of population supporting capacities based wholly on extensive grazing, which can then be incorporated with values obtained from other land uses. This is because land use planning for optimum subsistence production will usually involve a combination of major land uses, and the productivity of each should first be separately determined before they can be integrated into the most suitable planning scenario.

The basis for determining the capacity of an area of land to support people who subsist on extensive grazing is the output from a land evaluation. It gives the most productive types of pastoralism, in physical terms and, if an economic assessment has also been completed, in financial and economic terms. The potential for primary productivity is converted into secondary livestock products that can include meat, milk, hides and skins, wool, fuel and draught power.

The assessment continues with the calculation of edible calories and protein that would be produced by the livestock products, derived from information on the nutritional composition of these products. Dietary and other constraints, such as minimum protein requirements for human growth, are applied to estimate potential population supporting capacities at different input levels. These are converted into potential population densities, in persons per hectare, given by administrative divisions. These densities can be compared with present and anticipated future population densities. They can also be examined against food demands, socio-economic needs, and current policy issues about land use planning.

Estimates of population supporting capacities based on pastoral production systems have been made by Pratt and Gwynne 1977, Blair Rains and Kassam 1980, and Jahnke 1982, for low rainfall areas in West and East Africa and, as shown in Table 12.1, are typically in the order of 2 persons per sq km. The table is indicative, and relates population to one land characteristic only, that of mean annual rainfall.

Table 12.1 POPULATION SUPPORTING CAPACITIES OF EXTENSIVE GRAZING SYSTEMS IN SEMI-ARID AFRICA (according to calorie requirements met exclusively by meat and milk, from Jahnke 1982)

Mean annual rainfall (mm)	Population supporting capacity	
	People/sq km	ha/person
200	1.2	83
300	1.8	56
400	2.4	42
500	2.9	34
600	3.5	29

Where mean annual rainfall is below about 400 mm in the tropics, extensive grazing may well be the only viable land use option open to subsistence agriculture. But at 400 mm and above, rainfed annual cropping becomes increasingly important in meeting dietary requirements. As illustrated by Jahnke 1982, if only one-tenth of an area receiving 400 mm is cultivated, and if only 400 kg/ha of millet are harvested from this area, the food productivity of cropped land is still seven times higher than that of land producing food via livestock. If this quantity can be produced annually it will meet the subsistence grain requirements of two adult livestock herders.

From this it is clear that where cropping can be incorporated with extensive grazing in an integrated land use system, the population supporting capacity of the area is much higher than where people are dependent on extensive grazing alone. The relative merits of these two major land uses for supporting people can be compared further when an economic assessment is also included in a land evaluation. Frequently, extensive grazing has a higher income per capita than arable cropping and is less damaging to the environment, but it is much less favourable in terms of income generated per unit area and of population supporting capacity.

13. PRESENTATION OF RESULTS

13.1 REVIEW AND FIELD APPRAISAL

Provisional land use alternatives for a range of land utilization types concerned with extensive grazing have now been prepared, and should be subjected to an independent assessment by individuals not involved in the evaluation itself. The group should include local livestock owners and government representatives, rangeland and livestock husbandry specialists, and those who were consulted when the evaluation was being planned.

Their task is to confirm or alter within reason the suitability classes given to the land units, using their own local knowledge, common sense and experience. The group should visit sites in each suitability class, accompanied by the surveyors who have been responsible for the evaluation, and see their descriptions of land utilization types and draft maps of land suitability. This field check is particularly important if the classification has been prepared with the aid of computers, to ensure that errors have not crept into the results. When the group identifies assessments that do not agree with their experienced judgments, the most likely sources of error will be in the sets of critical values that comprise the factor ratings of the land use requirements.

Future financial investment and implementation of land use plans depend on the final land evaluation being endorsed by this independent group. Many livestock projects aiming to improve extensively grazed areas are unsuccessful due to incorrect assessments of physical, economic or social suitability, which could have been avoided if they had been subjected to a thorough external review.

13.2 LAND SUITABILITY CLASSIFICATION

The final suitability classification is based on the findings of this external assessment, combined with the results of the physical, economic and social evaluation and an environmental impact assessment. Provisional suitabilities may be revised following comparison of land uses with the land.

Two basic criteria should be followed. The boundary between suitable and not suitable land, usually classed as S3 and N1, is fixed as the point at which a profitable enterprise becomes a loss-making one. Secondly, no land can be classed as suitable if the environmental impact and social consequences of the intended uses are not also acceptable.

It is recommended that the final land suitability class of each land use system is the lowest class obtained from the provisional suitabilities. These should be tabulated together by land use systems, to provide a condensed overview of the separate assessments and an aid in the subsequent choosing between suitable land uses. This approach provides a straightforward method of rejecting any land uses that are not up to standard. Clear statements should accompany the tables of the grounds on which the final suitabilities are based.

The final classification should follow that given in Section 2.3, with up to four levels of suitability being employed: orders, classes, subclasses and units. Following this structure, each land unit in the survey area should be classified for its fitness for each defined land utilization type.

13.3 PRESENTATION OF RESULTS

The results of an evaluation should be presented so that they are readily understood by intended users who require clear and sufficient information on which to base their individual and collective decisions on land use planning and land management. There are four categories of users, each having different backgrounds and information requirements:

- i. Senior administrators and planners are the first category. They should not be expected to have technical training, and they will require a succinct summary of the recommendations. The major issues on which these are based should also be given and not oversimplified, and the range of options open for development must be clearly presented in map, table and report form.
- ii. Technical staff, who will be directly involved in implementing the recommendations, form the second and probably the largest category of users. It is the responsibility of the agency that commissioned the evaluation to ensure that the information given in the report is disseminated to these staff in a form that they can apply. Their commitment to implementation will be strengthened if they understand the reasoning behind the work they will be required to complete.
- iii. Professional workers and specialists form the third category. The report must meet the professional and technical standards of the international community, and of the advisers to funding agencies.
- iv. Pastoralists whose livelihoods are made within the survey area will also require information. They may be barely literate, but they will often possess the greatest amount of practical knowledge about extensive grazing and care of livestock. The findings of a land evaluation could be presented to them using audio-visual techniques, preferably supported by illustrated booklets compiled in their vernacular language. The willing cooperation of pastoralists is essential for the successful implementation of a grazing programme, and a range of measures should be considered for transferring technical knowledge to them.

For the first three categories of users, the results of a land evaluation should be given in a main report, and technical details in supplementary reports or appendices. These will be of particular value if the land evaluation has to be revised or updated in the future as land uses develop and change.

The six principal sections of the main report are as follows:

- i. synopsis of findings and recommendations, which can be termed an executive summary, based on the objectives of the survey;

- ii. definitions and descriptions of land utilization types suited to the survey area;
- iii. assessment of the suitability of each land utilization type for each mapped land unit;
- iv. predictions of the economic and social consequences of applying each land utilization type on each land unit for which it is physically suitable;
- v. assessment of the environmental impact of each land utilization type on each land unit;
- vi. management specifications for land utilization types on each of the land units for which they are suitable.

In land evaluations for extensive grazing, vegetation surveys are frequently conducted. Where these, or any other specialized studies on climatic variables, animal diseases, linkages between major land uses, etc., are carried out, the results should be incorporated as additional sections in the main report.

13.3.1 Maps and Tables

These results should be presented wherever possible in the form of maps, tables and accompanying text, bearing in mind that tables are more frequently read than text, and maps more frequently than tables. Hence maps should be able to be read independently of text or tables, by having self-explanatory tabular legends written in their margins.

Compilation of land suitability maps can be by one of three means:

- i. At the largest scale of the survey one large map is prepared of the land units. The mapping legend shows the land suitability classes of each of these units for each land utilization type, and the sizes of the units, as in Table 13.1. For convenience here alpha-numeric titles are given to the land units and land utilization types; in practice the units should be named according to local place names, and the land uses described by abbreviated titles such as 'sedentary pastoralism with smallstock and subsidiary cattle'.
- ii. The most common and most easily understood method of presenting land evaluation results is by means of a series of land suitability maps, individually produced for each land utilization type, as in Figure 13.1. Their internal boundaries are those of the land units, and within them the suitability of each unit is written on the map and emphasized by shading or colouring. They are compiled at a smaller scale, and each map is preferably underlain by sufficient topographical information printed in half-tone to aid location in the field.
- iii. If the land evaluation assesses many land utilization types, a summary map may help users to grasp quickly the principal findings. This map should show the recommended use or uses for each land unit, based on the highest suitability class

assigned to each unit, and titled, for example, ‘development potential for extensive grazing’. It will be of particular value to decision-makers who need a map that is easily understood when read in conjunction with the executive summary report.

Table 13.1 TABULAR LEGEND OF SINGLE LAND SUITABILITY MAP

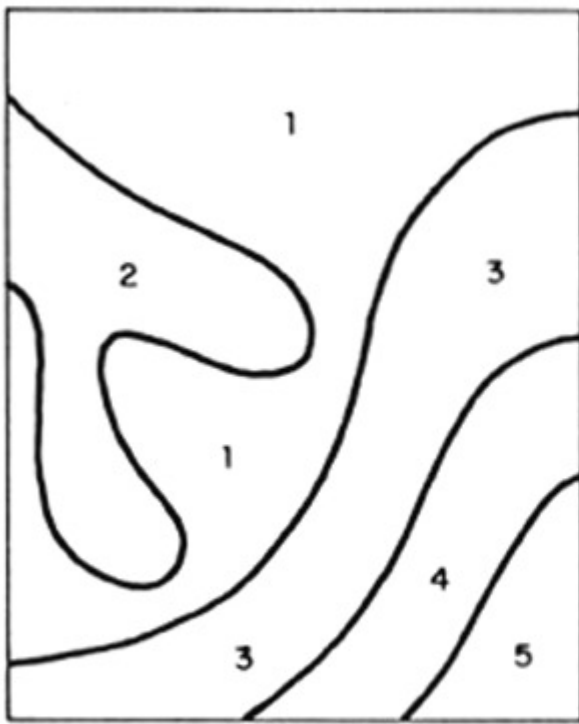
Land Units	Area ha	Land Utilization Types					etc.
		A	B	C	D	E	
1	10,560	S2m	S3m	S2e	N1f	s2m	
2	24,380	S2r	S2n	S1	S3r	S1	
3	9,750	S3e	N1m	S2e	N2r	S2m	
etc.							

A large amount of supporting information can be presented in tables and subsidiary maps, of which the more useful are:

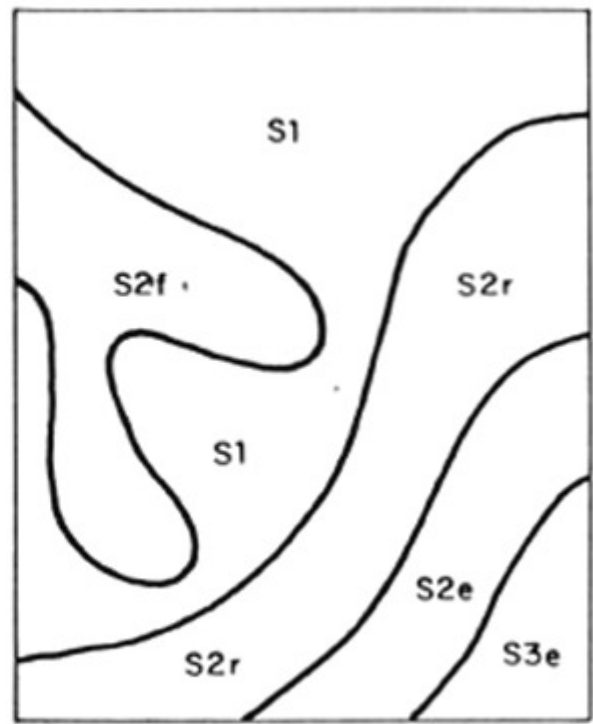
- i. summary descriptions of the land utilization types;
- ii. tables of land use requirements of the land utilization types;
- iii. summary values of the measured land characteristics of each land unit (full analytical results of surveys of soil, water, vegetation, etc., should be placed in appendices);
- iv. land qualities of the land units;
- v. present land uses, with areas shown on maps and livestock yields and production in tables;
- vi. summary findings of economic, social and environmental assessments;
- vii. management specifications for suitable land use systems.

