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# LAND EVALUATION FOR AGROFORESTRY: THE TASKS AHEAD

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# LAND EVALUATION FOR AGROFORESTRY: THE TASKS AHEAD

Anthony Young


## ABSTRACT

The objectives and procedures of land evaluation and the nature of the results obtained are outlined. The present state of development of evaluation methodology is reviewed for kinds of land use related to agroforestry: crop production, forestry and livestock production. The stages in the development of a methodology of land evaluation for agroforestry are described, namely: an environmental data base, formulation of appropriate agroforestry land utilization types, determination of land use requirements, construction of biophysical models, assessment of environmental impact and sustainability, method for comparison between agroforestry and non-agroforestry land utilization types, and testing through case studies. Land evaluation draws upon data from, and interacts with, many other ICRAF projects in agroforestry research. The principal outputs from a land evaluation research programme will be: (i) a systematic assessment of the environmental suitabilities of specified agroforestry land utilization types; (ii) a method for comparison of the suitability, including environmental, economic and social aspects, of land utilization types, both agroforestry and non-agroforestry, on different land units. The results will permit quantitative estimates of the potential contribution of agroforestry to sustainable production over specified areas of land.

## 1. OBJECTIVE

The objective of this paper is to formulate a means by which the approach and methods of land evaluation can be applied to agroforestry. It commences with a review of land evaluation, first in its general aspects and secondly as it has been applied to the component land use elements of agroforestry: crop production, forestry and livestock production. Next comes discussion of the need for land evaluation in agroforestry and the problems which arise in its application.

These accounts lead to the formulation of a set of related activities which it appears practicable to undertake, and which, if successful, will converge towards a methodology for the application of land evaluation to agroforestry. An important element is how the various current activities in agroforestry research in general, and the work of ICRAF in particular, can contribute to the land evaluation activities; and, conversely, how land evaluation fits into the broader sphere of agroforestry research and its application to practical land development.

## 2. THE NATURE AND PURPOSE OF LAND EVALUATION

### 2.1 What is land evaluation?

Land evaluation is the process of assessment of land performance when used for specific purposes, in order to identify and compare promising kinds of land use. Essentially it is a procedure for comparing land with land use, where land refers to all the factors of the physical environment, including climate, landforms, soils and vegetation. More precisely, land evaluation involves comparison between the environmental requirements of various kinds of land use and the properties possessed by different areas of land.

Take, as a simplified example, the growth of a single tree or crop species. Clearly, what grows well in a semi-arid environment will not do so in the rain forest zone, and vice versa. For each plant species there is a range of conditions which are highly favourable for its growth, a wider range within which it will grow but not so well, and sets of conditions (e.g. too wet or too dry, too acid or too alkaline) in which it will not grow at all. In the terminolog of land evaluation, these sets of environmental conditions are, respectively, highly suitable, suitable and not suitable for the tree or crop. Many environmental properties, e.g. temperature, moisture availability, soil reaction, drainage, need to be assessed in this way, and account taken of their interactions.

There is a second way of looking at the comparison between land use and land, that of taking a specific area of land as the basis. Any given area of land possesses a distinctive set of properties, of climate, soils, vegetation, etc. Under such conditions there will be some trees or crops which grow very well, some which grow satisfactorily, and others which fail and die. That is, taking a specific area, it will be found that different plant species are highly suitable, suitable, or not suitable for the environment of that area.

The same approach to that outlined above for a tree or crop species considered in isolation can be applied to cropping systems (rotations, intercropping, etc.); to crops grown under specified management conditions (e.g. with or without fertilizer); or to com-

binations between trees, crops and pastures. Any land use system, described in as much detail as the intensity of the study requires, can be evaluated as to its suitability in different environments. The term employed to refer to a defined land use system, taken as the subject of land evaluation, is a land utilization type.

These simplified examples illustrate the potential of land evaluation for answering questions of two kinds:

i. For a given kind of land use, where are the areas to which it is best suited?

ii. For a given area of land, what is the most suitable use?

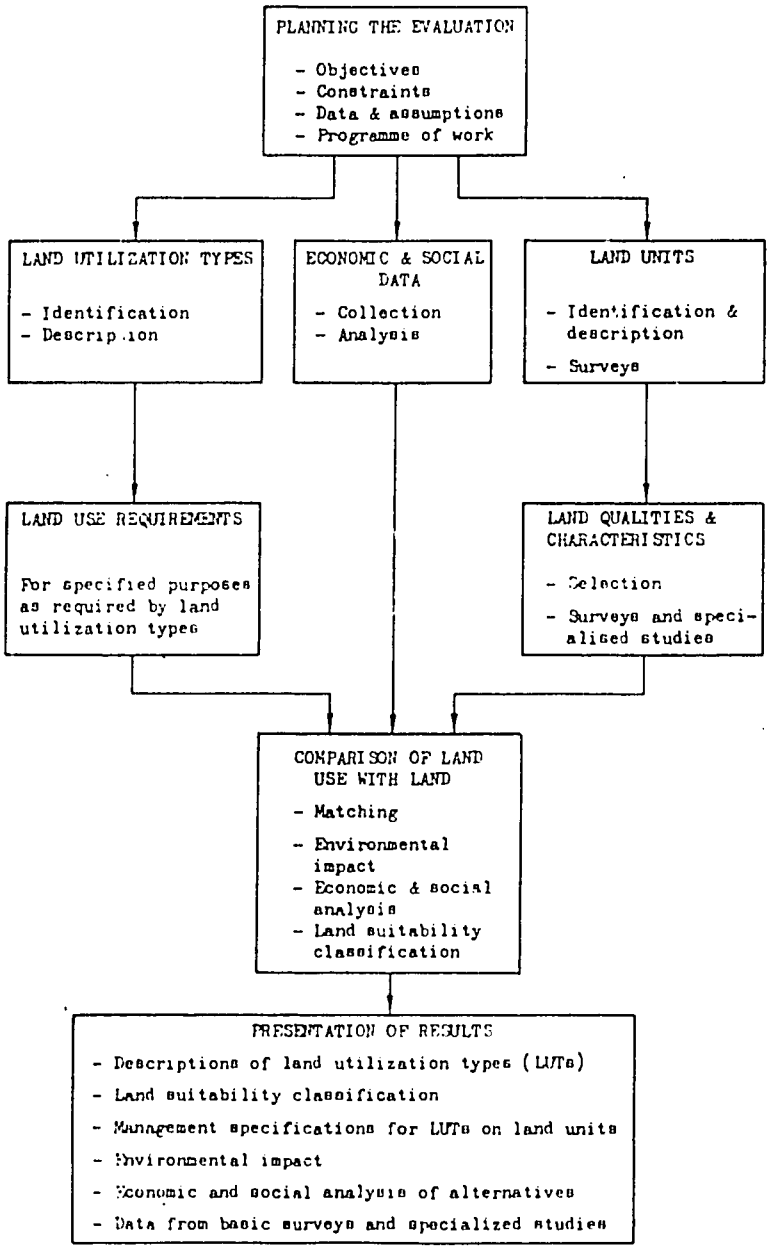
## 2.2 Procedures of land evaluation

The procedures of a land evaluation study are shown in simplified form in Fig. 1. They commence with formulation of the objective of the study, frequently within the framework of a land development project. Two parallel sets of activities are then initiated: studies of promising kinds of land use, and surveys of the land. The studies of land use lead to the identification of a range of alternative land use systems which appear to meet the objectives and to be relevant both to the physical and to the social and economic context of the area. These systems are progressively amplified and refined, leading to their description as land utilization types.

Next, the land use requirements of each land utilization type are identified; requirements, for example, for temperature regime, moisture, nutrients, soil erosion hazard, or absence of pests and diseases. Each land utilization type has different requirements: for example, each crop requires different climatic and soil conditions, the soil nutrient requirements differ according to whether mechanized or manual harvesting is specified.

Parallel with the activities directed towards land use come surveys and specialized studies of the land. The first task is to identify and survey relatively homogeneous areas of land, called the land units. This term refers not to a particular scale or type of mapping unit, but to any area of land taken as the basis for

Figure 1. Outline of Procedures in Land Evaluation.
Source: FAO (1984a, p. 27).



land evaluation: for example, in broad reconnaissance surveys, land systems might form the mapping units, whilst in more detailed surveys they might consist of land facets, soil series or vegetation communities. Having identified and mapped each area, the relevant properties of the land units are surveyed and recorded: for example moisture availability, soil depth, soil nutrient availability, erosion hazard, presence of pests and diseases, or terrain conditions which affect mechanization.

These two sets of activities are brought together in the comparison of land use with land. The first stage of comparison is matching, in which the requirements of each kind of land use are compared with the properties of each area of land. Thus moisture requirements of a crop of land use system are compared with the moisture availability of each land unit, nutrient requirements with nutrient availability, the susceptibility of the land use to erosion with the erosion hazard, etc.. Matching leads to a first approximation of land suitability, in terms of physical land use requirements only.

These provisional suitabilities are then subjected to further stages of analysis, in terms of environmental impact, economic analysis, and social consequences. Some combinations of land use with land which appeared suitable in physical terms may be rejected on grounds of adverse environmental consequences, negative economic return or unacceptable social effects.

These further stages of analysis lead to land suitability classification, giving the suitability of each surveyed land unit for each defined land utilization type. In the land suitability classification normally employed there are two suitability orders, S Suitable and N Not Suitable, divided into five suitability classes as follows:

| | | | |
|---|---|---|---|
| S1 | Highly suitable | N1 | Currently not suitable (physically possible, but not economically viable) |
| S2 | Moderately suitable | | |
| S3 | Marginally suitable | N2 | Permanently not suitable |

Further subdivision is possible, into land suitability subclasses and units. Subclasses show the type of limitation, e.g.

moisture deficiency, salinity, adverse conditions for mechanization. Land suitability units consist of further subdivision into areas with relatively uniform management requirements and a specified range of productive capacity.

## 2.3 Results of land evaluation

The principal results of a standard land evaluation survey are:

i. Descriptions of land utilization types relevant to the area.

ii. An assessment of the suitabilities of each land utilization type for each of the mapped land units, together with reasons for this assessment.

iii. Management specifications, for land utilization types on each of the land units for which they are suitable.

iv. An account of the consequences of each land utilization type on each land unit: including required inputs, expected outputs (products, services and other benefits), environmental impact, social consequences, and economic analysis.

These results are presented as one or more land suitability maps, together with a report.

# 3 THE DEVELOPMENT OF LAND EVALUATION METHODOLOGY

## 3.1 Introduction

The methods of land evaluation arose out of practical field projects. Land development planning calls for answers to the kinds of question noted above: where are the best sites for a given kind of land use (e.g. tea, forest plantations), and what is the best use for a particular area of land? This field experience was brought together and systematized in the Framework for land evaluation (FAO, 1976).

