DIAGNOSTIC AND DESIGN METHODOLOGY MANUAL SERIES NO. 2

W O R K I N G P A P E R

N O.

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RESOURCES FOR AGROFORESTRY DIAGNOSIS AND DESIGN

DRAFT FOR COMMENT

A HANDBOOK OF USEFUL TOOLS AND MATERIALS

INTERNATIONAL COUNCIL FOR RESEARCH IN AGROFORESTRY

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ACKNOWLEDGEMENTS

The methodological guidelines presented in this resource book have been the subject of concerted effort at ICRAF for over two years. It began with the identification of the need for a methodology to enable researchers to identify priority topics for research in agroforestry, and the adoption of a systems approach to agroforestry as one of the cornerstones of ICRAF's institutional strategy (Steppler, 1981). It has continued and received a prominent place in ICRAF's Programme of Work under the leadership of Dr. Bjorn Lundgren, ICRAF's Director.

The present document, one of several planned publications in ICRAF's Diagnostic and Design Manual Series, was compiled and edited by J.B. Raintree with disciplinary contributions from the following ICRAF staff members:

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HOW TO USE THIS HANDBOOK

This book is not meant to be read. It is intended, rather, as a resource to be *used* by agroforestry workers in the field in conjunction with a companion document, *Guidelines for Agroforestry Diagnosis and Design*, which is being published simultaneously as ICRAF Working Paper No. 6 (22 pp.). The companion volume, which *is* meant to be read, gives an introduction to ICRAF's Diagnostic and Design methodology, explains the logical framework of the D&D approach and presents the suggested methodological procedures in outline form. The present volume, *Resources for Agroforestry Diagnosis and Design*, is a compendium of optional supplementary materials, which contains a far more detailed set of methodological guidelines and suggested procedures, and a collection of useful analytical tools and resource materials.

The two-volume publication format has been chosen as a means of facilitating ease and flexibility in the use of the D&D methodology. Not all of the procedures described in the *Resources* will be applicable to every situation. Because the D&D methodology has been designed to fit a wide range of applications in varying land use circumstances, it must be adapted somewhat to fit particular applications and tailored to the needs and resources of the user. While users of the D&D methodology may be happy to have the detailed guidelines contained in the *Resources*, there is a danger of getting lost in the details and 'not being able to see the forest for the trees.' To avoid this difficulty, the reader is referred to the *Guidelines* for an overview of the methodology and summary outline of the procedures as a whole, and to the *Resources* for detailed procedural suggestions on the implementation of each step. In the final analysis, the user must pick and choose from among the suggested procedures and assemble an adapted set of procedures which is appropriate to the situation at hand. By alternating between the *Guidelines*, for general orientation purposes, and the *Resources*, for detailed procedural suggestions, the user should be able to make intelligent and flexible use of the D&D methodology to meet his particular needs.

ORGANIZATION OF THE HANDBOOK

A glance at the table of contents will reveal that this book is organized into three sections. Part 1 contains the detailed Step-by-Step Guidelines for each stage in the application of the methodology. Part 2 contains a collection of Worksheets designed to facilitate the acquisition and processing of diagnostic and design information. The third section, the Appendix, contains a variety of resources (tools and materials) for agroforestry-oriented diagnosis and design, along with further step-by-step instructions and guidelines which are either of an optional nature or considered too longthy for inclusion in Part 1.

The Worksheets, if it is decided to use them, can be a great aid to the effective application of the D&D process by a multidisciplinary team. By providing a pre-defined set of output targets, the Worksheets complement the step-by-step guidelines in giving concrete form and direction to the sequence of group activities. Used flexibly by the team, the Guidelines-plus-Worksheets constitute a kind of 'blueprint' for the D&D exercise, a working agreement or protocol for coherent group progress toward the goal of an eventual interdisciplinary consensus on all major aspects of diagnosis and design for the target land use system.

The real 'heart' of this handbook, however, is the lengthy Appendix of useful analytical tools and resource materials. In its present form the Appendix can be considered a beginning for what will, hopefully, evolve over time into a genuinely useful and comprehensive set of resources for *positive diagnosis* of land use systems and *precision design* of agroforestry technologies. We are a long way from that goal, however, in the present early stage of the scientific development of agroforestry.

HOW TO CONTRIBUTE TO THE DEVELOPMENT AND USE OF THE D&D METHODOLOGY

It should be emphasised that this is an *evolving* methodology. ICRAF has been working concertedly on the methodology for over two years and has brought it to the present preliminary state of completion though collaboration with research partners in more than twenty test sites around the world. To complete the development of the methodology and adapt it to the wide range of potential uses in different environmental, social and institutional settings will require much wider collaboration and assistance from the global community of agroforestry workers.

The present set of documents has been published in Working Paper form in order to facilitate widespread testing and critical review of the D&D methodology by potential users around the world. Thus, the methodology is being launched with an appeal to agroforestry researchers and field workers for constructive criticism and comment. In about a year's time the manuals will be revised to incorporate useful suggestions on how to improve the methodology and make the D&D process more accessible to interested users. Needless to say, suggestions arising from actual applications of the methodology in the field will carry greater weight in subsequent revisions than those resulting from a mere reading of these documents, but all manner of critical review and comment is welcome.

Methodological considerations aside, the ultimate objective of using the D&D methodology to advance the science and practice of agroforestry in the field will require a great many applications to generate a large volume of case study information pertaining to a wide range of physical and socioeconomic environments. To facilitate the documentation of diagnostic and design information and dissemination to potential users, ICRAF has initiated a publication series on *Case Studies in Agroforestry Diagnosis and Design.* Reports published in this series will be available from ICRAF on request, and users of the methodology are urged to submit case studies for possible publication. A computer-based global data bank of D&D results is also being developed at ICRAF headquarters in Nairobi. Users of the methodology who do not wish to prepare a full case study report are urged to request the forthcoming data recording forms in order to place their case information on record in the data bank. In this way ICRAF hopes to assist the development of agroforestry in the same way that case studies have aided the development of medical science.

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PART 1

STEP-BY-STEP GUIDELINES

PREDIAGNOSTIC STAGE

OVERVIEW

PURPOSE: The purpose of the Prediagnostic Stage is to lay the groundwork for the Diagnostic and Design Stages which follow by describing the diagnostically relevant characteristics of the chosen land use system and its environment.

PERSONNEL: It is suggested that a Prediagnostic Working Group be formed to carry out this task. It is highly desirable, but not absolutely necessary, that the Working Group contain at least one senior scientist who will continue on as part of the D&D Field Team at the Diagnostic Stage.

SOURCES OF INFORMATION: The two main sources of prediagnostic information are:

1) *Existing documentation* on the study area, including published and unpublished research reports, soil surveys, meteorological records, census reports, maps, air photographs, etc., supplemented by consultations with experts familiar with the study area; and 2) *Reconnaissance visits* to the study area, partly to familiarize the Working Group with the area and to aid in the interpretation of existing documentation, but also to collect supplementary information through direct observation of environmental features and land use patterns and through interviews with qualified informants (local officials, extension agents, articulate farmers, researchers familiar with the area, etc.). See Appendix A-1 for further suggestions on sources of prediagnostic information.

SUGGESTED PROCEDURES:

Step 1. Environmental Description of the Study Area

Step 2. Differentiation of Land Use Systems Within the Area

Step 3. Preliminary Description of Selected Land Use System(s)

GENERAL GUIDELINES

The aim is not description per se, but description for the purpose of diagnosis and design. The amount of documentation produced at this stage will vary from application to application. Good documentation is necessary if different personnel are to carry out the next stage or if a formal report or project proposal is planned. On the other hand, brief notes will suffice if it is judged that there is no particular value in extensive documentation.

SPECIFIC PROCEDURAL SUGGESTIONS

STEP 1. ENVIRONMENTAL DESCRIPTION OF THE STUDY AREA

The purpose of the information gathered at this step is to characterise the environment of the land use system or systems which will be selected for more detailed attention in succeeding steps and thus to provide a context for the interpretation of information about the focal system(s). For completeness and clarity it is convenient to divide the environmental description into three substeps: 1) description of the *biophysical environment*, 2) description of the *socioeconomic environment* and, if sufficient information is available, 3) description of the organization (structure and function) of the *human ecosystem* in which all dimensions of the relevant environment are integrated.

1.1 Biophysical Environment

1.1.1 Worksheet

Worksheet 1.1 has been provided to assist in the selection and recording of relevant environmental information in accordance with the guidelines given in Appendix A-2. The suggested information system is based on ICRAF's Environmental Data Base for Agroforestry and is designed to provide a standard set of descriptors for aspects of the biophysical environment which are relevant to land use systems in general and agroforestry systems in particular.

Minimally, the information categories described in Appendix A-2 are meant to be suggestive of what may be relevant to know about the environment of the study area and as such it is not absolutely necessary to use the suggested recording system to satisfy the purpose of this step. However, the use of this information system is highly recommended if you wish to maximise the international accessability and comparability of your case data and particularly if you intend to contribute to ICRAF's global data bank on agroforestry or to the publication series on Case Studies in Agroforestry Diagnosis and Design.

See Appendix A-2 for detailed guidelines on the use of Worksheet 1.1

1.1.2 Additional Climatic Information

In some cases additional climatic information may be required to assess land use constraints and agroforestry potentials. Where water is a limiting factor for agriculture, it may be particularly useful to undertake a more detailed assessment of water availability throughout the year.
Part 1 of Appendix A-3 contains detailed guidelines for

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computation of water budgets. Part 2 contains a more general discussion of temperature effects on plant development. The Working Group should evaluate the need for additional climatic information and compile the necessary data from existing sources.

1.2 Socioeconomic Environment

Relevant information on the socioeconomic dimensions of the environment may be more difficult to identify and collect, but is no less important than biophysical information as a determinant of land use decisions. The categories of socioeconomic information suggested in Worksheet 1.2 are designed to provide a reasonably complete, and yet efficient, coverage of potentially useful background information. The level of detail in the completed Worksheet will obviously depend on the availability of existing information. Following a reasonable effort to gather the information to complete Worksheet 1.2, the Working Group should restrict further expenditure of time and energy to those categories which it knows, or strongly suspects, will be relevant to the deliberations of the D&D Team. Unexpectedly important information gaps can be filled by the D&D Team or a subsequent working group once the relevance of the missing information has been established. (This comment applies to all categories of information at any stage in the D&D process).

See Appendix A-4 for detailed guidelines on completion of Worksheet 1.2.

1.3 Structure and Function of the Human Ecosystem

The human ecosystem (i.e. an ecosystem whose organization reflects the dominant influence of human activity) is a distinctive level of integration comprising both biophysical and socioeconomic dimensions of the environment characterized in 1.1 and 1.2. It is the effective environment of long term relevance to the land use systems and management units to be identified and described in Steps 2 and 3.

A descriptive understanding of the main structural and functional attributes of the larger human ecosystem can assist in identifying the most important land use systems within the study area for D&D attention. It can also aid in the understanding of those systems and, perhaps more importantly, in the diagnosis of problems and potentials which exist beyond the boundaries of the unit systems. These notes and the detailed procedures described in Appendix A-5 are designed to assist the user in arriving at a meaningful prediagnostic overview of the human ecosystem. The suggested procedures may, of course, be adapted to fit the needs and resources of the user.

The first step in most cases will be to define the boundaries of the human ecosystem in order to set limits on what is to be described. If the analysis applies to a watershed management project, then the watershed may be conveniently taken as the ecosystem unit, providing there are no overriding socioeconomic considerations (e.g. a different scale for the effective community or market organization of the area). Whatever weighting is ultimately given to the various factors, the definition of system boundaries for D&D purposes should reflect both socioeconomic and biophysical considerations.

Once defined, the system may be treated as a homogeneous unit or it may be stratified by geographical or social criteria. If it is treated as a homogeneous unit, the components, the status of the ecosystem and its relationship to the outside may then be inventoried (using checklist 1 in Appendix A-5 part 1) The various different components are defined by their role within the ecosystem: energy sources, physical resource base (land, water, soil), primary producers (vegetation), secondary producers (also consumers - animals for milk, meat, labour), consumers (people, one or more groups including migrant/seasonal labourers), and savings/investment stores (cash, buildings, other infrastructure, capital items). These components, their condition, the exchanges between them, external inputs and system outputs constitute a structural/functional outline of the human ecosystem and its links with the larger environment.

If the human ecosystem is to be stratified by geographical area and/or by population subgroup, the analysis emphasizes exchanges between subareas and groups within the ecosystem. This approach is useful where there is a pronounced difference in land management technology or internal division of labour by group or area. For example if there is a strong association of two socioeconomic groups with two respective land units and types of production, then the modified input-output analysis in Appendix A-5 (Checklist 2 and related text) may help to clarify the roles of the two groups relative to each other, the immediate biophysical environment, and the larger ecosystem.

This second type of analysis (check list 2) is intended as a prelude to the identification of problems and potentials at the ecosystem scale. It includes a modified input-output matrix defined by ecosystem subdivisions (or groups) and basic needs of the inhabitants. Surplus and deficits may be reported in addition to inputs, outputs and statis condition.

See Appendix A-5 for detailed guidelines and Appendix B-8 for optional diagramming tools.

STEP 2. DIFFERENTIATION OF LAND USE SYSTEMS WITHIN THE STUDY AREA

For diagnostic and design purposes it is important to distinguish clearly between the different land use systems found in the study area. Each distinct land use system can be expected to have its own unique set of constraints and potentials, different from those of other land use systems in the area. Diagnosis and design are system-specific activities, so it is crucial, right from the start, to have a clear definition of the system(s) being addressed. All subsequent information will relate to the systems so defined or to their environments.

As conceived from D&D purposes, a *land use system* has both biophysical and socioeconomic dimensions. To define a land use system thus involves specifying the particular *combination* of biophysical and socioeconomic characteristics which distinguish it from other land use systems in the area. It could be that a difference of even only one salient characteristics, e.g. soil type (a biophysical characteristics) or land tenure (a socioeconomic characteristic), may justify the classification

of two otherwise similar farms in different land use system categories. On the other hand, it is also possible that several minor differences do not, in the judgement of the Working Group, add up to a significant difference, requiring a separate land use system classification.

There are no hard and fast rules for assigning farms (or other land use units) to one category or another, but basically the deciding criterion is a pragmatic one: Whether or not a difference of one or more characteristics is likely to result in a *significantly different set of land management constraints and potentials,* requiring separate diagnostic and design treatment. Based on this criterion the Prediagnostic Working Group must come to its own decision. Keep in mind, however, that this is only a preliminary classification. The D&D Team may, on the basis of its survey findings, decide to modify the initial classification to bring it more into line with identified technological options.

To simply the task of the Working Group in arriving at a preliminary classification of land use systems within the study area, Step 2 is broken down into three substeps:

2.1 Identification of land units with a relatively homogeneous set of biophysical characteristics.

2.2 Identification of management units and their characteristics.

(Alternatively, the order of the preceeding steps could be reversed).

2.3 Identification of those combinations of land units and management units which represent distinctive land use system.

2.4 Selection of priority land use system(s) for D&D attention.

Worksheet 2 is provided to record the results of this stepwise process. Specific guidelines follow below.

2.1 Identification of land units

A *land unit* is an area or type of land which possesses relatively homogeneous biophysical characteristics. All land within a land unit has similar resource potential and hazards, and compared with other parts of the study area. It is the basic unit for diagnosis of biophysical resource constraints and potentials.

It should be noted that the term "land unit" is not restricted to a particular scale or degree of homogeneity. In reconnaissance studies covering large areas, the land units may cover areas of hundreds of square kilometres and possess substantial internal variations of land characteristics. In more detailed studies, the appropriate land units will be smaller and more uniform. Whatever areas of land are perceived as the appropriate physical basis for the diagnostic survey are taken as the "land units" for the survey.

Possible mapping units which can serve as land units include *land systems* or *land facets,* terms taken from the land systems approach; *land capability subclasses* or *land capability units,* taken from the method of land capability classification; and *soil associations* or *soil series*

as distinguished in soil survey. For definitions of these mapping units, and accounts of the methods of survey, see Dent and Young (1981). Land systems or soil associations are appropriate at reconnaissance scales or survey, while land facets, land capability units or soil series are appropriate in detailed surveys. For most diagnostic survey work, land facets will form the appropriate land units. However, where a reliable map of any one of the above kinds, at a suitable scale, already exists, it will be time-saving to accept the units which it shows as the land units for survey purposes.

If no such map exists, the land systems approach (also known as the method of integrated survey) is recommended. It is a rapid method of survey in which all factors of the physical environment are taken into account simultaneously. The method is first to identify the *land systems* which occur in the study area, and then the *land facets* which occur in each. The land systems are first delineated (i.e. their boundaries are drawn) on air photographs for the whole of the study area, these boundaries being subsequently transferred to a map. Land facets will then be identified, but need only be delineated for sample parts of each land system. If air photographs are not available, the Working Group should follow basically the same procedure using whatever topographic maps and survey information are available.

Worksheet 2 has been prepared for the land systems approach. If other mapping units are being used, then the headings for columns 1 and 2 must be changed accordingly.

Column 1. *Land Systems*. A land system is defined as an area with a recurring pattern of land facets. Most land systems are initially identified and defined in terms of their landforms; they are then described in terms of the full range of environmental factors (as in Worksheet 1.1). Examples of land systems are an undulating plain, a range of hills, and a coastal or alluvial plain. Some land systems are given local names, e.g. the Masambara Hills Land System.

To complete column 1, simply decide what land systems are present in the study area and enter their names or brief descriptive phrases. Be sure to leave enough vertical space between entries to allow for recording of subsequent information in columns 2-12.

Column 2. *Land Facets*. A land facet is an area within which, for most practical purposes, biophysical conditions are uniform. All land within a land facet can be expected to respond similarly to management. Land facets frequently occur in regular sequences, within a land system, from hill crest to valley floor; they often correspond to elements in a soil catena. For example, a land system characterized by moderately undulating relief might include the following land facets: steeply sloping land with shallow soils; gentle to moderate slopes with deep, freely drained soils, and poorly-drained valley floor. A convenient method for identifying land facets is to draw a representative cross-section of the land system and mark off the land facets, showing their relative positions and getting an approximate idea of their relative extent.

Once identified, the major land units may be entered into column 2, leaving space for the information which is to follow.

2.2 Identification and Characterization of Management Units within Each of the Identified Land Units

Once the major biophysical divisions of the study area have been identified, the next step is to differentiate the types of management units found within each of the major land units. *(Alternatively, one could begin with the management units and then differentiate them according to their location in different land units).* It may be that there is no simple relationship between land units and management units. Thus, there may be more than one type of management unit per land unit, or a single management unit type may span several different land units (e.g. several different farms of the same type spread over several land units, or even a single farm with parts in different land units). Flexible use should be made of Worksheet 2 to indicate the relationships between management units and the associated land units.

Each set of entries in columns 3 and 4 refer to a *single* management unit type characterized in terms of the scale (column 3) and the social identify (column 4) of the typical management unit. Columns 5-10 are for notes on the main characteristics of each unit which are likely to be important for purposes of diagnostic classification. Needless to say, if the Working Group identifies other characteristics, not on the Worksheet, which are considered important for the purposes of this step, then they should also be noted. Specific guidelines for completing columns 3-10 follow directly.

Column 3. Scale of the Management Unit. Enter one of the following terms which best describes the scale of the management or production unit: *small, medium* or *large*. Since the scale of production is a relative dimension which varies from area to area, indicate the range (in hectares) of the scale terms you are using for the study area in the space provided on the Worksheet.

Column 4. Social Identity of the Management Unit. The social identity of the management unit may be a bit harder to define and will require some judgement. The most important criterion is to choose a term which best describes the social unit which acts collectively in making and implementing land management or production decisions. For example, the most common units might be: the family farm (in some cases it may be useful to distinguish between different types of family units, e.g. nuclear or extended); the corporation (private or parastatal); the cooperative farm; various communal farm units (organized along traditional rather than modern cooperative lines); etc. The Working Group should feed free to use other categories as necessary to adequately characterize the relevant units. (Obviously a different set of terms might be needed to characterize forestry management units operating within the study area).

Column 5. Labour Sources. What are the main sources of labour for the management unit? Possibilities include: family labour, hired labour, communal labour, reciprocal exchange labour, etc. Add other categories to adequately characterize labour resources. If more than one type of labour is used, list in order of importance.

Column 6. Land tenure. Common forms of agricultural land tenure include: Freehold ownership, lease, rent, tenancy (usually implies share-cropping and a more inclusive set of social rights and obligations vis-a-vis the landlord), communal tenure (distinguish between collective and individual use rights), etc. Tenure rights in forestry production systems usually reside with government, parastatal or private owners, but an additional descriptive phrase may be necessary to characterise use rights of the labour force (e.g. as in taungya systems or where workers are permitted to gather firewood, make charcoal, etc.). Tenure rights and restrictions exert a strong influence on land management decisions, so feel free to use other terms or descriptive phrases to adequately characterize this feature of the land use systems.

Column 7. Land preparation tools. One of the most distinguishing features of agricultural land use systems is the type of tool used for land preparation. Indicate the predominant tools used by the management unit for clearance (if relevant) and cultivation, e.g.: axe, machette, fire, etc. for land clearance; tractor, animal-drawn plough, dibble stick, etc. for cultivation. Add other terms as necessary.

Column 8. Inputs. List major agricultural inputs such as fertilizer, manure, pesticides, herbicides, etc. used by the management unit.

Column 9. Economy. Indicate the main production emphasis of the management unit, i.e. subsistence, commercial, or mixed. Some judgement must be exercised here. There are very few, if any "pure" subsistence economies left in the world today. Almost every household land management system has a cash production component, however limited. We arbitrary propose the following definitions: A *subsistence* system will be defined as one in which the major production goal is to satisfy the basic needs of the land management unit, even if this involves a supplementary cash production component. A *mixed* system, by contrast, is one in which the basic needs and cash production objectives are nearly equal. A *commercial* system is one in which cash cropping or home processing activities constitute the mainstay of the economy of the management unit, even if there is a supplementary subsistence-oriented production component (e.g. a large home garden, a fruit orchard for domestic use, or perhaps a domestic fuelwood lot). Minor variations on the main production emphasis may be indicated in the space provided in the Worksheet by a brief descriptive phrase.

Column 10. Major products. Indicate the two or three most important products of the land management unit. These should describe the main outputs of the system (whether for domestic use or sale) in terms of the production emphasis indicated in column 6; e.g. for subsistence system: "maize, beans and squash;" for mixed systems: "maize, beans and squash for subsistence, coffee for cash;" for commercial systems:"milk and cheese".

2.3 Differentiation of Land Use Systems. Having separately characterized the physical and management aspects of land use, the next task is to combine the two sets of characteristics and distinguish those combinations which define distinctively different land use systems within the study area.

Column 11. Reference Number. Review the information previously entered in columns 1-10, evaluate whether the combination of characteristics associated with the different management units (Step 2.2) within each of the land units (Step 2.1) are *sufficiently different* to justify distinguishing different land use systems, and assign a reference number to each of the systems so distinguished. This step involved analysis and grouping of similarities and differences between rows of data displayed in the Worksheet. It undoubtedly requires a lot of judgement and may occassion extended discussion among members of the Prediagnostic Working Group.

Criteria for distinguishing different land use systems are entirely relative. It may be that in the judgement of the Working Group only one significant difference is sufficient to warrant different land use systems classifications. Or it may be that several minor differences do not, in the judgement of the group, add up to a major difference in land use system type for purposes of the D&D exercise. It is up to the Working Group to decide. No foolproof guidelines can be given for the completion of this step.

The aim should be to produce an heuristic classification of land use systems which are sufficiently different from each other (on salient biophysical and/or socioeconomic dimensions) to require separate diagnoses and potentially different approaches to design.

Column 12. Naming of Land Use Systems. This is simply a naming step. The purpose of giving a name to each of the land use systems distinguished by a separate number in column 11 is to facilitate communication about them. Usually a short descriptive phrase (e.g. smallholder subsistence farming) will suffice as a name for a system.

2.4 Selection of Priority Land Use System(s) for D&D Attention

Having differentiated the major land use systems within the study area, the next step is to decide which of them will receive priority attention in the Diagnostic and Design exercise. Priortization is necessary since, in most cases it will not be possible to survey each and every land use system in the study area in a single field exercise, particularly if there are many.