13.3.2 Main text of report

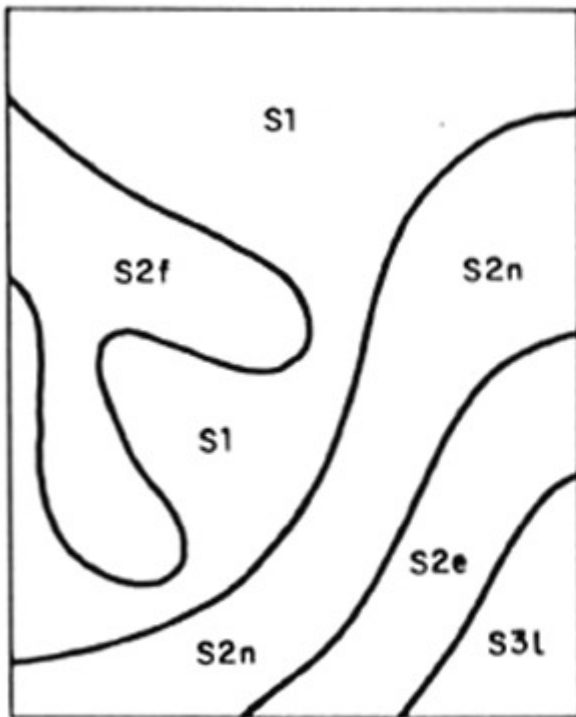
Land evaluation reports vary as widely as the objectives of the surveys on which they are based. A major variation is in the level of detail of descriptions of the land utilization types, ranging from summary descriptions fixed early in the survey to detailed descriptions subject to successive modification as the evaluation progresses. In the



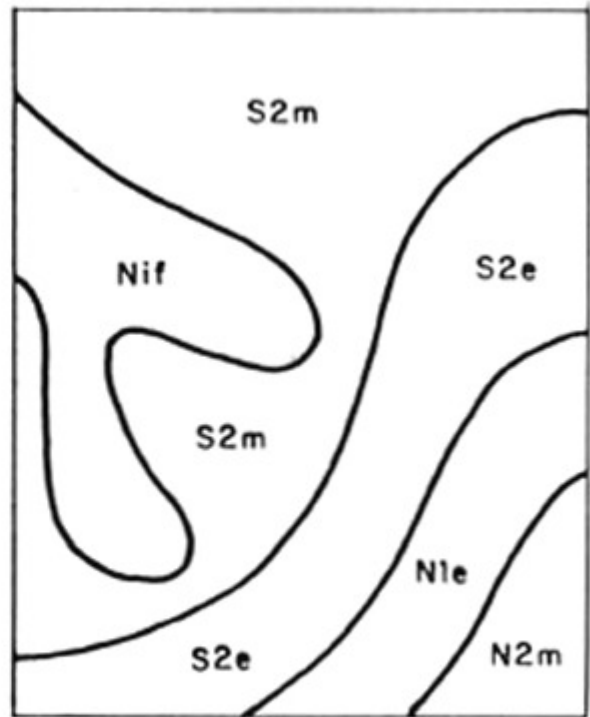
LAND UNITS



CAMELS AND SMALLSTOCK



TRANSHUMANT CATTLE



SEDENTARY PASTORALISM

Figure 13.1 Individual land suitability maps for different land utilization types

former case, useful in reconnaissance surveys, land utilization type descriptions are a small part of the report; in the latter they form a major output, as in semi-detailed surveys of more complex areas where extensive grazing may be only one of several major land uses under consideration. Report contents will also vary according to whether the evaluation is of only physical suitability or also includes an economic analysis.

Given these variations in emphasis, the text of the report should include the following sections:

Preface

Executive summary of results and recommendations

1. Objectives and initial assumptions of the survey
 - Constraints, opportunities, issues and policies
2. Physical, economic and human setting of the area
 - Climate, geology, landforms, soils, vegetation, hydrology, land uses, population and settlement, land tenure, infrastructure and services
3. Methods of survey (and of specialized studies, if required)
 - Evaluation procedures and logistics
 - Basic resources survey methodology
 - Specialized investigations - vegetation survey, livestock census, economic studies, etc.
 - Data analyses
4. Land utilization types
 - Descriptions of each type
5. Land use requirements
 - Land use requirements and limitations for each land utilization type
 - Methods of factor rating
 - Classes of factor ratings for land utilization types
6. Land units
 - Descriptions of each land unit
 - Land qualities and land characteristics of each land unit
7. Matching
 - Procedures and results
 - Provisional land suitability classification
 - Outline economic and social assessment (if only physical evaluation is required)
8. Environmental impact assessment
(if required)

9. Economic and social analysis

- Gross margin analysis
- Discounted cash flow analysis
- Social impact of land use changes

10. Recommendations

- Final results of suitability classification
- Recommended land use systems
- Outline management specifications for land use systems
- Estimated yields and production

Appendices

- Results of climatic, agro-ecological, soil and vegetation analyses
- Results of specialized surveys
- Detailed management specifications for each suitable land utilization on each land unit

Glossary and references.

13.4 MONITORING AND REVISION

The results of a land evaluation appear in an organized, systematic format in the final maps, tables and report, but they are frequently derived from a cyclical process of survey, description and analysis. Land utilization types are refined as the survey proceeds; emphasis on the measuring of relevant land characteristics may vary with intended uses of the land; economic and social analyses can draw attention to unsuitable land uses not foreseen by the physical evaluation; the independent review of the provisional land suitability classification will usually require changes before it is finalized.

Further adjustments are likely when the findings are implemented in the broader context of land use planning. Monitoring of a land evaluation, and revision of components where feasible and necessary, will enhance its usefulness and act as a valuable training exercise for future evaluations.

The results of a land evaluation will contribute to meeting specific objectives in extensive grazing and development. These include:

- i. the setting of policy guidelines and priorities;
- ii. the assessment of present and future needs of pastoralists, and the systematical evaluation of the ability of the land to meet them;
- iii. the proposal of changes in land uses through the identification of sustainable alternatives;
- iv. the recommendation of improvements that can be made in management of livestock reared by extensive grazing.

Although contributing to these objectives, land evaluation is only a means to the end of improved land use, achieved through land use planning. For this it is essential that a plan for grazing development and management, and the means for its implementation, are drafted. It is at this point that land evaluation merges into land use planning, which requires that further wide-ranging studies are undertaken outside the scope of land evaluation. These studies will be both subsequent to the evaluation and part of a broader survey of which evaluation is an integral part. The users of these guidelines however have a responsibility to see that the results of their land evaluation are made available without delay, so that they can be implemented through the wider context of land use planning.

APPENDIX A. ANIMAL NUTRITION AND LIVESTOCK UNITS

A.1 ANIMAL NUTRITION

In order to support body processes and to promote production, animals must receive regular supplies of nutrients. These are broadly defined as protein (Section A.1.1), energy (A.1.2), minerals (A.1.3), vitamins (A.1.4) and water. Under extensive systems of animal husbandry, the animal may not be able to obtain an adequate diet throughout the year, because of the seasonal variation in the quantity or composition of the herbage.

Nutrient requirements of animals differ with species, age and the types and levels of production. For example, ruminant animals are able to digest bulky cellulose-rich plant material which are indigestible to sheep and horses. Food requirements are frequently divided into those required:

- i. for the maintenance of body functions, and
- ii. for growth, the production of milk and for work.

Production requires fodder of better quality than that required for maintenance only. When the nutritive quality of the fodder falls below that required for maintenance, body tissues are depleted and there is a loss in weight.

In order to predict animal performance it is necessary to measure the nutrient content of the food and the nutrient requirements of the animal. Several methods have been developed for measuring all the important nutrients.

Estimation of the amount and type of feed an animal ingests needs to be carefully assessed, as free-grazing animals are able to select their diet. Two methods of estimation are in general use:

- i. imitative sampling, based on accurate observation and timing of the plants and plant parts consumed, supplemented by a botanical survey of the observed area; and
- ii. the oesophageal fistula, which enables samples to be taken from the material actually consumed by the animal.

A.1.1 Protein

Proteins are nitrogen-containing organic compounds that are present in all living matter and are essential for animal production. Adult ruminant animals obtain the protein they require for body maintenance and growth from plant material via micro-organisms that are present in their gut. These micro-organisms also enable the ruminant animal to utilize non-protein nitrogen, which they do in proportion to the amount of protein they use. Therefore only the nitrogen content of a fodder, rather than its protein content, needs to be

determined by chemical analysis. The content of nitrogen is determined by traditional or automated Kjeldahl techniques, and the percentage of crude protein (CP) is calculated by multiplying the nitrogen percentage by 6.25.

Only a proportion of the constituents eaten by the animal is assimilated. The proportion of protein is termed the digestible crude protein (DCP). This has been determined using animals or sophisticated laboratory techniques for a wide variety of fodders. From the results formulae have been developed that satisfactorily predict the digestible crude protein content when only the crude protein percentage is known.

For temperate grasses:

$$\text{DCP} = 0.929 \text{ CP} - 3.48 \text{ (SD } \pm 0.66 \text{) (Holter and Reid 1959)}$$

For tropical grasses:

$$\text{DCP} = 0.899 \text{ CP} - 3.24 \text{ (SD } \pm 0.84 \text{) (Milford and Minson 1965).}$$

In temperate grasses the critical level of CP in fodder, below which voluntary intake of dry matter by beef cattle and sheep is depressed, is 8.5 percent. In tropical grasses the equivalent is 7 percent, or approximately 1 percent of nitrogen (Whiteman 1980). At one extreme a level of 3.8 percent CP (0.6 percent N) is sufficient to maintain zebu cattle (**Bos indicus**). At the other, the protein requirements for maximum growth of steers, young stock and lactating animals are greater than those of older and non-lactating animals (NRC 1978, 1981, 1984, 1985).

Low levels of DCP in herbage likewise depress the intake of food by animals, and any limit on the quality of feed is important to determine. Seasonal low levels of DCP in many extensive grazing systems in the tropics are the principal cause of low animal production. Some modification is usually required to assessments of DCP obtained from conventionally-cut samples, as in most situations animals are able to select herbage which may have double the CP content of cut samples.

A.1.2 Energy

Various methods are available to evaluate the energy requirements of animals:

i. Total Digestible Nutrients (TDN)

This method is often referred to in the older literature, particularly American. TDN is calculated by summing the results of the Weende system of proximate analysis (Gohl 1981) by:

$$\text{DCP} + \text{digestible carbohydrate (N-free extract} + \text{crude fibre)} + 2.25 \times \text{digestible crude fat (ether extract)}.$$

One kg of TDN is often taken as the equivalent to 4 400 kcals of digestible energy (DE) (explained under Partitioning of Energy below).

ii. Digestibility value (D value) or Digestible Organic Matter (DOM)

Digestibility is measured by using animals (in vivo) for digestion experiments or estimated by various laboratory (in vitro) methods and given as percentage of dry matter. D values are similar to TDN for forages with a low percentage of lipids.

iii. Unité Fourragère (UF) or Scandinavian Feed Unit (SFU)

This method of evaluating energy requirements is used in France and its former colonies, and in Scandinavian countries. A UF or SFU feed unit is equivalent to the energy content of 1 kg of barley. All feeds are expressed in this system as the effect they have on animal performance as compared to the effect of 1 kg of barley. For conversion, 1 UF is equivalent to approximately 3 820 kcal DE.

A.1.2.1 Partitioning of energy

The energy of feedstuffs can be expressed in terms of joules (J), calories (C) or kilocalories (kC). Not all the energy in feed is completely available for herbivores. Therefore a system of partitioning the energy in feed has been developed, in order to determine that which is available. It is related to the various losses that occur in the animal, with the various energy fractions being determined or calculated from the feed.