The Framework is a slim volume, giving the approach and principles of land suitability evaluation, definitions of terms, and the outline of a set of procedures. It does not, however, go into detail on procedures, nor does it give very much information on the specific criteria to be used in assessing suitability for different purposes.

Experience in using the Framework has shown that, on the one hand, the overall approach and principles have proved to be robust and flexible; they have stood up to application at different scales of survey, to different kinds of land use and other variations in circumstances. Surprisingly few modifications or additions to the general approach have proved to be necessary.

On the other hand, many users have called for more specific detail on the procedures and criteria to be used in evaluations. This need has been felt both by those engaged in practical studies, and by those attending or conducting training courses in land evaluation. As a result of this need, FAO embarked on the preparation of a series of more detailed guidelines on land evaluation for major specific kinds of land use: rainfed agriculture, forestry, irrigated agriculture and livestock production (FAO, 1983, 1984a, 1984b; the guidelines for livestock production are at an early stage of preparation). Since these kinds of land use can be regarded as components in agroforestry systems, it is relevant to examine what distinctive features and problems arose in applying land evaluation principles to them.

## 3.2 Rainfed crop production

Although entitled Guidelines for land evaluation for rainfed agriculture (FAO, 1983), the first of these manuals in fact refers not to agriculture in its wider sense but to crop production (annuals and perennials). It is the most detailed of the guidelines, setting out specific steps to be followed, and giving proformas for use at each stage.

Rainfed crop production can be regarded in some respects as the 'normal' or standard form of land use. Thinking in terms of suitability for maize, sorghum, rubber, tea, etc., within a given socio-economic context (smallholder farming, estate agriculture) formed the major basis on which most of the principles were formulated in addition, the Framework has been more widely applied to assessment for crop production than for any other kind of land use.

The major systematic contributions arising from this study were to identify the land qualities which can affect suitability for crops, and to divide these into three groups: qualities affecting growth, management and conservation. The main qualities affecting plant growth (and survival) are radiation, temperature, moisture, nutrients, drainage, soil rooting conditions, and absence of various adverse conditions, e.g. flood hazard, soil toxicities, pests and diseases. Some growth requirements are common to all or most plants but many are specific to individual crops. Land qualities affecting management include soil workability, terrain conditions affecting ease of mechanized operations, accessibility and location. These conditions are often specific to kinds of management (e.g. mechanized cultivation) but to some degree independent of the crop grown. In crop production the principal land quality affecting conservation is the degree of soil erosion hazard.

These three groups of land use requirements can be treated independently to some extent. This permits, for example, the identification of areas suited to the growth of maize, irrespective of method of management; those suited to mechanized agriculture, irrespective of crop; and areas which are suited for annual crops on grounds of conservation, such assessments being different for cultivation with and without soil conservation works. For a specified

land utilization type these component suitabilities can be combined, to give areas suitable for, e.g., "large-scale mechanized maize cultivation with conservation bunds", or " smallholder non-mechanized maize cultivation without physical soil conservation works".

This technique of disaggration of the land utilization type, and of its land use requirements, clearly has potential applications to agroforestry. At the simplest level, growth requirements of the component elements in an agroforestry system---crops, trees, pastures ---could first be assessed in isolation, providing necessary but not sufficient conditions for their success in combination. It might also be possible to isolate management requirements of specific agroforestry techniques, e.g. alley cropping.

## 3.3 Forestry

Evaluation for forest plantations, whether for timber or fuelwood, is similar in principle to that for agricultural tree crops, e.g. oil palm, rubber. The delay between establishment and harvest is frequently longer for forest products, whilst the major harvest at any given site comes in one year, in contrast to the extended yield period of agricultural tree crops. The management requirements for forestry include the requirements for various methods of timber harvesting, but this feature is not wholly distinctive since agricultural tree crops also have specialized harvesting requirements. Land evaluation procedures for both cases follow similar lines, ending with economic analysis by discounting procedures, to take account of the time delay between planting and harvest.

There are, however, two distinctive features of forest land evaluation, both potentially relevant to agroforestry: the inclusion of the standing forest as a component of land and the special situation of conservation forestry (FAO, 1984b).

The definition of land includes its existing vegetation. In evaluation for crop production, it is normally assumed that this will be cleared, and attention is concentrated on forecasting the crop growth. In the case of forestry based on natural forests, however, there is no need to take this indirect method of forecasting growth rates from climatic and soil variables. The net effect of the latter has already resulted in the standing forest,

and the resources available are assessed by the technique of forest inventory.

The second distinctive case arises where conservation is the primary purpose of forestry. For agricultural use or, indeed, forest plantations, the existence of a high erosion hazard is a limitation, adverse to the proposed use. In contrast, the situation in sloping water catchment areas at present under forest is that the greater their potential erodibility, the more highly suited do they become for retaining the present protective forest cover. In the case of afforestation of eroded or otherwise degraded land, the severity of the degradation, and thus of the need for rehabilitation, becomes one criterion of suitability. This situation is conceptually distinct.

Both these circumstances can be relevant to agroforestry. The standing forest is utilized as a resource in some agroforestry practices, whilst the need for soil conservation and/or rehabilitation is frequently a reason for calling in advice on the potential of agroforestry interventions.

## 3.4 Irrigated agriculture

As agroforestry is uncommon on irrigated land, the procedures set out in these guidelines (FAO, 1984b) are not directly relevant. Where it is indirectly valuable, however, is in the development of methods of economic land suitability classification. The repayment, in financial and/or social terms, of the cost of capital works is an essential feature of irrigation development, and the guidelines set out the relationships between net farm income and net incremental irrigation benefit, criteria which can be applied to other forms of land development which involve substantial capital expenditure.

## 3.5 Livestock production

Preparation of guidelines on land evaluation for livestock production is at an early stage. The first workshop was held in December 1983, confined to extensive grazing, defined as those forms of livestock production which rely largely or entirely on a feed base consisting of natural or semi-natural vegetation. The distinctive features, calling for special treatment in land evaluation,

were identified as follows:

i. The two-stage character of livestock production: from climate and soil conditions to vegetation growth, and from the feed base of vegetation to animals.

ii. The capacity of livestock to move, thus permitting the use of different land areas in different seasons (nomadism, transhumance, seasonal movement between valley and hill pastures).

Both these features are applicable to agropastoral systems, the first necessarily so in all cases, the second where seasonable movement between grazing lands takes place.

## 3.6 Scale of survey and kinds of application

Land evaluation is applicable at all scales of land use planning: global/continental, national, regional, district, village and farm level. At the global level, its most notable application has been in the strategic studies of food-producing capacity conducted by the FAO, in the Agro-Ecological Zones project and the Land, Food and Population project (FAO, 1978/81). The most widely known land evaluation studies are those at the national or major region level, for example surveys of the whole of Ethiopia, of Sierra Leone, of north-east and north-central Nigeria, and large areas of Indonesia (where the evaluation system is computerized).

Applications at district or regional level have been numerous usually within the framework of development projects. Studies at village or farm level do not readily become known, but are probably few in number.

In national and regional applications the typical product of surveys are maps showing areas suitable and not suitable for growth of individual crops, for mechanized cultivation, or for intensive or extensive livestock production. Such studies serve the purpose of identifying potential project areas, e.g. for a smallholder tea-growing or livestock ranching scheme. Thus the principal focus of surveys at this scale has been that of answering the question,

"where are the best areas of development of a particular kind of land use?" - frequently cultivation of specific crops.

At the district or project level, the above question may still arise, sometimes specific to one crop, e.g. which land is and is not suited to sugar cane, but the focus is frequently different. A common objective is the allocation of land to major kinds of use, e.g. annual crops, perennial crops, grazing, forestry; this occurs particularly in land settlement schemes. At the later stages of project planning, evaluation extends to the study of whether a specified kind of land use is economically viable on a given land area, and which of two or more uses is the more beneficial.

Thus land evaluation has been applied to the following kinds of question:

i. Which are environmentally the best areas for a number of specified kinds of land use - frequently for particular crops?

ii. How should the land within a given area be allocated between different uses?

iii. On a given area of land, which of several alternative uses is the more beneficial?

Can such questions be answered with respect to agroforestry land utilization types? For the first, the answer is clearly yes for the plant components - trees and crops - but it will be some time before it can be answered with respect to agroforestry systems. The second question, allocation of land to different uses, occurs in agroforestry design procedures: having determined that certain interventions can aid in solving land use problems, then a necessary element in design is decided which areas of land are suited to which agroforestry practices. The third type of question is clearly applicable in the form, "which of a number of possible land use changes is the most beneficial - agroforestry, improved agriculture or forestry?

# 4 LAND EVALUATION FOR AGROFORESTRY

## 4.1 The need

The following quotations illustrate recognition of the need for applying land evaluation to agroforestry.

"To build up the scientific credibility of the discipline... researchers should always compare the potential of agroforestry with that of monocultures" (G. Budowski, in MacDonald (1982), p. 13).

"It may well be years before one can accurately assess what proportion of the land is actually better suited for agroforestry practices than for monocultures" (Foreword to MacDonald (1982), p. vii).

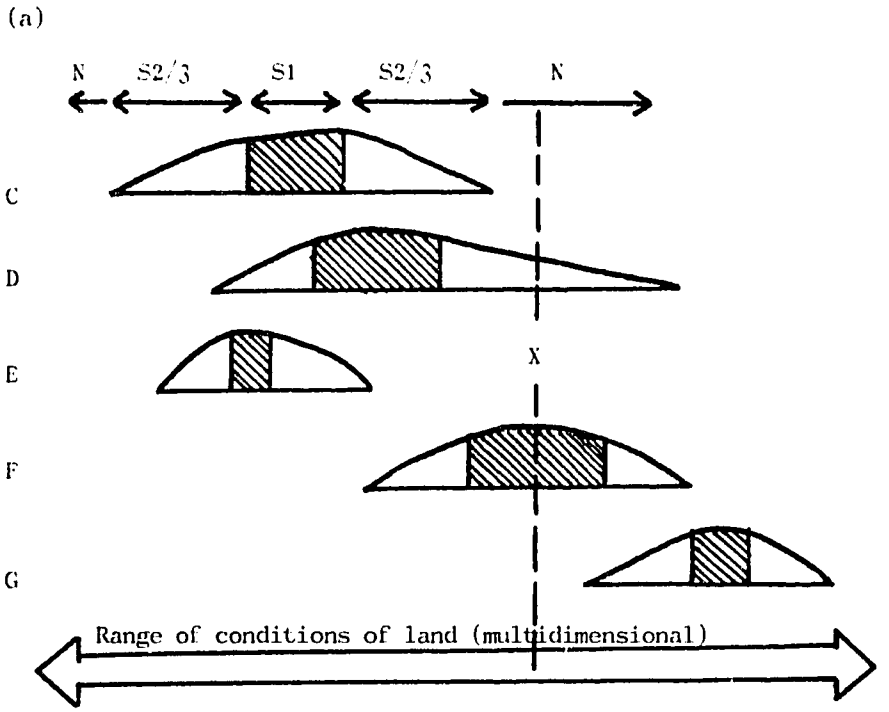
"Agroforestry...may well be the best answer to solving problems of rural development in specific sites or regions. For others, it may be just as good as any other land use or even less suitable" (Editorial to Vol. 1, No.1 of 'Agroforestry Systems').