It is difficult to predict the capacity of the D&D field team, i.e. how many systems the team will be able to survey in a single exercise, since this will depend on weather, logistical factors, the complexity of the systems, the degree of difference between the systems, etc. As a general rule, however, it will be difficult to survey more than one distinctly different system per week of field time. Thus, if the exercise is planned to be of two weeks duration (the usual upper limit for sustained field survey activity by a highly qualified multidisciplinary team), then only two systems can be surveyed. This, of course, does not preclude the possibility of subsequent survey exercises to deal with any remaining systems in the study area.

Priortization of the systems at the Prediagnostic Stage will aid the D&D Team to focus its efforts on the most important systems first and then proceed to the others in turn. The number of systems to be dealt with will depend, not only on the number of distinct land use systems in the study area, but also on the objectives of the exercise. If some of the existing systems fall outside the scope of the exercise (e.g. large commercial farms in an exercise which is mandated only to focus on smallholders), then the task is correspondingly simplified.

What criteria should be used in selecting priority systems? Obviously, the selection will be based on the judgement of the Prediagnostic Working Group, but it may be helpful to think in terms of the following suggested criteria:

1) The selected system(s) should be *representative* of important land use systems within the country, so that the results of the D&D exercise and any resulting research and development activity may find wider relevance beyond the study area. Importance, in this sense, may be judged either on the basis of the size of the potential recommendation domain for the agroforestry technologies which may result, or by some measure of the importance of the problems which the identified technologies may solve (even if the recommendation domain is not large). For example, a land use system which is at present of limited spatial extent, could become the target of an agroforestry R&D effort if it is judged to be one that will figure prominently in the *future* of the study area or some significant portion of the country as a whole.

2) The selected system(s) should be in *need of technical assistance* to solve pressing land use problems, either of a production of conservation nature, or both. Otherwise, perhaps research and development resources should be committed elsewhere, where problems in need of a solution do exist.

3) There should be at least a prima facie *potential for an agroforestry approach* to the improvement of the selected land use system(s). Although the D&D team is not automatically obliged to return an agroforestry-oriented recommendation if in its judgement no significant agroforestry potentials exist, it will be helpful in making best use of the human and other resources committed to the exercise to pre-screen the target systems for relevance to an agroforestry approach. (See Appendices C-5 and C-6 for an indication of the scope of the agroforestry approach)

STEP 3. <u>DESCRIPTION OF THE SELECTED LAND USE SYSTEM(S)</u>

The information provided at this Step will be crucial to the D&D Survey Team in making a rapid entry into the diagnosis of the system. The Prediagnostic Working Group should be aware, however, that the D&D Survey Team may, on the basis of more in-depth survey work, find it necessary to modify the preliminary description by the Working Group. An effort should be made to make the preliminary description as complete and accurate as possible within reason, keeping in mind that the main purpose is to provide a good starting point for the diagnostic survey and that, in any case, it will not be possible to anticipate all information needs.

The main source of information for this Step will be interviews with qualified informants, supplemented by any available documentation on the focal system(s). Basic instructions for each substep are given below, with more detailed suggestions for specific or alternative procedures in Appendices A-6 through A-10.

3.1 Preliminary Description of Household Production Subsystems

The main purpose of this step is to characterize the production objectives and the location of the related production activities on the land management unit. Worksheet 3.1 provided for this step is oriented toward the description of household management units, although it could be used with minor adaptations for multipurpose management units which have some other basis of social organization. Likewise, although the "basic needs" approach which underlies the Worksheet (See Appendix A-6) is most fully and usefully employed in dealing with systems which attempt to produce a wide range of outputs to satisfy a variety of production objectives, the Worksheet can also be used for other land use systems with more narrowly defined objectives, providing that those objectives can be classified under one or more of the production objectives listed in column 1 of the Worksheet. Thus a specialized commercial land management unit would have most of the entries under the cash subsystem. The same crop or animal component may be listed under several production subsystem headings (e.g. a particular food crop could be listed under food, cash, and social expenditure headings; firewood could come under fuel, cash and raw materials for cottage industry headings; livestock could have multiple purposes food, cash, and savings/investment enterprises. By the same token, there could be several locations on the management unit where specific production/objectives are fulfilled.

To complete Worksheet 3.1 simply list the specific crop, tree or animal component in the space provided under the headings in column 1 *and* in each box of the location matrix where the component is produced. Modify or add other production objectives or locations as needed to adequately characterize the system.

In cases where Worksheet 3.1. does not, even with modifications, provide an adequate basis for description of management objectives and the location of associated land use activities, a different matrix format should be devised by the Working Group. For example, in the case that the client for the D&D exercise is a forestry or watershed management project, the management objectives and locations would be quite different from those in Worksheet 3.1 (appropriate to farm households). Alternative guidelines are given in the Appendix for forestry (A-7) and watershed (A-8) applications.

The use of alternative Worksheets to describe different management units does not, of course, preclude the *complementary use* of Worksheet 3.1 to describe any household (or other multipurpose management unit) which may also exist within the project area. Thus, in a complex situation involving forestry and watershed management units together with farmers, at least 3 different Worksheets could be completed, one for each set of management objectives.

3.2 Additional Land Use Information

Completion of the foregoing section will not, in most cases, complete the description of the system. Depending on the type of production technologies or management objectives, the following additional information might also be needed:

Agricultural Production

a) Intensity of agricultural land use (see Appendix A-10 for suggested indices)

b) Most common crop rotations

c) Most common intercrop combinations

d) Cropping calendar

Forestry Production

a) Establishment practices

b) Maintenance operations

c) Management system

d) Harvest practices

e) Rotation schedule

(See Appendix A-7).

Livestock Production

a) Type of livestock and herd structure

b) Role of livestock in the system (consumption, sale, savings, draught power, etc.).

c) Seasonal feed sources

d) Management practices

(See Appendix A-9).

Agroforestry Practices

a) Component combinations (trees with herbaceous crops and/or livestock)

b) Role of the tree in the system (production/service roles)

c) Interaction of trees with other components (in space and/or time)

d) Spatial arrangement of components (zonal/mixed)

e) Management practices (pruning, lopping, mulching, etc.)

(See Appendix C-5)

Watershed Management

a) Sources of water (type/location)

b) Type and distribution of water harvesting or drainage infrastructure

c) Condition of land surface in watershed

d) Distribution of land cover types (sketch map)

e) Condition of river and stream channels

f) Community groups potentially concerned with watershed management

(See Appendix A-8 for detailed guidelines)

3.3 Structural-Functional Description of the System

Worksheet 3.3. is designed to enable the analyst to determine the flow of inputs and outputs within the selected land use system. Both economic and ecological aspects of the system are included.

The main purpose of this description is not to identify problems but to assist in the understanding of some of the problems which will be identified later at the Diagnostic Stage. The Worksheet, in effect, describes the system's operating context and, hence, the context of the problems. This information will assist the D&D team to simulate the system's response to potential interventions. One use of the completed Worksheet which might be made is to produce a functional diagram of the system. See Appendix B-8 for guidelines on the construction of functional diagrams. It may be helpful but it is not necessary for the Prediagnostic working group to produce such a diagram in order to complete this step.

The Worksheet is comprised of 2 sections. The first section deals with the sources and uses of major inputs. The second section deals with sources and uses of outputs and includes by-product outputs such as soil erosion and surface water runoff.

Specific Guidelines for Completion of Worksheet 3.3

3.3.1 Inputs

Inputs have been subdivided into 3 main categories i.e. labour, land and other.

Labour is defined in terms of its availability for farming, off-farm and household activities. It is subdivided into family, hired and other e.g. community labour.

Land is here defined in terms of acreage and existing vegetation and/or infrastructure improvements, e.g. terraces, irrigation canals, fences etc. It is subdivided on the basis of whether it is owned, rented or has other use rights, e.g. communal land, forest land temporarily used for intercropping, etc.

Other is divided into capital and operational inputs. Capital items, other than the previously mentioned land-based infrastructural improvements, are draft animals, productive animals (dairy and/or beef cattle, pigs, sheep, goats, chicken), equipment (tractor, plough, irrigation pumps and pipes).

Most common operational inputs are planting material, fertilizers (organic and inorganic), chemicals (insecticides, pesticides, herbicides, drugs) raw material for cottage industries, water, fodder, fuel.

The main *activities* of the farm family (the uses of the inputs) are summarised below.

Primary activities

Cropping of annuals is here defined as producing, harvesting and selling of crops as well as development and maintenance of land infrastructure.

Cropping of perennials is here defined as producing, harvesting and selling of tree (products) as well as development and maintenance of land infrastructure.

Livestock keeping is here defined as rearing, grazing, watering and selling livestock (products).

Gathering is here defined as collecting products other than from cropping and livestock keeping for home consumption or cottage industries or livestock keeping.

Off-farm employment is here defined as family labour engaged in paid income generating activities off-farm.

Secondary activities

Cottage industries are here defined as the on-farm processing of purchased or farm produced raw materials into products for sale or home consumption.

Household maintenance is here defined as all regular household chores other than gathering including maintenance of household structures.

Livestock keeping is here defined as rearing, feeding, watering and selling livestock (products).

Note that livestock keeping can either be a primary or secondary activity depending on whether the animals are grazed or fed with products from primary activities.

3.3.2 Outputs

Products resulting from primary activities are crops, fruits, animals, livestock products (milk, eggs), fodder, fuel, (fuelwood crop residues, manure), water, timber and poles, organic fertilizers, manure, planting material, raw material for cottage industries and draft power. Water is considered a primary product when it is an output of a specific activity or a new infrastructural investment for the purpose of water storage or harvesting. Otherwise it is considered a by-product.

Products from secondary activities are processed food, shelter and cottage industry products.

The final uses of the products are subdivided into household consumption, sold for cash or recycled as inputs into the production system.

By-products of both primary and secondary activities may also constitute outputs, as in the case of soil erosion, surface runoff or deep percolation of water resulting from particular cropping systems, livestock raising activities or farm infrastructure. The effects (rather than uses) on the farm and off the farm are shown as land degradation (from soil erosion), as effects on specific activities (cropping for example), or as farm exports to the larger ecosystem. These may serve as positive or negative inputs to other farming units in the area.

3.4 Preliminary Identification of Major Land Use Problems and Potentials (Optional)

On the basis of the groundwork undertaken to complete the preceding Prediagnostic Steps, the Working Group will have developed a preliminary appreciation of the outstanding land use problems and potentials of the selected systems. Although, this area will be covered again in greater depth by the D&D Field Team, it would be a pity not to benefit from the thinking already done in the Prediagnostic stage. Therefore, a brief characterization of the major land use problems and potentials identified by the Working Group would be desirable.

The information should refer to problems and potentials at two levels: that of the local ecosystem and that of the management unit. Information on the latter would tend to be system specific, so a separate entry should be made in Worksheet for each land use system. At the ecosystem level, the problems and potentials might be more general, but any system specific (or land unit specific) influences should be noted. It is not expected that the Working Group will go into great detail, but reference might be made to the detailed guidelines given in the Appendices.

3.4.1 Problems and Potentials at the Ecosystem Level

In the spaces provided in Worksheet 3.4 list:

Major Resource Limitations and Potentials

Some analysis of previously collected information and perhaps more supplementary information will be needed to complete this section. See Appendix B-9 for guidelines.

Major Conservation Problems and Potentials

This should be based mainly on the understanding development by the working group on the basis of its previous information gathering activities, supplemented by brief additional consultations with qualified informants. See Appendices A-5, A-8 and B-6 for guidelines.

3.4.2 Problems and Potentials at the Management Unit Level

Based mainly on interviews with qualified informants and existing surveys or research reports, complete the following sections of Worksheet 3.4. A separate Worksheet should be completed for each management unit type of relevance to the D&D exercise.

Failure to Meet Management Objectives

The aim here is to identify the major problems arising from the failure of the management unit (whatever if may be) to meet its management objectives (whatever they might be). In the case of household production systems, the basic needs supply subsystems identified in Step 3.1 provide a checklist for a quick preliminary assessment of household supply problems which will suffice for completion of this section. In the case of other types of management units with different management objectives, substitution or addition of other objectives will be necessary (e.g. non-household production units, forestry production or watershed management units as discussed in the instructions for Step 3.1).

Production Constraints

Specify, if known, what major management constraints (e.g. low soil fertility, lack of labour, poor erosion control, etc.) are responsible for the problems identified in the previous step (See Appendix B-6).

Outstanding Potentials for Overcoming the Identified Problems and Constraints

It is not necessary to spend a great deal of time on this section since this will be the main subject of the D&D field exercise. The aim here is simply to record existing thought on the most outstanding potentials for improvement of the system.

3.5 Final Preparations for the Diagnostic Survey

Before the Prediagnostic Working Group concludes its work in preparation for the activities of the multidisciplinary D&D Field Team, the following two items should be addressed.

3.5.1 Selection of Representative Management Units

Some effort should be made to identify a selected sample of management units which are broadly representative of the system(s) to be surveyed by the multidisciplinary field team at the Diagnostic Stage. A formal statistical sample is not required, but a list of about 20 representative farms, or other relevant management units, would aid the D&D team to gain a rapid entry into the diagnosis. A separate list should be prepared for each distinct land use system selected for D&D attention in Step 2.4.

'Representativeness' should be interpreted broadly to include examples of 'typical' management units as well as other management units which illustrate the range of significant variation within the selected system (e.g. smaller, average and larger farms within the range of size variation for the system). The list is intended as an aid to the D&D team in planning and giving an initial focus to its survey activities, although the Team may elect to go beyond the working list to clarify any diagnostic questions which may emerge in the course of the survey.

Worksheet 3.5.1 may be used to record the list of representative management units. This list should be developed on the basis of prior consultation with unit managers to check on the representativeness of the unit, as well

as the manager's willingness to be interviewed. The Working Group should avoid giving the impression, however, that the D&D Team will, without fail, interview the selected farmer, since it may not be possible to visit every farm on the list and, in any case, the D&D Team may decide to modify the list in the course of the exercise.

3.5.2 Suggested Composition of the Multidisciplinary D&D Field Team

Based on the foregoing description of the selected land use system(s), the Prediagnostic Working Group will have developed an appreciation of the types of problems and potentials likely to be encountered by the full multidisciplinary field team during the course of the diagnostic survey. This should allow them to identify the range of disciplines which should be represented in the D&D Team in order to insure adequate coverage of the selected land use system(s).

The exact requirements will vary from application to application, but the minimal requirement should be for a team which is competant to assess the likely biophysical and socioeconomic constraints and potentials of the selected system(s). For logistical and management reasons, however, it will be difficult to work with a D&D Field Team composed of more than five or six senior scientific personnel. It may be possible to economise somewhat on personnel resources by recruiting individuals who combine expertise in more than one discipline, but this should generally not be done at the expense of adequate disciplinary coverage of known or suspected aspects of the field situation which are likely to prove crucial for an accurate diagnosis.

In addition to the disciplinary requirements, the team should include at least one member with experience in field survey and informal interview methods as well as a person with in-depth knowledge of the study area, i.e. not just theoretical knowledge but a practical working familiarity with the area and its inhabitants. These could be, but need not be, the same person. The local expert need not be a senior scientific member of the team; a local research assistant or technician with a good knowledge of the area could be recruited for this role. In any case, someone will be needed to serve as local guide.

If langugage interpretation is required, two or three interpreters may be needed (since the field team may elect, after an initial period, to split up into smaller survey groups). These need not be professional interpreters, but it is important to select individuals who are able to interpret technical questions and answers in an unbiased way. Social dimensions of the interview situation should be considered in selecting interpreters. (Are women needed to talk to women? Are there ethnic or caste considerations that will affect the willingness of the farmer to be interviewed or the quality of the information he or she gives to the team?).

Although the composition of the multidisciplinary team will be heavily influenced by the needs of the Diagnostic Survey, some thought should also be given to the post-diagnostic Design Phase. Normally, best design results will be obtained if the technology design specialists are able to participate in the diagnostic survey. Ideally, it would be the same

core team that would participate from beginning to end. However, it may be desirable to supplement the core D&D team, once the general design requirements are known (following Step 6), by experts in particular aspects of relevant technology who, for various reasons, may not have been involved in the diagnostic field work. It will be impossible, at this early planning stage, to say exactly which types of supplementary expertise might be required, but it could be useful at this stage to identify individuals who would be willing to be members of a multi-disciplinary backup pool.

The space provided in Worksheet 3.5.2 may be used to record the suggestions of the Working Group. This concludes the Prediagnostic Stage.

DIAGNOSTIC STAGE

OVERVIEW

PURPOSE: The purpose of the Diagnostic Stage is to arrive at a diagnosis of the problems and potentials of the chosen land use system and to use this as a basis for derivation of design specifications for appropriate technological interventions in the system or its environment.

PERSONNEL: Normally a high level multidisciplinary team, reflecting the discplinary competance to handle all likely aspects of the diagnostic situation, will be the preferred way of meeting the personnel requirements of this stage. In some cases a smaller interdisciplinary working group, in consultation with a multidisciplinary backup pool, may be able to carry out the diagnosis. Care should be taken to insure that the composition of the D&D Field Team is adequate to cover the socioeconomic as well as the biophysical aspects of the diagnostic situation. If at all possible, it is highly advisable in research-oriented applications to involve the eventual researchers directly in the diagnostic process as members of the D&D Field Team. Ideally, the same group that does the diagnosis should carry through with the Design Stage activities as well. For logistical and management reasons the size of the D&D Team should not normally exceed five or six individuals. Beyond this size communication and coordination within the group becomes difficult. The success of the group process will be enhanced by selected of team members with a high aptitude for teamwork.

SOURCES OF INFORMATION: Area reconnaissance and diagnostic survey of representative management units within the selected system(s), supplemented by information compiled at the Prediagnostic Stage.

SUGGESTED PROCEDURES:

Step 4. Diagnostic Survey

Step 5. Diagnostic Analysis

Step 6. Derivation of Specifications for Appropriate Technology

GENERAL GUIDELINES

The aim of the Diagnostic Stage is to arrive at an appreciation of the problems and potentials of the target land use system and its environment and to use this information as a basis for the derivation of design specifications for appropriate technological interventions. To facilitate this activity the suggested procedure for information gathering and analysis has been broken down into three Steps and further divided into substeps. Not all of the suggestions contained in the following guidelines and the accompanying appendix material will be relevant to each application. The user is encouraged to use the methodology flexibly and to select and adapt the suggested procedures to meet the needs and resources of the specific application.

SPECIFIC PROCEDURAL SUGGESTIONS

STEP 4. DIAGNOSTIC SURVEY

This step is subdivided into two parts. The first is intended to allow the D&D field team to obtain a general environmental orientation to the study area, to view the target system(s) in context, and to plan the remainder of the survey. The second part focuses in more closely on the diagnosis of system problems and potentials through survey of a selected sample of representative management units.

4.1 Orientation and Reconnaissance

Once the D&D field team is assembled in the study area, the first steps to be taken are to review the Prediagnostic background material, if this has not already been done, and to take a reconnaissance tour of the study area. A motor vehicle will normally be used for this 'windshield survey' but frequent stops should be made to allow the team members to view the landscape, visit representative management units, have informal discussions with local residents, and in general begin to develop a feel for the area. It is advisable to include in the reconnaissance survey party local guides, interpreters, and researchers or technicians familiar with the area. These persons may themselves be sources of information on the area and may also serve as intermediaries, assisting the team to obtain information directly from local farmers and qualified informants.

General guidelines for environmental observations at this stage are given in Appendix B-1. Supplemental suggestions are given in other appendices for forestry (A-7) and watershed (A-8) applications and for description and possible stratification of the human ecosystem (A-5) for D&D purposes. A general familiarity with the purpose and content of succeeding steps will also aid the team in making observations which may be relevant to the tasks ahead.

Minimally, the team should use the opportunity of the reconnaissance survey to interpret and, if necessary, refine the Prediagnostic description of the area. Notes may be made on the worksheets, if these have been used, or alternately it might be useful for each team member to have a blank set of prediagnostic worksheets for supplementary note taking as the exercise progresses. Maps, air photos and other sources of supplementary information should also be available for consultation throughout the reconnaissance survey.

The amount of time devoted to this initial orientation and reconnaissance activity will vary, but normally one to three days at the most will be sufficient in 'rapid appraisal' type applications. The process of environmental observation will continue throughout the survey of representative management units, so not too much time should be lost before starting the unit level survey. The important thing, always, is to view the management units *in context*.

At the end of the reconnaissance period the full D&D team should meet to discuss its observations, make any necessary additions to or modifications of the Prediagnostic description, and develop a plan of action for carrying out the remainder of the survey. Among other things, the team should review the suggested procedures and decide exactly how the team will proceed (i.e. which procedures to apply, at what level of detail, what modifications might be necessary to adapt specific procedures to the situation at hand, etc.). Once agreed upon, the implementation plan which the team develops at this point will become the 'blueprint' for the exercise. Although the plan may be modified, of course, as the exercise progresses, in coordinating individual efforts toward a coherent interdisciplinary exercise it will generally be found useful to have some such plan, which everyone agrees to follow.

4.2 Survey of Representative Management Units

General Guidelines

Having gotten an orientation to the general environment, the focus now shifts to the diagnosis of problems, constraints and potentials of the land use system(s) selected for priority D&D attention in Step 2.

Using the list(s) of representative management units provided by the Prediagnostic Working Group in Worksheet 3.5, the D&D Field Team chooses a set of management units to survey each day. It is advisable to keep the team together during the first few days of the survey of each system in order to build up a shared image of the system, but in the latter part of the survey the team may elect to split up into smaller survey parties to cover a larger sample of management units or to focus in on problems requiring specialized attention.

Each night the survey team assembles to discuss the results of the day's survey work, sharing information and building up an increasingly clear picture of the problems, constraints and potentials of the focal land use system(s). The team may begin to use the analytical Worksheets accompanying Step 5 as "note paper" to record tentative findings. Problems requiring more concentrated attention are identified and the following day's sample selected accordingly. The process is analogous to detective work, i.e. using the clues provided to zero in on the major problems and constraints.

It is essential that the survey information be digested and understood as the team goes along, since this is the only way the team will be able to focus in on aspects of the situation needing further attention. Statistical rigor is far less important, in the final analysis, than achieving a satisfactory sense of having *understood* the situation. The team will know where the weaknesses are in its understanding and the survey process should be continuously adjusted to correct these weaknesses. The proper

place for rigor in this type of survey is in the understanding which is being build up rather than in adherence to a mechanical procedure for achieving this understanding.

Midway through the survey of a particular system the team may feel that it is necessary to take a morning off, or even a full day, from the survey work to summarize the results obtained so far and catch up on the analysis. It is far better to devote enough time to the analysis than to rush on with the aim of surveying a larger sample. Variations on the main diagnostic themes can be dealt with later through more formal survey procedures in followup activities, but this will be possible only if the multidisciplinary team takes the time to *understand* the main themes while it is still in the field. The temptation to rush ahead accumulating completed survey forms with the idea that 'we can analyse them later' should be strictly avoided.

Specific Guidelines

Guidelines on diagnostic interviews for agroforestry purposes are given in Appendix B-2. A sample diagnostic survey form, based on a compilation of previous survey forms used by ICRAF's D&D team, is given in Appendix B-3. This sample checklist and data entry form can be used flexibly as a basis for developing the team's own *working checklist* which is appropriate to the land use system(s) to be diagnosed. Although the sample survey form is intended to be widely applicable, some modifications may be needed to adapt it to the local situation. In preparing an appropriate survey form, the team may find it useful to consult Steps 5 and 6 to clarify the kind of information that will be needed for later analytical steps (see also Appendices A-5 through A-9 and B-1 through B-9).

The working checklist (B-3) is intended to be used as a 'prompt' to guide the interviewer through the survey process in a flexible manner. It is *not a questionnaire* to be read out to the person being interviewed. This reflects a deliberate methodological tactic based on two considerations: In the first place, this survey includes non-interview aspects, direct observations to be made by the D&D Field Team. Secondly, a checklist rather than a questionnaire format is more conducive to a smooth flow of communication with the farmer. Equiped with a checklist to remind them of what points to cover, the interviewers are encouraged to use maximum ingenuity and conversational skills to elicit the required information from the relevant respondents. This type of structured but open-ended survey procedure is best accomplished by senior scientific personnel (rather than junior level 'enumerators'), since it requires considerable skill and judgement in the elicitation and interpretation of information. (See Appendix B-2 for suggested interview techniques and guidelines.)