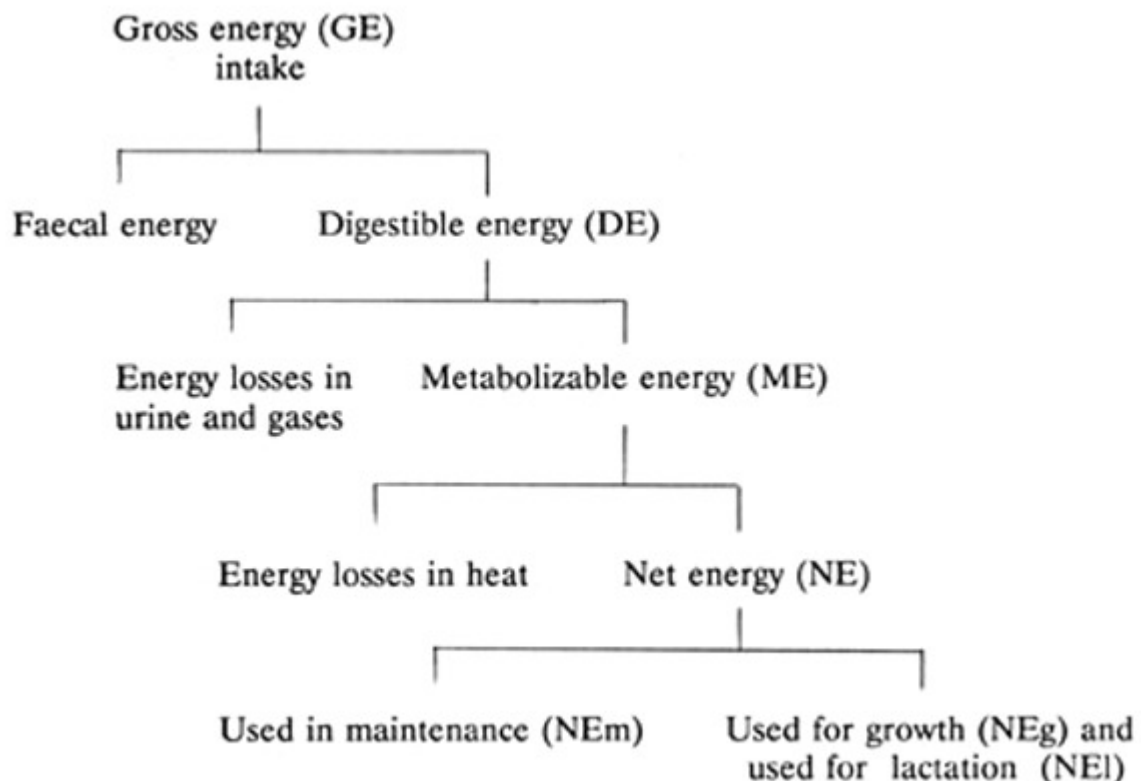


Figure A.1

Diagram showing use of energy by animals

Animal requirements can also be calculated from 'feeding trials', including those using a respiration chamber. The Net Energy, strict maintenance only, resting metabolism (NEm) requirements have been proved to be very similar for different animals of the same size when they are acclimatized to 20°C ambient temperatures. This requirement can be given in a simple formula for most large herbivores:

$$\text{NEm} = 70 \times W^{0.73}$$

where NEm = net energy requirement at maintenance in kC

m

W = body weight in kg.

The energy requirements of animals for growth, activity, pregnancy and lactation are in general rather complicated, and are given in the form of tables in NRC 1978, 1981, 1984, 1985. The system of GE, DE, ME and NE in Figure A.1 is at present used in most anglophone countries.

A.1.3 Minerals

The essential minerals for livestock are calcium, phosphorus, magnesium, potassium, sodium, iron, copper, cobalt, zinc and manganese (Ca, P, Mg, K, Na, Fe, Cu, Co, Zn and Mn). Mineral concentrations in feeds are determined by spectrophotometry and chemical methods. The requirement of animals for these elements are known to varying degrees of precision, since what are adequate levels of several of them are determined by relative levels of others. The requirements of several minerals are however well known.

The phosphorus requirements of animals have been most widely investigated, and it has been determined that 0.2-0.25 percent phosphorus in fodder is adequate for most categories of livestock. The calcium-phosphate ratio used to be considered of importance, but may not be so, provided the level of phosphorus in the feed is adequate. However, many tropical forages have less than 0.1 percent phosphorus, and this is considered inadequate.

Although tropical forages are a poor source of many minerals in the dry seasons, evidence of mineral deficiencies most commonly occurs during the wet seasons. Then, the provision of mineral supplements, such as residues from the industrial processing of seeds, is most beneficial. The usual explanation given for wet season mineral deficiency is that in this period animals gain weight because of adequate supplies of protein and energy. Therefore their mineral requirements are high. During the dry seasons there is little or no growth of forage and their mineral requirements are correspondingly lower.

A.1.4 Vitamins

A number of organic compounds are necessary for animal health, although only in very small quantities; these chemically unrelated substances are collectively termed vitamins. The micro-organisms in the guts of ruminant animals are able to synthesize adequate

amounts of several vitamins. Other vitamins, or precursor substances from which vitamins are formed in the bodies of animals, are normally present in natural vegetation in adequate amounts for most of the year. The period when vitamins are most limited is when the forage is dry and possibly deficient in vitamin A. This deficiency can result in reduced fertility of animals.

A.2 LIVESTOCK UNITS

In order to compare the suitability of different areas of land when grazed by different species of livestock, they can be described by means of a common reference unit. This is termed a tropical livestock unit (TLU), equivalent to an animal of 250 kg

0.73

liveweight, or preferably of 250 kg metabolic weight. Metabolic weight rather than liveweight is recommended, as voluntary feed intake is proportional to the metabolic

0.73

weight of an animal, which is liveweight kg and is related to the voluntary feed intake of the animal. Table A.1 gives liveweights, metabolic weights and TLU conversion factors based on metabolic weights for the common animals that graze extensively.

Table A.1 **WEIGHTS AND TLU CONVERSION FACTORS OF LIVESTOCK**
(after Jahnke 1982)

<u>Species</u>	<u>Liveweight</u>	<u>Metabolic weight</u>	<u>TLU conversion factor</u>
Camels	250 kg	56 kg	1.0
Horses	200	48	0.85
Cattle	175	43	0.75
Mules	175	43	0.75
Llamas	150	39	0.7
Donkeys	125	34	0.6
Alpacas	50	17	0.3
Sheep	25	10	0.2
Goats	20	9	0.15

These figures relate to mature animals. It should be noted that small animals and juveniles have higher metabolic rates than those of larger or older animals, and relative to their size they require more food. Daily dry matter food intake varies from 1.5 to 6 percent of body weight, the higher figure relating to fast-growing juveniles. When their maintenance alone is required, it is satisfactory to estimate the fodder intake of mature cattle and sheep as 1.5-2 percent of body weight.

Table A.2 GRASS CONTENT, CATTLE INTAKE AND SURPLUS/DEFICIT OF CRUDE PROTEIN AND SOME MINERALS IN MONGU DISTRICT, ZAMBIA. Source: Mulungushi (1986)

Terrain/Location	CP	P	Na	K	Ca	Mg	Mn
LOWLANDS							
1. Kataba valley							
a. Content % DM	3.8	0.37	0.07	0.49	0.12	0.04	
b. Calculated intake g	273	267	15.10	35.1	8.64	2.97	436 (ppm)
c. +Surplus/-Deficit g	- 195	+ 12.6	+ 1.50	+ 13.5	- 5.30	- 5.6	+ 396 (ppm)
d. % Surplus/Deficit	- 41	+ 90	+ 41	- 62	- 38	- 62	+ 990
2. Litoya valley							
a. Content % DM	7.0	0.20	0.08	2.7	0.3	0.2	
b. Calculated intake g	504	14	5.76	194.0	21.6	14.4	379 (ppm)
c. +Surplus/-Deficit g	+ 36	0	+ 2.16	+ 172	+ 7.6	+ 5.8	+ 339 (ppm)
d. % Surplus/Deficit	+ 7	0	+ 60	+ 800	+ 54	+ 65	+ 47
3. Looma plain							
a. Content % DM	2.3	0.10	0.004	0.22	0.11	0.05	
b. Calculated intake g	165	0.70	0.3	15	7.9	3.6	91 (ppm)
c. +Surplus/-Deficit g	- 302	- 3.33	- 3.2	- 5.7	+ 1.6	- 5.0	+ 51 (ppm)
d. % Surplus/Deficit	- 64	- 95	- 88	- 26	- 43	- 58	+ 127
4. Nalikuwanda Lui							
a. Content % DM	3.4	0.4	0.004	0.3	0.1	0.2	
b. Calculated intake g	244	28	0.3	21.6	7.9	15	129 (ppm)
c. +Surplus/-Deficit g	- 224	+ 14.0	- 3.2	0	- 6.1	+ 6.4	+ 89 (ppm)
d. % Surplus/Deficit	- 49	+ 50	- 88	0	- 43	+ 74	+ 222
5. Zambezi floodplain							
a. Content % DM	7.0	0.07	0.1	1.8	0.2	0.1	
b. Calculated intake g	504	5	7.9	129	15	7.9	567 (ppm)
c. +Surplus/-Deficit g	+ 36	- 9	+ 4.3	+ 108	+ 10	- 0.79	+ 527 (ppm)
d. % Surplus Deficit	+ 7	- 64	+ 119	+ 500	+ 7	- 9	>+ 1000
UPLANDS							
6. Mweeke upland							
a. Content % DM	3.0	0.04	0.004	0.5	0.09	0.1	
b. Calculated intake g	216	2.88	0.3	36	6.48	7.9	119 (ppm)
c. +Surplus/-Deficit g	- 252	- 11.22	- 3.2	+ 14.4	+ 7.52	- 0.7	+ 79 (ppm)
d. % Surplus/Deficit	- 53	- 79	- 88	+ 66	- 53	- 8	+ 197
7. Kaande upland							
a. Content % DM	3.9	0.09	0.002	0.4	0.1	0.1	
b. Calculated intake g	280	4.68	0.1	28	7.9	7.9	132 (ppm)
c. +Surplus/-Deficit g	- 187	- 9.32	- 3.5	+ 7.2	- 6.1	- 0.7	+ 92 (ppm)
d. % Surplus Deficit	- 39	- 66	- 97	+ 33	- 43	- 8	+ 230

DM = Dry matter; CP = Crude protein

Cattle maintenance requirements:

CP	468 g d ⁻¹	(NRC 1970) Assuming CP as 6.5% of DM intake
CP	14.0 "	(NRC 1970)
Na	3.6 "	(Whiteman 1976)
K	21.6 "	(Whiteman 1976)
Ca	14.0 "	(NRC 1970)
Mg	8.6 "	(Whiteman 1976)
Mn	40 ppm d ⁻¹	(Whiteman 1976)
DM	7200 g d ⁻¹	(NRC 1970)

Table A.3 CONCENTRATIONS OF MINERALS IN GRASS AND THEIR INTERPRETATION IN TERMS OF DEFICIENCIES/SURPLUSES FOR GRASS PRODUCTION (MAY - JUNE) IN MONGU DISTRICT, ZAMBIA (adapted from Mulungushi 1986)