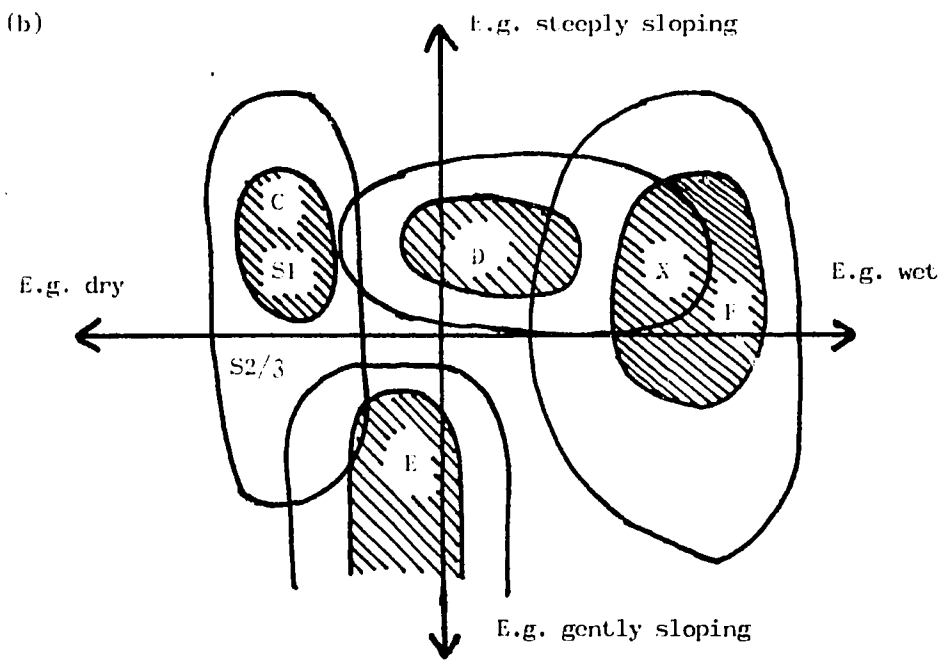
"More fundamentally, we even lack relevant methods on how to assess the social, economic and ecological feasibility of complex agroforestry systems, and how to compare them in quantitative terms with other forms of land use" (ICRAF Programme of Work for 1983, p.2).

Two related points are implied by these quotations. First, that any specific agroforestry practice will function optimally under one set of environmental conditions, somewhat less efficiently but still successfully under a wider range of environments, while in other conditions it will not work at all. This is shown in Figure 2, in which the range of environments, in reality multi-dimensional, is shown schematically; C, D, E, ... are land utilization types, any of which may or many not be agroforestry systems. For any particular land utilization type, the most efficient range of conditions is shaded.

The second aspect follows as a necessary implication, namely that for any given site, some land utilization types will function

Figure 2. RELATIONS BETWEEN ENVIRONMENTAL CONDITIONS AND LAND UTILIZATION TYPES. The multidimensional nature of the environment is schematically reduced to one dimension in (a) and two dimensions in (b).



very well, some moderately well, whilst many others will be unsuited to the land conditions. Thus at point X in Fig. 2, types D and F are suitable, with F the more highly suited.

This schematic view illustrates the two major aspects of land evaluation applied to agroforestry:

i. For a specified land utilization type (agroforestry), on which sites will it function most effectively?

ii. For a given site, which land utilization types (agroforestry and non-agroforestry, possibly several of each) will be most beneficial?

## 4.2 What is already known?

If the question is asked, "Can we define a number of agroforestry-based land utilization types, and give for each the environmental conditions that are highly suitable, moderately suitable and not suitable?", the answer at present must be no.

This does not mean, however, that no knowledge of environmental requirements exists. Many experts, both within and outside ICRAF, would be prepared to recommend specific agroforestry designs suited to particular environments. This is done by the older method, long employed in both agricultural and forestry advisory work, of experience, local knowledge and judgement.

This method depends on a high level of skill and experience on the part of those offering advice,something which is not easily acquired or transmitted. It would usefully supplement the method of skilled judgement to have a body of information, assembled, arranged and presented in a systematic manner, to which reference could be made.

In the terminology of land evaluation, agroforestry is a major kind of land use. Are there known to be any environments to which agroforestry, taken as a whole, is particularly well suited or appears to be not suited?

It is clear that there are agroforestry practices and systems of different kinds which function effectively in a wide range of tropical and subtropical environments; the existence of successful agroforestry systems, indigenous or modern, is sufficient evidence of this. The range includes the 'three worlds of the tropics', the humid (rain forest), subhumid (savanna) and semi-arid, as well as tropical highland variants of these. Agroforestry practices have been successful on both steeply and gently sloping relief, and on soils ranging from sandy to clayey and strongly acid to alkaline. Depositional landscapes (alluvial land) are less often found under agroforestry, although it is by no means absent from them. Other than the limits set to tree, crop and pasture growth by extreme aridity or cold, there are few tropical and subtropical areas which may not have potential for some kind of agroforestry.1/

If the experience of ICRAF, in being called to give advice for specific areas, is any guide there are certain sets of conditions to which agroforestry is (or is believed to be) particularly appropriate. Advice is often called for with respect to moderately or steeply sloping lands, and soils of medium to low fertility. This is frequently coupled with the fact that such areas have experienced soil erosion, soil degradation (particularly lowering of fertility) or degradation of vegetation resources (forest or pasture). In short, advice on the potential of agroforestry is often sought for marginal and/or degraded lands. This, however, is also the case with other forms of intervention by government agencies. It could well be that agroforestry functions excellently on gently sloping relief with deep, loamy soils, but if farmers are getting cereal yields of 3-5 tonnes per hectare on a sustainable basis they do not seek to enquire if alternative systems could do better.

The above applies to agroforestry taken as a whole. At the opposite end of the scale, a considerable body of data could be assembled from existing sources on the growth requirements of the individual components of agroforestry systems: trees, crops and pastures. The current ICRAF multipurpose tree survey is adding to knowledge on the first of these.

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1/ Design problems are more serious in the temperate zone, where radiation or temperature are more often limiting, and the low sun angle increases the shade cast by trees.

Between these extremes --- between 'agroforestry' and Acacia albida or maize --- there is relatively little systematic knowledge of environmental requirements. A first step towards acquiring such knowledge is to find appropriate levels of generalization at which to define and describe appropriate agroforestry land utilization types. This is discussed further in Section 5.3.

## 4.3 Problems

It might be thought possible, prima facie, to take the existing land evaluation procedures devised for agriculture and forestry and specifically the "Guidelines" for these (FAO, 1983, 1984a), and combine them into a methodology for evaluating agrosylvicultural systems. Methods for assessing livestock production, when further refined, would similarly be incorporated into evaluation of agropastoral and agrosylvopastoral systems.

Certainly, these methodologies have a major contribution to make. Many specific problems have been covered, for example the treatment of conservation requirements or the relations between evaluation in physical and economic terms.

Evaluation for agroforestry, however, involves considerably more than a synthesis of methods drawn from its contributory forms of land use. Among reasons for this are:

i. The need to find appropriate ways to define and describe agroforestry land utilization types.

ii. The less advanced state of knowledge, as compared with crop production and forestry, of the environmental limits of agroforestry systems.

iii. The key role, in agroforestry, of interactions between the tree and non-tree components of a system.

Means of finding solutions to these problems need to be built into the research programme, as discussed in Section 5.

## 4.4 Comparison with the diagnosis and design methodology

Land evaluation is a practical methodology, applicable to all kinds of rural land use, and employed in field projects to assist land development. So also is the ICRAF diagnosis and design (D and D) methodology, developed specifically with respect to agroforestry but incorporating features of the farm systems approach applicable to agricultural land use in general (Raintree et al., 1983a, 1983b). As these two methodologies are far from identical, and yet were developed for purposes which are overlapping, it is relevant to examine points of similarity and difference. It should be noted that the procedures of diagnosis and design, although already successfully applied in many field projects, are regarded as being at an advanced draft stage and are still evolving in detail.

As a basis for comparison, reference should be made to the outline of D&D methodology given in ICRAF Working Paper 6, in particular to Figures 1 and 2 and the summary of 12 main steps therein (Raintree, 1983a, pp. 8-16).

Some of the contrasts between the two sets of procedures do not exist in principle but are de facto differences in surveys carried out to date. The major contrasts are:

i. Aims: land evaluation is normally intended for direct implementation, D&D for the design of a research programme.

ii. Differences in scales of space and time.

iii. Contrast in emphasis: environmental aspects receive more attention in land evaluation, social aspects in D&D.

iv. Absence from land evaluation of the problem diagnosis procedure of D&D.

v. Absence from D&D of detailed field surveys of the environment.

vi. Greater attention in land evaluation to comparison between alternative forms of land use.

First, there is a difference of aim. Land evaluation is intended for direct application to land use planning; diagnosis and design is directed towards designing a research programme that will, if successful, be capable of implementation in land use planning. It is true that parts of a D&D report may give the impression of being a project plan, but this is because of its requirement that a viable land use design, capable of being implemented by the farmers, should be formulated as a basis for design of research. Basically there is the difference that in land evaluation procedures, it is assumed that the necessary technologies of land use are known and proven, in the D&D methodology that they need to be tested and verified. Note, however, that D&D does contain provision for immediate application, in that in the event that certain parts of the technology are considered proven, "planning decisions" can proceed directly to "dissemination", i.e. implementation (op. cit., Fig.1).

There are further de facto differences of space and time. Land evaluation is most commonly applied to areas ranging from 1000 km up to a whole region or country. Some D&D studies have taken regions as large as 1000 km as an initial basis (and potential future area for implementation) but in practice their attention is narrowed down to quite a small area, such as a representative watershed. A typical regional land evaluation study takes 2-5 years, over half of this on field survey. In D&D the first-cycle diagnosis is accomplished in 2-3 weeks, and the succeeding design a few months (although the full iterative cycle, requiring achievement of research results, is likely to take a minimum of 5 years).