Special care should be taken to address the team's queries to the most relevant and knowledgeable person within the management unit. Men, women children may each have different roles with regard to management decisions and production activities on the farm. Try to address the questions on particular aspects to the responsible persons. For example, women may be more involved with and know more about firewood than men; men may be specialised on cash crop production, whereas women may have greater responsibility for food production; women may have supplementary cash cropping or processing enterprises about which the men may know very little, and vice-versa; children may have major responsibility for certain activities like herding, etc.

After a few days survey work, the team may begin to feel that it has identified the major problems and that the need is now to focus in on these problems and speed up the survey process somewhat to cover a larger sample of farms. If the team so decides, the survey checklist may be streamlined to focus on the problem subsystems and related causal factors. Care should be taken, however, to remain open to 'surprises' which may emerge from survey of subsequent units.

At all times in this kind of survey work, the team should try to 'follow its nose.' Somehow, the image of Sherlock Holmes, the master detective, always comes to mind in D&D survey work. It is, perhaps, a useful image to help keep the team on the case.

The survey exercise continues until the team feels that it has developed a sufficient diagnostic understanding of the selected land use system(s) to complete the analytical Worksheets (5.1-6.4). Obviously, in a time-limited D&D exercise the criterion of 'sufficient information' must be interpreted pragmatically. Generally, however, the team will reach the point where it feels that further survey will not add appreciably to its understanding of the system. At this point the Diagnostic Survey may be terminated, although the team retains the option of resuming limited survey activities to clarify critical questions of diagnosis and/or, particularly, design (see Step 9.1).

STEP 5. DIAGNOSTIC ANALYSIS

Although the analysis of diagnostic findings is a continuous, iterative process which has been ongoing throughout the survey period, the time will come for the team to pull all of its findings (recorded on the checklist forms) together, complete the analytical Steps 5.1-5.3, reach a consensus and record the results. One or more sets of Worksheets might be used as 'note paper' by the team in reaching the eventual consensus. Another set of Worksheets could then be used to record the findings in an orderly and final form. The team may elect a 'rapporteur' to take responsibility for recording the 'official' version of the Worksheets. A separate set of Worksheets should be completed for each separate land use system being diagnosed.

In the step by step guidelines which follow, Steps 5.1 and 5.2 focus on the diagnosis of problems at the management unit (farm) level. Step 5.3 deals with problems at the ecosystem or community level. Step 6 integrates the diagnostic findings at both levels and arrives at a set of general design specifications for appropriate technological interventions in the system.

5.1 Analysis of Production Problems

For reasons of completeness and convenience, the analysis of production problems at the management unit level may be broken down into four substeps, corresponding to Worksheet sections 5.1.1-5.1.4.

5.1.1 Present Supply Problems

The purpose of this Step (which corresponds to Prediagnostic Step 3.4. but at a deeper level of analysis made possible by the Diagnostic Survey), is to record the major problems experienced by the management unit in

meeting its production objectives. In most cases the symptoms will be in the nature of supply problems, i.e. shortfalls of basic commodities brought about by the failure of the management unit to meet its production objectives.

To complete section 5.1.1, simply indicate the nature of the major diagnosed supply problems together with a note on the farmer's perception of the severity of each problem. The problems could conveniently be listed in order of priority for solution in the farmer's thinking. A certain amount of aggregation of the survey findings will be necessary. It may be best to think in terms of the 'typical farm' for a given land use system, while taking care not to lose sight of 'typical variations' from the norm. The aim is to arrive at a system-specific, but not farm-specific, diagnosis, which will be of use in identifying priorities for technological improvements in a somewhat 'generalized' system of a given type.

If the management unit is other than the household, or equivalent multi-purpose production unit, the basic needs categories may not directly apply and, consequently, problems in meeting management objectives will have to be assessed in other terms, i.e. those previously defined by the Prediagnostic Working Group in Step 3.1. In any case, the purpose of this step is to describe the major problems involved in the failure of the management unit (whatever it might be) to meet its management objectives (whatever they might be). A separate copy of the Worksheet should be completed for each separate land use system being diagnosed, incorporating any necessary modifications in the suggested categories.

5.1.2 Causal Factors and Constraints Involved in the Creation of Present Supply Problems

The findings of the trouble-shooting analysis carried out on site in the course of the survey of management units should now be summarised in section 5.1.2 of the Worksheet. A simple *listing* of all causal factors and constraints which are considered to have a significant role in the generation of the identified supply problems will suffice at this point. There may be some discussion on what is to be considered a 'significant' causal factor or constraint, but the team should not at this stage spend much time trying to sort out relationships between causes since this will be done at Step 5.1.4.

5.1.3 Household Strategies for Coping with the Identified Problems and Constraints

Summarize briefly what the team has learned about how unit managers try to cope with identified problems (e.g. purchase of staple foods or firewood to make up for production shortfalls) and constraints (e.g. crop rotation, use of farmyard manure, purchase of fertilizer, etc. to cope with low soil fertility). The purpose of the notes entered into section 5.1.3 of the Worksheet at this point is to bring the farmers' strategies momentarily to the forefront of the team's thinking in order to fix them in the mental background of all subsequent analytical steps. This will become particularly relevant in assessing the farmers' potential responses to technological innovations, but it is also helpful in throwing additional light on the nature of the problems they are facing.

5.1.4 Systems Analysis of Constraints and Potentials

The activities of this step are called 'systems' analysis because it is here that the various elements of the total problematique are considered as a whole, with particular attention to interrelationships among the elements. This step is the heart of the diagnosis.

By now the team will have achieved an appreciation of the many factors (listed in Worksheet section 5.1.2) involved in the causation of the identified performance problems (listed in section 5.1.1). It remains now to organize that understanding. In doing this the team must weigh the various factors, explore that interrelationships among them, and identify the critical constraints, bottlenecks and causal syndromes in the pattern thus revealed.

Two diagramming techniques are recommended to aid the team in carrying out the systems analysis required for this step: *causal diagramming* and *functional diagramming* (see introduction to these techniques in Appendices B-7 and B-8, respectively).

Causal Diagramming

When used judiciously as a tool in analyzing relationships among causal factors, causal diagramming has been found in previous D&D applications to be very useful, particularly when it comes to removing impasses to a team consensus on the analysis of the total problematique.

Different team members may have different perceptions of what is *the* problem or what is *the* cause of a particular problem. Usually, the often lengthy and heated discussions which can arise over this issue are pointless, since, as the list produced for Worksheet 5.1.2 will indicate, there may be *many* contributing causes to any problem. What is needed at this step is to sort out the various relationships among causal factors, and this is precisely what a causal diagram can do.

An additional value of the technique is the stimulus a causal diagram can give to the team's perception of *potential intervention points* within the system where specific technologies may have an effect in removing or reducing constraints. Causal diagramming, thus, provides a *bridge between diagnosis and design.* What is learned by this technique about the functional potentials inherent within the system for problem-solving interventions comes into the design specifications in Step 6.

Functional Diagramming

Functional diagrams are, likewise, an aid to arriving at an understanding of system functioning which may be used in conjunction with causal diagramming. The particular use of a functional diagram is to show, not so much causal connections between aspects of a problem, as *flows* of concrete inputs and outputs between components of the system. Such a diagram may be useful in visualizing 'how the system works' and this may be helpful in arriving at a better understanding of system problems. Functional diagramming is recommended mainly as an *adjunct* to the use of causal diagramming at this step, since the main purpose of the step is to arrive at a causal understanding of system problems. If structural-functional diagramming may be helpful in this respect, then its use is recommended. (It has another use as well, at the Design Stage, in thinking through the probable effects of particular technological innovations).

In both cases what is recommended is a *judicious use* of the respective diagramming techniques. While it is possible to construct complete causal and functional diagrams of the *entire* land use problematique, it may not be helpful to do so since complete diagrams are normally too complex to be of much practical value as an aid to understanding. Several partial diagrams to assist the team in clarifying specific aspects of the general problematique might be more useful than one monstrous diagram.

Whatever analytical techniques are finally used to aid the D&D team to discover and develop a clear representation of the major causal relationships involved in the generation of the diagnosed problems, the final analysis should pinpoint the important limiting *constraints* and causal *syndromes*. A constraint is any factor which limits or reduces the effectiveness of the production subsystem in achieving its objectives. A syndrome is any set of causal relationships which reveals how a problem, constraint or degradation process arises within the system. When using causal diagrams some syndromes may be easily recognized by the presence of positive or negative feedback loops which reveal how degradation processes or constraints are generated and perpetuated within the system.

Once this analysis is completed, the results should be recorded, either in the form of a causal diagram (supplemented by a functional diagram if helpful) or some other *clear and unambiguous representation* of the major constraints and causal syndromes, together with written explanatory notes. The space provided in Worksheet 5.1.4. may be used for this purpose, adding additional pages as necessary to adequately document the major diagnostic findings.

The general outlines of potential interventions will already start to emerge from this analysis of the problem complex. Team members may note potentials which occur to them in the course of the diagnostic analysis, but it would be conducive to a more objective consideration of a wider range of potential interventions if the team defers detailed consideration of potentials until Step 6, when the full analysis of system needs and problems will have been completed.

5.2 Assessment of Sustainability Problems

The foregoing analysis focuses on present production problems, but it is important also to consider the future productivity or *sustainability* of the focal land use system(s). To elaborate on the medical analogy, having diagnosed present constraints and syndromes, the team should now come up with a *prognosis* for the system, i.e. a prediction of *future system performance*. This involves examining trends inherent in the system (either present trends or likely future trends), extrapolating them into the future and anticipating what problems the system will have in meeting its objectives at the future date.

Two distinct kinds of factors must be considered in making this assessment:

1) conservation problems and degradation trends affecting the ability of the resource base to support a given level of production demand (see Appendices A-8, A-10, B-5 and B-6)

2) the level of demand likely to be placed on the system in future (see below)

The exercise consists basically of imagining how the system will respond under different assumptions about relevant aspects of these two sets of factors. In making the assessment, relevant information is drawn from all preceeding steps.

The level of population pressure will, obviously, play an important role in determining the level of future demand on the system, but population pressure alone may not be responsible for all degradation processes in the system (some might be the result of improper land use per se). The team should decide which of the following scenarios are relevant to consider:

1) "If present trends continue...." (This is simply an extrapolation into the future of present trends vis-a-vis both the above sets of factors. It may incidentally cover one of the following population pressure scenarios.)

2) Constant population pressure scenario. (Assuming that the current level of population pressure is maintained, i.e. that population growth and outmigration cancel each other out.)

3) Increasing population pressure scenario. (Assuming that there is a net increase in population in the study area. The present rate of population growth would be covered under scenario #1 above, but it might be useful to consider the effects of higher or lower rates of increase, if there is reason to believe that either of these conditions might obtain.)

4) Decreasing population pressure scenario. (Assuming that there is a net decrease in population due to outmigration or other demographic processes, what effects would this have on the system?)

One useful way of proceeding would be to examine the diagram(s) produced in Step 5.1.4 and try to visualize how the system would respond to the various scenarios. For example, under the increasing population pressure scenario it would be relevant to ask: What present problems would be intensified? What new problems would emerge? How might the farmer respond to these conditions? Would the system be expected to break down altogether, or might it stabilise at some low-level equilibrium?

The results of the team's deliberations at this step may be noted in Worksheet 5.2. They will be helpful at a later point (Steps 6.1 and 8) in deciding on a design strategy.

5.3 Assessment of Problems and Potentials at the Ecosystem/Community Level

The rationale for a separate assessment of problems and potentials at the ecosystem and/or community level stems from the fact that they may be different from those identified at the individual farm or management unit level. For example, it may be the case that the cause of a problem on one farm may arise on another, or that the farm in question is exporting problems to its neighbours, or that the origin of a problem cannot be attributed to a specific management unit or land use system at all, but arises instead as a condition of the ecosystem as a whole, or as the result of processes occuring on the boundaries between

management units or systems (e.g. gully erosion along roadsides or in the spaces between farms). Moreover, even where problems can be attributed exclusively to one land use system, potential solutions to these problems may exist in other systems or geographic subdivisions of the study area or the wider environment. For these reasons, although each distinct land use system should receive its own diagnosis, it is necessary to go beyond the system-specific concerns of sections 5.1 and 5.2 above in order to complete the diagnosis of problems and potentials.

This task may be broken down, for convenience, into two parts as follows:

5.3.1 Distribution of Production Problems and Potentials

As at the farm level, problems and potentials are related to productivity, sustainability and distribution, and can be subdivided in accordance with the basic needs categories: food, water, fuel, shelter, raw materials for cottage industry, cash, savings/investment, and social production and expenditure. Problems and potentials can be inferred in large part from the completed checklists for structure and function of the human ecosystem (Appendix A-5, part 1, checklists 1 and 2), supplemented by observations and interview information arising from the Diagnostic Survey.

To integrate the diagnosis at the ecosystem/community level, the incidence of problems should be linked to the land use system, the geographic location and/or the population group in which the problem symptoms are felt. The problem specification should indicate which of the basic needs are affected and what are the immediate or apparent causes of the problem. Is the cause a *condition* of the ecosystem as a whole or can it be attributed to a source? If so, is the source within or outside the local ecosystem/community? If inside, locate the source area, land use system, source activity and associated population group (if pertinent). An example of a problem originating outside the ecosystem is a falling regional market price for local cash crops. A problem endemic to the ecosystem could be crop failures caused by erratic rainfall. An example of a problem caused by a process that can be located at a particular source is erosion of cropland caused by heavy runoff from upstream grazing areas.

Having identified the problems and assigned them to sources, the next step is to consider potentials, either for solving the identified problems or for realizing special opportunities for increased production of certain outputs in particular parts of the ecosystem (see Appendix B-9 for guidelines on a general assessment of resource potentials and limitations). Finally, the exercise is concluded by comparing problems and potentials in different subdivisions of the local ecosystem/community to determine whether there are any problem-solving linkages to be made, which would suggest an integrated ecosystem/community level approach to design.

Detailed guidelines for this type of analysis are given in Appendix A-5 (part 2) along with an example of the identification of design potentials in one land use system to solve problems in another. The results of such an analysis may be recorded on Worksheet 5.3.1.

5.3.2 Larger-Than-Farm Scale Conservation Problems

The other, complementary, use of ecosystem scale diagnosis is to identify significant conservation problems and potentials which exist either outside the boundaries of particular land use systems, or which exist within the land use system but, for one reason or another, do not emerge prominently from the unit level diagnosis. The example of erosion gullies between farms or along roadways has already been cited. Other examples might include overgrazing of common lands, deforestation of public watersheds, siltation of water courses, etc. Even where the causes of such problems are at least partially attributable to particular land use systems within the study area, complete solutions may require a larger-than-farm level approach to design.

Detailed guidelines are given in the Appendix for assessment of land management problems and degradation hazards in general (B-6) and watershed management problems in particular (A-8). The aim here is to supplement the system-specific diagnosis of conservation problems and potentials (vis-a-vis the sustainability of production systems at the unit management level) with an assessment of problems and potentials within the ecosystem at large.

Results may be entered in the space provided in Worksheet 5.3.2.

STEP 6. DERIVATION OF SPECIFICATIONS FOR APPROPRIATE TECHNOLOGY

This is the final and most integrative step of the Diagnostic Stage. It is here that the design implications of all preceeding steps (including those of the Prediagnostic Stage) are analysed and spelled out in terms of a complete set of *design specifications* for appropriate technology. To insure full treatment of all important design considerations, this step has been broken down into four substeps. The notes entered in the corresponding Worksheets (6.1 - 6.4) will, collectively, constitute the terms of reference for subsequent design activities. That is to say, they will define the *design problem* to be tackled by the team at the Design Stage.

6.1 Development Strategy

Before commencing on the actual design of technologies for improvement of the diagnosed land use systems, it is imperative that the team come to a general consensus on three overriding questions:

1) What is the appropriate scale for design activities?
2) What general approach to take in developing existing land use systems?
3) How to deal with the time dimension in agroforestry design?

These questions involve certain interrelated issues which, once resolved, would tend to define the general design strategy for the area, thereby giving shape to subsequent design thinking. It is unlikely that these issues can be completely resolved before getting down to the detailed design work (Step 7), but at least a preliminary level of agreement on the general approach should be reached before commencing the Design Stage. The design strategy can always be amended to accord with new possibilities arising from the detailed design work.

What is the Appropriate Scale for Design Activities?

As a general rule, we have said that design of appropriate technologies should be thought of, in the first instance, as a system-specific exercise. This is to insure greater relevance of the eventual technologies to the actual needs and potentials of existing land use systems. In some cases, however, a larger scale design approach may be called for to deal with problems or potentials arising within the ecosystem or community at large. Indications of the need for supplementary 'larger-than-farm' scale design are the major output of Step 5.3. Departures from the management unit or system-scale focus toward smaller scale designs might also be required to deal with problems associated with the intra-household distribution of labour or production opportunities (e.g. women's cash crop or processing enterprises).

A project has been initiated at ICRAF to systematically investigate the role of scale factors in agroforestry diagnosis and design, and to develop suggested guidelines to aid in resolving questions regarding the appropriate scale of agroforestry interventions (Rocheleau, 1983). These will be made available in due course in the form of Working Papers and updated versions of the present manual. In the meantime, it may suffice to simply be aware of the possibility of different scales of design to address different needs and potentials within the diagnosed area.

What General Approach to Take in Developing the System?

The options can be succintly stated as follows:

a) improving vs. transforming approach

b) problem-solving vs. potential realizing approach

Neither of these issues necessarily involve mutually exclusive options, but thinking of then as 'partial options' helps clarify important differences in emphasis which could lead to radically different designs. The first issue is whether it is best to take a design approach which aims at making discrete technical interventions in the system to bring about incremental improvements, or whether the approach should aim at total transformation or substitution of the existing system by a new system of land use.

Generally speaking, experience has tended to indicate that total system transformation is rarely acceptable to farmers. On the whole, small-scale, traditional land users are far more likely to respond favourably to incremental improvements in their existing system. Since the 'adoptability' criterion in technology design will, in the final analysis, be the determining one with regard to the practical impact of an otherwise good design, as a first principle of design, preference should be given to an 'improving' approach (Torres, 1980; Raintree, 1983). (See Appendix C-1).

This injunction does not stand without qualification, however. There are situations in which a 'transforming' approach to design may be indicated: notably, when dealing with modern, commercialized farmers who have demonstrated a willingness in the past to adopt innovations which have resulted in major changes in their pattern of land use, *or* when dealing with traditional systems that have been stressed to the breaking point and in which there is simply not much scope for improvements based on the traditional way of doing things.

As previously stated, the two approaches are not mutually exclusive. For example, in the case of a worn out traditional system where a transforming approach may be indicated, the designers can still try to incorporate familiar elements of the old system into the design for the new one. It is psychologically important, for a good rate of adoption, to give the farmers something they can relate to.

In general, traditional farmers will be more susceptible to a transforming approach to cash crop rather than subsistence food production. Only in extreme cases, should the team contemplate a design which changes the basic production objectives of the management unit with respect to food crops grown for home consumption. Food habits are notoriously hard to change; although, in historical perspective, most of the major food crops now grown in the world present local introductions from past ages of exploration and contact. But the modern situation took a long time to bring about.

On the related issue of whether to aim at providing solutions to existing problems or whether to try to realise inherent potentials within the system for more optimum use of existing resources, the conservative, adoption-oriented strategy would tend to favour the problem-solving approach. In general, farmers are more likely to respond favourably to technologies which offer solutions to perceived problems than to those which do not. Again, the two strategies are not mutually exclusive. A good overall design might incorporate elements of both. Nevertheless, to maximize the chances of awakening the farmer's interest in adopting the new technology, perceived problem-solving elements should be incorporated into the design. Once the main 'selling points' have been included in the design, there is no reason, given the extreme design flexibility of multipurpose agroforestry trees and production systems, why additional design elements cannot be incorporated. These might address unperceived problems, or problems with a low priority for solution in the farmer's thinking, or perhaps latent resource potentials of the system. (See Appendix C-2 for further notes on multipurpose design strategies.)

How to Deal with the Time Dimension in Design?

The main issue here is: *static* vs. *dynamic* design. Agroforestry systems are likely to be a long time on the ground. Once land is committed to a specific form of land use involving long-lived trees, the system cannot be lightly changed. Moreover, a certain amount of research and development work is likely to be necessary before most agroforestry technologies are ready for dissemination to potential users. It would be a disappointing use of resources to spend five or ten years perfecting a new agroforestry technology, only to discover that in the meantime the target system had changed so much as to render the design obsolete. For these reasons it is necessary to give adequate thought to the time dimension in agroforestry and to favour, whenever possible, a dymanic approach to design.

Minimally, a dynamic design approach would involve taking account of the trends and sustainability problems inherent in the system (viewed in the context of its wider environment) and at least attempting to insure that the technologies envisaged *leave scope* for developments which may become necessary or desirable in the future. A more complete approach to dynamic

land use design would involve actually designing a stepwise series of technology developments for the system. Obviously, this would be a much more ambitious design undertaking, but perhaps the effort would be worthwhile in some cases. Although it is difficult, at present, to give examples of proven agroforestry design which demonstrate this stepwise approach, some general design principles can be suggested (See Appendix C-3).

One of the possibilities which a dynamic approach to design would tend to open up is that of a phased introduction of both problem-solving and potential-realizing technologies, i.e. first the problem-solving technologies and then, once the system has been stabilised, technologies which realise higher potentials for improved resource use could be added. A useful principle to keep in mind in all of these considerations is the fact, as Collinson (1981) has expressed it, that the existing system is the base upon which changes can be most successfully grafted.

To complete the step, the team should record the conclusions of its deliberations on the above issues in the space provided in Worksheet 6.1. Brief notes, indicating the team's recommendations and rationale with respect to a general strategy for development of the target systems/area will suffice as a basis for further design thinking. It should be recognised, of course, that once the team has actually embarked on the formal design exercise, many ideas may emerge on technical options for implementing the general design strategy and that these concrete ideas may prompt the team to reinterpret or reformulate the development strategy.

6.2 Functional Potentials for Problem-Solving Interventions

Based on the proceeding analysis of present supply problems, production constraints, causal syndromes and farmer strategies together with the team's assessment of sustainability problems and bearing in mind the problems in the wider ecosystem (Step 5) and the general development strategy for the system (Step 6.1), the next step is to identify points within the system where interventions might be made to remove, reduce or by-pass constraints, alleviate detrimental syndromes, and solve or mitigate supply problems. The perception of these *intervention points* will naturally come simultaneously with the perception of the *functional nature of the interventions* at each point.

As previously noted, a causal diagram of the system problematique can be an excellent aid to this process. If a causal diagram has been produced, the team simply studies the diagram and, for each node in the causal network, asks such questions as: Can we think of anything that could be done to remove, reduce or by-pass this constraint? What would be the functional nature of a constraint-reducing intervention? What does this tell us about the functional needs of the system at this point and, hence, the functional potentials for technology interventions? Particular attention should be given to interventions which could reduce the effects of the major problem-causing syndromes within the system. Attention should also be given to functional potentials for the solution of problems (identified in Step 5.3) which exist within the wider ecosystemic environment of the focal system(s).

The above questions will bring the team very close to thinking about the specifics of design, but the full benefit of the team's diagnostic preparations will only be realised if it can *restrain the design imagination* just a little while longer. This means keeping the suggestions abstract

rather than going directly to concrete technological alternatives at this point. Only if the thinking about functional potentials is couched in broad, abstract terms will the team be able to appreciate the full range of functional alternatives. Once the jump is made to concrete technological suggestions, the discussion will take on a very lively dynamic of its own which might tend to obscure some of the less obvious, but no less interesting, alternatives. In other words, the interventions should be expressed abstractly in terms of *functions*, rather than concretely in terms of *technologies*, at this point.

Once the team has exhausted all the thinkable possibilities for functional interventions in the system, these should be loosely prioritized, and listed as *functional specifications* for problem-solving technologies in Worksheet 6.2. Some selectivity and judgement should be exercised at this point (i.e. the team should not list trivial interventions), but the general tone of the thinking should not be overly critical just yet. The purpose of this step, after all, is to begin to open up thinking about alternatives (including non-agroforestry alternatives). The time for critical assessment will come later.