No.	Location of grass sample	1	2	3	4	5		6		7		8
		% N	% P	P/N ratio	P and/or N limitation	% K	100 K/N	% Ca	100 Ca/P	% Mg	100 Mg/P	ppm/Mn
1	Zambezi Floodplain	0.77	0.07	0.092	-	0.74	96 D *	0.26	359 S *	0.11	148 S *	236 S *
2	Namitome valley	0.57	0.07	0.126	-	0.78	137 S	0.19	269 S	0.12	179 S	326 S
3	Mwiilwe dambo (dry part)	0.42	0.01	0.014	P+N	0.33	78 D	0.31	5032 S	0.07	1096 S	251 S
4	Mwiilwe dambo (wet part)	0.63	0.07	0.108	-	1.27	202 S	0.31	458 S	0.12	174 S	339 S
5	Mawama dambo	0.70	0.11	0.156	N	0.49	71 D	0.28	254 S	0.14	132 D	276 S
6	Kataba upland	0.36	0.04	0.103	N+P	0.16	45 D	0.06	150 S	0.07	176 S	48 S
7	Kataba valley (Sianda)	0.60	0.05	0.077	P	0.49	81 D	0.12	258 S	0.04	88 S	436 S
8	Kataba valley (Liamutinga)	0.72	0.04	0.061	P	0.62	86 D	0.13	294 S	0.03	78 S	366 S
9	Kataba valley (Kataba)	0.65	0.04	0.067	P	0.80	123 S	0.26	608 S	0.13	31 D	696 S
10	Litoya valley	1.12	0.20	0.183	-	2.06	238 S	0.31	150 S	0.23	108 S	379 S
11	Nakata dambo	0.41	0.05	0.114	N+P	0.30	72 D	0.08	180 S	0.04	83 S	45 S
12	Looma plain	0.58	0.09	0.156	N	1.51	262 S	0.22	244 S	0.07	75 S	1564 S
13	Looma plain (wet)	0.36	0.02	0.051	P+N	0.22	61 D	0.11	655 S	0.05	268 S	91 S
14	Lui valley (Nalikhanda)	0.55	0.05	0.091	P	0.28	51 D	0.10	201 S	0.17	342 S	129 S
15	Zambezi floodplain (Liangati)	1.12	0.08	0.069	P	1.84	164 S	0.18	232 S	0.10	125 S	567 S
16	Mweeke upland	0.48	0.04	0.078	P+N	0.49	102 S	0.09	241 S	0.11	284 S	119 S
17	Lukulo dambo	0.31	0.00	0.010	P+N	0.16	51 D	0.14	4516 S	0.08	2506 S	72 S
18	Kaande upland	0.62	0.09	0.15	P+N	0.35	56 D	0.09	106 S	0.08	86 S	132 S

* D = Deficit; S = Surplus

4. P = Phosphorus limiting; N = Nitrogen limiting

P or N - criteria for P/or N limitation: P < 0.05% = P deficiency

N < 0.5 % = N deficiency

P/N > 0.15 = N deficiency

P/N < 0.05 = P deficiency

5. Potassium - criterion for surplus or deficiency: 100 * K/N > 100 = surplus; < 100 = deficiency (Bergmann & Neubert, 1976)

6. Calcium - criterion for surplus or deficiency: 100 * Ca/P > 60 = surplus; < 60 = deficiency (Bergmann & Neubert, 1976)

7. Magnesium - criterion for surplus or deficiency: 100 * Mg/P > 35 = surplus; < 35 = deficiency (Bergmann & Neubert, 1976)

8. Manganese - criterion below 20 ppm deficient for maintenance, below 50 ppm deficient for reproduction

GLOSSARY

(G) at the end of a definition means that it is derived from the FAO Glossary of Terms used in Pasture and Range Survey, Research and Management (Ibrahim 1975).

ACCEPTABILITY: The readiness with which animals select and eat forage (G).

AERIAL COVER: The proportion of the ground surface, in percentage, under live and dead aerial parts of plants (as opposed to basal cover).

ANIMAL UNIT: A term used in the U.S.A. for one mature cow with calf (liveweight of 454 kg or 1 000 lb) (G).

ANNUAL: A plant that completes its life span from seed within a single year (G).

BASAL COVER: The proportion of ground surface, in percentage, under a bunch or tuft of grass, measured at harvested height, which is usually 4-5 cm for cattle, (as opposed to aerial cover). Synonyms are basal area and ground cover (G).

BIOMASS: The quantity of organic substance at a given time on a given area; for example, as in the weight of vegetative matter removed by clipping a sample area (G).

BROWSE: i. the current twigs and shoots, with or without attached leaves, of shrubs, trees and woody vines that are browsed by livestock;

ii. the act of grazing plant parts as in i (G).

BUSH: i. a growth of shrubs or small trees;

ii. a low shrub, branching from the ground;

iii. an area covered by shrubs;

iv. a general term for an area of uncleared land (G).

CARRYING CAPACITY: The maximum number of animals on a given area of land that can survive the greatest period of stress each year. The term does not refer to sustained production. It has sometimes erroneously been confused with the term grazing capacity, in which the amount of forage is the limiting factor (G).

CIAT: Centro Internacional de Agricultura Tropical, Cali, Colombia.

CONVERSION TABLE: The matrix table that gives the individual land suitability rating per land quality for each land utilization type and the resulting overall land suitability.

COVER: The proportion of the ground surface, in percentage, under live and dead parts of plants. (It is essential to make the distinction between aerial and basal cover when evaluating for extensive grazing.)

CP: Crude protein, in percentage, of dry matter; usually taken as 6.25 times its nitrogen content.

C3 PLANTS: Plants with the Calvin biochemical pathway of photosynthesis, so named because a compound containing three atoms of carbon (3-phosphoglycerate) is the first product of carbon dioxide fixation in photosynthesis. Apart from their biochemistry, C3 plants differ from C4 plants in morphology and physiology. They have relatively low water use efficiency and relatively high CP content at maturity. The legumes are C3 plants.

C4 PLANTS: Plants with the Hatch and Slack pathway of photosynthesis, in which a 4-carbon compound (oxaloacetate) is produced. The largest group of C4 plants is the grass subfamily Panicoideae, suited to areas with high temperatures in the growing season. C4 plants show water use efficiencies up to twice as high as C3 plants, and crude protein concentrations at maturity half those of C3 plants.

DIGESTIBILITY: The proportion, in percentage, of ingested food that is absorbed by the animal.

DIGESTIBLE CRUDE PROTEIN: The amount or proportion of ingested crude protein, calculated by an empirical formula (see also Appendix A).

DISCOUNTED CASH FLOW ANALYSIS: An economic analysis based on the reduction of future benefits and costs to some lower value assumed to be their present worth. The process is by discounting, roughly the reverse of adding interest.

DRY MATTER: The weight of plant material after oven drying at 70°C.

ENVIRONMENTAL IMPACT ANALYSIS: A process in which predictions are made of the impact of future development projects on the land.

EXTENSIVE GRAZING: The land utilization type in which animal feed comes mainly from rangelands, and over which the animal roams extensively.

FEED: Any non-injurious edible material having nutritive value to livestock. It may be harvested forage, rangeland or seeded pasture forage, grain or other processed material (G).

FODDER: The dried, cured plant material used as animal feed (G).

FORAGE: Animal feed of herbage and browse obtained from extensive grazing.

GRASSLAND: Land covered with grass and with less than 2 percent tree or shrub cover.

- GRAZING CAPACITY:** i. The maximum stocking rate possible that a rangeland can support without deterioration (G);
- ii. The maximum stocking rate of an animal type with a specific production objective that a certain land unit can support without deterioration during a defined grazing season.

GRAZING EFFICIENCY: The proportion of the forage production or forage standing crop that is ingested by the grazing animal.

GRAZING ORBIT: A circle centred on the home of an animal that is grazed by the animal throughout the year. For a nomadic animal, its grazing orbit has an ill-defined centre but the circumference of the circle remains the outer limit of the area that it grazes. A transhumant animal has two or more grazing orbits, used at different seasons, and attached by the migration routes taken between them.

GROSS MARGIN ANALYSIS: The calculation of the annual income of an enterprise by taking the value of sales, subtracting costs of production, and obtaining the resulting profit or loss.

HERB: A flowering plant that dies back to the ground each year without persistent woody stems remaining above the ground. Included are ferns, grasses and forbs, as distinct from shrubs and trees (G).

HERBAGE: The standing crop of herbs.

HERBAGE LOSS FACTOR: The proportion of the forage production or forage standing crop that is lost to grazing as a result of trampling, fouling and decomposition.

ILCA: International Livestock Centre for Africa, Addis Ababa, Ethiopia.

INPUTS: The material inputs, e.g. seed, water reticulation, veterinary materials, and other inputs, e.g. labour hours, applied to the use of the land.

ISSS: International Society of Soil Science.

ITC: International Institute for Aerospace Survey and Earth Science, Enschede, The Netherlands.

KEY ATTRIBUTE: An important feature of a land utilization type that can affect its land use requirements and management specifications on a particular land unit. A set of key attributes serves to provide a background or context to a land use, and a listing of technical specifications to be followed by operators of that land use.

LAND: An area of the surface of the earth, the characteristics of which embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area, including those of the atmosphere, the rocks, landforms, soil and underlying ecology, the hydrology, the plant and animal populations and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by man (FAO 1976).

LAND CHARACTERISTIC: An attribute of land that can be measured or estimated, and which can be employed as a means of describing land qualities or distinguishing between land units of differing suitabilities for a specified use.

LAND QUALITY: A complex attribute of land that acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use (FAO 1976).

LAND SUITABILITY: The fitness of a given type of land for a specified kind of land use (FAO 1976).

LAND SYSTEM: A large tract of land formed by an association of land facets and within which there is a repetitive pattern of topography, soils and vegetation identifiable with remote sensing techniques. Land systems form the basis of the most widely employed and practicable method of dividing landscapes in the first stages of a land classification.

LAND UNIT: An area of land defined by land qualities and land characteristics, which can be demarcated on a map.

LAND USE: The function of the land determined by natural conditions and human intervention. Land uses are categorized according to status and employment of the land, as in grazing land, and are separated into present and potential land uses.

LAND USE SYSTEM: A specific land utilization type applied to a particular land unit. The concept is identical to that of a farming system, but is applied to all kinds of land use.

LAND UTILIZATION TYPE: A kind of land use described in sufficient detail so that the necessary inputs and management actions can be planned, and the outputs estimated.

0.73

METABOLIC WEIGHT: liveweight kg, and related to the voluntary feed intake of an animal.

MODELLING: The building of physical, conceptual or mathematical simplifications of the real world as models. These help to show relationships and may be used to predict the effects of management on the real world.

NOMADISM: A type of pastoralism in which livestock owners follow the irregularities of the weather in search of drinking water and pastures for their herds and flocks.

NORMALIZED DIFFERENCE VEGETATION INDEX: A composite parameter, obtained from remote sensing, of the reflectance values in the red and infrared bands of vegetation. It is represented by the formula:

$$\frac{\text{infrared-red}}{\text{infrared+red}}$$

which indicates the proportions of vegetation (reflecting well in the infrared) and bare soil. The NDVI therefore gives an indication of the quantity of standing crop in extensively grazed areas.

NRC: National Research Council, U.S.A.; referred to in these Guidelines by their publications on nutrient requirements for various livestock species.

NUTRITIVE VALUE: The relative capacity of a given forage to furnish nutrition for animals (G).

OVERGRAZING: A stocking rate above grazing capacity that will lead in the foreseeable future to rangeland deterioration. An area may be overstocked for a short period without decreasing rangeland condition.

OVERSTOCKING: Synonym of overgrazing.

PALATABILITY: Characteristics of different plants that require a grazing animal to make a choice between which of them to eat. It is conditioned between two or more feeds or different parts of them by both animal and environmental factors (G).

PASTORALISM: A livestock husbandry system that includes seasonal herding of animals grazing extensively on communal rangeland. The three main types of pastoralism are: nomadic, transhumant and sedentary pastoralism.

PASTORALIST: A livestock owner who grazes his herd or flock on communal rangeland.

PASTURE:

- i. Grass or other growing plants used as feed by grazing animals.
- ii. A grazing area enclosed and separated from other areas by a fence.
- iii. Areas of seeded grassland used for grazing (a more limited definition) (G).

PERENNIAL: A plant that lives for three or more years (G).

PROPER USE FACTOR: The maximum proportion of the forage that may be grazed without causing rangeland deterioration by accelerated erosion, nutrient depletion, soil degradation and undesirable vegetation changes.

RANCH: A farm with specific boundaries, together with its land and improvements, used for grazing and animal production (G).

RANCHING: A livestock husbandry system in which animals graze on private and usually fenced land (as opposed to pastoralism).

RANGELAND: A tract of land currently used for grazing by livestock or wildlife, where natural vegetation is the main forage resource.