Both methodologies give attention to analyzing the social impact of possible land use changes. The D&D procedures go into more specific detail on this aspect, particularly as regards adoptability of innovations by farmers. Some of these procedures have, in fact, recently been adapted and explicitly incorporated into the guidelines on land evaluation for forestry. Conversely, land evaluation procedures set out in more detail methods for the identification of land units, and survey of their environmental properties; but again a summary of such procedures has been incorporated into the most recent version of the D&D methodology. In both cases, the difference is one of the relative emphasis: in

land evaluation, the focus is on environmental suitability, with social and economic analysis providing the necessary support. In D&D procedures the focus is on the farmer, his needs and problems, and the appropriateness of proposed solutions to those needs, with environmental considerations tending to be treated as a necessary background: this is shown by the position of "environmental description" as Step 1, in the prediagnostic stage.

There is one feature of emphasis in D&D which is largely missing, or at least not itemized, in land evaluation procedures. This is the problem-orientation approach of D&D. Analysis of problems commences with shortfalls in the supply system of the farmer: for food, fuel, shelter, cash, etc.. D&D methodology next analyzes the causal networks leading to these shortfalls, some of which may be socio-economic in origin (e.g. shortage of labour) but many arise from the land, e.g. decline in soil fertility, drought hazard, seasonal pasture shortage. "What are the farmers' problems?" and "What are the underlying causes of these problems" are focal points in the diagnosis stage of D&D; the former question is socio-economic, the latter frequently proves to be environmental in origin.

Land evaluation procedures (to date) lack the stage of "identification of problems" or its equivalent. There is often a tacit assumption that the land surveyed is in reasonably good condition, i.e. not seriously degraded. The "properties of the land units" (Figure 1) could certainly be properties in a degraded condition, e.g. pasture biomass, forests from which the most valuable timber species have been extracted, but there is no explicit recognition of this possibility. Where such problems of the farmers and/or the land exist, the point at which they could be identified would be under "Initial consultations: objectives", which is the starting point of land evaluation procedures. It is implicit, however, that any such problems have already been identified by government or perhaps some preceding study; there is no point at which the land evaluation team is itself called upon to analyze the present problems. The focus is different: to maximize benefits, rather than to solve problems. This need not mean solely economic benefits; environmental and social gains are taken into account. Hence, land evaluation procedures could benefit by inclusion of a more specific element of diagnosis of problems and their causes.

Land evaluation quite clearly directs more attention to the spatial differentiation of appropriate forms of land use, as brought about by variations in environmental conditions. This is its primary aim. Hence a considerable part of the time and effort in an evaluation goes into mapping land units and describing their physical properties. It is true that if a land systems or soil survey already exists, comprehensive, reliable and at a sufficiently detailed scale, it can be taken as the basis for evaluation without further primary survey. In most parts of developing countries this is not the case. Land evaluation projects therefore commonly set up activities in remote sensing and field survey to collect such data. This has not been done in D & D projects to date: in part owing to the shorter time scale, they make do on whatever cartographic and other environmental information is already available, supplemented by the diagnosis team keeping its eyes open for resource problems, and gathering information on these from farm interviews. It contains provision for listing separately "farmers' perception" and "diagnosis team perception" of environmental problems, e.g. soil erosion.

When the time is reached for the field implementation, on a substantial scale, of the results of D and D research, then a thorough study of which agroforestry practices are suited to which areas of land will be desirable. The history of tropical land development contains many examples of costly errors through attempting land use changes with inadequate knowledge of environment. However, since at this later stage the land utilization types - agroforestry technologies - will be reasonably well formulated and proven, a land evaluation survey based on known technology could then be conducted.

One further feature of land evaluation is not so strongly represented in the D and D methodology. This is comparison of the relative desirability, on any specific site, of alternative land use systems. This is a focal point of land evaluation: out of land utilization types A, B and C, which is the more beneficial on site X? In D and D procedures this is most nearly represented by Step 9, 'Design evaluation', and has appeared earlier in Step 7, 'Technology appraisal', in which non-agroforestry as well as potential agroforestry technologies are reviewed. It is fair to say, however, that having arrived at one or more potential agroforestry solutions, there is no systematic procedure set out for comparing them with

solutions in terms of improved agriculture or forestry. In practice, some D and D studies have made such comparisons in economic terms, using the MULBUD computer programme for cost-benefit analysis of multiple cropping situations (Etherington and Matthews, 1982).

There are some apparent opportunities for mutual improvements by incorporating elements of one procedure into the other. These are:

i. The social analysis stage of land evaluation could profitably make use of detailed techniques of field social survey and analysis devised for D and D.

ii. A means should be found of incorporating the stage of diagnosis of problems (socio-economic and environmental) into land evaluation.

iii. D and D should direct greater attention at differentiation of conditions of the physical environment, and could make use of land evaluation methods as a means of doing so.

iv. Some of the methods for systematic comparison between alternative kinds of land use, developed by land evaluation, could be applied in D and D to compare proposed agroforestry designs with non-agroforestry forms of land use improvement.

## 5 STAGES IN THE DEVELOPMENT OF A METHODOLOGY

There are three starting points for a programme of research: the objectives and principles of land evaluation, the special features of its application to crop production, forestry and livestock production, and the present state of knowledge on agroforestry Taking these as a basis, a programme to develop a practical set of guidelines on land evaluation for agroforestry would need to contain the following elements:

i. An environmental data base.

ii. The formulation of appropriate land utilization types as a basis for suitability analysis.

iii. Land use requirements, for agroforestry components (trees, crops, livestock) and technologies.

iv. Biophysical models of interactions between trees and other components of agroforestry systems.

v. An assessment of the environmental impact, and hence sustainability, of agroforestry systems.

vi. A methodology for comparison between agroforestry and other land use systems, on a given site.

vii. Case studies to test the above.

Contributory to the programme, although not a research element in the same sense, would be to hold an international workshop on land evaluation for agroforestry, with the objective of bringing together relevant ideas and experience.

No specific research needs are set out for economic analysis or for the examination of the social impact of land use, both of which form essential elements in land evaluation procedures. This is because these aspects are adequately covered by present ICRAF research. Economic analysis forms an activity within the Systems Programme. Its most substantial output to date has been the MULBUD

computer programme for cost: benefit analysis of multiple cropping systems (Etherington and Matthews (1982). The methods incorporated into the MULBUD programme are very similar to those employed in economic analysis for land evaluation (cf. Dent and Young, 1981, Chapter 11; FAO, 1983, Section 9.4), and can be utilized without additional modification.

The analysis of the social impact of land use changes has been developed in some detail in the diagnosis and design methodology (see Section 4.4 above). Elements from this methodology were incorporated into the social analysis section of the guidelines on land evaluation for forestry (FAO, 1984a, pp. 100-103). These methods are adequate as a basis for assessment of social impact in land evaluation for agroforestry.

## 5.1 An environmental data base

### 5.1.1 General

The term 'environmental data base' is here employed in the broad sense, to refer to first, the structured base on which information is stored, and secondly, the body of information stored within it. The former is subdivided into the form of the standardized body of information and the manner of its computerized storage. Storage is through use of a data base management system, a commercially-produced software package designed for holding information on a number of fields (= variables) for a set of records (= sites). Thus an environmental data base includes:

i. A structured and standardized set of information about land, giving items of data to be recorded (e.g. mean annual rainfall, slope angle) and environmental classification systems to be employed e.g. of climate, soil, vegetation).

ii. A method for computerized input, storage and retrieval of this set of information, consisting of files in a data base management system.

iii. The body of information that has been collected and stored in this way.

The outline structure of the ICRAF environmental data base is shown in Figure 3. There are two main files: a sites file and a requirements file. Subsidiary to these is a source file, giving details of sources of information that are recorded in coded or abbreviated form in the main files.

Initially held on an internally-written storage program, the data base was transferred in early 1984 to the KnowledgeMan data base management system on the IBM-PC microcomputer.

Although not part of the environmental data base as such, the system employed for the ICRAF computerized library data base uses the broad climatic zones and some other terms from it as indexing terms, thus permitting retrieval of published work related to a specified broad environment.

### 5.1.2 The sites file

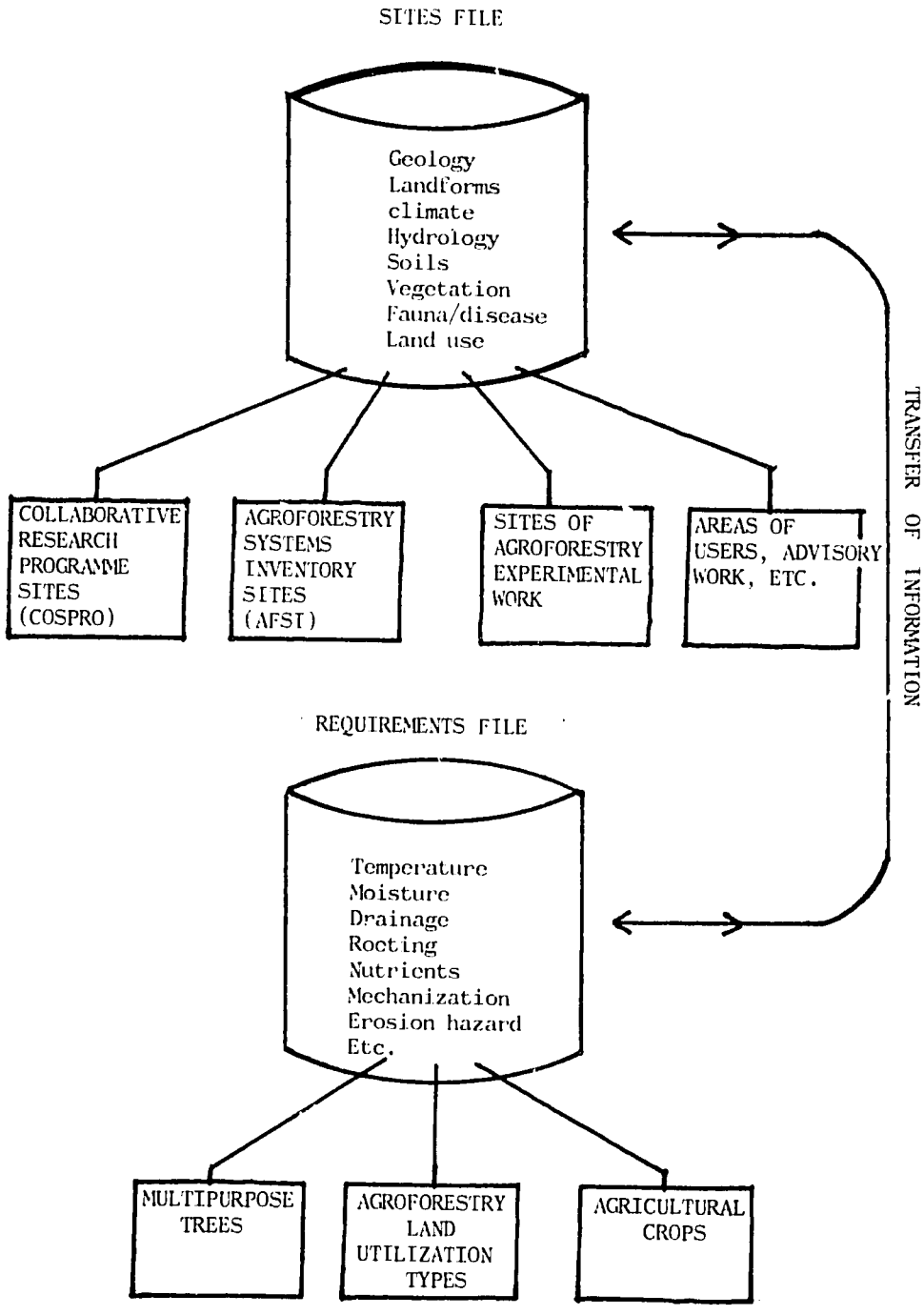
Site information consists of records of the physical environment of particular locations, or sites, which have been associated with agroforestry. A site may be a point or small area, for example one place where a multipurpose tree is recorded as growing; a larger contiguous area, for example that chosen for a diagnostic and design project; or a non-contiguous range of sites, for example those within which an agroforestry system is practised.