6.3 Potentials for Improved used of Resources

Drawing on environmental and economic information gathered from previous Prediagnostic and Diagnostic Steps (1-5), the focus at this step is on deriving design specifications for improved used of existing or introduced resources (e.g. new crops more suited to the land qualities of the area, alternative uses of land or labour resources, etc.). The discussion of land evaluation methods in Appendix B-9 may be helpful in thinking through the biophysical potentials of the area. Insights into potentials of a more socioeconomic nature (e.g. more efficient use of labour) will mainly come from the Diagnostic Survey. Economic potentials for new crops or increased production of existing crops may be discovered by reviewing information collected at Steps 1 and 4. Reference should be made to the general development strategy (6.1) when entertaining suggestions for 'potential realizing' technology.

Notes on the team's conclusions may be entered in Worksheet 6.3. There may be some overlap with the results of the previous step.

6.4 Possible Constraints on Candidate Technologies

One of the main advantages of a systematic diagnostic approach to agroforestry (or non-agroforestry) design, is the increased probability of developing good designs based on a *complete* set of design specifications. The design specifications could not be considered complete however, if the team fails to specify possible constraints inherent in the system on potential technologies; hence, the need for this final pre-design step.

Needless to say, the assessment of potential constraints on new technology at this step will be of a preliminary nature, since the team will not yet have considered specific candidate technologies in detail. Once this is done (in Step 7) a more focussed assessment of specific constraints pertinent to the candidate technologies can be undertaken. The purpose of this initial assessment is to identify the *general constraints* which would apply to *any* candidate technology, so as to give greater focus to the initial design considerations (i.e. not to waste time on technological suggestions which have little or no potential for fitting into the existing system). It will always be possible to revise the assessment of constraints

if, at a later point in the design process, it becomes apparent that the design itself may change the pattern of constraints on candidate technologies.

Attention should be focused on assessing two different kinds of potential constraints: *resource constraints* and *interactional constraints*.

Resource constraints are those which may limit the suitability or the performance of a candidate technology by virtue of the system's inability to satisfy one or more of the resource requirements of the technology, e.g. climatic or soil requirements, labour or capital requirements, management skill, etc.

Interactional constraints are those which may limit the suitability or performance of a candidate technology by virtue of adverse interactions with existing system components, e.g. faunal pests, a strong local prejudice against the planting of trees on cropland, an unfavourable interaction with labour requirements of existing enterprises at a critical period in the establishment or operation of the new technology, etc.

As the last example indicates, there is no absolute diving line between the two types of constraints, since the unfavourable labour interaction could also be categorised as a resource constraint. Nevertheless, there are many possible constraints on candidate technologies which would be hard to classify as resource constraints; for these the category of interactional constraints has been suggested. The point here is not to come up with an airtight classification scheme but, rather, to avoid overlooking any potentially significant constraints on new technology, at least as far as possible in this preliminary assessment. The proposed categories should be used flexibly for this purpose.

Space is provided in Worksheet 6.4 to list the identified potential constraints as additional (negative) specifications for appropriate technologies. Completion of this Worksheet brings to a close the Diagnostic Stage of the D&D exercise.

DESIGN STAGE

OVERVIEW

PURPOSE: The purpose of the Design Stage is to follow through on the diagnostically derived specifications to develop a general design concept for an improved land use system and, where possible, to develop initial 'best bet' designs for prototype component technologies.

PERSONNEL: If at all possible, the same persons who participate in the diagnostic exercise as part of the D&D Field Team should carry through with the activities of the Design Stage. These may be supplemented by individuals with particular expertise in relevant aspects of technology design, either by bringing them into the D&D Team at this point or by separate consultations.

SOURCES OF INFORMATION: Output of design specifications from the Diagnostic Stage, review of relevant information in the body of technical knowledge, and Team discussion.

SUGGESTED PROCEDURES:

Step 7. Technology Appraisal

Step 8. Technology Design

Step 9. Design Evaluation

GENERAL GUIDELINES

Up to this point in the D&D process the design imagination has been held in check somewhat in order to insure adequate and objective diagnostic preparation and to avoid the 'pet technology' syndrome. Now, on the basis of a more-or-less complete set of diagnostically derived design specifications, the technological imagination may finally be unleased.

The level of detail achieved in the design result will depend upon a number of factors: the time and personnel resources available for the D&D exercise, the number and complexity of land use systems addressed, the specific nature of the technological potentials, the state of the technology art, the availability of design information, etc. These and other factors affecting the design result are discussed in the companion volume to this document (ICRAF, 1983). In general, for 'rapid appraisal' type applications, wherein the amount of time available for design work may be severely limited, the aim of the multidisciplinary D&D Team should be to develop initial *design concepts*, leaving the more detailed design work to be addressed by a smaller working group in a later followup phase.

To give form and coherence to the design activities of the D&D Team, a stepwise approach is suggested. The logical order of steps is: *Technology Appraisal* followed by *Technology Design* followed by *Design Evaluation*. For convenience and completeness a number of substeps have been introduced. In most cases *reiteration* of the procedural sequence will be required to adjust the various design elements to each other and produce a well-integrated overall design.

SPECIFIC PROCEDURAL SUGGESTIONS

STEP 7. TECHNOLOGY APPRAISAL

Logically and psychologically this step is conveniently broken down into three substeps: Body of Knowledge Review, Preliminary Identification of Technological Alternatives, and Preliminary Appraisal of Alternatives. The Body of Knowledge Review is a logical requirment, inasmuch as it is impossible to design technologies without reference to the body of technological knowledge. The separation of the preliminary technology identification and appraisal steps is a psychological tactic designed to encourage a more complete consideration and listing of all potentially interesting alternatives (both agroforestry and non-agroforestry) before starting to evaluate critically and focus down to a more restricted set of technologies for further design consideration. While it may be psychologically helpful to follow this phased approach initially, it will be obvious to the team in the course of the exercise that the three substeps in Step 7 will have to be treated *reiteratively*, i.e. the team will probably find it useful to return to the first step, after going through the sequence once, to repeat the sequence again in order to reconsider and refine the output. This applies to all activities at the Design Stage.

7.1 Body of Knowledge Review

The Body of Knowledge Review is, obviously, a continuous process which is carried on throughout the entire research and development cycle. The extent to which a full review of existing knowledge can be accomplished

in a time-limited D&D exercise is obviously limited. In most cases it will be necessary to supplement the limited rapid appraisal review by a more thorough information search at the post-D&D exercise Followup Stage. The purpose of including a state of knowledge review as a discrete step at the beginning of the Design process is to *initiate* the review process and to allow team members to prepare themselves to make pertinent contributions to the next step of the design process.

Since the review process is likely to be a fairly unstructed kind of activity, it may be best to allow each team member to pursue it individually. In other words, it may be desirable to have an *intermission* in group work at this point(the length of which would depend on how the exercise has been scheduled). Even in a time-constrained rapid appraisal exercise, it would be useful to schedule a little 'free time' apart from the group discussion process to allow each team member to digest the diagnostic results and review his sources of relevant information in preparation for the resumption of interdisciplinary discussions.

Since it would be difficult to document the results of this step, no Worksheet is provided. Each team member simply carries forth the results of his deliberations as part of his mental background to subsequent design activities, along with any documentary materials he may have assembled in the course of his review.

Sources of Information

In principle, there are no restrictions on the sources of information which could be consulted at this step. Pragmatically, however, available information may be quite limited, particularly in a rapid appraisal field exercise. The body of knowledge on agroforestry-related land management options and technologies is largely unorganized at present. This is a problem which is being addressed by various programme activities at ICRAF (notably the Technology Programme, the Information and Documentation Programme, and the Global Inventory of Agroforestry Systems Project within the Systems Programme at ICRAF) as well as other researchers and reviewers all around the world. Hopefully, the body of knowledge on agroforestry technologies will be much better documented in future.

In the meantime, several items in Appendix C have been included in this manual to provide at least some assistance to D&D teams engaged in rapid appraisal exercises. Although some of these Appendices are intended for consultation on specific points arising at later steps at the Design Stage they may also be consulted at this step for general information purposes, particularly in relation to the scope and content of agroforestry alternatives. Although some general information on non-agroforestry alternatives is included, these are less adequately documented, largely because the need is less than in the case of agroforestry.

7.2 Preliminary Identification of Technological Alternatives

This is basically a 'brainstorming' step (Delp *et al.*, 1977) in which the team members put forward suggestions for concrete technologies which would appear, initially, to satisfy the design specifications given in Step 6. Both agroforestry and non-agroforestry technologies should be considered.

Of course, some preliminary judgement must be exercised at this step, and some light pre-screening done, to insure that irrelevant or obviously infeasible technologies are eliminated from the suggestions, but not too much emphasis should be placed just yet on critical evaluation of the technologies. That will come in the next step. The main purpose now is simply to get as many initially interesting suggestions out on the table for subsequent discussion. The advantage of this two-step approach is that, by withholding critical judgement for the time being, it may serve to encourage the brainstorming process and help open up thinking about alternatives.

Also, since many potentially interesting agroforestry technologies may be of a presently undeveloped nature, the team should not worry unduly at this stage about the 'state of the art' with respect to the technologies they are brainstorming (this will be explicitly considered in Step 10). It may be that the final recommendations will be for a research project to develop the promising agroforestry technologies. This comment applies mainly to research-oriented D&D exercises. In development-oriented exercises the team, of course should, be more conservative.

Worksheet 7.2. is provided for listing of all initially interesting technological suggestions. Some technologies will jump full-blown into the well-prepared minds of the team members. Others may need a little discussion and conceptual development before they can be listed as concrete suggestions.

7.3 Preliminary Appraisal of Alternatives

Now is the time to unlease the critical capabilities of the team. The alternatives listed at the preceding step should be ruthlessly scrutinized. This is still a 'preliminary' appraisal step, however, in that the alternatives are here evaluated with respect to their *suitability for inclusion* in a design for an improved system, but that design synthesis itself (the result of Step 8) will be subjected to a more complete ex ante evaluation in Step 9.

At this stage the first step is to scrutinize the list of alternatives and decide whether any of them can be ruled out immediately because of infeasibilities arising from the constraints on potential technologies listed in Step 6.4. Once that is done, the pros and cons of the remaining alternatives are actively discussed. This discussion takes place within the context of the overall development strategy for the target system, as outlined in Step 6.1. The primary design criteria are: *productivity*, *sustainability*, and *adoptability*.

Relevant questions to consider would include, among others: Does the proposed alternative have the potential to make significant improvements in the productivity of the system? Does it make best use of available resources by improving returns to the most limiting resources? Is it a sustainable technology? What effect will it have on resource degradation syndromes within the system and its wider environmental setting? Is it an adoptable technology? What aspects of the technology might limit its adoption? Could it be modified in some way to remove the adoption constraints? How do the alternative technologies compare with each other in these respects? What combination of alternatives represents the best opportunity for meeting the criteria for improved system performance?

The initial assessment of technological alternatives will be essentially qualitative and intuitive. Nevertheless, a systematic comparison of alternatives should be attempted. Appendix C-4 contains a Technology Assessment Scoresheet designed to assist the team in arriving at an objective comparison of candidate technologies in terms of the above mentioned criteria. Time and resources permitting, a more quantitative evaluation may be undertaken (in Step 9), once an integrated design has been proposed (in Step 8), or alternately, in a pre-project Follow-up Stage (see Step 11).

The suggested output of this step, which can be recorded in Worksheet 7.3, is a list of candidate technologies for possible inclusion in the design for an improved land use system. The degree of specification for the proposed component technologies will not be very high at this stage, since that will depend on the outcome of the next step. To complete Step 7 it may be necessary to run through substeps 7.1 to 7.3. more than once.

STEP 8. DESIGN OF TECHNOLOGY FOR AN IMPROVED LAND USE SYSTEM

This is the *design synthesis* step, wherein the team is asked to pull together the most promising component technologies into a design for an improved land use system which meets as many of the Design Specifications (Step 6) as possible. Needless to say, a separate design may be needed for each of the diagnosed land use systems within the study area.

If this Step is to be taken as part of a rapid appraisal D&D exercise, the outcome might be best described as a 'preliminary design' which may need to be refined in subsequent post-exercise followup activities. If time is very limited, the team may decide to focus only on the most significant problems and potentials of the system. If this step is taken as part of an extended exercise which is not time-constrained, then the design result may be more complete. In any case, the outcome of this step will be subject to review and possible modification following the Design Evaluation in Step 9.

The focus will normally be on arriving at a generalized design for the typical management unit within the diagnosed system; although, if needed, the team may elect to develop additional or modified designs for 'typical variations' on the basic system type or for other scales of design. While the ideal outcome might be an integrated design for the complete system, for practical reasons the team may find it necessary or convenient to consider different parts of the system separately, at least initially. For example, a solution to a firewood problem might be considered separately from solutions to specific food or cash production problems. On the other hand, there may be scope for combined solutions to several problems, e.g. a single type of tree planting for both firewood and building materials, or the combination of a production role with a conservation or service role (see Appendix C-2). Other things being equal, an integrated design combining several functions may be more 'elegant' and make more efficient use of resources than several separate designs for component technologies, but this design tactics should not be stretched too far. It may be that a set of separate, simple interventions, aimed at different aspects of the design specifications, would be more adoptable than a complex integrated design.

To assist the team in its deliberations at this step, the design process has been subdivided into two substeps: 8.1 General Design Considerations and 8.2 Specific Design Procedures, each with an associated set of Appendices.

8.1 General Design Considerations

Now that the team has some specific candidate technologies in mind, the general development strategy outlined in Step 6.1 should be reviewed with the aim of deciding how, specifically, it is to be implemented in the design. It may be that the specific candidate technologies may suggest permissible modifications in the development strategy.

At this point it might be helpful to reconsider the guidelines and design tactics suggested in Appendices C-1 to C-3 with the more specific possibilities in mind. It may also be useful, in starting with an adequate conception of the scope of agroforestry potentials, to review the Classification of Agroforestry Systems in Appendix C-5 and the Examples of Agroforestry Systems and Practices in Appendix C-6. Of course, the team may have reference to these and other design resources at any point in the design process.

The specific procedures given below are oriented toward the design of *agroforestry* solutions. Before launcing into the sequence, however, the team should first decide whether an agroforestry technology should be used to address a particular problem or potential or whether a *non-agroforestry* technology would offer a better solution. In making this determination, the team will draw on the results of its deliberations in Step 7. But before making a final decision the team should consider the following general point.

It may be very difficult at this early stage in the development of agroforestry to make objective comparisons between agroforestry and other land management technologies, since the information base for agroforestry is not nearly as well developed as for other technologies. We may know what the other technologies can or cannot do, but in most cases we can only hypothesize about the performance of agroforestry technologies. Therefore, *if* the agroforestry alternatives are at least hypothetically promising, and *if* the objective of the D&D exercise is to come up with proposals for *research*, then the team may be justified in going ahead with an agroforestry design in order to be able to visualize the research that would be needed to develop and objectively evaluate the performance of an agroforestry technology vis-a-vis non-agroforestry alternatives. In development-oriented applications, where the premium is on producing recommendations for immediate dissemination, the team will have to be more conservative.

8.2 Specific Design Procedures

To arrive at a specific design for a component technology it is suggested that the team work systematically through the following sequence of design questions. This is a *reiterative* sequence. Since, in order to fit the various elements of the design together into a workable whole, the various decisions taken in response to each question may require some mutual adjustment, the team may need to repeat the sequence a few times before arriving at a final proposal for a particular technology. It will also need

to be repeated for each separate technology, and perhaps once again to optimize the design as a whole. This latter iteration could perhaps be postponed until after the first run of the Design Evaluation sequence (Step 9).

What Functions?

The first step is for a team to decide what function or combination of functions will be addressed by the design. These could be functional potentials for problem-solving interventions or potentials for improved resource use (as identified in Steps 6.2 and 6.3). the identified functions could be aimed at fulfilling a productive role, a service role or a combination of both (see Appendices C-5, C-8 and C-9 for examples of different production and service roles played by trees).

What Locations?

For each function or combination of functions the team now decides what would be the best location within the management unit. Appendix C-7 contains a function-location matrix tool which the team may find helpful in thinking through the optimum locations for different functions.

What Components?

Having narrowed down the choice of locations for the various functions, the next step is to narrow doen the choice of component species to perform the functions. Obviously, the choice of component species may affect the previous decisions about locations and functional combinations, which may require some adjustment in the next iteration.

Appendices C-8 through C-12 contain information on woody and herbaceous components which may be considered by the team for inclusion in the design, along with any other locally important species. C-8 presents tables of prominent woody species and the uses or functions they perform in existing agroforestry systems in six different regions of the world, with references for additional information. C-9 contains ecological and management information on the most promising multipurpose trees and shrubs for agroforestry systems. C-10 presents a bibliographic listing of multipurpose tree lists and descriptions. C-11 contains a table of additional characteristics of woody species, beyond end-use or functional characteristics, to be considered in selecting components at a more detailed level of design. C-12 contains a table of other, mainly non-woody, components for possible inclusion in agroforestry designs, classified by ecological zone.

How Many of Each Component?

Although the scarcity of data on performance of species components in agroforestry systems may not allow precise quantitative estimates of productive yield or service benefits, some rough 'back of the envelope' estimates should be made of the approximate number of components (or scale of the enterprise in which they are involved) that will be required to achieve the required functional result (or some signigicant fraction of it that is worth considering). Such estimates may suggest the need to re-evaluate the functional potentials of certain components or technologies. It may also require rethinking of the locations for the

components. If, for example, a hedgerow fuelwood production technology is seen to be incapable of meeting household energy requirements, the team may wish to consider the addition of a small woodlot on marginal land within the farm (e.g. inside or at the source of an erosion gully). In general, the team should not shy away from the finding that one or more of the initially promising technologies may not, in itself, be capable of completely fulfilling its intended role. The rethinking that this will occassion can only improve the final design.

What Spatial Arrangements?

This question will have been partially answered by the location decision, but it remains to specify the exact arrangement of plants at each location on the management unit. Some mutual adjustment of location and plant arrangement decisions may be necessary. Appendix C-13 presents a general discussion of plant arrangement possibilities and decision criteria which supplements the examples of agroforestry arrangements given in Appendix C-5. C-14 considers aspects of the special forms of spatial arrangement required for shelterbelts and windbreaks.

What Management Programme?

The final step is to decide how exactly the components are to be managed so as to fulfill their intended functional roles with the system. The exact set of management questions to be answered will depend on the nature of the envisaged technology, but a minimal list would include: How will the components be established? What maintenance and harvest operations will be performed and when? What management practices will be needed to control interactions between adjacent components? etc. Care should be taken to insure that the management recommendations do not contravene the design constraints identified in Step 6.4.

Since management options may introduce a high degree of flexibility into agroforestry designs, the whole sequence may need to be reconsidered in the light of the management alternatives for specific components, locations and plant arrangements.

Documentation of the Design Result

The degree of design precision which is appropriate and achievable at this stage of the design process will depend upon a number of factors mentioned above. Much more latitude for experimental variation in the design will be possible in research-oriented applications than in development-oriented ones intended to produce a disseminable design product. Indeed, many of the above questions may not be answerable on a scientific basis at the present time, for the simply reason that the research base for answering specific questions may not yet exist. In that case, the design should embody sufficient latitude for experimental variation to answer the major design questions. Even a development-oriented followup project may require a modest research component to settle presently unanswerable design questions.

The aim in any case should be to produce a 'best bet' design concept based, if necessary, on the intuitive judgement of the team. This will serve to define the *prototype technology* for further research and development.

Once the team has completed the iterative decision process and arrived at a best bet result, the design outcome be documented in Worksheet 8, adding additional pages for diagrams, descriptions, etc., as necessary to complete the documentation in a preliminary form. Later, after the Design Evaluation (Step 9), a more complete documentation of the design should be produced in a form which is easily understandable by persons who did not participate in the design exercise. At that point it may be helpful to call in the service of graphic specialists.

STEP 9 EX ANTE EVALUATION OF THE DESIGN

Having produced a design the next step is to evaluate it. This step differs from the previous appraisal of candidate technologies (Step 7.3) in that it is concerned, not with an initial assessment of partial design alternatives, but with a fairly thorough evaluation of the complete design in terms of its potential impact on the land use system considered as a whole. It is similar to Step 7.3 in the sense that both are carried out *before* the actual technologies have been developed, tested and evaluated in the field. In other words, this is still a *theoretical exercise* which does not, in any way, constitute or substitute for a full field evaluation of the envisaged technologies on the ground.

The purpose of this step is to critically examine the theoretical potential of the proposed design to satisfy the specifications for an improved land use system given in Step 6. It also serves the additional purpose of suggesting ways in which the design might be modified to adapt it better to its envisaged role within the system. As such it is a step in the overall iterative process which, depending on the results of the evaluation, may suggest the desirability of returning to an earlier stage of the design process to refine the initial attempt and produce a more productive, sustainable and adoptable design. (This same process of reiterative evaluation and redesign will reappear again at the on-site field testing stage of the D&D followup activities. It is the *means* by which the overall D&D process enables agroforestry research and development workers to develop a progressively more appropriate and effective design.)

Two levels of evaluation are possible at this step. The first, based on rapid appraisal methods which rely heavily on the experience and intuitive or clinical judgement of the D&D team, is appropriate to applications in which time or available information are limiting constraints. The second, based on more in-depth or quantitative methods, is appropriate to applications in which time and information are not limiting. The first step in the evaluation process is for the team to decide which level of evaluation to attempt and which specific procedures to follow. It may be that a combination of levels will be feasible, i.e. more thorough quantitative procedures could be followed for specific aspects of the evaluation.

If the team elects to apply only the rapid appraisal procedures, then there will probably be a need to plan for a followup phase to carry out at least some aspects of the more detailed evaluation. This could be accomplished either as a pre-project followup activity, or as one of the activities of the first stage of project implementation. Even if the team elects to use the more detailed evaluation methods, it should also complete both parts of Worksheet 9.1, first as a working tool to identify those areas of the design needing detailed evaluation, and then to record the team's final ex ante assessment of the potential impact of the proposed design (based on the in-depth evaluation).

9.1 Rapid Appraisal Methods

Two interrelated evaluation procedures are suggested which can be accomplished by the D&D team in the field, or shortly after the field exercise providing that there is a possibility to return to the study area to carry out the design survey.

Rapid Survey of Farmers' Response to the Design

The final decision on the appropriateness of the design will be made by the intended users themselves, in the form of the decision to adopt or reject the proposed technologies. It is only reasonable to try to assess the farmers' initial response to the design proposals at this point. To accomplish this the team, or some part of it, should return to the field to discuss the design with selected farmers previously visited at the Diagnostic Survey stage. The team may select the most articulate farmers for this visit, but care should be taken to insure the representativeness of the ad hoc sample of farmers selected for this purpose. This activity is complementary to the use of the technology evaluation scoresheet; some survey information will be necessary to complete Worksheet 9.1 (i.e. to assess the level of farmer enthusiasm for the proposed technologies and to check with farmers on other aspects of the ratings.)

Technology Evaluation Scoresheet

The Technology Evaluation Scoresheet given in Appendix C-4, previously encountered in Step 7.3, reappears now as Worksheet 9.1, to be completed by the team as an output from the present Step. If the team has already used this scoresheet in Step 3, it will still be relevant to complete a fresh version now that the design has been narrowed down to a more concrete and specific proposal. The evaluation procedures used to assign a score to each of the candidate technologies in the final design will remain largely qualitative in nature, but the purpose will be different from the previous use of the scoresheet: Before, the aim was to select component technologies for inclusion in the design. Now, the aim is to arrive at and document the team's final assessment of the appropriateness of the proposed design as a whole, and to assess its potential impact on the target system (see detailed guidelines for use of the scoresheet in Appendix C-4). The team may also wish to use causal and functional diagrams (produced at Step 5) to trace out the likely impacts of specific technologies.

Using the completed scoresheet together with Worksheet 6 (documenting the Design Specifications), the team may now go on to assess the *completeness of the design* and its *potential to remedy the problems and weaknesses of the diagnosed system.* It may not have been feasible for the team to aim at a design which addresses all of the diagnosed problems and potentials of the system, but it will be useful for the team to state how far it considers it has gone in this respect. Also, it is never too late to modify or elaborate the design to correct deficiencies which may become apparent at this point. Part 2 of Worksheet 9 is provided for the team to document its conclusions, including recommendations for further design and/or design evaluation work.