RANGELAND CONDITION: The status of forage and soil of a given rangeland area in relation to the optimum status that could be obtained under the prevailing environmental conditions (G).

RESOURCES: Conditions and elements of the environment exploitable by mankind.

SAVANNA: Vegetation with a grass component and a woody component in which the shrub and tree cover together do not cover more than 20 percent.

SHRUBLAND: Land with a shrub cover at least twice the tree cover.

SOUR GRASS: Grass that, in mature condition, is ingested in such low quantities that cattle cannot maintain weight. Examples are **Hyparrhenia hirta** and **Heteropogon contortus**.

STANDING CROP: The total amount of above-ground biomass of one or more plant species, or the vegetation within an area at a specific time (G).

STOCKING RATE: The actual number of animals, expressed in either animal units or animal unit months, on a specified area at a specific time (G).

SWEET GRASS: Grass that, in mature condition, meets the maintenance requirements of cattle and sheep. Examples are **Panicum spp.**, **Digitaria spp.** and **Urochloa mozambiquensis**.

TROPICAL LIVESTOCK UNIT: A reference standard against which livestock reared in the tropics are compared when their grazing requirements are being determined. It is equivalent to an animal of 250 kg liveweight, or preferably of
0.73
250 kg metabolic weight.

TRANSHUMANCE: A type of pastoralism in which pastoralists regularly graze their livestock in two or more geographically separated grazing orbits within a year.

UNIVERSAL SOIL LOSS EQUATION: A model for predicting the weight of soil loss by rain water.

USUFRUCT: The right to use the resources of an area; for example the grazing, drinking water, access routes and fuelwood, without having an ownership title to the land.

UBT: Unité Betail Tropical is a bovine of 250 kg liveweight.

UTILIZATION FACTOR: The proportion of the forage production or forage standing crop that is utilized by grazing, including both the herbage consumed and the loss due to trampling, fouling and decomposition.

REFERENCES AND RELATED WORKS

- Advisory Board on Wildlife Management. Wildlife management in the national parks.
1964 Report to Secretary of the Interior. Udall, Washington.
- Allden, W.C. Problems of animal production from Mediterranean pastures. In: Hacker,
1981 J.B. (ed.). Nutritional limits to animal production from pasture. Proc. Int.
Symposium, Queensland. CAB International, Wallingford, U.K.
- Amuyunzu, C.L. Land resources inventory as a basis for land evaluation and rural
1984 development: the role of remote sensing techniques. A case study of Narok
District, Kenya. MSc thesis, ITC, Enschede, The Netherlands. 115 pp.
- Andrade, A. Landscape ecological planning. A case study of part of the Llanos
1985 Orientalis, Colombia. MSc thesis, ITC, The Netherlands. 139 pp.
- Armstrong, J.S. Modelling a grazing system. Proc. Ecol. Soc. Australia, 6: 194-202.
1971
- Arnold, G.W. Grazing behaviour. In: Snaydon, R.W. (ed.). Managed grasslands.
1987 Ecosystems of the World, Vol. 17B. Elsevier, Amsterdam. 285 pp.
- Astle, W.L., Webster, R. and Lawrence, G.J. Land classification for management
1969 planning in the Luangwa Valley of Zambia. J. Appl. Ecol., 6: 143-169.
- Baig, M.S. Inventory and evaluation of rangeland. An example for rangelands in arid
1977 zones, worked out for Quetta-Pishin area, Baluchistan, Pakistan. MSc thesis,
ITC, Enschede, The Netherlands.
- Bakkit, A.E.K. Rangeland survey of a transect between the Nile and Gush Rivers,
1986 Sudan. MSc thesis, ITC, Enschede, The Netherlands. 278 pp.
- Barnard, C. and Frankel, O.H. Grass, grazing animals and man in historic perspective.
1964 In: Barnard, C. (ed.). Grasses and grassland. Macmillan, London.
- Barnes, D.L. and Franklin, M.J. Runoff and soil loss on a sandveld in Rhodesia.
1970 Rhodesia Proc. Grassld. Soc. Sth. Afr. 5: 140-144.
- Bartolome, J.W. and Kosco, B.H. Estimating browse production. J. Range Mngt. 35:
1982 671-672.
- Bawden, M.G. and Tuley, P. The land resources of southern Sardouna and southern
1966 Adamuwa Provinces, Northern Nigeria. Land Resources Study No. 2,
Directorate of Overseas Surveys, Tolworth, U.K. 120 pp.
- Bawden, M.G. and Carroll, D.M. The land resources of Lesotho. Land Resources Study,
1968 Directorate of Overseas Surveys, Tolworth, U.K. 89 pp.

- Bayer, W. and Waters-Bayer, A. Crop-livestock interactions for sustainable agriculture. 1989 Gatekeeper Series No. SA 13. International Institute for Environment and Development, London. 16 pp.
- Behnke, R.H. The herders of Cyrenaica; ecology, economy and kinship among the 1980 Bedouin of eastern Libya. University of Illinois Press, U.S.A. 197 pp.
- Bergmann, W. and Neubert, P. Pflanzendiagnose und Pflanzenanalyse. Fisher, Jena, 1976 Germany. 711 pp.
- Bille, J.C. Etude de la production primaire nette d'un écosystème sahelien. Travaux 1977 et documents de l'ORSTOM, 65, Paris.
- Bille, J.C. Woody forage species in the Sahel: their biology and use. Proc. 1st Inter. 1979 Rngld. Cong., Soc Range Mgnt., Denver, Colorado, U.S.A.
- Blair-Rains, A. and Kassam, A.H. Land resources and animal production. In: Land 1980 resources for populations of the future. FAO/UNFPA, Rome. pp. 303-332.
- Bouare, S. Une méthodologie de lever des ressources naturelles pour l'évaluation des 1985 terres dans les zones onchocerciennes: le cas du Cercle de Bougouni. MSc thesis, ITC, Enschede, The Netherlands.
- Boudet, G. Problems posed in the estimation of the rate of stocking of natural 1975 pastureland in tropical zones. Proc. Sem. on Evaluation and Mapping of Tropical African Rangelands, Bamako, Mali, 3-8 March 1975. ILCA, Addis Ababa, Ethiopia.
- Bourliere, F. and Hadley, M. The ecology of tropical savannas. Ann. Rev. Ecol. Syst. 1: 1970 125-152.
- Bourliere, I. Tropical savannas. Ecosystems of the World 13. Elsevier, Amsterdam. 1983
- Braun-Blanquet, J. Plant sociology: the study of plant communities. Hofner, New York. 1972
- Breman, H., Diallo, A., Traore G. and Djiteye, M.M. The ecology of annual migrations 1978 of cattle in the Sahel. In: Hyder, D.N. (ed.). Proceedings of the First International Rangeland Congress. Soc. Range Mgnt., Denver, Colorado, U.S.A.
- Breman, H., Keulen, H. van and Ketelaars, J.J.M.H. Land evaluation for semi-arid 1984 rangeland: a critical review of concepts. In: Siderius, W. (ed.). Proceedings of the Workshop on Land Evaluation for Extensive Grazing. ILRI, Wageningen, pp. 229-245.

- Breman, H. and Traore, N. (ed.). Analyse des conditions de l'élevage et propositions de politiques et de programmes: République du Mali. OCDE, Paris. 243 pp. 1987
- Butterworth, M.H. Animals in relation to land use. In: Nestel, B. (ed.). Development of animal production systems. Elsevier, Amsterdam. 1984
- Caldwell, M. Primary production of grazing land. In: Cooper, J.P. (ed.). Photosynthesis and productivity in different environments. IBP 3, London. Cambridge University Press. 1973
- Calle, R.E. Producción y mejoramiento de la Alpaca. Banco Agrario del Peru, Lima. 1986
- Cassady, J.T. The effect on rainfall, soil moisture and harvesting intensity of grass production on two range sites in Kenya. E. Afr. Agr. For. J. 39: 26-36. 1973
- Child, R.D. and Byington, E.K. Potential of the world's forages for ruminant animal production. Winrock International Livestock Research and Training Centre, Morrilton, Arkansas, U.S.A. 1981
- Christian, C.S., Noakes, L.C., Perry, R.A., Slatyer, R.O., Stewart, G.A. and Traves, D.M. Survey of the Barkly Region, Northern Territory and Queensland 1947-1948. Land Research Series 3. CSIRO, Melbourne, Australia. 50 pp. + 4 maps. 1952
- Christian, C.S. and Stewart, G.A. Methods of integrated surveys. In: Principles and methods of integrated surveys. Unesco Conference, Toulouse, pp. 233-288. 1968
- Centro Internacional de Agricultura Tropical. Tropical pastures programme 1986. 1986 Annual report, Cali, Colombia.
- Coe, M.J., Cumming, D.H. and Phillipson, J. Biomass and production of large African herbivores in relation to rainfall and primary production. Oecologia 22: 341-354. 1976
- Condon, R.W. Estimation of grazing capacity on arid grazing In: Stewart, G.A. (ed.). Land evaluation. Macmillan, Melbourne, Australia. 1968
- Condon, R.W., Newman, J.C. and Cunningham, G.M. Soil erosion and pasture degeneration in central Australia. Part III: the assessment of grazing capacity. J. Soil Con. Serv., N.S.W., 25: 225-250. 1969
- Connolly, J. Linear programming and the optimum carrying capacity of range under common use. J. Agr. Sci. 83: 259-265. 1974
- Cooper, J.P. Potential production and energy conversion in temperate and tropical grasses. Herbage Abstracts 40: 1-15. 1970

- Cooper, J.P. and Tainton, N.M. Light and temperature requirements for the growth of
1968 tropical and temperate grasses. *Herb. Abstr.* 38: 167-176.
- Cornet, A. Utilisation de modèles simples de bilan hydrique et de production de
1983 biomass pour déterminer les potentialités de production de parcours en zone
saharienne Sénégalaise. In: Vanpraet, L. (ed.). *Méthodes d'inventaire et de
surveillance continue des écosystèmes pastoraux sahéliens; applications au
développement. Actes du Colloque tenu a Dakar les 16, 17, 18 novembre 1983.*
Rep. Sénégal/Lab. Nat. de l'élevage et de res. vet., Dakar, Senegal. pp.59-82.
- Cossins, N. and Mourik, D. van. Socio-economic aspects of LEEG. Working Group F.
1984 In: Siderius, W. (ed.). *Proceedings of the Workshop on Land Evaluation for
Extensive Grazing*, ILRI, Wageningen. pp. 329-330.
- Cossins, N.J. The productivity and potential of pastoral systems. *ILCA Bulletin* 21:
1985 10-14.
- Cottam, G. and Curtis, J.T. An application of the point centred quarter method to the
1961 sampling of grassland vegetation. *J. Range Mgnt.* 14: 63-69.
- Coupland, R.T. *Grassland ecosystems of the world: analysis of rangeland and their uses.*
1979 IBP 16. Cambridge University Press.
- Crane, T.D. Plant poisoning in animals: a bibliography. *The Veterinary Bulletin* 43:
1973 165-177 Pt. I; 43: 231-249 Pt. II.
- Demiruren, A.S. The improvement of nomadic and transhumance animal production
1974 systems. AGA/MISC/74/3. FAO, Rome.
- Dent, D.L. *Acid sulphate soils: a baseline for research.* Pudoc, The Netherlands.
1985 250 pp.
- Dent, D.L. and Young, A. *Soil survey and land evaluation.* George Allen and Unwin,
1981 London. 278 pp.
- Deshmukh, I.K. and Baig, M.N. The significance of grass mortality in the estimation of
1983 primary production of African grasslands. *Afr. J. Ecol.* 21: 19-23.
- DHV. Countrywide animal and range assessment project. DHV Amersfoort/ITC,
1980 Enschede, The Netherlands. 7 vols.
- Edwards, K.A., Classer, G.A. and Schrotten, E.H.J. The water resource in tropical Africa
1983 and its exploitation. ILCA, Addis Ababa, Ethiopia.
- Edwards, P.J. Grazing management. In: Tainton, N.M. (ed.). *Veld and pasture
1981 management in South Africa.* Shuter and Shooter, Pietermaritzburg, R.S.A.