Details of the site information stored, with discussion of reasons for selection of data items and classification systems, are given in "An environmental data base for agroforestry" (Young, 1983), and only a brief outline is given here. 1/

A standardized set of information was compiled by discussion with ICRAF staff on what were the most important features of the environment relevant to agroforestry. Information is included on geology, landforms, climate, hydrology, soils, vegetation, fauna and disease, and land use; of these factors, climate and soils are recorded in most detail and geology only briefly.

1/ Note that the 1983 printing of this Working Paper describes only the sitesfile as the requirements file had not then been constructed.

Figure 3. SIMPLIFIED STRUCTURE OF THE ICRAF ENVIRONMENTAL DATA BASE



Three levels of detail are specified: Summary level, Level (semi-detailed) and Level 2 (detailed). Each level contains 15 fields (data items) for site identification and location, and fields which give reliability of information. Inclusive of these, the numbers of fields included are as follows: Summary level - 43, Level 1 - 75, Level 2 - 140. Information can be input at any level, and output at the same or a less detailed level.

The Summary level contains only classifications for each of the environmental factors. For geology, landforms, climate, hydrology, soils, vegetation and land use, broadly generalized classifications are given. In addition, the following classifications have been adopted as standard:

| | |
|---|---|
| Climate: | the Köppen climatic classification. |
| Soils: | the FAO Soil Map of the World classification |
| Vegetation: | the Unesco classification. |

The following types of site are, or will be, included on the sites file:

i. Sites of the ICRAF collaborative research programme (COSPRO).

ii. Sites of the ICRAF agroforestry systems inventory (AFSI).

iii. Sites of agroforestry field trials.

iv. Any site supplied by a user, e.g. for advisory work.

An example of output from the sites file, at the Summary level, is given as Table 1. Outputs at levels 1 and 2 will be found in Young (1983).

### 5.1.3 The requirements file

For storing the requirements and limitations of agroforestry components, such as trees and crops, the full record of the physical environment contained in the sites file is often not appropriate. A single data source usually contains only a limited number of criteria, for example climatic requirements only, storing which in the sites file would lead to large numbers of empty fields.

Table 1. THE ICRAF ENVIRONMENTAL DATA BASE: EXAMPLE OF OUTPUT FROM THE SITES FILE, SUMMARY LEVEL.

ICRAF ENVIRONMENTAL DATA BASE: AFSI SITES — Summary level

SOLORUNS:CATTLE UNDER TREES

Ref.AFSI / 4 — Source AFSI:KNIGHT — Input by AY — Date 13.06.84

| | | Reliability |
|---|---|---|
| **LOCATION** | | |
| Country SOLOMON IS. — Location W.PROV,KULUMBANGARA IS. | | |
| Latitude 8 . S TO . — Longitude157. E TO . | | 1 |
| **GEOLOGY** | CRYSTALLINE BASIC | 1 |
| **LANDFORMS** | GENTLE | 2 |
| **CLIMATE** | HUMID TROPICS | 1 |
| Koppen | Af HUMID TROPICS, PERMANENTLY HUMID | 2 |
| Alt. zone | 0-500 | |
| **HYDROLOGY** | WELL DRAINED | 1 |
| **SOILS** | LATOSOLS | 1 |
| FAO | Fo ORTHIC FERRALSOLS | 2 |
| **VEGETATION** | Area: RAIN FOREST | 1 |
| | Site: PLANTED | |
| **LAND USE** | AF:TREES,LIVESTOCK | 1 |
| Agroforestry | SEE LAND USE | 1 |

A full account of the requirements file will be given in a subsequent working paper. In brief, the file is based on the land evaluation concept of land qualities, e.g. temperature regime, moisture regime, drainage conditions, etc.. Each quality may be recorded in terms of a different land characteristics, for example, moisture regime or requirements may be expressed in terms of mean annual rainfall, growing period, confidence limits for these, etc..

The following types of information will be included in the requirements file:

i. Requirements of agricultural crops.

ii. Requirements of multipurpose trees.

iii. Requirements of pasture species and, if available, of livestock.

iv. Requirements of agroforestry land utilization types.

Of the above, requirements of crops are available from a number of FAO studies, both global and for countries. Requirements of multipurpose trees are given in various published sources, and will be transferred from the environment fields of the ICRAF multipurpose trees inventory (von Carlowitz, 1984). It may prove more difficult to obtain requirements of livestock owing to the earlier stage of development of land evaluation in this field. The final group, requirements of agroforestry land utilization types, is a major objective of the land evaluation project as a whole, which will take time to achieve.

Data can be retrieved in various forms, illustrated for the growth requirements of individual plant species (trees or crops) as follows:

i. All environmental requirements of a given species, e.g. requirements of Acacia albida.

ii. Requirements for a specified land quality (e.g. moisture) or land characteristic (e.g. mean annual rainfall) of all species recorded.

iii. Selection of those species suited to a given combination of site conditions, e.g. species suited to altitude 1000-1500 m, rainfall <600 mm, shallow soils.

An example of output of the first kind is given as Table 2.

## 5.2 Agroforestry land utilization types

It is evident that land suitability for agroforestry cannot be assessed without clear definitions of the kinds of land use being referred to---in evaluation terminology, the land utilization types. The first principle of land evaluation is that suitability can only be assessed with respect to specified kinds of use. In evaluation procedures, identification, refinement and description of land utilization types follows initial discussions, preceding determination of requirements (Figure 1, p.5).

All forms of agroforestry possess one distinctive feature as land utilization types, namely that by definition they include at least two components, tree and non-tree. The former consists necessarily of multipurpose trees, again by definition; it may include agricultural tree crops, e.g. coffee, coconuts. The non-tree component may include agricultural crops, pasture species and livestock species.

At the most disaggregated level, it is possible to assess environmental requirements of individual species of tree, crop, pasture plants and livestock. These may be subdivided, trees into varieties (e.g. the varieties of Leucaena leucocephala), crops into cultivars and livestock into breeds. These may be referred to as components of agroforestry.

A second descriptive term is the agroforestry practice, consisting of components combined in some particular manner in space and time, e.g. a live fence, alley cropping, a planted tree fallow. Agroforestry practices alone are rarely a sufficient form of description for assessment of requirements. Some are more appropriate to certain environments, e.g. windbreaks to dry climates, whilst others appear to function better over a limited range of conditions, e.g. 'home gardens' are mainly found in wetter regions. For the most part, however, practices serve as

Table 2. THE ICRAF ENVIRONMENTAL DATA BASE: EXAMPLE OF OUTPUT FROM THE REQUIREMENTS FILE.

Explanation of headings:

| | |
|---|---|
| LAND USE | On this file, species of multipurpose tree. |
| LAND QUALITY | Requirements grouped according to broad type, e.g. requirements for temperature regime, moisture regime, rooting conditions. |
| SUBDIVISION | Subdivision of land quality, e.g. temperature regime. Subdivided into growth (general) requirement, tolerance to high temperatures and tolerance to low temperatures. |
| LAND CHARACTERISTIC | The value employed to measure or express the land quality; e.g. different sources express tolerance to low temperatures as mean minimum of the coldest month, absolute minimum, and frost frequency. |
| LOCATION | The area to which suitability data refer. |
| SUITABILITY | The suitability level to which data refer: |
| OB | Observed (no data on growth or performance) |
| SS | Suitable (growth or performance satisfactory) |
| S1 | Highly suitable |
| S2 | Moderately suitable |
| S3 | Marginally suitable |
| NN | Not suitable (performance not satisfactory) |

The oblique stroke (/) indicates that suitability is bounded, the hyphen (-) that it is not bounded; e.g.

| | | |
|---|---|---|
| nn/ SS / nn | 20 - 30 C | Suitable between 20° and 30° C and Not suitable outside this range |
| - SS - | 20 - 30 C | Suitable between 20° and 30° C but suitability level beyond this range not known |

LOWER VALUE/INCLUDED and HIGHER VALUE/EXCLUDED — Data in these columns appears in different forms illustrated by the following examples:

(a) Numerical data: example, temperatures for growth, expressed as mean annual temperature

| | | |
|---|---|---|
| - SS - | 20 - 30 C | Suitable in range 20 - 30° C |
| - OB - | 22 C | Observed on site with 20° C |

(b) Non-numerical data: example, drainage (aeration) requirements, expressed as soil drainage class:

| | | | |
|---|---|---|---|
| nn/ SS /nn | WELL DR. | # W'LOGGED | Suitable on well drained sites, Not suitable on waterlogged sites |

SOURCE — Reference number to the source of data, details of which are stored on a separate file. Souce 1 is the ICRAF multipurpose tree inventory.

RELIABILITY — A subjective estimate of the reliability of the data:

| | | |
|---|---|---|
| 1 | High | Primary direct observation |
| 2 | Medium | |
| 3 | Low | Including highly generalized data |

Note that certain land characteristics, including latitude, soil texture, soil reaction and soil type, may be employed to express suitability in a manner which does not make it clear which kind of effect, i.e. which land quality or qualities, is being assessed. Such land characteristics are grouped at the end of the lists.