9.2 Detailed Evaluation Procedures

Supplementary to the rapid appraisal procedures described above, the D&D team, or some appropriatedly composed followup working group, may elect to apply selected procedures of economic, ecological and social impact evaluation. Appendix C-15 contains suggested guidelines for detailed ex ante economic evaluation of the candidate technologies. Guidelines for social and ecological evaluation will be forthcoming in future editions of this resource book.

FOLLOWUP PLANNING STAGE

OVERVIEW

PURPOSE: The purpose of the Followup Planning Stage is to assess research needs to develop and test the proposed technologies, to identify topics requiring further D&D attention, and to develop an implementation plan for an appropriate research and development project.

PERSONNEL: The D&D Field Team, before it adjourns, can be expected to accomplish the initial planning of post D&D exercise followup activities. For development of a detailed project implementation plan, however, it is suggested that a Followup Working Group be appointed. Ideally, the Working Group should contain one or two persons who participated in the previous stages as part of the D&D Field Team, but the Working Group may be smaller than the full multidisciplinary D&D Team (which, in any case, may be consulted from time to time during the Followup phase). The Working Group should preferably contain at least some of the persons who will be responsible for the implementation of the envisaged D&D project. The final details of project planning and the iterative mid-project D&D review and revision process may be left to the project implementers.

SUGGESTED PROCEDURES:

Step 10. Identification of Research Needs

Step 11. Identification of Topics Needing Further D&D Attention

Step 12. Development of a Project Implementation Plan

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GENERAL GUIDELINES

A design for new land management technology, no matter how elegant or appropriate to the needs of the target land use system, will come to naught unless it is followed up by a plan to put it into action in the field. Having developed, as a result of the preceeding steps, a design concept for an improved land use system, the next major activity is to decide what course of action would be needed to implement the proposed improvements, i.e. what actions would be necessary to get the design off the drawing boards and into the landscape. Given the present state of knowledge in agroforestry and the relative scarcity of scientifically validated technologies, it is unlikely that many of the proposed technologies will be ready for immediate dissemination to potential users. In most cases the envisaged agroforestry technologies will need to pass through a process of research and development before they can be considered ready for dissemination. Hence, the emphasis in what follows on identification of research needs (Step 10) and development of an implementation plan (Step 12) for an agroforestry R&D project. Step 11 is included to record recommendations for further diagnostic and design followup work which the D&D Team, in rapid appraisal applications, may feel is necessary before a detailed project implementation plan can be prepared.

The level of detail reached in the planning of followup activities will depend on the type of D&D application and the stage of planning. What can be accomplished by a 'rapid appraisal' D&D Team in a time-limited exercise is only to sketch out the general outlines of suggested followup activities. The development of a detailed project plan will normally be the responsibility of a followup working group. If, on the other hand, the 'rapid appraisal' option has been skipped over in favour of a straightforward time-extended application of the D&D methodology (see ICRAF, 1983 for further explanation of these two options), then the team may aim for a more detailed level of planning in the first round. In either type of application, once the research and development project gets under way and begins to generate feedback information, the continuing, iterative D&D process will provide a basis for periodic refinement and modification of the plan of action in accordance with the implementation team's experience in the field.

SPECIFIC PROCEDURAL SUGGESTIONS

STEP 10. IDENTIFICATION OF RESEARCH NEEDS

10.1 State of the Art Review

The identification of the type of research needed to develop the agroforestry technologies envisaged in the design for the improved land use system will depend in large measure on the current state of the technology art. To accomplish the necessary state of the art assessment, the D&D Team should review existing experience with the candidate technologies and decide in which of the following categories each candidate technology should be placed:

TECHNOLOGY CLASS	SUITABILITY
1. Notional	Suitable mainly for on-station experimentation and prototype development; possibility for limited on-farm trials as an explicitly *experimental* activity (if farmers are willing to accept the trials on these terms)
2. Preliminary	Suitable for on-site trials and on-station research to develop and refine the preliminary prototype
3. Validated	Suitable for immediate extension throughout the recommendation domain with on-farm adaptive research (possibly accompanied by on-station backup) to adjust the technology to site-specific variations.

The terms 'on-farm' and 'on-site' are used interchangeably here in reference to trials of technology conducted under real field conditions within the study area, although the latter term might be preferable to distinguish trials located outside of farm boundaries, e.g. in forest or watershed sites.

As the terms for the different categories imply, the assessment hinges on the degree of knowledge and prior research and development work on the different technologies. A 'notional' technology is one that has had very little, if any, prior research or field experience. The inclusion of any such technologies in the design implies an *hypothesis* to the effect that *if* the technology were to be developed it could have a theoretically high potential for affecting significant improvements in the diagnosed land use system. A 'preliminary' technology is one that has received some previous research attention (at least with respect to its composite elements), or is known to exist in traditional land use systems which are similar to the diagnosed land use system on major points of relevance. The implication is that preliminary technologies are sufficiently developed to be included in on-farm trials, but that the purpose of such trials should be to develop further and improve the prototype technologies. A 'validated' technology is one that has a well founded basis in research or in existing usage (in the target system or some highly similar one) and is considered ready for widespread dissemination throughout the recommendation domain. The implication is that, with the possible exception of some relatively minor on-farm adaptive research, a 'validated technology' is essentially not in need of further development before it can be released to appropriate land use systems. For a technology to qualify under this final category it should have been previously submitted to on-farm trials and found to be an adoptable technology, as indicated by its adoption record among farmers representative of the recommendation domain.

While the state of readiness of the candidate technology is the primary factor in deciding whether to classify it in one category or another, in borderline cases other factors may need to be taken into account before reaching a final decision. These include:

Whether the envisaged followup is essentially research-oriented or development/dissemination-oriented

For development-oriented projects, where premature dissemination of a new technology could have serious negative consequences, the classification should be made on a conservative basis. For research-oriented followup activities, more latitude could be allowed providing there is a favourable attitude toward farmer-involvement in research (see next paragraph).

Farmers' and research or extension officers' attitude towards on-farm trials

If the technology is on the borderline between notional and preliminary categories, a favourable attitude toward on-farm experimentation may justify classification in the 'preliminary' category, while a negative attitude would suggest the wisdom of assigning a new technology to the 'notional' category to insure adequate research station testing and development before going onto farms.

Riskiness of the proposed technology

If the candidate technology poses little or no risk to the potential user, this may affect the classification decision in the direction of on-farm trials or even dissemination on a limited scale. If, on the other hand, the technology is considered a high risk one which would result in real difficulties for the user if it failed, then the decision would be influenced in the opposite direction. The main question is whether more research at a less advanced stage would result in the type of knowledge that would make it possible to reduce the assessed risk sufficiently to advance it to the next stage.

Need for the candidate technology to be exposed to a wider range of environmental conditions

Providing the technology has at least the possibility of inclusion in the 'preliminary' category, if what is needed to develop it further is exposure to new environmental conditions (i.e. other than those in which it was initially developed and tested), then, providing the other conditions are met, this classification may be justified in research-oriented projects.

Need for the candidate technology to be exposed to real farming system conditions

Here again the main decision is whether, to advance further in the development of the technology, it is necessary to subject it to on-farm trials to test the farmer's reaction and see how it integrates into the existing land use system. This, by definition, is the meaning of a 'preliminary' technology, for which on-farm trials would be the research method of choice.

Worksheet 10.1 is provided to record the results of this technology classification exercise.

10.2 Outline of Specific Experiments

Having identified the general type of research appropriate for each technology, it remains to specify precisely what experiments would be required to generate the needed research knowledge. Research in

agroforestry is similar, but not identical, to research in agriculture and forestry. There are a number of factors associated with agroforestry technology which might suggest departures from conventional experimental methodology. Various considerations involved in choosing an appropriate experimental approach for a given piece of agroforestry research are discussed in Appendix D-1.

Appendix D-2 contains an excerpt from a research project proposal developed by ICRAF's Collaborative and Special Projects Programme in collaboration with research partners in Kenya. This may serve an an example of the kind of research plan which is the intended output of this stage of the D&D process. In most cases, however, it will not be possible to reach the level of detail shown in the example by the end of a 'rapid appraisal' exercise. The example illustrates the type of output which can be expected from a small working group in the followup period after the D&D field exercise.

Worksheet 10.2 is provided for the D&D Field Team to record its research recommendations in outline form. Additional pages, diagrams, etc. may be added, as necessary.

STEP 11. IDENTIFICATION OF TOPICS NEEDING FURTHER D&D ATTENTION

At the conclusion of the D&D exercise the rapid appraisal D&D Team may feel that certain topics, relating either to the diagnosis or the design, are in need of further attention during the post-exercise followup period before a detailed project implementation plan can be drawn up. Typical examples might include the need for more detailed ex ante ecological economic and/or social evaluation of the likely impact of the design on the target system or community, or perhaps the need for more detailed design development based on a more thorough review of the literature or on 'desk top' modeling of specific design alternatives.

Certain aspects of the required followup might be taken up by a Followup Working Group prior to the commencement of the planned research and development project, if considered necessary before a detailed project proposal can be developed. Other aspects might best be undertaken in the course of project implementation. Appendix D-2 (section 1.3.1) contains an example of some calculations involved in an ex ante analysis leading to the refinement of a *design* for an experimental alley cropping system.

An example of activities undertaken at the project implementation stage in order to refine the *diagnosis* may be drawn from another D&D site. At the Kathama site in the semiarid zone of Machakis District in Kenya, the initial rapid appraisal diagnosis indicated the following problems experienced by farm households: low soil fertility due to soil mining, a shortage of fuelwood for domestic consumption and household industry, severe erosion problems occuring both within and outside the farm boundaries. The rapid appraisal diagnosis could detect these problems, but it could not give them a precise quantitative specification. Consequently, once the on-site research was under way, several 'special studies' were undertaken with the intention of developing at least a rough quantitative estimation of the magnitude of the diagnosed problems. These studies ranged in duration from 3 months to a year. One focused on the soil nutrient balance of manured and unmanured cropland and involved monitoring of soil inputs and outputs during the cropping season. Another

involved measurement of annual stickwood increment on grazing land to assess the potential of meeting fuelwood requirements from this type of land. Another study undertook to conduct a landscape scale analysis of the entire project site to ascertain the incidence of erosion problems in relation to existing land use and drainage patterns in the area. This, coupled with a sociological study of the potential agroforestry and conservation roles of traditional cooperative self-help groups in the area (mainly women's organizations), led to the development of designs for larger-than-farm level erosion control measures. All of these 'special studies' were undertaken by students under the supervision of ICRAF staff through a cooperative agreement with the Forestry Departments of Wageningen University.

This example indicates both the nature of typical D&D related followup activities and one possibility for tapping available manpower resources to implement special diagnostic and design studies. The example is drawn from one of ICRAF's early D&D methodology development sites and reflects the staffing constraints and opportunities opperant at the time. Other, full-scale agroforestry R&D projects would, of course, have different staffing opportunities. The main point to emphasize is that in some cases relatively short duration 'special studies' might be suitable for filling in specific information gaps in diagnosis and design, while in other cases long term monitoring throughout the project implementation phase may be required to obtain the necessary information.

Worksheet 11 is provided for the D&D Team to record its recommendations on topics for further diagnostic and design activity and to make any suggestions it may have on how the required information might best be obtained.

STEP 12. DEVELOPMENT OF A PROJECT IMPLEMENTATION PLAN

In most rapid appraisal type applications of the D&D methodology the D&D Field Team will, in all likelihood, not be in a position to develop a fully detailed project implementation plan. Not only will time be limited, but critical financial and administrative decisions may not yet have been taken. What the Team, in such situations, should aim for is to produce an outline of its recommendations for features to be included in an eventual project implementation plan developed by a pre-project working group and/or the project implementation staff itself. Even though these recommendations on project design may be substantially modified as a result of wider technical or administrative considerations taken up following the initial D&D exercise, the D&D Team should make an effort to give project planners the benefit of the perspective developed in the course of the exercise by the full multidisciplinary team.

One aspect of project design to which the D&D Team (and subsequent project planners) should give particular attention is that of building *internal feedback mechanisms* into the project implementation plan, as necessary to institutionalize the iterative and continuing D&D process throughout the course of project implementation. Figures 1 and 2 depict the essential features of the D&D process as an element of the 'internal guidance system' of a research and development project.

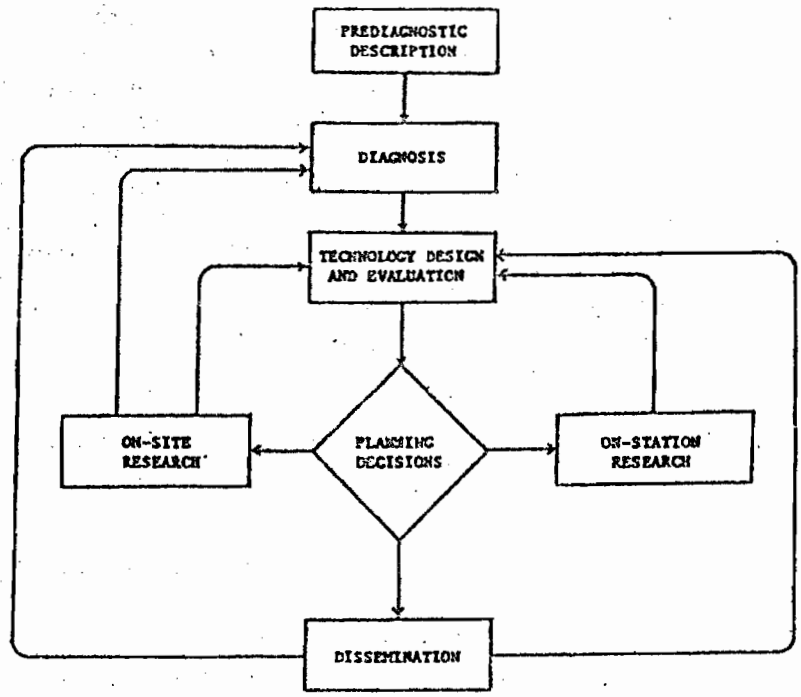

Figure 1. Components of project design incorporating the D&D process as part of the project's internal guidance system. Note feedback loops.

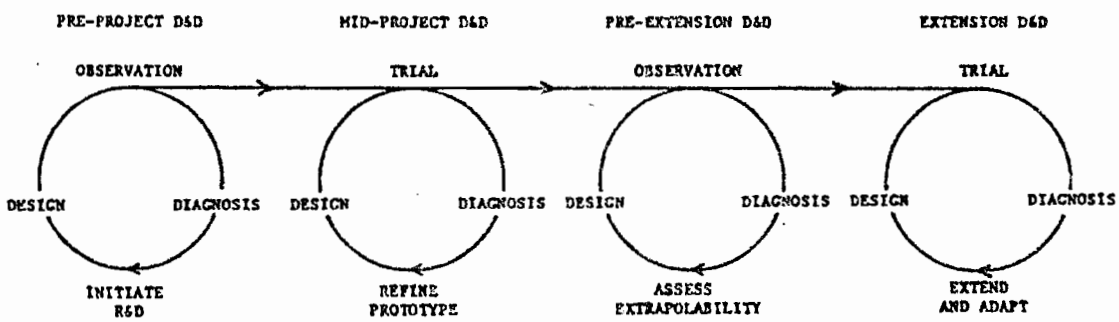

Figure 2. The iterative D&D process in the life cycle of a technology generation and dissemination project.

The potential role of the continuing D&D process as a followup to the initial project formulation application is discussed at greater length in *Guidelines for Agroforestry Diagnosis and Design* (ICRAF, 1983). It will suffice here to note that some such in-built feedback mechanism is a necessary component of project design, which will allow project implementers to: 1) assess the impact of technological interventions in the target land use system, 2) rediagnose the changed situation resulting from intervention in the system, 3) redefine the newly emergent set of constraints and potentials and refine or reformulate the technology design, and 4) in general take advantage of the often neglected opportunity in project implementation to profit from the mid-project *learning experience* and to apply what is learned to the ultimate goal of developing truly productive, sustainable and adoptable agroforestry technologies for the target land use system(s).

In its recommendations for feedback mechanisms to be incorporated into the eventual project implementation plan, the D&D Team should given attention to three things:

1) Insuring adequate communication between on-site researchers and farmers (or other unit managers at the site);

2) Insuring adequate communication between on-site researchers, on-station researchers, and extension personnel who may be responsible for the eventual dissemination of the resulting technologies;

3) Scheduling of periodic internal project review exercises to identify and discuss needed refinements in both the diagnosis and the design and to plan further R&D activities in accordance with this updated information on the project's progress toward the objective of developing an effective and adoptable set of improvements for the target land use system(s).

Worksheet 12 is provided for the D&D Team to record its recommendations and suggestions for the project implementation plan.

This concludes the initial D&D exercise.

REFERENCES CITED IN THE TEXT

Collinson, M.P. 1981. A low cost approach to understanding small farmers. Agricultural Administration 8(6): 433-450

Delp, P., A. Thesen, J. Motiwalla and N. Seshadri. 1977. Systems Tools for Project Planning. International Development Institute, Bloomington, Indiana.

Dent, D. and A. Young. 1981. Soil Survey and Land Evaluation. George Allen and Unwin. London.

Raintree, J.B. 1982. A methodology for diagnosis and design of agroforestry land management systems. ICRAF. Nairobi. (mimeo)

Raintree, J.B. 1983. Strategies for enhancing the adoptability of agroforestry innovations. Agroforestry Systems.

Rocheleau, D. 1983. Development of Methodologies for agroforestry diagnosis and design at varying scales of application. In house discussion paper. ICRAF. Nairobi. (mimeo)

Steppler, H.A. 1981. A Strategy for the International Council for Research in Agroforestry. ICRAF. Nairobi. (mimeo)

Torres, F. 1980. Research objectives in agroforestry: a conceptual approach. *In:* T. Chandler and D. Spurgeon (eds). International Cooperation in Agroforestry. ICRAF. Nairobi.

Note: References cited in the Appendices are given at the end of each Appendix.

PART 2

WORKSHEETS

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WORKSHEET 1.1

BIOPHYSICAL ENVIRONMENT: BASIC CHECKLIST

REF. NO. _____ AREA NAME _____

		RELIABILITY
LOCATION	_____	____
	_____	
Latitude	_____	____
Longitude	_____	____
Altitude(m)	_____	____
GEOLOGY	_____	____
LANDFORMS	_____	____
CLIMATE		
Generalized type	_____	____
Köppen classif.	_____	____
HYDROLOGY		
Waterlogging	_____	____
River Regime	_____	____
Degradation	_____	____
SOILS		
Generalized type	_____	____
Local Classif.	_____	____
Degradation	_____	____
VEGETATION		
Area in general	_____	____
Specific Localities	_____	____
Degradation	_____	____
LAND USE (by Land Unit)*		
_____	_____	____
_____	_____	____
_____	_____	____
_____ (Unit)	_____ (Uses)	____

1 Reliable
2 Probable
3 Guess

NOTES:

*See guidelines Step 2.1. for definition of Land Unit.

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WORKSHEET 1.2

SOCIOECONOMIC ENVIRONMENT

Reliability codes: 1. Reliable, 2. Probable, 3. Guess.

HUMAN FACTORS			Reliability rating
Population density	_____		_____
Population growth rate	_____		_____
Sex ratio	_____		_____
Ethnic composition of population			_____
Other relevant social differentiations of population			_____
Migration trends			_____
Settlement history			_____
Current settlement pattern			_____
Size of holding	_____ Average	_____ Range	_____
Labour utilization pattern			_____
Land tenure			_____
Land use traditions			_____

SOCIOECONOMIC DATA SHEET CONT'D

INFRASTRUCTURE	Reliability rating
Roads and transport	_____
Agricultural input supply	_____
Processing facilities	_____
Storage facilities	_____
Water supply	_____
Extension services	_____
ECONOMY	
Area exports	_____
Area imports	_____
Marketing structures	_____
Agricultural commodity prices (indicate subsidies if any)	_____
Use of agricultural inputs	_____
Agricultural input prices (indicate subsidies if any)	_____

SOCIOECONOMIC DATA SHEET CONT'D

	Reliability rating
Degree of mechanization	_____
Degree of commercialization	_____
Availability of credit	_____
Opportunities for non-farm employment	_____
Important cottage industries	_____

ADDITIONAL NOTES

WORKSHEET 2

DIFFERENTIATION OF LAND USE SYSTEMS WITHIN THE STUDY AREA

Step 3.1		Step 3.2								Step 3.3	
1	2	3	4	5	6	7	8	9	10	11	12
Land Unit		Management Unit									
Land System	Land Facet	Scale*	Soc.Ident.	Labour Source	Land Tenure	Land Prep. Tools	Inputs	Economy	Major Products	Ref. No.	Land Use System

*Scale Definition: Small = _____ha, Medium = _____ha, Large = _____ha
(indicate range)

WORKSHEET 3.1

PRELIMINARY DESCRIPTION OF HOUSEHOLD PRODUCTION SUBSYSTEMS

LAND USE SYSTEM _____

PRODUCTION OBJECTIVES (specify outputs)	LOCATION OF PRODUCTION ACTIVITIES						
	Crop land	Grazing land	Residential Area	Borders			
FOOD							
FUEL							
SHELTER							
RAW MATERIALS							
CASH							
SAVINGS/INVESTMENT							

WORKSHEET 3.3

STRUCTURAL-FUNCTIONAL DESCRIPTION OF THE LAND USE SYSTEM

1. INPUTS

USES OF INPUTS	SOURCES OF INPUTS					
	LAND			LABOUR		
PRIMARY PRODUCTION	Owned	Rented	Other	Family	Hired	Other
___ Annual cropping	___	___	___	___	___	___
___ Perennial cropping	___	___	___	___	___	___
___ Livestock keeping	___	___	___	___	___	___
___ Gathering	___	___	___	___	___	___
___ Off-farm employment	___	___	___	___	___	___
___	___	___	___	___	___	___
___	___	___	___	___	___	___
SECONDARY PRODUCTION						
___ Livestock keeping	___	___	___	___	___	___
___ Household maintenance	___	___	___	___	___	___
___ Cottage industries	___	___	___	___	___	___
___	___	___	___	___	___	___
___	___	___	___	___	___	___

OTHER INPUTS	Farm Produced	Purchased	Rented	Other (Specify)	Uses
___ Draft power	___	___	___	___	___
___ Productive animals	___	___	___	___	___
___ Machinery	___	___	___	___	___
___ Hand tools	___	___	___	___	___
___ Planting materials	___	___	___	___	___
___ Water	___	___	___	___	___
___ Manure	___	___	___	___	___
___ Fertilizers	___	___	___	___	___
___ Pesticides	___	___	___	___	___
___ Herbicides	___	___	___	___	___
___ Feed	___	___	___	___	___
___ Timber/poles	___	___	___	___	___
___ Fuel	___	___	___	___	___
___	___	___	___	___	___
___	___	___	___	___	___
___	___	___	___	___	___

WORKSHEET 3.3 Cont'd

2. OUTPUTS

SOURCE ACTIVITIES (Specify)	PRIMARY PRODUCTS	PRODUCTION	HOUSEHOLD CONSUMPTION	SALE
_____	Field crops	___	___	___
_____	Fruits	___	___	___
_____	Animals(live)	___	___	___
_____	Animal products	___	___	___
_____	Draft animals	___	___	___
_____	Feed	___	___	___
_____	Organic fertilizer	___	___	___
_____	Planting material	___	___	___
_____	Timber/poles	___	___	___
_____	Fuel	___	___	___
_____	Raw material	___	___	___
_____	Water	___	___	___
_____	_____	___	___	___
_____	_____	___	___	___
_____	_____	___	___	___
	SECONDARY PRODUCTS			
_____	Processed food	___	___	___
_____	Cottage ind.prods.	___	___	___
_____	Shelter	___	___	___
_____	_____	___	___	___
_____	_____	___	___	___
_____	_____	___	___	___

	BY-PRODUCTS	EFFECTS On-farm	EFFECTS Off-farm
_____	Water(runoff and groundwater)	_____	_____
_____	Soil(erosion and sedimentation)	_____	_____

WORKSHEET 3.4

PRELIMINARY IDENTIFICATION OF MAJOR LAND USE PROBLEMS AND POTENTIALS

3.4.1 Problems and Potentials at the Ecosystem Level

Major Resource Limitations and Potentials

Major Conservation Problems and Potentials

WORKSHEET 3.4 cont'd

3.4.2 Problems and Potentials at the Management Unit Level

Failure to Meet Management Objectives

Production Constraints

Outstanding Potentials for Overcoming the Identified Problems and Constraints

WORKSHEET 3.5.