- Eicher, C.K. and Baker, D.C. Research on agricultural development in sub-Saharan Africa: a critical survey. MSU International Development Paper 1, Michigan State University, East Lansing. 335 pp.
1982
- Elwell, H.A. A soil loss estimation system for Southern Africa. Compiled work of the Rhodesian Multidisciplinary Team on Soil Loss Estimation, Salisbury, Rhodesia.
1978
- Elwell, H.A. Design of safe rotational systems. Department of Conservation and Extension (Conex), Salisbury, Rhodesia. 50 pp.
1980
- Elwell, H.A. and Stocking, M.A. Developing a simple yet practical method of soil loss estimation. Tropical Agriculture, 59: 43-48.
1982
- Esselink, P. and Gils, H. van. Ground-based reflectance measurements for standing crop estimates. ITC Journal 85-1: 47-52.
1985
- Esselink, P. Schotel, J. and Gils, H. van. Nitrogen and phosphorus limited primary production of annuals: a case study of semi-natural grazing lands (dehesas) in south west Spain with implications for their exploitation. ITC publ., Enschede, The Netherlands.
1988
- Etter, A. A landscape ecological approach for grazing development. A case study in the Colombian Llanos Orientales. MSc thesis, ITC, Enschede. 130 pp.
1985
- FAO. A framework for land evaluation. Soils Bulletin No. 32. FAO, Rome. 72 pp.
1976
- FAO. Report on the Agro-ecological Zones Project. Vol. 1. Methodology and results for Africa. World Soil Resources Report No. 48/1. FAO, Rome.
1978
- FAO. A provisional methodology for soil degradation assessment. FAO, Rome. 84 pp.
1979
- FAO. Land resources for populations of the future. Report of the Second FAO/UNFPA Expert Consultation. FAO, Rome.
1980
- FAO. Guidelines: land evaluation for rainfed agriculture. FAO Soils Bulletin No. 52. 1984a
FAO, Rome. 249 pp.
- FAO. Land evaluation for forestry. FAO Forestry Paper No. 48. FAO, Rome. 123 pp.
1984b
- FAO. Water quality for agriculture. Irrigation and Drainage Paper No. 29, Rev. 1. 1985a
FAO, Rome. 174 pp.
- FAO. Guidelines: land evaluation for irrigated agriculture. FAO Soils Bulletin No. 55. 1985b
FAO, Rome. 243 pp.

- FAO. Guidelines for land use planning. Inter-departmental Working Group on Land Use Planning. FAO, Rome. 1990
- Farid, M.F.A., Shawket, S.M. and Abdel-Rahman, M.H.A. Observations on the nutrition of camels and sheep under stress. Workshop on Camels, Khartoum. 1979
- Ferguson, W. Adaptive behaviour of cattle to tropical environments. *Tropical Science* 1971 13: 113-122.
- Ferguson, Wankja. Land ecology and land evaluation in the Tajo-Tietar area, Caceres Province, Spain. Vol II: Rangeland evaluation. ITC, Enschede, The Netherlands. 1983
- Garcia, O., Aycardi, E.R., Zuluaga, F.N., Rivera, B. and Henao, F.J. Review. ACOVEZ 1982 6. CIAT.
- Gatahi, M.M. Land qualities and land characteristics relevant for major utilization types: an assessment with Kenyan examples. In: Siderius, W. (ed.). Proceedings of the Workshop on Land Evaluation for Extensive Grazing. ILRI, Wageningen. pp. 245-255. 1984
- Gils, H. van. Countrywide animal and range assessment, Botswana. Proc. Int. Congr. Neth. Soc. Landscape Ecol., Veldhoven. Pudoc, Wageningen. 1981
- Gils, H. van. Rangelands of the world. Unifying vegetation features. In: Siderius, W. (ed.). Proceedings of the Workshop on Land Evaluation for Extensive Grazing. ILRI, Wageningen. pp. 17-27. 1984
- Gils, H. van and Wijngaarden, W. van. Vegetation structure in reconnaissance and semi-detailed surveys. *ITC Journal* 84, Enschede: 213-218. 1984
- Gils, H. van. Redden schapen de heide? (Do sheep save the heathlands?) Proc. 3rd Works. on Heathland Mgnt., 5 Sept 84, Ede, The Netherlands. 1985
- Gils, H. van, Zonneveld, I.S. and Wijngaarden, W. van. Vegetation and rangeland survey. Lecture note No. 7, App. D., ITC, Enschede, The Netherlands. 1985
- Gils, H. van. Mid-altitudinal vegetation of the Macronesian island Santo Antao (Cape Verde). In press. 1988
- Gohl, B. Tropical feeds. Animal Production and Health Series No. 12. FAO, Rome. 1981 571 pp.
- Goodall, D.W. and Gist, C. Terrestrial models: introduction and main programmes US/IBP Desert Biome. Res. Mem No. RM 73-75. Utah State University, U.S.A. 1973
- Goodall, D.W. and Perry, R.A. (eds.). Arid land ecosystems: structure, functioning and management. IBP 17, Vol. 2. Cambridge University Press. 605 pp. 1981

- Graham, N.Mc.C. Maintenance and growth. In: Neimann-Sorensens, A, and Tribe, D.E. 1982 (eds.). Sheep and goat production. World Animal Science Vol. A.2. Elsevier, Amsterdam.
- Grossman, D. Primary production of rangeland: practical and interpretive problems. 1982 Proc. Grassld. Soc. S. Africa 17: 76-78.
- Grouzis, M. and Methy, M. Determination radiométrique de la phytomasse herbacée 1983 en milieu Sahélien: perspective et limites. Acta Oecol. Plant 4: 241-257.
- Gryseels, G., McIntyre, J. and Anderson, F.M. Research with a farming systems 1986 perspective at ILCA. ILCA Bull. 25: 17-23.
- Gunn, R.H. and Nix, H.A. Land units of the Fitzroy region, Queensland. Land 1977 Research Series 39. 228 pp.
- Hacker, R.B. Rangeland inventory and evaluation in Australia. In: Siderius, W. (ed.). 1984 Proceedings of the Workshop on Land Evaluation for Extensive Grazing. ILRI, Wageningen. pp. 61-68.
- Hardin, G. The tragedy of the commons. Science 162: 1243-1248. 1968
- Harris, P.S. An analysis of the pastoral resource and development opportunities for 1989 Menagesha, and Haikoch and Butajira. UNDP/FAO Assistance to Land Use Planning Project ETH/87/006, Addis Ababa, Ethiopia. 168 pp.
- Hashim, M. and Hermelink, P. Landscape ecological survey of Kouf National Park in 1981 Libya. MSc thesis, ITC, Enschede.
- Haylett, D.G. Runoff and soil erosion studies at Pretoria. S. Afr. J. Agr. Sc. 3: 379-394. 1960
- Heady, H.F. Rangeland management. McGraw-Hill, New York. 435 pp. 1975
- Heady, H.F. Multiple uses of rangelands. In: Nestel, B. (ed.). Development of animal 1984 production systems. World Animal Science A.2. Elsevier, Amsterdam.
- Hiernaux, P. Inventory of the browse potential of bushes, trees and shrubs in an area 1983 of the Sahel in Mali: methods and initial results. In: Le Houerou, H.N. (ed.). Browse in Africa. ILCA, Addis Ababa. pp. 197-210.
- Hill, I.D. (ed.). Land resources of central Nigeria. Vol. 3: Agricultural development 1979a possibilities in the Jema'a Platform. Land Resources Study No. 29. Directorate of Overseas Surveys, Tolworth, U.K. 117 pp.

- Hill, I.D. (ed.). Land resources of central Nigeria. Vol. 4b: Agricultural development possibilities in the Benue Valley. Land Resources Study No. 29. Directorate of Overseas Surveys, Tolworth, U.K. 148 pp.
1979b
- Hill, M.O. TWINSPAN: a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Cornell University, Ithaca, New York.
1979
- Holechek, J.L. An approach to setting the stocking rate. *Rangelands*, 10 (1): 10-14.
1988
- Holter, J.A. and Reid, J.R. Relationship between the concentrations of crude protein and apparently digestible protein in forages. *J. Anim. Sci.* 18: 1339-1349.
1959
- Houerou, H.N. Le and Hoste, C.H. Rangeland production and annual rainfall relations in the Mediterranean Basin and the Africa Sahelo-Sudanian Zone. *J. Range Mngt.* 30: 181-189.
1977
- Houerou, H.N., Le (ed.). Browse in Africa. ILCA, Addis Ababa.
1983
- Humphrey, L.R. Environmental adaptation of tropical pasture plants. Macmillan, London.
1981
- Humphrey, R.R. Range ecology. Ronald Press, New York. 234 pp.
1962
- Humphrey, R.R. Range condition analysis: a practical ecological approach to the classification of rangelands. In: Proc. 9th Intern. Grassl. Cong., Sao Paulo: 1437-1442.
1966
- Huntley, B.H. and Walker, B.H. Ecology of tropical savanna. *Ecol. Stud.* 42. Springer-Verlag, Berlin.
1982
- Ibrahim, K. Glossary of terms used in pasture and range survey, research, ecology and management. FAO-AGPC-MISC/34. FAO, Rome. 162 pp.
1975
- ILCA. International Livestock Centre for Africa. Proceedings of the Seminar on Evaluation and Mapping of Tropical African Rangelands. Bamako, Mali, 3-8 March 1975. ILCA, Addis Ababa.
1975
- ILCA. Livestock production in the subhumid zone of West Africa. System Study No. 2. ILCA, Addis Ababa.
1979
- ILCA. Proceedings of the Symposium on Browse in Africa. ILCA, Addis Ababa.
1983
- ILCA. Annual report 1985/86. ILCA, Addis Ababa. 87 pp.
1986

- ITC. Projet de développement rural integre de la région du Kaarta, République du
1977 Mali. ITC, Enschede.
- Jahnke, H.E. Livestock production systems and livestock development in tropical Africa.
1982 Kieler Wissenschaftsvirlag Vauk, Kiel, Germany. 253 pp.
- Jeanes, K.W. Ecological survey and rangeland resource appraisal of the Senanga West
1985 Cattle Development Area Project Proposal. Vol. II, App. C. Ministry of
Agriculture, Lusaka, Zambia. 143 pp.
- Jensen, A. Seasonal changes in near infrared reflectance ratio and standing crop biomass
1980 in a saltmarsh community dominated by **Halimione portulacoides** (L) Aellen.
New Phyt. 86: 56-67.
- Kallala, A. Land evaluation in relation to erosion effects in central Tunisia using aerial
1984 photographs and Landsat imagery. MSc thesis, ITC, Enschede, The
Netherlands.
- Kaplan, Y. The ecosystem of the Yahudia nature reserve with emphasis on the dynamics
1984 of germination and development of **Quercus ithaburensis** Decne. PhD thesis,
Agricultural University of Wageningen. 339 pp.
- Kappeyne, J. The Zimbabwe remote sensing forest survey. Zimb. Agric. J. 82: 165-170.
1985
- Karstad, L., Nestel, B. and Graham, M. (eds.) Wildlife disease research and economic
1980 development. Proc. Works. Kakete, Kenya, Sept 80. IDRS, Ottawa, Canada.
- Kassam, A.H., Velthuisen, H.T. van, Sloane, P.H., Fischer, G.W. and Shah, M.M.
1989 Livestock productivity. Working Paper No. 7. Assessment of Population
Supporting Capacity for Development Planning in Kenya. AGL-FAO/IIASA,
Rome. 97 pp.
- Kekem, A.J., van. A land evaluation study in the Mount Kulala Marsabit area, northern
1984 Kenya. In: Siderius, W. (ed.) Proceedings of the Workshop on Land Evaluation
for Extensive Grazing. ILRI, Wageningen. pp. 257-274.
- Kekem, A.J., van. Soils of the Mount Kulal Marsabit area. Reconnaissance Soil Survey
1986 Report No. R12. Kenya Soil Survey, Nairobi. 157 pp.
- Kellerman, T.S. and Coetzer, J.A.W. Hepatogenous photo-sensitivity diseases in South
1984 Africa. Techn. Comm. Dep. Agric., 193. RSA, Pretoria.
- Kessler, J.J. Grazing trials at village enclosures in the Dhamar montane plains, Yemen
1987 Arab Republic. RCIP Comm. No. 20. DHV, Amersfoort, The Netherlands.
53 pp.