Table 2 (continued).

| LAND USE | LAND QUALITY | SUB-DIVISION | LAND CHARAC-TERISTIC | LOC-ATION | SUITABILITY | | | LOWER VALUE/ INCLUDED | HIGHER VALUE/ EXCLUDED | SOURCE | RELIABILITY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CASSIA SIAMEA | TEMPERATUR | GROWTH | ANN.TEMP | WORLD | - | SS | - | 22 | - 28 C | 2 | 2 |
| CASSIA SIAMEA | TEMPERATUR | GROWTH | ALTITUDE | SUDAN | - | OB | - | 500 M | | 1 | 1 |
| CASSIA SIAMEA | TEMPERATUR | GROWTH | ALTITUDE | WORLD | / | SS | - | 0 | - 1000 M | 2 | 2 |
| CASSIA SIAMEA | TEMPERATUR | HEAT TOL. | MAX.HOTMO. | WORLD | - | SS | - | 23 | - 35 C | 2 | 2 |
| CASSIA SIAMEA | TEMPERATUR | COLD TOL. | MIN.COLDMO | WORLD | - | SS | - | 20 | - 24 C | 2 | 2 |
| CASSIA SIAMEA | TEMPERATUR | COLD TOL. | ABS.MIN. | SUDAN | - | OB | - | 14 C | | 1 | 1 |
| CASSIA SIAMEA | MOISTURE | GROWTH | ANN.RAINF. | SUDAN | - | OB | - | 800 | - 900 MM | 1 | 1 |
| CASSIA SIAMEA | MOISTURE | GROWTH | ANN.RAINF. | W.AFR. | nn/ | S3 | /ss | 400 | - 1000 MM | 3 | 2 |
| CASSIA SIAMEA | MOISTURE | GROWTH | ANN.RAINF. | WORLD | - | SS | - | 650 | - 950 MM | 2 | 2 |
| CASSIA SIAMEA | MOISTURE | GROWTH | ANN.RAINF. | W.AFR. | s3/ | SS | - | 1000 | - 1500 MM | 3 | 2 |
| CASSIA SIAMEA | MOISTURE | GROWTH | RAIN REGIM | SUDAN | - | OB | - | HIGH SUN | | 1 | 1 |
| CASSIA SIAMEA | MOISTURE | GROWTH | RAIN REGIM | WORLD | - | SS | - | HIGH SUN | | 2 | 2 |
| CASSIA SIAMEA | MOISTURE | CRIT.PER. | DRY SEASON | W.AFR. | nn/ | S3 | /ss | 4 | - 5 MO. | 3 | 2 |
| CASSIA SIAMEA | MOISTURE | CRIT.PER. | DRY SEASON | W.AFR. | s3/ | SS | - | 6 | - 8 MO. | 3 | 2 |
| CASSIA SIAMEA | MOISTURE | CRIT.PER. | DRY SEASON | WORLD | - | SS | - | 4 | - 6 MO. | 2 | 2 |
| CASSIA SIAMEA | MOISTURE | CRIT.PER. | W/T,LOWEST | SUDAN | - | OB | - | 2 | | 1 | 1 |
| CASSIA SIAMEA | DRAINAGE | - | DRAIN.CL. | SUDAN | - | OB | - | WELL DR. | | 1 | 1 |
| CASSIA SIAMEA | DRAINAGE | - | DRAIN.CL. | WORLD | - | SS | - | FREE DR. | | 2 | 2 |
| CASSIA SIAMEA | DRAINAGE | - | DRAIN.CL. | W.AFR. | - | SS | - | WELL DR. | | 2 | 3 |
| CASSIA SIAMEA | ROOTING | - | EFF.DEPTH | WORLD | - | SS | - | PREF.DEEP | | 2 | 2 |
| CASSIA SIAMEA | | | LATITUDE | SUDAN | - | OB | - | 5 N | | 1 | 1 |
| CASSIA SIAMEA | | | LATITUDE | WORLD | - | OB | - | 1 | - 5 N | 2 | 2 |
| CASSIA SIAMEA | | | SOIL TEXT. | SUDAN | - | OB | - | HEAVY | | 1 | 1 |
| CASSIA SIAMEA | | | SOIL TEXT. | WORLD | - | SS | - | LIGHT/MED | | 2 | 2 |
| CASSIA SIAMEA | | | REACTION | SUDAN | - | OB | - | NEUTRAL | | 1 | 1 |
| CASSIA SIAMEA | | | REACTION | WORLD | - | SS | - | NEUTR/ACID | | 2 | 2 |
| CASSIA SIAMEA | | | US SOIL | SUDAN | - | OB | - | AQUIC USTI | =FLUVENT | 1 | 1 |

Sources: 1: ICRAF MPT inventory 2: Webb et al., 1980 3: FAO, 1974 4: Baumer 1983

a descriptive term for land utilization types described in more detail, and one means of classifying them.

At the most aggregated level there is the agroforestry system, described in detail with respect to its biological, technical, economic and social aspects. The Chagga home gardens on the slopes of Mount Kilimanjaro, Tanzania, are an example of such a system. As employed in the ICRAF agroforestry systems inventory, the term refers to existing systems, traditional or modern.

Agroforestry systems are frequently specific to the social and economic setting of a particular area. Consequently the precise environmental requirements are not always transferable to other areas. For example, land with many boulders can be cultivated where the accepted practice is hand hoeing, or where strong communal spirit or cheap labour availability permits their removal. However, the agroforestry system may well be appropriate as a land utilization type in evaluations for specific local areas.

For formulation of land use requirements on a broader scale, a more generalized form of land utilization type is needed. This would contain the technical elements in some detail, including plant species, but would give the social and economic conditions only in generalized terms as a setting. An example of such a description is:

Practice: alley cropping. Trees: Cassia siamea, Melia azedirach. Crops: maize, with field beans and/or cowpea in rotation; fallow infrequent. Livestock: work oxen only. Inputs: improved seed; fertilizers, manure and crop protection chemicals nil or low. Management: ox ploughing, hand weeding, hand harvest. Conservation: trees aligned along contour if land sloping. Social and economic setting: low capital and high labour intensities, smallholdings (generally 5 ha), low income levels (GDP < 500 per capita 1984).

The above degree of detail appears to be the appropriate form for specification of a land utilization type for systematic evaluation purposes. On the one hand it is sufficiently specific to make formulation of environmental requirements practicable;

on the other, sufficiently generalized to make it available for consideration over a reasonably wide range of social and economic circumstances. More detail can be added as appropriate, e.g. tree-row spacing and pruning regime in the above example. The definition of a land utilization type permits the degree of detail to be varied as required by circumstances.

## 5.3 Land use requirements

Following description of land utilization types, the next and critical stage in evaluation procedures is determination of their land use requirements, the environmental conditions under which the specified land use is expected to function afficiently, moderately well or to fail. The requirements are needed for individual agroforestry components, principally multipurpose trees and crops, and for agroforestry land utilization types as a whole.

It is a matter of debate among land evaluation specialists whether land use requirements should be assessed in terms of land qualities or land characteristics (cf. Dent and Young, 1981, pp. 162-165). Land qualities are broad attributes of land, each of which acts in a district manner in its influence on the suitability of land for a particular kind of use; examples are moisture availability, rooting conditions, nutrient supply, erosion hazard, and potential for mechanization. Land characteristics are attributes of land that can be measured or estimated, e.g. mean annual rainfall, slope angle, soil drainage class. If land qualities are taken as the basis for assessment, they must normally be assessed in terms of land characteristics, singly or in combination. There are relatively few land qualities, less than 30 that are widely employed, but many hundred land characteristics.

All of the FAO guidelines to date base their assessments on land qualities measured or described in terms of land characteristics. Land qualities serve as a primary check, to ensure that all relevant influences of environment on land use have been taken into account. Decisions are then made on which land characteristics are to be employed to describe each quality; e.g. whether moisture regime is to be described in terms of mean annual rainfall, mean growing period, rainfall/evapotranspiration ratio, or specified confidence limits for any of these.

Land use requirements are specific to the use, e.g. moisture requirements of sorghum, tea, rice. Land qualities and characteristics are specific to land units, e.g. the moisture availability of Land Units A, B, C. To facilitate matching between the two, requirements and land qualities are expressed in closely corresponding terminology and units, for example:

| Land use requirement | Land quality |
|---|---|
| Temperature requirements | Temperature regime |
| Moisture requirements | Moisture regime |
| Nutrient requirements | Nutrient availability |
| Tolerance of salts | Presence of salts |
| Requirements for mechanization | Land conditions affecting mechanization |
| Susceptibility to erosion hazard | Erosion hazard |

As a starting point in determining land qualities relevant to agroforestry, a comparison has been made between the qualities listed in the FAO guidelines on rainfed crop production and forestry, together with those identified at the first workshop on evaluation for extensive grazing. Those qualities the influence of which occurs rarely are omitted and some qualities combined.

The results are shown in Tables 3 and 4. Table 3 is a summary of the land qualities, grouped into those which affect plant growth, management and conservation; direct estimates of growth, e.g. forest inventory, crop yield data, form a further group. There is finally a set of land characteristics which may influence two or more land qualities. These are classifications, employed as a substitute for more detailed data. Three, slope angle, soil texture and soil reaction, are characteristics commonly used to describe requirements or tolerance, without it being made clear which influence on the plant or the land use is being assessed; for example is soil reaction being considered as an indicator of aluminium toxicity, nutrient availability or sodicity?