PREPARATIONS FOR THE DIAGNOSTIC SURVEY

3.5.1 List of Representative Management Units

3.5.2 Suggested Composition of the Multidisciplinary D&D Field Team

WORKSHEET 5.1

ANALYSIS OF PRODUCTION PROBLEMS

5.1.1 Present Supply Problems

5.1.2. Causal Factors and Constraints Involved in the Creation of Present Supply Problems

(add other pages as necessary

WORKSHEET 5.1 cont'd

5.1.3 Household Strategies for Coping with the Identified Problems and Constraints

5.1.4 Systems Analysis of Constraints and Potentials

(add other pages as necessary)

WORKSHEET 5.2

ASSESSMENT OF SUSTAINABILITY PROBLEMS

WORKSHEET 5.3

ASSESSMENT OF PROBLEMS AND POTENTIALS AT THE ECOSYSTEM/COMMUNITY LEVEL

5.3.1 Distribution of Production Problems and Potentials

5.3.2 Larger-Than-Farm Scale Conservation Problems

(add other pages as necessary)

WORKSHEET 6

SPECIFICATIONS FOR APPROPRIATE TECHNOLOGY

6.1 Development Strategy

6.2 Functional Potentials for Problem-Solving Interventions

(add other pages as necessary)

WORKSHEET 6 Cont'd

6.3 Potentials for Improved Use of Resources

6.4 Possible Constraints on Candidate Technologies

(add other pages as necessary)

WORKSHEET 7

TECHNOLOGY APPRAISAL

7.2 Initial List of Potentially Relevant Technologies

7.3 Candidate Technologies for Possible Inclusion in the Design

WORKSHEET 8

DESIGN FOR AN IMPROVED LAND USE

(ass other pages as necessary)

WORKSHEET 9

DESIGN EVALUATION

9.1 Technology Evaluation Scoresheet

EVALUATION CRITERIA / CANDIDATE TECHNOLOGIES											
1. PRODUCTIVITY											
1.1 Potential to Solve Household Supply Problems											
Primary Production Objectives											0 to 10 (no potential to full potential)
-											0 to 10 "
-											0 to 10 "
-											0 to 10 "
-											0 to 10 "
-											0 to 10 "
Secondary Production Objectives											
-											0 to 5 "
-											0 to 5 "
-											0 to 5 "
-											0 to 5 "
-											0 to 5 "
-											0 to 5 "
-											0 to 5 (inadequate to adequate)
1.2 Potential to Reduce Production Constraints											
- Most limiting constraint											0 to 5 (no potential to full potential)
- Contributing constraints											0 to 3 "
1.3 Potential to Improve Resource Use											
- Most limiting resource											0 to 5 "
- Other resources											0 to 3 "
2. SUSTAINABILITY											
2.1 Potential Impact on Future Resource Base											
- Solve severe degradation problems											0 to 10 "
- Solve lesser dagradation problems											0 to 5 "
- Improve use of source future resources											0 to 5 "
2.2 Potential Impact on Future Demand											
- Satisfy anticipated demand											0 to 10 "
- Future market potential (cash enterprises)											0 to 5 (inadequate to adequate)
3. ADOPTABILITY											
Does the technology address											
- a priority objective?											0 to 10 (No - Yes)
- a perceived need?											0 to 5 "
Will it use only available resources?											-5 to 5 (* see below)
Will it avoid interctional constraints)											-5 to 5 "
Is it risk free?											0 to 5 (No - Yes)
Will it yield quick benefits?											0 to 5 "
Is it simple to understand?											0 to 5 "
Is it compatible with the local culture?											0 to 5 "
Does the idea meet with enthusiastic reasonse from the intended users?											0 to 5 "
Is it adoptable by the poor?											0 to 5 "
Is it widely applicable beyond the study area?											0 to 5 "

NOTES:

* The possibility of a negative score is allowed for here to emphasise the importance of keeping within the limits defined in Step 6.4.

WORKSHEET 9 cont'd

9.2 Overall Ex Ante Evaluation of the Proposed Design

WORKSHEET 10

IDENTIFICATION OF RESEARCH NEEDS

10.1 State of the Art Review

10.2 Outline of Specific Experiments

(add other pages as necessary)

WORKSHEET 11

TOPICS REQUIRING FURTHER D&D ATTENTION

WORKSHEET 12

RECOMMENDATIONS FOR PROJECT PLANNING

APPENDIX

USEFUL TOOLS AND MATERIALS

APPENDIX A-1

SOURCES OF PREDIAGNOSTIC INFORMATION*

1. MAPS, AIR PHOTOS AND SATELLITE IMAGERY

Topographic Maps

Existence: Do topographic maps of the area exist? If so, at what scales? Date of survey or revision? Are they contoured?

Availability: Are the maps in print? Are they security-restricted? What is the procedure for security clearance and/or purchase? Address of the national survey organization and/or outlet for purchase?

This enquiry should be started at an early stage, since it is basic but can be time-consuming. Contour maps at 1:50,000 scale are desirable, but may often not be available.

Geological Maps

A geological map may be of indirect utility. Most countries have a national geological map, obtainable for the Geological Survey organization. Request also a list, or cartographic key, to such more detailed maps as may exist.

Vegetation and Land Use Maps

Maps showing vegetation and/or land use are not a regular product of most survey organizations, and no standard forms exist. A good ecologically-based map survey can, however, be highly indicative of the nature of environmental interactions and possibly land use problems, and thus enquiry into the existence and availability of such maps is worth while.

Air Photographs

Existence: Is there air photo cover of the area? Date? Scale? Quality?

Availability: Air photos will usually be security-restricted. What is the procedure for obtaining clearance? Address for purchase (national organization, or outside consultant companies?).

High quality photos, less than 5 years old, at 1:25,000 to 1:20,000 scale are the most desirable. Air photos serve two kinds of function:

1) Location: Photographs can often be a more reliable means than maps of finding routes and identifying locations in the field.

2) Interpretation: A rapid stereoscopic examination of air photographs is the best means of pre-field familiarization with an area, particularly with respect to landforms, vegetation and land use. They may subsequently be needed for more through interpretation.

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*Contributions from A. Young, T. Darnhofer, and J.B. Raintree for sections 1, 2 and 3, respectively.

Satellite Imagery

Landsat imagery provides a rapid overview of the area, enabling broad regional differences to be seen at a glance. Whilst considerably less useful than air photographs, owing to their very small scale and low resolution, Landsat images are usually much easier to obtain. There is no security clearance needed. To request a Geographic Computer Search Inquiry Form, write to:

EROS Data Center
Sioux Falls
South Dakota 57198
U.S.A.

Fill in the form for the study area. You will receive a computer print-out listing the best quality imagery available, plus an order form. A false colour composite enlarged to either 1:500,000 or 1:250,000 is the best product. Computer-enhanced imagery is also available from commercial sources, but the cost may not be justifiable.

2. CLIMATIC INFORMATION

Macroscale surveys for D&D exercises will be mainly useful for delimiting the agroclimatic range for mesoscale surveys. Such information can in most cases be obtained from:

- agroclimatic surveys published by WHO, UNESCO, FAO or UNEP
- climatological handbooks and atlases
- climatological data compilations

Mesoscale surveys containing more relevant meteorological data are generally compiled and published by national meteorological services. These should be considered the main sources for meteorological information.

To facilitate data collection for research purposes worldwide, the World Meteorological Organization (WMO) has issued a catalogue of meteorological data, listing all relevant references and sources. In many countries meteorological data is also collected by organizations and authorities other than the national meteorological services (e.g. agricultural and forestry departments, private companies, non-government volunteer organizations, international agencies, etc.). A local inventory of these sources can very often turn up useful climatological data.

It should be mentioned, however, that in many countries relevant climatological data, even if it exists, can be difficult to obtain (original documents not accessible, publications out of print, recent data not yet processed, old records badly documented or lost; even data stored on modern supports such as microfilm, punch cards or magnetic tapes may not be available due to reproduction problems). To retrieve such data may require considerable material and personnel resources.

Therefore, the following bibliographic list of sources of general climatological and specific meteorological information is given (not all of which may be specifically relevant for prediagnostic purposes).

General

WMO "*Guide to Agricultural Meteorological Practices*" WMO No. 134, 2nd edition 1981. An overall view of the scope of agricultural meteorology is given in 8 chapters under headings like: Agricultural Meteorological elements and their observation, Agromet, eorological forecasting, Application of Meteorology to Forestry etc.

Appendix I - Bibliography of literature on agricultural meteorology

Appendix II - List of periodicals of interest to agricultural meteorology

Appendix III - List of international organization of interest to agricultural meteorologists.

GEIGER R. "*The Climate near the ground*" (611 p) 1965 English translation, Harvard University Press. Textbook on basic microclimatology. It gives an exhaustive analysis of physical laws and their consequences on various meteorological elements including descriptions of the influences of topography vegetation and artificial devices on weather.

MOTHEITH J.L. "*Vegetation and the atmosphere*" 1976 N.Y. Academy Press. Summary of actual micrometeorological and ecological knowledge. Vol. 1. Summary of physical biological elements. Vol. 2. Case studies in agricultural, forestry and ecological fields.

J. HU. CHIANG "*Climate and Agriculture - an Ecological Survey*" Aldime Publishing Company 1968. 304 pp. Textbook on the general principles of agricultural climatology.

Y. SEEMANN Y. CHIRKOV, J. LOMAS, B. PRIMAULT "*Agrometeorology*" (324 pp) 1979. Springer Berlin. Introduction to the present day problems of agrometeorology, a series of accounts, each complete in itself, of agrometeorology problems.

G.W. ROBERTSON, "*The Role of Agrometeorology in Agricultural Development and Investment Projects*" WMO No. 536, 1980, 85p.

Climatology

LANDSBERG H.E. and other "*World Survey of Climatology*" Elsevier Publishing Company: Vol. 9: Climates of South and Western Asia 248 p. Vol. 10 Climates of Africa 604 p. Vol. 12. Climates of Central and South America. Summaries of the existing climatological knowledge for the area concerned with references for more detailed literature.

BLUETHGEN "*Allgemeine Klimageographie*" 2nd edition (German) 1966 720 p. WALTER DE GRUYTER and COM.BERLIN. Basic textbook on geographical climatology, covering the fields of analytical climatology, synoptical climate geography, general circulation, general types of climates, climate classification, changes in climate, climate modification by man.

L.H. BROWN, J. COCHEME "*A study of the agroclimatology of the highlands of East Africa.* WMO No. 339, 1973 197 p. Report on the FAO/UNESCO/WMO Project on the Agroclimatology covering the countries Ethiopia, Kenya, Tanzania and Uganda.

"*Agroclimatology of the highlands of Eastern Africa*". Proceedings of the Technical Conference Nairobi 1973. WMO No. 389 242 pages. Follow up of the agroclimatic survey carried out by FAO/UNESCO/WMO.

J. COCHEME, P. FRAUQUIN " *Agrometeorological survey of a semi-arid area in Africa South of the Sahara*" WMO No. 210, 1967 136 p. The subject covered include rainfall, crop transpiration, availability of water during different periods of the year, heat and light and the correlation between crops and climate.

"*Agroclimatology in the Semi-arid areas South of the Sahara*" Proceedings of the technical regional conference Dakar 1971 WMO No. 340, 1973, 253 p FAO/UNESCO/WMO interagency project. Follow up of the survey mentioned under reference 15.

E.G. DAVY, F. MATTEI, S.I. SOLOMON "*An Evaluation of Climate and Water Resources for Development of Agriculture in the Sudano-Sahelian Zone of West Africa*" WMO No. 459 1976. 289 p. General background information on agrometeorology and surface water resources in a large part of West Africa.

M. FRERE, J.Q. RIJKS, J. REA "*Estudio agroclimatologico de la Zona andima*" WMO No. 506, 1978 297 p. (Spanish). Outcome of an agriclimatology project carried out jointly by FAO/WMO and UNESCO. The first part of the note analyses the agrometeorological factors; the second part studies the main crops in the area and their reaction to agroclimatic factors.

AMARE-GETAHUN "*Agro-climates and agricultural systems in Ethiopia*" 1980. Agricultural systems, Vol. 5: 39-59.

I.J. JACKSON "*Climate, water and agriculture in the tropics*" 1977 Longman Corp. 248 p. This book examines characteristics of tropical rainfall and evaporation together with their implications especially related to agriculture landuse, and aspects such as soil erosion and irrigation.

Agrometeorology of Crops

"*Agrometeorology of the wheat crop*" Proceedings of the WMO Symposium in Brunswick 1973, WMO No. 396, 1974. 242 p.

"*Agrometeorology of the Maize Crop*" WMO No. 48, 1977 454 p. Proceedings of the Symposium on the Agrometeorology of the maize crop. WMO - Iowa State University, Iowa 1976.

F.S. DA MOTA "*Soya Bean and Weather*" WMO No. 498 1978 64 p.

G.W. ROBERTSON *"Rice and Weather"* WMO 423, 1975 40 p.

"Agrometeorology of the Rice Crop". Proceedings of the WMO/IRRI Symposium WMO No. 541 1980

Agro-Ecology

"Report on the Agro-ecological zones project" Vol. 1: Methodology and Results for Africa 1978. Vol. 2: Results for Southwest Asia 1978. Vol. 3: Results for Southeast Asia 1980. FAO World Soils Resources Report No. 48.

L.R. HOLDRIGE and others *"Forest Environments in Tropical Life Zones"* A pilot study., 1971, Pergamon press 747 p. Particular reference is made to chapter two on the Holdridge "life zone system" as proposed 1947

Miscellaneous

"Crop Water Requirements" FAO Irrigation and Drainage papers No. 24 1974 198 p.

M. FRERE, F. POPOV *"Agrometeorological Crop monitoring and forecasting"* FAO Plant Production and Protection Paper No. 17 1979 64 p.

"Windbreaks and Shelterbelts" WMO No. 59 1964 188 p. Established by a working group of the Commission of Agricultural meteorology this publication summarised the results of research on this subject. The bibliography lists about 550 references. (another approximately 300 references on shelterbelts for the period 1970-1980 are available through the National Agricultural Library, U.S. Department of Agriculture).

"Drought and Agriculture" WMO No. 392 1975 127 p. This publication gives consideration to many meteorological factors of drought including its definition and early recognition, its effect on plants animals and diseases as well as methods for alleviating its effects.

J.W. DAVIES *"Mulching Effects on Plant Climate and Yield"* WMO No. 388 1975 92 p. This publication deals with effect of mulching on the climate of the soil and microclimate near the ground. The effect of mulching on temperature and moisture regimes of the soil, soil erosion, soil physics, pest, diseases and the growth of weeds are given with the published experimental evidence.

W. BAIER, *"Crop Weather Models and their use in Yield Assessments"* WMO No. 458 1977, 48 p. A review of the techniques currently available for simulating and analysing crop responses to weather, with special emphasis on the operational use of empirical statistical yield models for periodic assessment of regional production.

"The effect of Meteorological Factors on Crop Yields and Methods of forecasting the yield" WMO No. 566 1982 54 p..

C. DANCETTE, J.F. POULAIN "*Influence de l'acacia albida sur les facteurs pedoclimatiques et les rendements de cultures*" 1969 Sols Africains XIII No. 3 (197-238).

H. SMITH, "*Light Quality, Photoperception and Plant Strategy*" Ann. Rev. Plant Physiology 1982, 33: 481-518

"*Symposium on Forestry Meteorology*" Proceedings of the Symposium on Forest Meteorology 1978 in Ottawa. WMO No. 527 1978: 233 p.

Bibliography

"*Agrarmeteorologische Bibliographie des Deutschen Wetter dienstes*" 1978, 1979, 1980. Annual bibliography on agricultural meteorological publications which have become known to the Central Office of the "Deutscher Wetterdienst" in the course of the year. (1980: 2263 references including short abstracts).

3. SOCIOECONOMIC INFORMATION

Sources of relevant socioeconomic information may be harder to identify than for biophysical information. Nevertheless, the following potential sources should be checked for information on the study area:

- the national census authority
- national and regional planning authorities
- ministries or departments of agriculture, economic development, rural welfare, rural health, etc.
- university departments (researchers in departments of economics, sociology/anthropology, planning, rural health, etc. may have published research reports on the area or have relevant information in manuscript form)
- university libraries
- libraries of international agencies
- non-government organizations working in the study area

4. INTERVIEWS WITH QUALIFIED INFORMANTS

Qualitative information on all of the above areas of concern may also be gleaned from interviews with local officials, teachers, extension agents, rural health workers, community workers, articulate farmers, etc., as well as from researchers familiar with the study area. For some aspects of prediagnostic information, these may be the main sources.

APPENDIX A-2

GUIDELINES FOR DESCRIPTION OF THE BIOPHYSICAL ENVIRONMENT*

ICRAF's Environmental Data Base for Agroforestry, from which the checklist of biophysical data in Worksheet 1.1 is adapted, is designed to assist in standardizing information of the environment of agroforestry systems and components in order to facilitate comparison on a global scale. Several options are available with regard to the level of detail of the information. Level 1 is designed to provide a broad characterization of the environment, suitable for large scale description and analysis. Level 2 is more detailed, containing finer subdivisions of the environmental information, and is suitable for more precise description on a smaller scale. Additional options are also contemplated: 'Level 0' (just the basics) and 'Level 3' (site specific information sufficient for detailed design work).

Worksheet 1.1 and the accompanying legend given in this appendix represent a slightly adapted version of level 1, intended to be widely applicable as a checklist for a general description of the biophysical environment for D&D purposes. In the event that more detailed information is needed and available, the Prediagnostic Working Group may wish to substitute the level 2 datasheet given in this appendix along with the level 2 legend. The substitution or addition of more detailed biophysical information may be done for all or only some of the basic information categories contained in Worksheet 1.1, as the Working Group feels necessary to provide an adequate Prediagnostic description of the environment of the study area. There is also the option of supplementing the basic information at a later stage, if the D&D Field Team or the post-D&D Followup Working Group discovers that more detailed biophysical information is needed.

Sample outputs of levels 1 and 2 of the Environmental Data Base are given at the end of this appendix, along with a sample of the provisional 'level 0' output. Since 'level 3' information is highly site specific and not very susceptible to standardization, no sample output is given.

To complete Worksheet 1.1, or the alternative level 2 datasheet, simply look up the descriptors given in the appropriate legend and choose the one which best characterizes the study area. If the relevant environment is highly heteorogeneous, more than one descriptor may be entered on the worksheet/datasheet, or alternatively, more than one worksheet/datasheet may be completed (each refering to some important subdivision of the environment, e.g. a 'land unit' as defined in Step 2.1).

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* Adapted from A. Young. 1983. An environmental data base for agroforestry. Working Paper No. 5. ICRAF. Nairobi.

LEGEND FOR WORKSHEET 1.1

Basic Biophysical Checklist

LOCATION

Indicate country, province, district, town, etc.	
Latitude	Degrees and minutes if known, to nearest degree if not.
Longitude	
Altitude(m)	Indicate average and range for the area

GEOLOGY

1 Crystalline, felsic	Igneous or metamorphic non-basic, e.g. granite, gneiss
2 Crystalline, basic	Ig. or met. basic or ultrabasic, e.g. basalt,andesite
3 Sedimentary, siliceous	Sedimentary other than calcereous,e.g.sandstone,shale
4 Calcareous	Limestones
5 Superficial deposits	Alluvium, boulder clay, blown sand, etc.
6 Other	
9 No data	

LANDFORMS

1 Steeply sloping	18°
2 Moderately sloping	$5-18^{o}$
3 Gently sloping	5°
4 Depositional landforms (excluding 5)	
5 Swamps	
9 No data	

CLIMATE

Generalized Type	Rainfall(mm)	Dry Months	Koppen Classes
1 Rain forest	1500	4	Af, Am
2 Savanna	600-1500	4-8	Aw, Aw", Cw, Cw"
3 Semi-arid	250-600	8-10	BSh, BSk
4 Arid	250	11-12	BWh, BWk
5 Humid subtropical	summar rainfall		Cfa
6 Mediterranean	winter rainfall		Cs
7 Temperate maritime	e.g. London		Cfb
8 Cool or cold (includes trop. high montane)			D, E
9 No data			

Köppen Classification

<u>Hot Climates</u>

1 Af Tropical rain forest, permanently humid
2 Am Tropical rain forest, short dry season ('monsoon forest')
3 Aw Savanna, one wet season
4 Aw" Savanna, two wet seasons

<u>Dry Climates</u>

5 Bsh Semi-arid, hot
6 Bsk Semi-arid, warm to cold
7 BWh Arid, hot
8 BWk Arid, warm to cold

Köppen Classification Cont'd.

Warm Climates

10 Cfa Humid subtropical, montane rain forest
11 Cfb Temperate maritime
12 Cw Highland savanna, one wet season
13 Cw" Highland savanna, two wet seasons
14 Cs Mediterranean

Cold Climates

15 D Temperate continental, tropical and subtropical montane
16 E Cold tundra, high montane

9 No data

HYDROLOGY

Surface waterlogging

1 None
2 Seasonal
3 Permanent
9 No data

River regime (of largest river in the area)

1	Perennial	Nearly always at least some discharge throughout the year
2	Seasonal	Dry for part of the year
3	Intermittant	Flows only for short periods after rains
4	None	No river in the area
9	No data	

Degradation of river regime

Has the river flow regime deteriorated over time? (lower or shorter flow, more flash floods?)

1	Absent	No evidence of degradation
2	Present	Degradation present but not severe
3	Severe	Severe degradation
9	No data	

SOILS

Generalized Type	FAO soil classes included	Description & synonyms
1 Latosols	ferralsols, acrisols luvisols, nitosols	'Red & yellow' tropical soils, ferallitic & ferruginous soils, oxisols & ultisols
2 Vertisols	vertisols	Black cracking clays, 'black cotton soils'
3 Calcimorphic soils	chernozems, phaeozems, kastanozems, redzinas	Free $CaCO_3$ present, includes brown soils of semiarid zones, 'chestnut soils'
4 Desert soils	xerosols, yermosols	Sand or rock, slight or no horizon development
5 Saline or alkaline soils	solonchak, solonetz	Of desert or coastal origin
6 Cleys, alluvial soils or peat	gleysols, fluvisols, planosols, histosols	Poorly drained valley floor & swamp soils, gleys but not versti vertisols
7 Shallow or immature soils	lithosols, rankers, regosols, arenosols, andosols,	Exclusing desert soils which are placed in class 4
8 Temperate soil types	cambisols, podzols, podzoluvisols, greyzems	Brown earths, podzols,'podzolic soils'
9 No data		

Local Soil Classification .....

Soil degradation

Have soil properties deteriorated as compared with their condition in the past? Which, if any, of the following types of degradation are prominent in the area?

1	Water erosion	Including sheet and/or gully erosion
2	Wind erosion	
3	Salinization or sodication	
4	Chemical degradation	Including acidification, lowering of bases or nutrients, toxicities except as in 3
5	Physical degradation	Loss of pore space, compaction, decline in permeability & water storage capacity, etc.
6	Biological degradation	Decline in organic matter or soil biological activity
7	Fertility decline	Lowering of the capacity of the soil to produce crops, through combination of chemical, physical & biological degradation (to be used where precise causes are unknown)
9	No data	

VEGETATION

Generalized type

Note types important in the area

1	Rainforest	Incl. evergreen, semi-deciduous & montane
2	Tropical deciduous woodland	Savanna woodland, crowns 40% cover
3	Savanna	Tree/shrub over 40%, predominantly broadleaved with well-developed grass cover
4	Thorn scrub or thorn woodland	Xeromorphic vegetation, predominantely thorny and/or microphyllous
5	Grassland	Of any origin excluding sown pastures
6	Semi-desert vegetation	
7	Desert	
8	Temperate deciduous woodland	
10	Coniferous woodland	Excluding plantations (see 13)
11	Montane vegetation	Excluding montane grassland (see 5)
12	Swamp	Incl. mangrove and other coastal swamp
13	Planted vegetation	Incl. crops, forest plantations, sown pasture, etc.
9	No data	

Degradation of vegetation

Is there evidence of vegetation degradation as compared to past conditions? Are there widespread symptoms of any of the following forms of degradation?