- Kessler, J.J. and Ohler, F.M.J. Interventions dans les pays du Sahel: une approche
1983 écologique. Univ. Agron./CABO, Wageningen, The Netherlands. 72 pp.
- Ketelaars, J.J.M.H. Evaluating rangeland as feed resource for livestock production. In:
1984 Siderius, W. (ed.) Proceedings of the Workshop on Land Evaluation for
Extensive Grazing. ILRI, Wageningen. pp. 165-181.
- Keulen, H. van and Wolf, J. Modelling of agricultural production: weather, soils and
1986 crops. Pudoc, Wageningen.
- Keulen, H. van, Breman, H., Kek, J.J. van der, Menke, J.W., Stroosnijder, L. and Uithol,
1986 P.W.J. Prediction of actual primary production under nitrogen limitation. In:
Ridder, N. de et al. (eds.) Modelling of extensive grazing production systems.
Proc. ILCA/ARO/CABO Workshop. Bet Dagan, Israel, 5-9 Feb 1985. pp.
42-80.
- Konczacki, Z.A. The economics of pastoralism. Frank Case, London.
1978
- Kooiman, A. Land cover, land use and soil erosion in the Upper Komering catchment,
1987 South Sumatra, Indonesia. ITC, Enschede. 122 pp.
- Lamprey, H.F. Pastoralism yesterday and today: the overgrazing problem. In:
1983 Bourliere, F. (ed.) Ecosystems of the world, Vol. 13: Tropical savannas.
Elsevier, Amsterdam.
- Lantinga, E.A. Productivity of grassland under continuous and rotational grazing.
1985 PhD thesis. Agricultural University, Wageningen. 111 pp.
- Leeuw, P.N., de. Factors affecting remote spectral measurements at ground level and
1983 low altitude in herbaceous vegetation in Kenya. In: Vanpraet, C.C. (ed.)
Méthodes d'inventaire et de surveillance continue des écosystèmes pastoraux
sahéliens: applications au développement. Actes du colloque tenu a Dakar les
16, 17, 18 novembre 1983. Rep. Sénégal/Lab. Nat. de l'élevage et de Res. Vet.,
Dakar. 439 pp.
- Leeuw, P.N., de. Pastoral production systems and land utilization types. In: Siderius, W.
1984 (ed.) Proceedings on Land Evaluation for Extensive Grazing. ILRI,
Wageningen. pp. 119-133.
- Lek, J.J. and Keulen, H. van. Calculation method for regional annual forage availability
1986 of natural pastures in the Sahel. CABO, Wageningen. 86 pp.
- Lieth, H.G. Primary production of major vegetation units of the world. In: Lieth, H.
1975 and Whittaker, R.H. (eds.) Primary productivity of the biosphere. Springer-
Verlag, New York, pp. 202-215.

- Lieth, H.G. and Whittaker, R.H. Primary productivity of the biosphere. Springer-Verlag, New York. 1975
- Little, D.A. Observations on the phosphorus requirement of cattle for growth. Res. in Vet. Soc. 28: 258-260. 1980
- Livingstone, I. Pastoralism: an overview of practice, process and policy. FAO, Rome. 1985 79 pp.
- Maarel, E. van der, Janssens, J.G.M. and Louppen, J.M.W. TABORD: a program for structuring phytosociological tables. Vegetatio 38: 143-153. 1978
- Mahler, P.J. (ed.) Manual of multipurpose land classification. Soil Inst. of Iran. 81 pp. 1970
- Makin, M.J., Kingham, T.J., Waddams, E.A., Birchall, J. and Eavis, W.B. Prospects for irrigation development around Lake Zwai, Ethiopia. Land Resources Study No. 26. Directorate of Overseas Surveys, Tolworth, U.K. 316 pp. 1976
- Mannetje, L.t'. Measurement of grassland vegetation and animal production. CAB Pastures and Field Crops Bulletin No. 52. CAB International, Wallingford, U.K. 1978
- Margaris, N.S., Adamandiadou, S., Siafaca, L. and Diamantopoulos, J. Nitrogen and phosphorus content in plant species of Mediterranean ecosystems in Greece. Vegetatio 55: 29-35. 1984
- McCown, R.L., Haaland, G. and Haan, C. de. The interaction between cultivation and livestock production in semi-arid Africa. In: Hall, A.C., Cannell, G.H. and Lawton, H.W. (eds.) Agriculture in semi-arid environments. Ecological Studies No. 34. Springer-Verlag, Berlin. 1979
- McDonald, I.W. Detrimental substances in plants consumed by grazing ruminants. In: Morley, F.H.W. (ed.) Grazing animals. Elsevier, Amsterdam. 1981
- McDowell, L.R. Mineral deficiencies and toxicities and their effect on beef production in developing countries. In: Smith, A.J. (ed.) Beef cattle production in developing countries. Proc. Conf. Edin. University of Edinburgh, U.K. 1976
- McKell, C.M. and Norton, B.E. Management of arid land resources for domestic livestock forage. In: Goodall, D.W. and Perry, R.A. (eds.) Arid land ecosystems: structure, functioning and management. IBP 17, Vol. 2: 455-478. Cambridge University Press. 1981
- McNaughton, S.J. Grassland-herbivore dynamics. In: Sinclair, A.R.E. and Norton-Griffiths, M. (eds.) Serengeti. University Press, Chicago. pp. 46-81. 1981

- Michieka, D.O. and Braun, H.M.H. Land evaluation for extensive cattle range at Kiboko Range Research Station. Proc. Sem. Land Eval. for Range. Use. Kenya Soil Survey, Misc. Pap. 11: 14-23. Nairobi, Kenya.
1977
- Milford, R. and Minson, D.T. The relationship between crude protein content and the digestible crude protein content in tropical pasture plants. J. Br. Grassl. Soc. 20: 177-179.
1985
- Milner, C. and Hughes, R.E. Methods for the measurement of the primary production of grassland. IBP No. 6. Blackwell, Oxford, U.K.
1968
- Milton Moore, R. Australian grasslands. Australian National University Press, Canberra.
1970
- Morley, F.H.W. (ed.) Grazing animals. World Animal Science No. B.1. Elsevier, Amsterdam.
1981
- Morris, M.J. An abstract bibliography of statistical methods in grassland research. Forest Service Misc. Pub. No. 1030. USDA, Washington.
1967
- Mulungushi, S.J. Agricultural land use in Mongu South, Zambia. MSc thesis, ITC, Enschede, The Netherlands.
1986
- Munn, R.E. Environmental impact assessment: principles and procedures. SCOPE, Toronto.
1975
- National Research Council. Water quality criteria. US Environmental Protection Agency, Washington. 592 pp.
1972
- National Research Council. Nutrients and toxic substances in water for livestock and poultry. Washington. 93 pp.
1974
- National Research Council. Nutrient requirements of dairy cattle. Fifth Revision. National Academy of Sciences, Washington.
1978
- National Research Council. Nutrient requirements of goats. National Academy of Sciences, Washington.
1981
- National Research Council. Nutrient requirements of beef cattle. Sixth revision. National Academy of Sciences, Washington.
1984
- National Research Council. Nutrient requirements of sheep. National Academy of Sciences, Washington.
1985
- Nestel, B. Development of animal production systems. Elsevier, Amsterdam.
1984

- Noy-Meir, I. Stability of grazing systems: an application of predator-prey graphs.
1975 J. Ecol. 63: 457-481.
- Noy-Meir, I. Spatial effects in modelling of arid ecosystems. In: Goodall, D.W. and
1981 Perry, R.A. (eds.) Arid land ecosystems: structure, functioning and
management. IBP 17, Vol. 2: 411-432. Cambridge University Press.
- Olang, M.C. Vegetation cover assessment in Turkana District, Kenya. In: Siderius, W.
1984 (ed.) Proceedings of the Workshop on Land Evaluation for Extensive Grazing.
ILRI, Wageningen: 183-195.
- Owen-Smith, N. Factors influencing the consumption of plant products by large
1982 herbivores. In: Huntley, B.T. and Walker, B.H. (eds.) Ecology of tropical
savannas. Springer-Verlag, Berlin.
- Oxby, C. Group ranches in Africa. Pastoral Network Paper 13d. Overseas
1982 Development Institute, London.
- Papanastasis, V.P. and Liacos, L.G. Production and management of Kermes oak
1983 bushland for goats. In: Houerou, H.N. Le (ed.) Browse in Africa. ILCA,
Addis Ababa: 375-381.
- Penning de Vries, F.W.T. and Djiteye, M.A. La productivité des pâturages sahéliens.
1982 Pudoc, Wageningen.
- Perry, R.A. Lands of the Alice Springs area, Northern Territory 1956-1957. Land
1962 Research Series No. 6. CSIRO, Melbourne. 280 pp.
- Perry, R. and Wilcox, D. A method used in Australia for estimating stocking rates.
1975 Proc. Sem. on Eval. and Mapp. of Trop. Afr. Range., Bamako, Mali, 3-8 Mar
75. ILCA, Addis Ababa.
- Plessis, M.C.F. and Mostert, J.W.C. Afloop en grondverliese bij die landbou-
1965 navorsingsinstituit Glen. (Runoff and soil losses on the Glen Agricultural
Research Station.) S. Afr. Tijdskr. Landbouwet. 8, Pretoria: 1051-1060.
- Pratchett, D. Botswana: recent range research findings. World Animal Review 48:
1975 18-25.
- Pratt, D.J. Problems in the assessment of livestock carrying capacity. Proceedings of the
1975 Seminar on Land Evaluation and Mapping of Tropical African Rangelands,
Bamako, Mali, 3-8 March 1975. ILCA, Addis Ababa.
- Pratt, D.J. and Gwynne, M.D. Rangeland management and ecology in East Africa.
1977 Hodder and Stoughton, London.
- Price Gittinger, J. Economic analysis of agricultural projects, 2nd edition. Johns
1982 Hopkins University Press, Baltimore.