Table 4 gives the land qualities in more detail, subdivided in some cases, e.g. temperature regime/requirements divided into general temperatures for growth, (tolerance of) extremes of heat, and (tolerance of) extremes of cold. The major kinds of land use

Table 3. LAND QUALITIES RELEVANT TO AGROFORESTRY: SUMMARY.

| | Land quality |
|---|---|
| A. QUALITIES AFFECTING GROWTH | |
| REQUIREMENTS | |
| BASED MAINLY ON CLIMATE | Radiation<br>Temperature<br>Moisture |
| BASED MAINLY ON SOIL | Drainage<br>Rooting<br>Nutrients |
| SPECIAL ASPECTS | Establishment<br>Maturing |
| LIMITATIONS | Hazards<br>Salts<br>Toxicities<br>Biological |
| B. DIRECT ESTIMATES OF GROWTH | Production |
| C. QUALITIES AFFECTING MANAGEMENT | |
| MANAGEMENT OPERATIONS | Mechanization<br>Soil workability<br>Land preparation<br>Storage and processing<br>Timing of production |
| LOCATION AND ACCESS | Location<br>Size and accessibility |
| D. QUALITIES AFFECTING CONSERVATION | Soil degradation<br>Hydrological degradation<br>Biological degradation<br>Loss of amenity |
| E. LAND CHARACTERISTICS AFFECTING MULTIPLE LAND QUALITIES | |
| BASED ON CLIMATE | Latitude<br>Climatic type |
| BASED ON LANDFORMS | Slope |
| BASED ON SOIL | Soil texture<br>Soil reaction<br>Soil type |
| BASED ON VEGETATION | Vegetation type |

Table 4. CHECK LIST OF LAND QUALITIES FOR AGROFORESTRY. Source: check lists in guidelines on land evaluation for rainfed agriculture (R), forestry (F), irrigated agriculture (I) and extensive grazing (G).

| Land quality/ Land use requirement or limitation | Source | | Subdivision of land quality | Land characteristics (examples) |
|---|---|---|---|---|
| A. QUALITIES AFFECTING GROWTH | | | | |
| 1. Radiation regime/ Radiation requirements | RFIG | 1 | For growth | Total radiation<br>Net radiation<br>Sunshine hours, annual<br>Sunshine hours, gr.seas. |
| | | 2 | Photoperiodism | Day length/season<br>(Latitude) |
| 2. Temperature regime/ Temperature requirements | RFIG | 1 | For growth | Mean annual temp.<br>Mean growing season<br>Altitude<br>Mean, hottest month<br>Mean, coldest month<br>(Climatic type)<br>(Latitude) |
| | | 2 | Heat tolerance | Mean max. hottest mo.<br>Extreme max. |
| | | 3 | Cold tolerance | Mean min. coldest mo.<br>Absolute min. temp.<br>Frost frequency |
| 3. Moisture availability/ Moisture requirements | RFIG | 1 | For growth | Growing period<br>Mean annual rainfall<br>Rainfall, growing season<br>Rel. $E_T$ Deficit<br>Confidence limits for four above<br>Rainfall/Eo<br>Rainfall regime<br>(Climatic type) |
| | | 2 | Critical periods | Rainfall critical period<br>Rainfall driest month<br>Rel. ET deficit crit. per.<br>Groundwater depth, lowest |
| | | 3 | Drought hazard | Dry season, length<br>Probability signif. drought |
| | | 4 | For animals | Distance to source<br>Water quality, salts |

| | | | | | |
|---|---|---|---|---|---|
| 4. | Soil drainage/ Aeration (oxygen) requirements | RFTG | 1 | - | Soil drainage class<br>Groundwater depth, mean<br>Groundwater depth, highest<br>Period waterlogging |
| 5. | Rooting conditions/ Rooting requirements | RFTG | 1 | - | Soil effective depth<br>Stones and gravel<br>Outcrops and boulders<br>Soil structure<br>(Soil texture) |
| 6. | Nutrient availability/ Nutrient requirements | RFTG | 1 | Total/general | Class |
| | | | 2 | Availability | (pH) |
| | | | 3 | Retention | CEC<br>OM %<br>Clay % |
| | | | 4 | N | Total |
| | | | 5 | P | Available<br>Reserve/total |
| | | | 6 | K | Exchangeable<br>Reserve/total |
| | | | 7 | Other nutrients | Various |
| 7. | Conditions for germination and establishment/ Requirements for same | RFG | 1 | - | Surface sealing/crusting<br>(Soil texture)<br>Measures of climatic reliability/season |
| 8. | Conditions for ripening, maturing/ Requirements for same | R | 1 | - | Dry season, length<br>Humidity/season |
| 9. | Climatic and physiographic hazards/Susceptibility to same | RFTG | 1 | Flood | Flood frequency<br>Period of inundation |
| | | | 2 | Landslide | Obs. freq./estim. hazard |
| | | | 3 | Wind, storm | High wind frequency<br>Exposure (indices) |
| | | | 4 | Fire | Length dry season<br>Obs. freq./estim. hazard |
| | | | 5 | Hardship for animals | High temperatures<br>Low temperatures, frost, snow |
| 10. | Salts/ Tolerance of salts | RFTG | 1 | Salinity | ECE<br>TSS<br>(Soil type) |
| | | | 2 | Sodicity | ESP<br>SAR<br>(pH, alkaline)<br>(Soil type) |

| | | | | |
|---|---|---|---|---|
| 11. Soil toxicities/ Tolerance of same | RFIG | 1 | Aluminium/acidity | pH<br>Exchangeable Al |
| | | 2 | Carbonates | $CaCO_3$ %<br>Depth to calcrete |
| | | 3 | Acid sulphate | Presence<br>Estimated hazard |
| | | 4 | Micronutrients | Presence of toxicities |
| 12. Biological hazards/ Susceptibility to same | RFIG | 1 | Weeds | Observed/estimated |
| | | 2 | Pests | Animals, predators<br>Birds<br>Insects |
| | | 3 | Diseases | Plant diseases, obs./est.<br>Animal diseases, obs./est. |
| B. DIRECT ESTIMATES OF GROWTH | | | | |
| 13. Direct observations or estimates of yield or production | RFIG | 1 | Existing resources | E.g. by forest inventory, pasture survey |
| | | 2 | Predicted yield | E.g. by crop yield modelling, forest site index |
| | | 3 | Survival | Observed or estimated |
| | | 4 | Genetic potential | Measures of biological diversity, presence of species |
| C. QUALITIES AFFECTING MANAGEMENT | | | | |
| 14. Conditions affecting mechanization/ Requirements for mechanization | RFIG | 1 | For operations before and during growth | Slope angle<br>Outcrops, boulders<br>Terrain class |
| | | 2 | For harvesting | Slope angle<br>Outcrops, boulders<br>Terrain class |
| 15. Soil workability/ Requirements for soil workability | RIG | 1 | - | Class<br>Soil structure<br>(Soil texture) |
| 16. Conditions affecting land preparation/ Requirements for land preparation | RFI | 1 | Movement of earth, rock | Slope<br>Microrelief<br>Outcrops, boulders |
| | | 2 | Vegetation clearance | Vegetation cover |
| 17. Conditions affecting storage and processing/ Requirements for same | RIG | 1 | Storage | E.g. humidity |
| | | 2 | Processing | E.g. humidity |

| | | | | |
|---|---|---|---|---|
| 18. Timing of production/ Requirements for same | R | 1 | - | E.g. harvest dates |
| 19. Location/ Requirements for location | RFIG | 1 | - | E.g. distance to markets, to road |
| 20. Size and internal accessibility/ Requirements for same | RFIG | 1 | Size of potential management units | Hectares |
| | | 2 | Internal access (by man) | E.g. slope |
| | | 3 | Internal access by animals | E.g. Swamps, dense vegn. |
| | | 4 | Conditions affecting fencing, hedging | E.g. availability of materials |

D. QUALITIES AFFECTING CONSERVATION AND ENVIRONMENTAL IMPACT

| | | | | |
|---|---|---|---|---|
| 21. Soil degradation hazard/Soil degradation susceptibility | RFG | 1 | Water erosion | Modelled or estimated soil loss, bare ground<br>Modelled or estimated soil loss under land use<br>Slope angle |
| | | 2 | Wind erosion | Modelled or estimated soil loss, bare ground<br>Modelled or estimated soil loss under land use<br>Wind severity/frequency |
| | | 3 | Soil physical degradation | (Soil texture)<br>Organic matter % |
| | | 4 | Salinization | Present soil salinity<br>Groundwater level<br>Groundwater salt content<br>(Soil type) |
| | | 5 | Soil chemical degradation | (pH) |
| | | 6 | Biological degradation | Organic matter % |
| 22. Degradation of hydrological regime/Requirements for preservation | FI | 1 | River flow | - |
| | | 2 | River water quality | - |
| | | 3 | Groundwater level | - |

| | | | | |
|---|---|---|---|---|
| 23. Biological degradation/ Requirements for preservation | FG | 1 | Vegetation degradation | Present veg. status |
| | | 2 | Species preservation, plant | Presence of rare species<br>Genetic diversity |
| | | 3 | Species preservatic , animal | Presence of rare species |
| | | 4 | Effects on disease | - |
| 24. Loss of amenity, recreation/ Requirements for preservation | F | 1 | - | Existing use for recreation, amenity |

## E. LAND CHARACTERISTICS AFFECTING MULTIPLE LAND QUALITIES

| | Land characteristics | Land qualities or subdivisions affected |
|---|---|---|
| 1 | Latitude | Photoperiodism, Temperature for growth |
| 2 | Climatic type | Radiation for growth, Temperature for growth, Moisture for growth/critical periods/drought hazard |
| 3 | Slope angle | Landslide hazard, Mechanization, Land preparation, Internal access, Soil erosion hazard |
| 4 | Soil type | Drainage, Rooting, Nutrients, Salts, Toxicities |
| 5 | Soil texture | Rooting, Nutrients, Mechanization, Workability |
| 6 | Soil reaction (pH) | Nutrient availability, Salts, Al-toxicity |
| 7 | Vegetation type | Synthesis of growth requirements a d direct estimate of vegetation resources |

for which each quality has been considered relevant are indicated. The last column gives land characteristics most commonly employed, singly or in combination, to describe each quality.

Thus the environmental features relevant to each of the types of land use contributory to agroforestry can be combined and grouped into 24 land qualities with 65 subdivisions. It should be noted, however, that in any specific evaluation study, some qualities do not affect the land utilization types under consideration, whilst others have no significant effects on suitability within the area concerned. It is frequently found that no more than 12 land qualiti are relevant to a specific evaluation.

The use of land qualities, measured or estimated by means of land characteristics, has been taken as the initial method of suitability assessment for agroforestry, and as the basis of the requirements file of the environmental data base.

## 5.4 Biophysical models of interactions

In an agroforestry system there are both ecological and economic interactions between the tree and non-tree components. That there should be economic gains, say in the role of trees in supplying farmers' needs for fuelwood and fruit, is not alone sufficient to justify adoption of agroforestry. Were such an economic balance of production the only advantage, then trees, crops and animals would best be kept on separate parts of a farm, each optimally managed for their kind of production. An example of this is the farm or village woodlot managed solely for timber or fuelwood production; this is community (social) forestry, but it is not agroforestry.

Basic to the concept of agroforestry is that net beneficial effects arise from ecological interactions between trees, crops and animals. For the case of the tree/crop interface, these have been reviewed by Huxley (1983, see especially Figure 4, p.6; cf. also Nair, 1984, Figure 11, p.49). The interactions take place through the media of microclimate and soil. The principal effects are:

i. Shade: normally effects of shade by trees on crop growth; also possible adverse effects on tree form through non-optimal spacing from point of view of sylvicultural management.

ii. Moisture: complex mutual effects, involving above-ground plant matter, roots, micro-climate and soil moisture.

iii. Nutrients and soil organic matter: beneficial effects of tree leaf litter, together with tree-crop competition for soil nutrients.

iv. Soil physical conditions: normally beneficial effect of trees, including through soil organic matter increase.

v. Shelter: microclimatic effects on wind speed and their consequences.

vi. Conservation: medium to long-term effects on soil.