1	Decreased plant density or biomass	Including deforestation, denudation, decreasing density and/or size of plants
2	Unfavourable change in species composition	Incl. bush encroachment, invasion of unpalatable species, lack of straight trees
3	Insufficient regeneration	As evidenced, for example, by lack of young trees.

LAND USE

What forms of land use are prevalent in the area? List by land unit in which the land use type is found (see guidelines for Step 2.1 for definition of land unit).

1	Annual crops	Including cassava, hill rice, vegetables if on a field scale; excluding swamp rice, vegetables if on a small plot/garden basis
2	Tree and shrub crops	Including fruit trees; excluding crops listed under 3
3	Field perennial crops	Sugar cane, sisal, pineapple, bananas
4	Swamp rice	If irrigated, code also as 6
5	Gardens	Intensive cultivation on small plots
6	Irrigated agriculture	Including rice if water brought to fields but not if retention of rainfall only; including irrigated grazing
7	Grazing of natural pastures	Including nomadic grazing, rancing
8	Grazing of improved pastures	Sown or substantially improved pastures
10	Forestry, natural forests	For timber and/or products
11	Forest plantations	
12	Recreation and tourism	
13	Wildlife conservation	With specific intention of this purpose
14	Water catchments	With specific intention of this purpose
15	Engineering uses	Any form of construction
16	Unused	No specific intention of use
17	Other uses	

No data

ICRAF ENVIRONMENTAL DATA BASE: LEVEL 2 DATASHEET

DATA SET

User's initials ..... User's ref. ..... Title .....

SITE REFERENCE NO. _____

User's ref. no. _____ Title ..... Source .....

Country ..... Location .....

Latitude _____ Longitude _____ Rel. _____/ Altitude _____ Rel. _____/

GEOLOGY

ROCK TYPE _____/ ..... RELIABILITY _____/

Grain size _____/ Geological formation: name .....

age ..... lithology .....

LANDFORMS

LANDFORMS OF AREA _____/ RELIABILITY _____/

Description .....

Slope angle at site: _____ degrees or _____ percent

Relative relief _____

At site: slope curvature _____/ position on slope _____/

CLIMATE

GENERALIZED CLIMATIC TYPE _____/ RELIABILITY _____/

KÖPPEN CLIMATIC CLASS _____/ RELIABILITY _____/

Altitude zone _____/ Rainfall regime _____/

Mean annual temp. _____ Mean annual rainfall _____ No. of dry months _____

Mean temp., hottest month _____ Mean temp., coldest month _____

Rainfall, driest month _____ Occurrence of frost _____/

Mean annual Eo _____ By which method? .....

Humidity index r/Eo _____ Growing period _____

HYDROLOGY

SURFACE WATERLOGGING _____/ RELIABILITY _____/ Groundwater type _____/

Groundwater depth: average _____ lowest _____ highest _____

Flooding frequency _____/ River regime _____/ Degradation _____/

SOILS

GENERALIZED SOIL TYPE _____/ RELIABILITY _____/

FAO CLASSIFICATION: MAIN GROUP ..... RELIABILITY _____/

SOIL UNIT .....

Other soil class ..... on .....Classification

Texture _____/ Reaction _____/

Drainage _____/ Other features _____/ .....

Texture class: topsoil ..... B horizon .....

pH: topsoil _____ B horizon .....

Drainage class: _____/ Depth to limiting horizon _____

Soil degradation: type _____/ severity _____/

VEGETATION

STATUS OF VEGETATION _____/

GENERALIZED VEGETATION TYPE: SITE _____/ AREA _____/ RELIABILITY _____/

UNESCO CLASSIFICATION: SITE ..... RELIABILITY _____/

AREA .....

Physiognomic vegetation type .....

Vegetation association .....

Vegetation degradation: severity _____/

nature, causes .....

FAUNA AND DISEASE

AFF. PLANTS: termites _____/ Other _____/ .....

AFF. ANIMALS: tsetse _____/ Other _____/ ..... Rel. _____

LAND USE

MAJOR KIND OF LAND USE _____/ RELIABILITY _____/

Description .....

Agroforestry class _____/ .....

USER-DEFINED ADDITIONAL DATA

Coded 1 _____/ Coded 2 _____/ Coded 3 _____/

Numeric 1 _____ Numeric 2 _____ Numeric 3 _____

Descriptive 1 .....

Descriptive 2 ..... Descriptive 3 .....

GENERAL NOTES ON SITE

.....

.....

.....

.....

SUPPLEMENTARY DATA

ICRAF ENVIRONMENTAL DATA BASE

LEVEL 2: LEGEND SHEET

This sheet covers the full list of data items used in level 2.
The legend sheet gives only instructions, explanations and codes for completing the check-list. For background discussion, including reasons for data selected, see "An environmental data base for agroforestry information" ICRAF Working Paper, (1983).

Instructions in italics refer to computer-compatibility; they need not be followed if the data is to be stored and processed manually.

Using one copy of the check-list for each site, enter code numbers or fill in values. *Data shown as _____ must be numbers only.* Data shown as ..... may be words and/or numbers.

Multiple values. *Up to two values can be accepted for any data item.* Two (uncoded) numerical values are assumed to represent a range. *The computer will expect one value; to instruct that two are to be given, enter 888 (this applies to coded as well as numeric responses). If there are more than two values, the third onwards can be given under 'General Notes' at end.*

No data 'No data' includes 'not relevant, not applicable'. For 'no data' enter:

Coded data:	9
Numerical data:	999
Verbal data:	-

N.B. *Do not simply press the Return key, as this deletes the whole entry.*

Sentences. *In longer verbal data, do not use commas, semi-colons, colons except at ends of lines.*

Reliability codes. The following codes for reliability of information are used throughout:

1 Confident
2 Probable
3 Guess
9 No data

DATA SET. This refers to the data set as a whole, e.g. 'Sites of recorded AF Systems', or 'Growth requirements of multipurpose trees'.

User's initials	
User's ref.	User's reference to data set; may be a reference number and/or letters.
Title	Title of data set, see examples above.
Description of data set	This is not entered on each check-list, but on a separate sheet. For manual reference, it can be of any length. *For computer storage, it is entered only once, with a maximum of 5 lines.*

SITE

REFERENCE NO. _____	Sequential reference number; for any data set must be successively 1, 2, 3, ... etc.
User's ref. no. _____	If the site is already known to the user by a different number, it may be entered here; otherwise re-enter sequential number.
Title	Short title of site.

Source	Source of information, e.g. 'Parkinson (1979).'
Country	
Location	E.g. district, nearby town, experiment station.
Latitude _____ Longitude _____	*Enter minutes as a pseudo-decimal e.g. 15°47 as 15.47*
Reliability _____/	Give as 1 if confident to ∓ 1°.
Altitude (m) _____	
Reliability _____/	Give as 1 if confident to ∓ 100 m.

GEOLOGY

1	Crystalline, felsic	Igenous or metamorphic, non-basic, e.g. granite,gneiss
2	Crystalline, basic	Ig. or met., basic or ultrabasic, e.g. basalt, andesite
3	Sedimentary, siliceous	Sedimentary other than calcareous, e.g. sandstone, shal
4	Calcareous	Limestones
5	Superficial desposits	Alluvium, boulder clay,blown sand, etc.
6	Other	
9	No data	

Reliability _____/	See above
Rock type	Any known name; age can also be given if wished, e.g. Jurassic sandstone

Grain size:

1 Coarse grained
2 Medium grained
3 Fine grained
9 No data

Geological formation:

name ..... e.g. Kapata Beds
age ..... e.g. Jurassic
lithology ..... e.g. sandstone

LANDFORMS

Landforms of area: give more detailed (two-digit) class if appropriate and data sufficient, otherwise generalized class as for Level 1.

				degrees	percent	
1	Steeply sloping	Dominant	slopes	>18°	>30	
10	Very steep	"	"	>25°	>45	
11	Steep	"	"	18-25°	30-45	
2	Moderately sloping			5-18°	8-30	
12	Moderately steep	"	"	10-18°	18-30	
13	Moderate	"	"	5-10°	8-18	
3	Gently sloping	"	"	<5°	<8)	
14	Gentle	"	"	2-5°	3-8)	erosional landfor
15	Very gentle	"	"	<2°	<3)	
4	Depositional landforms (excluding 5)					
16	Alluvial					
17	Marine					
5	Swamps					
18	Freshwater					
19	Salt water					
9	No data					

Description ..... General description of landforms

Slope angle at site _____ degrees or _____ percent

If not a specific small area, angle not relevant, enter 777 degrees
If a small area, but no data on angle, enter 999 degrees

Relative relief (m) _____ local average highest difference, e.g. hill-valley

At site: slope curvature
1 convex
2 straight
3 concave
9 no data
)refers to shape in profile, i.e. cross-section

position on slope
1 crest
2 upper slope
3 midslope
4 lower slope
5 base
6 other (slopes of complex shape)
9 no data

CLIMATE

A. GENERALIZED CLIMATIC TYPE _____/ RELIABILITY _____/

The definitions of the generalized climatic types are in terms of the Köppen climatic classes included in each; where sufficient data are available, it is therefore better to fill in Section B below first. The guidelines are approximate only, for use where more detailed data are not available.

Code and name	Köppen classes included
1 Rain forest	Af, Am
2 Savanna	Aw, Aw", Cw, Cw"
3 Semi-arid	BSh, BSk
4 Arid	BWh, BWk
5 Humid subtropical	Cfa
6 Mediterranean	Cs
7 Temperate maritime	Cfb
8 Cool or cold	D, E
9 No data	

Approximate guidelines and notes

Code and name	Approximate guidelines (lowland tropics) Rainfall (mm)	Dry months	Notes	Typical locations
1 Rain forest	>1500	<4	Permanently humid or short dry season	Singapore Belem
2 Savanna	600-1500	4-8	Seasonally humid with dry season(s)	Lusaka Caracas
3 Semi-arid	250-600	8-10	Short rainy season; 'steppe', sahel	Delhi Niamey
4 Arid	<250	11-12	Desert	Khartoum Lima
5 Humid sub-tropical	Summer rainfall		East sides of continents; includes also montane rainforest	Hongkong New Orleans

6	Mediterranean	winter rainfall	Excluding semi-arid, arid, see 3,4 above	Rome San Francisco
7	Temperate maritime			London Wellington
8	Cool or cold		Includes tropical high montane	Moscow Kilimanjaro
9	No data			

B. KÖPPEN CLIMATIC CLASS _____/ RELIABILITY _____/

For definitions and key, see Attachment A.

A: Hot climates

1 Af Tropical rain forest, permanently humid
2 Am Tropical rain forest, short dry period ('monsoon forest')
3 Aw Savanna, one wet season
4 Aw" Savanna, two wet seasons

B: Dry climates

5 BSh Semi-arid, hot
6 BSk Semi-arid, warm to cold
7 BWh Arid, hot
8 BWk Arid, warm to cold

C: Warm climates

10 Cfa Humid subtropical; also montane rain forest
11 Cfb Temperate maritime
12 Cw Highland savanna, one wet season)Including
13 Cw" Highland savanna, two wet seasons) Köppen
14 Cs Mediterranean)a, b and c

D, E: Cold climates

15 D Temperate continental; also tropical and subtropical montane zone
16 E Cold tundra; also high montane zone
9 No data

Notes Cfb is used as an abbreviation to cover Cfb and Cfc
Cs excludes summer-rainfall climates which fall into BS or BW.

RELIABILITY _____/ Give as 1 if calculated or if estimated with much confidence; for other estimates, give as 2 or 3.

C. ALTITUDE ZONE

Computer will include this automatically if altitude has been included under site data above.

1	Lowland	Altitude < 750 m
2	Highland	" 750-2000 m
3	Montane	" > 2000 m
9	No data	

..5/

D. RAINFALL REGIME

1 Unimodal, maximum in summer (high sun period)
2 Unimodal, maximum in winter (low sun period)
3 Bimodal (only give as bimodal if clearly so)
4 Uniform (all-year wet with no clear maximum, or all-year dry)
9 No data

E. PRINCIPAL VALUES

Mean annual temperature, °C_____)
Mean annual rainfall, mm _____ _____)If no data enter 999
Number of dry months _____)
(tropics<60 mm, subtropics or other<30 mm)

Mean temperature, hottest month (°C) _____) In conjunction with data
Mean temperature, coldest month (°C) _____)given at Level 1, these
Rainfall, driest month (mm) _____)permit calculation of Köppen class

Occurrence of frost: 1 never or rare
2 common
3 every year
9 no data

Mean annual Eo (mm) _____ Open-water evaporation, observed or calculated
By which method? .....'Pan'= class A evaporation pan
'Penman' = calculated by Penman formula
or name other formula used

Computer will print rainfall: evaporation ratio, r/Eo

Growing period _____ Days, as calculated by FAO agro-ecological zones method.

Users may wish to add monthly values of temperature, rainfall and evaporation data at the end of the check-list. This information is not computer-stored.

HYDROLOGY

SURFACE WATERLOGGING _____/ RELIABILITY _____/

1 None
2 Seasonal — May include standing water
3 Permanent — " " "
9 No data

Groundwater type _____/

1 Fresh
2 Saline
9 No data

Computer will assume fresh unle
2 or 9 is marked, i.e. 'no data
implies there is doubt whether
saline.

Groundwater depth, m: average _____ approximate average for year
: lowest _____ usually late dry season
highest_____ wet season

Flooding frequency _____/ 1 never or rare 3 frequent
2 common 9 no data

..6

River regime: of largest river easily accessible from site (guideline < 5 km, but flexible according to circumstances)

1	Perennial	At least some discharge throughout year in every or nearly every year
2	Seasonal	Continuous discharge for some substantial period of every year, dry for part of year
3	Intermittent	Flow only for short periods, after rains
4	None	No easily accessible river
9	No data	

Degradation: has river flow regime has deteriorated adversely through human activities, e.g. lower or shorter base flow, more flash floods?

1	Absent	A positive statement that there has been no substantial flow degradation
2	Present	
3	Severe	
9	No data	

SOILS

A. GENERALIZED SOIL TYPE _____/ RELIABILITY _____/

The definitions of the generalized soil types are in terms of the FAO soil classes included in each (see Attachment B). The guidelines and synonyms are for use where the FAO class is not known.

Code and name	FAO soil classes included	Guidelines & synonyms
1 Latosols	ferralsols, acrisols, luvisols, nitosols	'Red and yellow' tropical soils; includes ferallitic and ferruginous soils (CCTA, French), oxisols and ultisols (US)
2 Vertisols	vertisols	Black cracking clays, 'black cotton soils'
3 Calcimorphic soils	chernozems, phaeozems, kastanozems, rendzinas	Free $CaCO_3$ present; includes brown soils of semi-arid regions (CCTA), 'chestnut soils'
4 Desert soils	xerosols, yermosols	Sand or rock; slight or no horizon development
5 Saline or alkaline soils	solonchak, solonetz	Of desert or coastal origin
6 Gleys, alluvial soils or peat	gleysols, fluvisols, planosols, histosols	See Note below
7 Shallow or immature soils	lithosols, rankers, regosols, arenosols, andosols	Excluding desert soils, which are placed in class 4
8 Temperate soil types	cambisols, podzols, podzoluvisols, greyzems	Brown earths, 'podzolic soils', podzols
9 No data		

..7/

Note. Poorly-drained soils of valley floors and swamps should be classed as 6, Gleys, unless there is positive evidence of being widely-cracking black clays (=2, vertisols).

FAO CLASSIFICATION: MAIN GROUP ...../ SOIL UNIT ...../ RELIABILITY_____/

Give the class of soil according to the FAO system (FAO/Unesco (1974) Soil Map of the World 1: 5 000 000, Volume 1, Legend). Attachment 2 gives the soil units and their letter codes, together with a summary and analogues in the US soil taxonomy. For further details, refer to the Legend Volume.

As the classification employs letter codes, these same codes are used in the data base, hence the symbol ...../

'Main group' refers to capital-letter (noun) classes, e.g. J Fluvisols. 'Soil unit' refers to two-letter (adjective-noun) classes, e.g. Je Eutric fluvisols. Enter letter code alone or, preferably, code plus name.

Other soil type	Any other known name; two or more names may be included.
On which classification?	Refers to previous question: international classification (e.g. US' French/ORSTOM) or local name.

B. PRINCIPAL SOIL PROPERTIES

Texture, reaction and drainage, predominant for profile.

Texture	1	sandy	sand, loamy sand
	2	loamy	sandy loam, sandy clay loam, medium loam, silty textures
	3	clayey	sandy clay, clay, heavy clay
	9	no data	
Reaction:	1	strongly acid	pH >5.0 (only if clearly so)
	2	acid	pH 5.0-6.5
	3	neutral	pH 6.5-7.5 (or if profile transgresses 7.0)
	4	alkaline	pH >7.5
	9	no data	
Drainage:	1	well drained	drained classes excessive, well drained
	2	imperfect	" " moderately well, imperfect
	3	poor	poor, very poor
	9	no data	
Other features:	1	shallow	limiting horizon (rock, laterite, etc.) at >5
	2	saline	
	3	other	Mark 3 and name feature
	9	none or no data	

The generalized information given at Level 1 is supplemented by the following more precise data if representative profile descriptions are available.

'Topsoil' refers to 0-20 cm depth or the plough/hoe layer.
'B horizon' has its standard pedological meaning, typically c. 50 cm depth.

Texture class: topsoil .....) Enter capital-letter abbreviation of
B horizon .....) standard international textural classes using 'Z' for silt, viz:

S, LS, SL, L, ZL, SCL, CL, ZCL, SC, C.

Reference: FAO (1977) Guidelines for soil profile description, 2nd edition.

pH: Topsoil _____ B horizon_____ In water at 1: 2.5 if data available

Drainage class _____/ The codes used are the same as the class numbers of the standard international system (FAO (1977), see above). To avoid confusion in computer storage, 'Class 0: very poorly drained' should not be used, but combined with, and entered as, Class 1.

1 Poorly drained (see note above)
2 Imperfectly drained
3 Moderately well drained
4 Well drained
5 Somewhat excessively drained
6 Excessively drained
9 No data

Depth to limiting horizon (cm) _____ To rock, laterite, or other obstruction to roots. If no limiting horizon recorded to at least 150 cm, enter 150. Note that the usual unit for soil depth, centimetres, is employed.

Users may wish to attach one or more soil profile descriptions to the check-list. This information is not computer-stored.

Soil degradation: type _____/ severity _____/

Is it believed that soil properties have deteriorated, and/or are deteriorating, as compared with their condition at some past period? The types of degradation are those given in FAO (1979), A provisional methodology for soil degradation assessment, except that an additional and more generalized descriptor is given, 'fertility decline', to be used where precise causes are not known.

1 Water erosion	Including sheet and/or gully erosion
2 Wind erosion	
3 Salinization or sodication	
4 Chemical degradation	Including acidification, lowering of bases or nutrients, toxicities (except as in 3)
5 Physical degradation	Loss of pore space, compaction, decline in permeability and water storage capacity, etc.
6 Biological degradation	Decline in organic matter, biological activity in soil
7 Fertility decline	Lowering of the capacity of soil to produce crops, through combination of chemical, physical and biological degradation.
9 No data	

Severity: 1 Absent — A positive statement that there has been no substantial soil degradation
2 Present
3 Severe
9 No data

VEGETATION

Vegetation status of site _____/

1 Natural vegetation	Communities of predominantly natural (self-sown) origin, even if believed to be subclimax or degraded
2 Planted vegetation	Communities predominantly planted, e.g. crops, forest plantations, sown pasture

..9/

9 No data

GENERALIZED VEGETATION TYPE SITE ..... AREA .....

If status (above) = 1, enter the same code for site and area
If status (above) = 2, enter 12 for site, and give observed or assumed vegetation of area as a whole.

Code and name	Description and notes
1 Rain forest	Including evergreen, semi-deciduous and montane
2 Tropical deciduous woodland	Savanna woodland, crowns>40% cover; S. America cerradão
3 Savanna	Tree/shrub cover<40%, predominantly broad-leaved, plus well-developed grass cover; S. America cerrado
4 Thorn scrub or thorn woodland	Xeromorphic vegetation, predominantly thorny and/or microphyllous
5 Grassland	Of any origin, including climatic, hydromorphic, montane, but excluding sown pastures, see 13
6 Semi-desert vegetation	
7 Desert	
8 Temperate deciduous woodland	
10 Coniferous woodland	Excluding plantations., see 13
11 Montane vegetation	Excluding montane grassland, see 5
12 Swamp	Including mangrove and other coastal swamp
13 Planted vegetation	Including crops, forest plantations, sown pasture (see also land use, below)
9 No data	

Reliability _____/

UNESCO CLASSIFICATION: SITE .....

AREA..... RELIABILITY _____/

Give the type of vegetation according to Unesco (1973). International classification and mapping of vegetation. As the classification employs letter codes, are employed in the data base, hence the symbol ...../ The subdivision should be given, e.g. III.A (not III). For detailed definitions, refer to the source given. Enter code plus name.

I	CLOSED FOREST	IV	DWARF-SCRUB AND RELATED COMMUNITIES
I.A	Mainly evergreen forest	IV.A	Mainly evergreen dwarf-scrub
I.B	Mainly deciduous forest	IV.B	Mainly deciduous dwarf-scrub
I.C	Extremely xeromorphic forest	IV.C	Extremely xeromorphic dwarf-shrubland
II	WOODLANDS	IV.D	Tundra
II.A	Mainly evergreen woodland	IV.E	Mossy bog formations with dwarf-shrub
II.B	Mainly deciduous woodland		
II.C	Extremely xeromorphic woodland		

..10

		V.	HERBACEOUS VEGETATION
III	SCRUB	V.A	Tall graminoid vegetation
		V.B	Medium tall grassland
III.A	Mainly evergreen scrub	V.C	Short grassland
III.B	Mainly deciduous scrub	V.D	Forb vegetation
III.C	Extremely xeromorphic (sub-desert) shrubland	V.E	Hydromorphic fresh-water vegetation
		VI	PLANTED VEGETATION

Physiognomic vegetation type ..... Description (maximum one line)
Vegetation association ..... Main genera or species, trees and shrubs and/or grasses etc.

Vegetation degradation: severity _____/
nature, causes .....

Is it believed that the vegetation is degraded as compared with its condition in some past period?

Severity: 1 Absent — A positive statement that it is believed there has been no substantial degradation
2 Present
3 no data

FAUNA AND DISEASE

Termites _____/ 1 Present 2 Absent 9 No data

Tsetse _____/ 1 Present 2 Absent 9 No data

Other significant fauna, plant or animal pests or diseases:

Affecting plants _____/ 1 Yes 2 No 9 No data
Details .....
E.g.: - animal pests (e.g. rabbits)
- bird pests (e.g. Quelea)
- locusts
- other insect pests
- soil fauna
- plant diseases

Affecting animals _____/ 1 Yes 2 No 9 No data
Details .....
Pests affecting stored produce, and diseases of humans, are not currently includec in the data base.

RELIABILITY _____/ Of information on fauna

LAND USE

Intercropping and other mixed systems, including agroforestry, are indicated by use of more than one code, e.g. coconuts with grazing beneath as 2 8 /, maize and coffee with fuelwood trees as 1 2 11 /. *For this item, the computer will accept up to three codes; enter 888 to request more than one, then if there are only two, enter zero for the third.* For agroforestry systems, see also below.