- Prince, S.D. Evaluation of range management. Procedures and the range management programme in Botswana. UNDP/FAO/BOT/82/001. FAO, Rome. 1984
- Prince, S.D. and Astle, W.L. Satellite remote sensing of rangelands in Botswana. I. Landsat MSS and herbaceous vegetation. *Int. J. of Rem. Sens.*, 7: 1533-1555. 1986
- Prince, S.D. and Tucker, C.J. Satellite remote sensing of rangelands in Botswana. II. NOAA, AVHRR and herbaceous vegetation. *Int. J. of Rem. Sens.*, 7: 1555-1571. 1986
- Purnell, M.F. and Leeuw, P.N. de. Definition of land utilization types for extensive grazing. Working Group C. In: Siderius, W. (ed.) *Proc. Workshop on Land Evaluation for Extensive Grazing*. ILRI, Wageningen. pp. 323-324. 1984
- Raven, P.H., Evert, R.F. and Eichhorn, S.F. *Biology of plants*, 4th edition. Worth Publishers Inc., New York. 1986
- Ren, J. The grassland characteristics and productivity of East Asia. In: Siderius, W. (ed.) *Proc. Workshop on Land Evaluation for Extensive Grazing*. ILRI, Wageningen, pp. 43-53. 1984
- Ridder, N. de, Stroosnijder, L., Cisse, A.M. and Keulen, H. van. Productivity of Sahelian rangelands: a study of the soils, the vegetation and the exploitation of that natural resource. Wageningen Agricultural University. 231 pp. 1982
- Ridder, N. de and Wagenaar, K.T. Energy and protein balances in traditional livestock systems and ranching in Eastern Botswana. *Agricultural Systems* 20: 1-16. 1986
- Remote Sensing Society. *Remote sensing for rangeland monitoring and management*. Remote Sensing Society, Department of Geography, University of Reading. 1983
- Robinove, C.J., Langford, R.H. and Brookhjaap, J.W. *Saline water resources of North Dakota*. US Geol. Survey Water Supply Paper 1428. 1958
- Rootselaar, G. van, Laan, F.B. van, Takken, W. and Figueiredo, J. Rangeland evaluation of the Urrongas Plains in the interior of the northern part of the province of Inhambane, Mozambique. FAO/UNDP/Ministry of Agriculture, Maputo, Mozambique. 77 pp. 1982
- Rosenzweig, M.L. Net primary productivity of terrestrial communities: prediction from climatological data. *American Naturalist* 102 (923): 67-74. 1968
- Rossiter, R.C. Ecology of the Mediterranean annual-type pasture. *Adv. Agron.* 18: 1-56. 1966
- Rustan, O.H. and Brochmann, C. *Guide to the fieldnote registration form for the Republic of Cape Verde*. Oslo University, Oslo, Norway. 18 pp. 1981

- Rutherford, M.C. Primary production ecology in Southern Africa. In: Werger, M.J.A. 1978 (ed.) Biogeography and ecology of southern Africa. Junk, The Hague.
- Sanchez, P.A. and Tergas, L.E. Pasture production on acid soils of the tropics. CIAT, 1978 Cali, Colombia.
- Sandford, S. Management of pastoral development in the Third World. Wiley, 1983 Chichester, U.K.
- Sandford, S. Organization and management of water supplies in tropical Africa. ILCA, 1983 Addis Ababa.
- Siderius, W. (ed.) Proceedings of the Workshop on Land Evaluation for Extensive Grazing. ILRI, Wageningen. 1984
- Simpson, J.R. and Stobbs, T.H. Nitrogen supply and animal production from pasture. 1981 In: Marley, F.H.W. (ed.) Grazing animals. Elsevier, Amsterdam.
- Simpson, J.R. and Evangelou, P. Livestock development in Subsaharan Africa. 1984 Westview Press, Boulder, Colorado.
- Sinclair, A.R.E. The resource limitation of trophic levels in tropical grassland ecosystems. J. Anim. Ecol. 44: 497-521. 1975
- Soest, P.J. van. Nutritional ecology of the ruminant. OSB Books, Corvallis, Oregon. 1982
- Sow, N.A. Range inventory and evaluation for domestic livestock and wildlife: a case study in Mali around Dyoumara (Kaarta). MSc thesis, ITC, Enschede, The Netherlands. 1981
- Stewart, R. Drug prevention of trypanosomiasis is highly successful. ILCA Newsletter 1985 4/2. Addis Ababa: 1-2.
- Stoddart, L.A., Smith, A.D. and Box, T.W. Range management; 3rd edition. McGraw-Hill Book Company, New York. 532 pp. 1975
- Story, R., Galloway, R.W., Graff, R.H.W. van de and Tweedie, A.D. General report on the lands of the Hunter Valley. Land Research Series No. 8. CSIRO, Melbourne. 152 pp. 1963
- Strange, L.R.N. African pastureland ecology, with particular reference to the pastoral environment of Eastern Africa. FAO Pasture and Fodder Crop Studies No. 7. FAO, Rome. 188 pp. 1980
- Strange, L.R.N. Human influences in African pastureland environments, with special reference to the arid and semi-arid pastoral regions of Eastern Africa. FAO Pasture and Fodder Crop Studies No. 8. FAO, Rome. 89 pp. 1980

- Stuart-Hill, G.C. and Mentis, M.T. Coevolution of African grasses and large herbivores.
1982 Proc. Grassld. Soc. Sth. Afr. 17: 122-128.
- Tainton, N.M. The grass plant and its reaction to treatment. In: Tainton, N.M. (ed.)
1981a Veld and pasture management in South Africa. Shuter and Shooter,
Pietermaritzburg, R.S.A.
- Tainton, N.M. The effect of defoliation on plant communities - some general
1981b considerations. In: Tainton, N.M. (ed.) Veld and pasture management in South
Africa. Shuter and Shooter, Pietermaritzburg, R.S.A.
- Thalen, D.C.P. Ecology and utilization of desert shrub range-lands in Iraq. Junk, The
1979 Hague.
- Thalen, D.C.P., Leemburg, J.A. and Beck, R. Estimating aerial biomass in semi-natural
1980 vegetation from spectral reflectance measurements. Preliminary experiences.
Acta Bot. Neerl. 29(5): 565-578.
- Tillman, A.D., Ridenour, H.E. and Getz, W.R. A guide to the feeding and nutrition of
1986 ruminants in the Tropics. Winrock International Institute for Agricultural
Development, U.S.A. 379 pp.
- Ting-Cheng, Z., Jiang-Dong, L. and Dian-Chen, Y. A study on the ecology of Yang-cao
1983 (**Elymus chinensis**) grassland in Northern China. Proc. 14th Int. Grassl. Cong.,
Lexington, Kentucky, 1981. pp. 429-431.
- Trollope, W.S.W. The growth of shrubs and their reaction to treatment. In: Tainton,
1981 N.M. (ed.) Veld and pasture management in South Africa. Shuter and Shooter,
Pietermaritzburg, R.S.A.
- Tsiouvaras, C.N., Noitsakis, B. and Papanastasis, V.P. Clipping intensity improves growth
1986 rate of Kermes oak twigs. Forest Ecology and Management 15: 229-237.
- Tucker, C.J., Vanpraet, C., Boerwinkel, E. and Gaston, A. Satellite remote sensing of
1983 total dry matter production in the Senegalese Sahel. Remote Sensing of
Environment 13: 461-474.
- Tyson, P.D. Climate and desertification in Southern Africa. Geo. J. Suppl. Iss. 2: 3-10.
1981
- Underwood, E.J. The mineral nutrition of livestock. CAB International, Wallingford,
1981 U.K. 180 pp.
- United Nations Educational Scientific and Cultural Organization. Tropical grazing land
1979 ecosystems. A state of knowledge report prepared by Unesco/UNEP/ FAO.
Unesco, Paris.

- Vacakis, F. et al. Study for the development of the livestock industry in Timfi Ioannina. 1982 Ministry of Agriculture, Athens.
- Vegten, J. van. Some aspects of the ecology of the Kgatleng District, Botswana: 1979 introduction of the range coefficient. Working Paper 27. NIR, Gaborone. 12 pp.
- Verboom, W.C. and Brunt, M.A. Ecological survey of Western Province, Zambia. Land 1970 Research Study No. 8. Directorate of Overseas Surveys, Tolworth. 133 pp + maps.
- Verboom, W.C. Animal protein-producing areas of Zambia. Vol I + Vol II. NCSR, 1981 Lusaka/ITC, Enschede. 246 pp + 156 pp.
- Vink, A. Landscape ecology and land use. Longman, London. 264 pp. 1983
- Voortman, R. A survey and evaluation of **dehesa** rangelands in south west Spain, 1978 including seasonal aspects of vegetation, management and behaviour of livestock (food selection). Univ. Groningen, ITC, Enschede. 68 pp.
- Voortman, R.A. Guidelines on land evaluation for rainfed agriculture in Mozambique 1985 (Basement complex). Serie Terra e Agua. Inst. Nac. Invest. Agron. Comm. 30, Maputo. 101 pp.
- Walker, B.H. Management of semi-arid ecosystems. Elsevier, Amsterdam. 398 pp. 1979
- Walker, B.H. and Noy-Meir, I. Aspects of stability and resilience of savanna ecosystems. 1982 In: Huntley, B.J. and Walker, B.H. (eds.) Ecology of tropical savannas. Springer-Verlag, Berlin.
- Walker, B.H. A review of browse and its role in livestock production in Southern Africa. 1983 International Symposium. In: Houerou, H.N. Le (ed.) Browse in Africa. ILCA, Addis Ababa.
- Walker, H. Ecology of tropical and subtropical vegetation. Oliver and Boyd, Edinburgh. 1973
- Wamukoya, O.K.W. (ed.) Proceedings of a seminar on land evaluation for rangeland 1977 use. Kenya Soil Survey, Misc. Soil Pap. 11. Nairobi.
- West, O. Fire in vegetation and its use in pasture management. CAB International, 1965 Wallingford, U.K.
- Westoby, M. Elements of a theory of vegetation dynamics in arid rangelands. Israel J. 1979-80 Bot. 28: 169-194.

- Whiteman, D.C. Tropical pasture science. Oxford Sc. Publ., Oxford.
1980
- Whittaker, R.H. Classification of plant communities. Junk, The Hague.
1978
- Whyte, R.O. Tropical grazing lands: communities and constituent species. Junk, The
1974 Hague. 222 pp.
- Wijngaarden, W. van. Specific problems in land evaluation for extensive grazing. In:
1984 Siderius, W. (ed.) Proceedings of the Workshop on Land Evaluation for
Extensive Grazing. ILRI, Wageningen. pp. 145-149.
- Wijngaarden, W. van. Elephants - trees - grass - grazers. Relationship between climate,
1985 soils, vegetation and large herbivores in a semiarid savanna ecosystem (Tsavo,
Kenya). ITC publ. 4, Enschede. 159 pp.
- Wilson, R.T. and Clarke, S.E. Studies on the livestock of Southern Darfur, Sudan. I:
1975 The ecology and livestock resources of the area. Trop. Anim. Hlth. Prod. 7:
165-187.
- Wilson, R.T. and Clarke, S.E. Studies on the livestock of Southern Darfur, Sudan. II:
1976 Production traits in cattle. Trop. Anim. Hlth. Prod. 8: 47-51.
- Wilson, R.T., Leeuw, P.N. de and Haan, C. de. Recherches sur les systèmes des zones
1983 arides du Mali: resultats préliminaires. ILCA, Addis Ababa.
- Wischmeier, W.H. and Smith, D.D. Predicting rainfall erosion losses. A guide to
1978 conservation planning. Handbook No. 537. USDA, Washington.
- Wood, S.R. and Dent, F.J. LECS: a land evaluation computer system methodology.
1983 Min. Agric. Indonesia/UNDP/FAO. Bogor.
- Woodruff, N.P. and Siddoway, F.H. A wind erosion equation. Soil Sci. Soc. Amer. Proc.
1965 29: 602-608.
- Yagil, R. Camels and camel milk. FAO Animal Production and Health Paper No. 29.
1982 FAO, Rome. 69 pp.
- Yath, Y.A. Landscape ecological survey of south Kongor, Jonglei, Sudan. MSc thesis,
1984 ITC, Enschede, The Netherlands.
- Yath, Y.A. and Gils, H. van. Multitemporal Landsat for land unit mapping on project
1986 scale of the Sudd floodplain, southern Sudan. Symp. Rem. Sens. for Res.
Devlpt. and Env. Mgnt., Enschede, Aug 86. pp. 531-532.
- Young, A. Tropical soils and soil survey. Cambridge University Press, Cambridge.
1976

- Young, A. Agroforestry for soil conservation. ICRAF Series on the Science and Practice of Agroforestry, Volume 4. CAB International, U.K. 276 pp.
1989
- Young, A. and Gils, H. van. Land qualities for extensive grazing and their rating. In: Siderius, W. (ed.) Proc. Workshop for Extensive Grazing. ILRI, Wageningen. pp. 327-328.
1984
- Zonneveld, I.S. Land evaluation for land(scape) science. ITC Textbook, Enschede. 134 pp.
1972
- Zonneveld, I.S., Gils, H. van and Thalen, P.C.P. Aspects of the ITC approach to vegetation survey. Doc. Phytosoc. IV, Lille: 1029-1063.
1979
- Zonneveld, I.S. Some consequences of the mutual relationship between climate and vegetation in the Sahel and Sudan. ITC J. 1980-82.
1980
- Zonneveld, I.S. Principles of land evaluation for extensive grazing. In: Siderius, W. (ed.) Proceedings of the Workshop on Land Evaluation for Extensive Grazing. ILRI, Wageningen, The Netherlands.
1984