These effects are not exclusive, e.g. effects of shade and shelter on moisture, or of conservation on soil nutrients. They may take place over various time scales.

In cases of sylvopastoral or agrosylvopastoral systems, any or all of the above types of interaction may occur at the tree/pasture interface, added to which are ecological effects of some complexity involving the livestock component, e.g. effects of shade on animal physiology, or the causal chain tree browse - animal - manure - soil nutrients.

It is a matter of research organization whether the elucidation of such interactions falls within or outside the land evaluation project. What is not in doubt is that a set of biophysical models permitting such interactions to be estimated is necessary in order to achieve land evaluation. This need is illustrated by the economic analysis of a Leucaena-maize-beans intercropping system given by Hoekstra (1983), in which the

economic computations rest on a basis of assumptions about interactions between leaf litter, soil nutrients and crop yield. The following are the most important required:

1. A shade model .
2. A climate/soil moisture model.
3. A plant/soil organic model.
4. A set of plant/soil nutrient cycling models.

The general form of the organic matter model for agroforestry has been set out by Young (1984b), and a review of organic matter, together with the outline of a nutrient cycling model, is given by Nair (1984, pp. 31-40).

## 5.5 Environmental impact and sustainability

One of the main advantages of agroforestry systems is their capacity to combine productivity with sustainability. This arises primarily through the regenerative effect of trees on soil fertility A further contribution is made by the role of trees in soil conservation, either in association with earth structures (e.g. in stabilizing bunds) or as an independent means of conservation (e.g. hedgerows aligned along the contour).

The analysis of environemntal impact is a standard step in land evaluation procedures (Figure 1). It occurs at two stages. First, the requirements for avoidance of soil or vegetation degradation, and the susceptibility of land units to such degradation, form part of the comparison between land use requirements and land qualities (cf. Table 4, Section D). Although this comparison should ensure basic fulfillment of conservation and sustainability requirements,environmental impact is further specified as a stage in analysis following matching. This is to ensure that all aspects of environmental impact are taken into account, including off-site effects, e.g. upon the stream flow regime.

There are overlaps between environmental impact analysis and the biophysical models described in the previous section, particularly with respect to the models for soil organic matter and nutrient cycling. In addition, work on soil conservation is al-

ready part of ICRAF's programme, first in the preparation of a handbook of soil conservation methods and secondly in the review of agroforestry in soil and water conservation. Outputs from these activities will need to be integrated into land evaluation procedures.

The output from this stage in land evaluation is an assessment of the suitability of each combination of land use with land unit, in terms of the sustainability of the land use system (internal environmental impact) and its external environmental effects.

## 5.6 Methods for comparison between agroforestry and non-agroforestry land utilization types

By the concluding stages of a land evaluation, a series of land utilization types have been examined with respect to suitability for each land unit. Those found to be not suitable are classified as such and rejected, giving reasons. The remaining kinds of land use, classified as highly, moderately or marginally suitable, form land use alternatives.

The utilization types may include both agroforestry and non-agroforestry systems. In a study directed primarily at agroforestry it is likely that they would consist of a number of different agroforestry systems, together with the present land use and at least one form of improved agricultural system and/or forestry system. In these circumstances, the basic question to be answered by the comparison, that of which land utilization type is to be preferred on each land unit, can be broken down into two parts:

i. Of the alternative agroforestry systems, which is the more suitable on each land unit?

ii. Is the best agroforestry system to be preferred to improved agriculture or forestry, on each land unit?

The existing land evaluation procedures for comparison between kinds of land use appear to be adequate for analysis of the above questions, without the need for additions or modifications specific

to agroforestry. Comparison is made initially in the following terms:

1. Initial matching: comparison of land use requirements with land qualities, leading to provisional suitability classification in terms of physical requirements.

The above step is followed by rejection of unsuitable land use/land unit combinations, and further analysis of those which remain in terms of:

2. Environmental impact.

3. Economic analysis.

4. Analysis of social consequences.

The means by which these four aspects of suitability are compared have been set out in the guidelines on land evaluation for forestry (FAO, 1984a, pp. 106-107). There are two basic methods. In the first, that of successive elimination, those land use/land unit combinations found to be provisionally suitable, in terms of physical requirements only, are examined to see whether they reach some specified standard of acceptability in terms of environmental impact, economic viability or social consequences. Failure to reach such standards results in classification of the combination as Not suitable.

In the second method, that of relative comparison, each combination of land use with land is allocated a relative 'score' ranging from, say, +3 through 0 to -3, in terms of environmental, economic and social consequences. The results are set out in the form of a matrix. This permits subsequent planning decisions to be taken on the basis of inspection of the various consequences and subjective judgement as to which is the more desirable.

## 5.7 Case studies

It is clearly necessary to test the methods developed through application of land evaluation methods to selected case study areas. At least two such studies should be made, one in the humid tropics

(rain forest zone) and one in either subhumid (savanna) or semi-arid climates. There would be an economy in data collection if existing sites with which ICRAF is associated were to be included. The COSPRO sites in Kenya (Kakuyuni) and Peru (Yurimaguas) appear in the first instance to be suitable. If, however, requests arise for ICRAF studies which could be carried out by means of land evaluation, then such opportunities could be additionally or alternatively taken.

## 5.8 An international workshop

All FAO projects on land evaluation have included the holding of at least one international workshop, in most cases two. These have the function of bringing together scientists from different backgrounds who can contribute ideas, or raise criticisms, which might not otherwise have received attention. The workshops are normally followed by publication of proceedings which, besides serving as a basis for the subsequent guidelines, contain material of independent value for future studies.

It is suggested that one such workshop on land evaluation for forestry should be held. This would be in Nairobi, approximately one year after commencement of land evaluation as a separately funded project.

# 6 THE TASKS AHEAD

## 6.1 Progress to date

During the present, preparatory phase of the land evaluation project, the principal outputs have been:

i. As a cooperative activity with FAO, Rome, completion of two sets of procedures which will be contributory to those on agroforestry: the guidelines on land evaluation for rainfed agriculture (FAO, 1983) and forestry (FAO, 1984a).

ii. Establishment of the environmental data base for agroforestry consisting of a sites file and a requirements file.

iii. Testing of the environmental data base, with reference to ICRAF collaborative research programme sites, agroforestry systems inventory sites and environmental requirements of multipurpose trees.

iv. Preparation of an account of the application of land evaluation to site selection for multipurpose trees (Young, 1984a).

v. Formulation of the research programme, as set out in this Working Paper.

## 6.2 Relations with concurrent research

It will be clear from the above account that land evaluation is highly interdependent with other research activities, both in land evaluation and agroforestry.

With reference to land evaluation, the basis provided by the FAO Framework for land evaluation and its subsequent detailed guidelines has already been noted. Ongoing cooperation is being maintained with the preparation of guidelines on evaluation for extensive grazing (being undertaken jointly by FAO, ILCA and ITC-Enschede); and with forthcoming work on land evaluation in

sloping lands, in which the treatment of soil conservation will be prominent.

Data on environmental requirements of crops will be drawn from previous FAO work, in particular the agro-ecological zones project (FAO, 1978-81) and country evaluation projects.

With reference to current ICRAF and other research activities, interaction will be necessary with the following:

- The agroforestry systems inventory; with reference to definitions of land utilization types and their associated environments.

- The multipurpose tree inventory; with reference to environmental requirements of trees.

- Aspects of the technology programme; with reference to biophysical models of tree-crop-environment interactions, climatological studies, and soil conservation.

- The diagnostic and design methodology; with particular reference to social analysis.

- Economic studies; with reference to economic analysis in land evaluation.

It will be abundantly clear that the land evaluation project cannot function in isolation!

## 6.3 Estimates of productive potential

There is a further type of enquiry which is now being asked of agroforestry, namely its potential contribution to production over relatively large areas, e.g. countries of ecological zones.

This may be illustrated by an example of a current FAO country study into the population-supporting capacity of Kenya. The questic was asked, "What is the potential contribution of agroforestry to production of fuelwood from agricultural lands, and production of food from presently forested land?"

This is a different scale of operation to that at which most previous ICRAF work has been conducted. To answer it would require knowledge of the extent of different climatic, landform and soil conditions in the country, the present land use pattern, and quantitative estimates of potential agroforestry production from different kinds of land.

Similar kinds of question can arise in many circumstances, for example, the potential contribution of agroforestry to sustainable production in semi-arid pastoral areas or steeply sloping rain forest lands. Such estimates of productive potential can be made at all scales, ranging from local areas to regions, countries or broad ecological zones.

## 6.4 What can land evaluation offer to agroforestry?

A certain dichotomy of aim exists in land evaluation. One purpose is to relate land use to conditions of the physical environment. Another and broader purpose is to provide the information needed as a basis for selection of the best kind of land use on each unit of land. This latter clearly requires considerable input and analysis over and above that of environmental aspects.

Both the more restricted and the broader purposes are relevant to agroforestry research, advisory work and extension. The aims of the former may be summarized by the questions:

i. For any defined agroforestry technique, in which physical environments will it function well?

ii. For any defined physical environment, which agroforestry techniques will function well?

If these two questions can be answered, then a primary basis of physical suitability, of land for different kinds of agroforestry, will have been provided. This is the stage that in evaluation terminology is called physical land suitability classification. It requires data first, from the environmental sciences, particularly climatology, geomorphology and soil science and secondly, from the technology of agroforestry land use.

The broader aspect of land evaluation, that of providing information on the consequences of land use alternatives from all aspects, including economic and social, involves much wider interaction with other research projects. In particular, the ICRAF diagnosis and design methodology also identifies forms of agroforestry technology and makes a choice between them, as the basis for design of a research programme directed towards a land use system that will be relevant, acceptable and viable. Given the similarities of aim, although there are differences in the scales and purpose to which each has to date been applied, it is possible that these two methodologies will become convergent.

There is provision in existing land evaluation procedures for treating all these kinds of question: for assessment of land use suitability with respect only to physical requirements, or with respect to all economic and social aspects in addition; and for studies conducted at the micro-scale (farm or village level) as well as district, regional, country or global studies.

The most distinctive contribution of land evaluation---and possibly that 'expected of it' by others---is that of assessing the environmental suitabilities of different kinds of agroforestry land use. For the wider purpose, that of comparing alternative forms of land use, there will need to be a higher degree of interaction with economic and social research. It is to be hoped that they may ultimately lead to a balanced integration of methods, leading to a greater contribution to development, through selection of agroforestry techniques and systems which are both matched to the resources and hazards of the physical environment and which best meet the needs and problems of the people.

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