MAJOR KIND OF LAND USE _____/ RELIABILITY _____/

..1:

Code and name	Notes
1 Annual crops	Including cassava, hill rice, vegetables if on a field scale; excluding swamp rice, vegetables if on a small plot/garden basis
2 Tree and shrub crops	Including fruit trees; excluding crops listed under 3
3 Field perennial crops	Sugar cane, sisal, pineapple, bananas
4 Swamp rice	If irrigated, code also as 6
5 Gardens	Intensive cultivation on small plots
6 Irrigated agriculture	Including rice if water brought to fields but not if retention of rainfall only; including irrigated grazing
7 Grazing of natural pastures	Including nomadic grazing, rancing
8 Grazing of improved pastures	Sown or substantially improved pastures
10 Forestry, natural forests	For timber and/or products
11 Forest plantations	
12 Recreation and tourism	
13 Wildlife conservation	With specific intention of this purpose
14 Water catchments	With specific intention of this purpose
15 Engineering uses	Any form of construction
16 Unused	No specific intention of use
17 Other uses	
9 No data	

Description .....

Agroforestry class _____/

Description .....

There is at present no standard or widely-accepted classification of agroforestry systems in use, within ICRAF or elsewhere. However, individual users may have their own classification systems which they wish to include in the data base. There is therefore space for a coded agroforestry class, followed by a verbal description. The user can insert class definitions, which will then be included in the printout. Code 9 or 999 should be allotted to No data/Not relevant.

USER-DEFINED ADDITIONAL DATA

Some additional data items are included in Level 2 of the data base. However, there may be items of environmental data specific to a particular data set which the user wishes to insert. Provision is made for inclusion of up to 3 coded items, 3 numeric items, and 3 descriptive (verbal) items. For the coded items, the user must define the classes.

GENERAL NOTES ON SITE

A short description of the main, or distinctive, features of the environment at the site. *Maximum of 4 lines; commas, colons and semi-colons may only be used at the ends of lines.*

SAMPLE OUTPUT

ICRAF ENVIRONMENTAL DATA BASE, LEVEL 0

NOTE ON DRAFT "Level 0" is a possible addition, giving the setting only, in terms of the classifications of each environmental factor. As it has not yet been programmed, the output envisaged is given in typed form, as follows:

SITE 1	BATU ARANG	RELIABILITY
LOCATION	PENINSULAR MALAYSIA 100 KM NW OF KUALA LUMPUR LATITUDE: 3.25 N LONGITUDE: 101.32 E	1
	ALTITUDE: 100 M	1
GEOLOGY	SEDIMENTARY, SILICEOUS	2
LANDFORMS	MODERATELY SLOPING	1
CLIMATE	RAIN FOREST	1
KOPPEN:	AF TROPICAL RAIN FOREST, PERMANENTLY HUMID	1
HYDROLOGY	WATERLOGGING: NONE	2
SOILS	LATOSOLS OR SERDANG-MUNCHONG ASSOCIATION ON MALAYSIAN CLASSIFICATION	1
VEGETATION	SITE: RAIN FOREST AREA: RAIN FOREST	1
LAND USE	FORESTRY, NATURAL FORESTS	1

SAMPLE OUTPUT

ICRAF ENVIRONMENTAL DATA BASE, LEVEL 1

SITE 1 BATU ARANG

		RELIABILITY
SOURCE	VARIOUS	
LOCATION	PENINSULAR MALAYSIA 100 KM NW OF KUALA LUMPUR LATITUDE: 3.25 N LONGITUDE: 101.32 E ALTITUDE: 100 M	1 1
GEOLOGY	SEDIMENTARY, SILICEOUS SHALES QUARTZITES ETC	2
LANDFORMS	MODERATELY SLOPING UNDULATING AND ROLLING TERRAIN WITH NARROW FLAT VALLEY FLOOR SLOPE ANGLE 6 - 12 DEGREES (10 - 21 PERCENT)	1
CLIMATE	RAIN FOREST	1
KOPPEN:	AF TROPICAL RAIN FOREST, PERMANENTLY HUMID ALT.ZONE: LOWLAND RAINFALL REGIME: BIMODAL ANNUAL TEMPERATURE 26.1 C ANNUAL RAINFALL 2437 MM WITH 0 DRY MONTHS	1
HYDROLOGY	WATERLOGGING: NONE GROUNDWATER: FRESH GROUNDWATER DEPTH, MEAN : NO DATA	2
SOILS	LATOSOLS OR SERDANG-MUNCHONG ASSOCIATION ON MALAYSIAN CLASSIFICATION TEXTURE : LOAMY TO CLAYEY REACTION: STRONGLY ACID TO ACID DRAINAGE: WELL DRAINED	1
VEGETATION	NATURAL SITE: RAIN FOREST AREA: RAIN FOREST SECONDARY LOWLAND EVERGREEN RAIN FOREST DIPTEROCARP FORMATION	1
FAUNA, DISEASE	TERMITES: PRESENT TSETSE : NO DATA AFF. PLANTS : AMBROSIA BEETLES	3
LAND USE	FORESTRY, NATURAL FORESTS SECONDARY FOREST (MALAY BELUKAR) AGROFORESTRY CLASS: 9 NONE AT PRESENT	1

GENERAL NOTES ON SITE

TYPICAL PERMANENTLY HUMID LOWLAND RAIN FOREST ENVIRONMENT WITH STRONGLY LEACHED SOILS. RAPID PLANT GROWTH. DESCRIPTION REFERS TO INTERFLUVES. ALSO PRESENT ARE FLAT ALLUVIAL VALLEY FLOORS WITH POOR DRAINAGE (MALAY LOPAK).

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Example of output from the Environmental Data Base, Level 2.

The Malaysian COSPRO site

```
SITE 1                BHTU ARANG
------
                                                          RELIABILITY
SOURCE          VARIOUS

LOCATION        PENINSULAR MALAYSIA
                100 KM NW OF KUALA LUMPUR
                LATITUDE:                                        1
                          3.25  N
                LONGITUDE:
                          101.32  E
                ALTITUDE:                                        1
                          100  M

GEOLOGY         SEDIMENTARY, SILICEOUS                           2
                COARSE GRAINED
                AND FINE GRAINED
                GEOLOGICAL FORMATION:
                   NO DATA
                   TRIASSIC?
                   SANDSTONES QUARTZITES ETC

LANDFORMS       MODERATELY SLOPING                               1
                UNDULATING AND ROLLING TERRAIN WITH NARROW FLAT VALLEY FLOORS
                SLOPE ANGLE 6  -  12  DEGREES
                          ( 10  -  21  PERCENT)
                RELATIVE RELIEF 50  M
                SLOPE CURVATURE: NO DATA
                POSITION       : NO DATA

CLIMATE         RAIN FOREST                                      1
       KOPPEN:  AF  TROPICAL RAIN FOREST, PERMANENTLY HUMID      1
                ALT.ZONE: LOWLAND
                RAINFALL REGIME: BIMODAL
                ANNUAL TEMPERATURE 26.1  C
                ANNUAL RAINFALL    2437  MM
                WITH 0  DRY MONTHS
                HOTTEST MONTH: 26.6  C
                COLDEST MONTH: 24.8  C
                DRIEST MONTH : 132  MM
                FROST NEVER OR RARE
                ANNUAL EO     : NO DATA
                HUMIDITY INDEX R/EO: NO DATA
                GROWING PERIOD: NO DATA

HYDROLOGY       WATERLOGGING: NONE                               2
                GROUNDWATER: FRESH
                GROUNDWATER DEPTH, MEAN    : NO DATA
                                   LOWEST  : NO DATA
                                   HIGHEST: NO DATA
                RIVER REGIME: PERENNIAL
                DEGRADATION : NO DATA

SOILS           LATOSOLS                                         1
                FAO CLASSIFICATION:                              2
                  MAIN GROUP: F FERRALSOLS AND N NITOSOLS
                  SOIL UNIT : NO DATA
                OR SERDANG-MUNCHONG ASSOCIATION ON MALAYSIAN CLASSIFICATION
                TEXTURE : LOAMY                    TO CLAYEY
                REACTION: STRONGLY ACID            TO ACID
                DRAINAGE: WELL DRAINED
                TEXTURE CLASS, TOPSOIL   : N.D.
                               B HORIZON: N.D.
                DRAINAGE CLASS: WELL DRAINED              TO SOMEWHAT EXCESSIVELY DR.
                NO DATA ON DEPTH TO LIMITING HORIZON
                DEGRADATION: NO DATA
                SEVERITY    : ABSENT

VEGETATION      NATURAL
                SITE: RAIN FOREST                                1
                AREA: RAIN FOREST
                UNESCO CLASSIFCATION:                            1
                  SITE: 1.A MIANLY EVERGREEN FOREST
                  AREA: AS SITE
                SECONDARY LOWLAND EVERGREEN RAIN FOREST
                DIPTEROCARP FORMATION
                DEGRADATION ABSENT
                -

FAUNA, DISEASE  TERMITES: PRESENT                                3
                TSETSE  : NO DATA
                AFF. PLANTS : AMBROSIA BEETLES

LAND USE        FORESTRY, NATURAL FORESTS                        1
                SECONDARY FOREST (MALAY BELUKAR)
                AGROFORESTRY CLASS:  9
                NONE AT PRESENT

USER-DEFINED ADDITIONAL DATA

NONE

GENERAL NOTES ON SITE

TYPICAL PERMANENTLY HUMID LOWLAND RAIN FOREST ENVIRONMENT
WITH STRONGLY LEACHED SOILS.  RAPID PLANT GROWTH.
DESCRIPTION REFERS TO INTERFLUVES.  ALSO PRESENT ARE
FLAT ALLUVIAL VALLEY FLOORS WITH POOR DRAINAGE (MALAY LOPAK).
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APPENDIX A-3

ADDITIONAL CLIMATIC INFORMATION*

This appendix is divided into two parts:

Part 1: Plant Water Requirements and Water Availability Assessments

Part 2: Temperature and Plant Development

Guidelines given in Part 1 for calculation of water budgets and assessment of water-related constraints and potentials for agriculture would be relevant to apply in cases where availability is limiting for agricultural production. Part 2 contains a more general discussion of considerations involved in assessing temperature effects on plant growth and development, which may be useful where temperature is thought to be a limiting factor.

PART 1: PLANT WATER REQUIREMENTS AND WATER AVAILABILITY ASSESSMENTS

Outline

1. Plant Water Requirements
1.1 Climatic effects on plant water requirments
1.2 Plant characteristics
1.3 Effect of local conditions
2. Water Availability
2.1 The water balance
2.2 Water availability
3. Levels of Water Availability Assessments
4. Water Budget Computations
4.1 Data requirements
4.1.1 Precipitation
4.1.2 Evaporation
4.1.3 Soil water storage
4.2 Water budget computations
5. Interpretation of the Water Budget - Example -
5.1 Monthly water budget
5.1.1 Location
5.1.2 Rainfall
5.1.3 Evaporation
5.1.4 Water balance
5.1.5 Water availability periods
5.1.6 Climatic zoning
5.1.7 General results for agriculture
5.2 10 Day water budget analysis
5.2.1 Rainfall
5.2.2 Evaporation
5.2.3 Water availability periods
5.2.4 Crop water requirements
5.2.5 General results for agriculture

*Contributed by T. Darnhofer

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PLANT WATER REQUIREMENT AND WATER AVAILABILITY ASSESSMENTS

1. PLANT WATER REQUIREMENTS

For their development plants need a certain amount of water which depends on various factors. To evaluate agricultural potentials, knowledge on the extent to which these requirements are met by the water supply is essential.

The plant water requirements are defined (FAO 1977) as "the depth of water needed to meet the water loss through evapotranspiration of a disease free plant, growing in large fields, under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment".

The plant water consumption is affected by:

- the climatic conditions
- the plant characteristics
- local agricultural practices

1.1 Climatic effects on plant water requirements

The climatic plant water requirement is given by the potential evapotranspiration which is defined as "the maximum quantity of water capable of being lost by a continuous stretch of vegetation covering the ground, when water supply to the soil is not limiting". "ET" is normally considered to be 20 to 25% less than Eo, the potential evaporation from an open water surface, mainly due to higher radiative reflection (albedo) of a plant cover, compared with a water surface.

1.2 Plant Characteristics

The effect of plant characteristics on plant water requirements is given by the plant (crop) coefficient (Kc), which presents the relationship between the potential evapotranspiration ET and the plant specific evapotranspiration. This coefficient varies with the plant species, its stage of growth, growing season and the weather conditions. For a larger number of agricultural crops these "Kc" coefficients have been established and guidelines for their applications are published (FAO 1977).

1.3 Effect of Local Conditions

Local conditions and agricultural practices, such as meso and micro climatic variations over time, distance and altitude, size of field, soil water availability, salinity, cultivation methods, will affect the plant water requirements. The quantification of these effects is rather complex and requires local field data.

2. WATER AVAILABILITY

2.1 The Water Balance

To estimate the amount of water, which can be used for biological processes, i.e. the quantity available for evapotranspiration, the water balance for a given area and a given period is established. The water balance can be expressed by the following equation.

Rainfall + inflow = changes in soil moisture + evaporation + percolation + runoff.

Assuming that there is no inflow (irrigation etc.) and considering percolation and runoff as one item, the equation can be written:

$$P = E + S + Ro \quad (1)$$

P : Rainfall
E : Evaporation
S : Change in soil water storage
Ro : Runoff including percolation

If rainfall and the storage capacity of the soil is known, the formula allows to calculate the amount of water available for evaporation processes and run off. As evaporation however cannot exceed maximal values, which are depending on atmospheric conditions and the vegetation, the run off can be determined. These maximal or potential evaporation values therefore represent the limits between excess and insufficient water availability.

2.2 Water Availability

To quantify the degree to which water requirements are met by the supply (precipitation), the ratio between the rainfall amount and the potential evaporation (or evapotranspiration) can be used, Accordingly this ratio has been used to characterize water availability classes in agro-climatic assessments (2,3,4).

TABLE 1: RATIO'S P/ET, P/Eo AND WATER AVAILABILITY CLASSES

	RATIO		CLASS DESIGNATION	GENERAL SIGNIFICANCE
	P/ET	P/Eo		
$P > E_t$	> 1	> 0.75	Humid, full humid	Max. water needs
$P > E_t/2$	0.5-1	0.375-0.75	Moist, Intermediate sub-humid	Normal water needs sub-humid
$P > E_t/2$	0.25-0.5	0.19-0.375	Moderate dry, semi-arid	Min. water need
$P \approx E_t/4-E_t/10$	0.1-0.25	0.075-0.19	Dry, Arid	Wilting point
$P < E_t/10$	< 0.1	< 0.075	Very dry	

3. LEVELS OF WATER AVAILABILITY ASSESSMENTS

In an initial approach, this can be achieved by calculating the monthly water budget for a given place and comparing it with selected levels of evapotranspiration chosen, to represent different ranges of plant water needs. (Optimum, normal, minimum requirements). Accordingly, periods with water availability above or below these tresh-holds, can be considered to be suitable or not, for the one or the other agricultural practice. The length of these periods can be referred to the vegetative cycle of agricultural crops and thus help to chose appropriate varieties.

Once a preliminary choice of the agricultural plant varieties is made, the specific plant water requirements (obtained by appropriate application of "Kc" values to the potential evapotranspiration) can be checked against the water availability data, to obtain indication on the suitability levels of the chosen varieties. In many cases however this analysis will require water balance assessments on a 10 day basis.

Risk assessments of crop yield reductions or failures can be made by the establishment of probability levels, of water availability. This is especially recommended in marginal rainfall areas where the inter-periodical variations are usually high.

Very detailed analysis of rainfall and evaporation records (water availability), local crop scientific water requirements and agricultural data, can allow the establishment of farming calendars and recommendations on farming practices such as planting periods, weeding, thinning, fertilizer applications and harvesting periods.

4. WATER BUDGET COMPUTATIONS

After having mentioned the purpose and the use of water balance assessments for agriculture, and having indicated some basic considerations on water balance and water availability, brief guidance on how to calculate the water balance practically shall be given.

4.1 Data Requirements

The water balance equation is written as follows:

$$P = E+S+Ro \quad (1)$$

Accordingly the required parameters are:
P = Precipitation
E = Evaporation
S = Change in soil water storage
(Ro = Runoff results, once the other factors are known).

4.1.1 Precipitation

The rainfall is directly measured with rain gauges, and is expressed in mm height of water, that would cover the surface if there would not be any infiltration, runoff, or evaporation. Depending on the period under consideration for the water balance calculations, the rainfall data has to be chosen accordingly. For practical reasons most of the surveys are based on monthly intervals. General assessments simply refer to average data, while probability estimations require actual monthly data over longer periods (10 years or more). More ambitious and detailed investigations usually use 10 day data.

For larger areas it is usually necessary to consider data from more than one station, in order to evaluate local differences. This is particularly advisable in regions where the topographic situation can cause important changes in the rainfall patterns within short distances.

4.1.2 Evaporation

As the water loss from a surface is depending on a variety of meteorological parameters, such as air humidity, air temperature,

available energy, wind and atmospheric pressure, an accurate determination of this component of the water balance equation, causes considerable problems.

4.1.2.1. Direct Measurements

Evaporation can be measured directly, with instruments such as evaporation tanks, lysimeters, evaporation balances, and evaporation tubes. (Evapotranspiration can only be measured with lysimeters). All this measuring devices, however modify the immediate environment more or less and are therefore not strictly representative. Big efforts have been undertaken to develop correlations between the results, obtained with different instruments and with similar types of instruments under different climatic conditions.

Internationally the class A evaporation Pan is the most used direct measurement instrument. In most cases empirically established coefficients are used to adjust the measured results to the local conditions.

4.1.2.2 Estimations of the Evaporation

With reference to the problems, related to the accurate measurement of evaporation, a number of methods and formulas have been developed to estimate the amount of water loss through evaporation. The best known methods were developed by Thornthwoit, Turc, Blaney/Criddle and Penman. The formulas designed by Penman in 1948, which has been slightly modified to adopt it to different climatic zones, is the most commonly used one.

This formula for the computation of the potential evaporation and the potential evapotranspiration, as used and recommended by F.A.O. reads as follows:

a) <u>Potential evapotranspiration</u>

$$E_T = \frac{\frac{p_0}{p} \cdot \frac{\Delta}{\gamma}\left[0.75 R_A\left(a + b\,\frac{n}{N}\right) - \sigma T_K^4 \left(0.56 - 0.079\sqrt{e_d}\right)\left(0.10 + 0.90\,\frac{n}{N}\right)\right] + 0.26\,(e_a - e_d)(1.00 + 0.54\,U)}{\frac{p_0}{p} \cdot \frac{\Delta}{\gamma} + 1.00}$$

b) <u>Evaporation of a free water surface</u>

$$E_0 = \frac{\frac{p_0}{p} \cdot \frac{\Delta}{\gamma}\left[0.95 R_A\left(a + b\,\frac{n}{N}\right) - \sigma T_K^4 \left(0.56 - 0.079\sqrt{e_d}\right)\left(0.10 + 0.90\,\frac{n}{N}\right)\right] + 0.26\,(e_a - e_d)(0.50 + 0.54\,U)}{\frac{p_0}{p} \cdot \frac{\Delta}{\gamma} + 1.00}$$

Explanation of the units used in the formula

The terms intervening in the formulae and in the working sheets are defined hereunder and expressed in the following units:

E_T = estimation of the potential evapotranspiration for a given period, expressed in mm;

E_o = estimation of the evaporation from a free water surface for a given period, expressed in mm;

P_o = mean atmospheric pressure expressed in millibars at sea level (1013) mb

P = mean atmospheric pressure expressed in millibars as a function of altitude for the station where the estimate is calculated;

Δ = rate of change with temperature of the saturation vapour pressure expressed in millibars per degree ^oC;

γ = the psychometric coefficient for the psychometer with forced ventilation = 0.66;

0.75 and 0.95: factors expressing the reduction in the incoming short wave radiation on the evaporating surfaces and corresponding respectively to an albedo of 0.25 and 0.05;

R_A = short wave radiation received at the limit of the atmosphere expressed in mm of evaporable water (1 mm = 59 calories) and taking for the solar constant the value of 2.00 cal.cm^{-2}. min.$^{-1}$;

a and b = coefficients for the estimation of total radiation from the sunshine duration

n = sunshine duration for the period considered in hours and tenths;

N = sunshine duration astronomically possible for the given period;

σT_K^4 = Blackbody radiation expressed in mm of evaporable water for the prevailing air temperature;

e_a = saturation vapour pressure expressed in millibars;

e_d = vapour pressure for the period under consideration expressed in millibars;

T^o_C = air temperature measured in the meteorological shelter and expressed in degrees Celsius;

T^o_K = air temperature expressed in degrees Kelvin where $T^o_K = T^o_C + 273$;

$U_{m/s}$ = mean wind speed at an elevation of 2 m for the given period and exp essed in m/sec.

It can be seen that the following meteorological data is required for the computation:

- sunshine duration or global radiation
- air humidity
- air temperature
- wind speed

The other data needed, concerns coefficients and physical parameters which are available from physical tables, or can be calculated with respective formulas.

F.A.O. has prepared working sheets and tables to facilitate the use of these formulae under field conditions where no sophisticated calculation facilities are available (F.A.O. 1977, 1979), (1,6).

4.1.3 Soil Water Storage

The amount of water which can be stored in the soil depends on the physio-chemical characteristics of the soil. For agricultural purposes, it is rather the amount of water which can be used by the crop - the soil water reserves - which is of importance. This amount not only depends on the mentioned soil characteristics but furthermore on the depth of the soil exploited by the roots of the plants.

Thus it appears extremely difficult to determine exactly the soil water reserves available for plants in different soils, at different stages of growth. For practical purposes, general assumptions are frequently made considering 80, 100 or 200 mm of soil water reserves as maximal values.

4.2 Water Budget Computations

Once the elements required for the water budget are gathered, either by measurement (precipitation), calculation (evaporation), or empirical assumptions (soil water reserves), the water budget can be established for the periods under consideration (month or 10 day periods) in accordance to formula 1.

Table 1 gives a sample of an average monthly water budget for Katumani (Kenya).

5. INTERPRETATION OF THE WATER BUDGET - EXAMPLE -

5.1 Monthly Water Budget

This water budget table allows for an initial assessment of the water supply situation of a given site. Based on the data contained in this table a "Water availability diagram" can be established, which shows the conditions graphically (Fig. 1).

Referring to Table 1 and Fig. 1, the following "sample" interpretations can be made.

5.1.1 Location

The site under consideration is situated in the tropical "mid highlands" (1° 34'S; 1601 m alt). Referring to the equatorial mean temperatures at sea level (approx. 27°C) and a general laps are of 0.55°C/100 m, a mean annual temperature between 18 and 20°C can be expected.

TABLE 1 : WATER BUDGET KATUMANI MACHAKOS (KENYA
(MONTHLY AVERAGES, FOR THE PERIOD 1970 - 1982

WATER BUDGET :
LOCATION : KATUMANI, MACHAKOS KENYA Period
1° 35 ^{o}S 37° 14° E ALT. 1601 m 1970 - 1982

Period	(=0.75E	P	WD	WS	EL	100 mm Storage GCH	GST	Ro	Ep	Ratio P/Eo	Ep/Eo
JAN	134	56	78					0	56	0.31	0.31
FEB	135	53	102					0	53	0.18	0.18
MAR	149	83	66					0	83	0.42	0.42
APR	117	153		36		36	36	0	117	0.98	0.75
MAY	93	61	32			-32	4	0	93	0.49	0.75
JUNE	77	11	66			- 4		0	15	0.11	0.15
JULY	72	7	65		7			0	0	0.07	0
AUG	86	4	82		4			0	0	0.04	0
SEPT	115	9	104		9			0	0	0.06	0
OCT	146	33	113					0	33	0.17	0.17
NOV	112	129		15		17	17	0	112	0.85	0.75
DEC	112	68	44			-17		0	85	0.46	0.57
TOTAL	1348	647	752	53	20	X	X	0	627	0.36	0.35

E_T = Potential Evapotranspiration (0.75 x Pot. Evaporation Eo) in mm

P = Precipitation in mm (Eo Pan Evaporation or calculated values)

WD = Water deficit = ET P

WS = Water surplus = ET P

EL = Evaporation loss (Small quantities which cannot be used for crop growing)

GCH = +Ground charge:- Ground discharge

GST = Ground storage (Maximum assumed 100 mm)

Ro = Runoff (Surplus after 100 mm ground charge)

Ep = Effective Rainfall: Ep = P-EL - Ro - GCH

P/Eo = Water availability ratio without ground water reserves*

Ep/Eo = Water availability ratio with ground water reserves**

* "Climatic Hygro period"

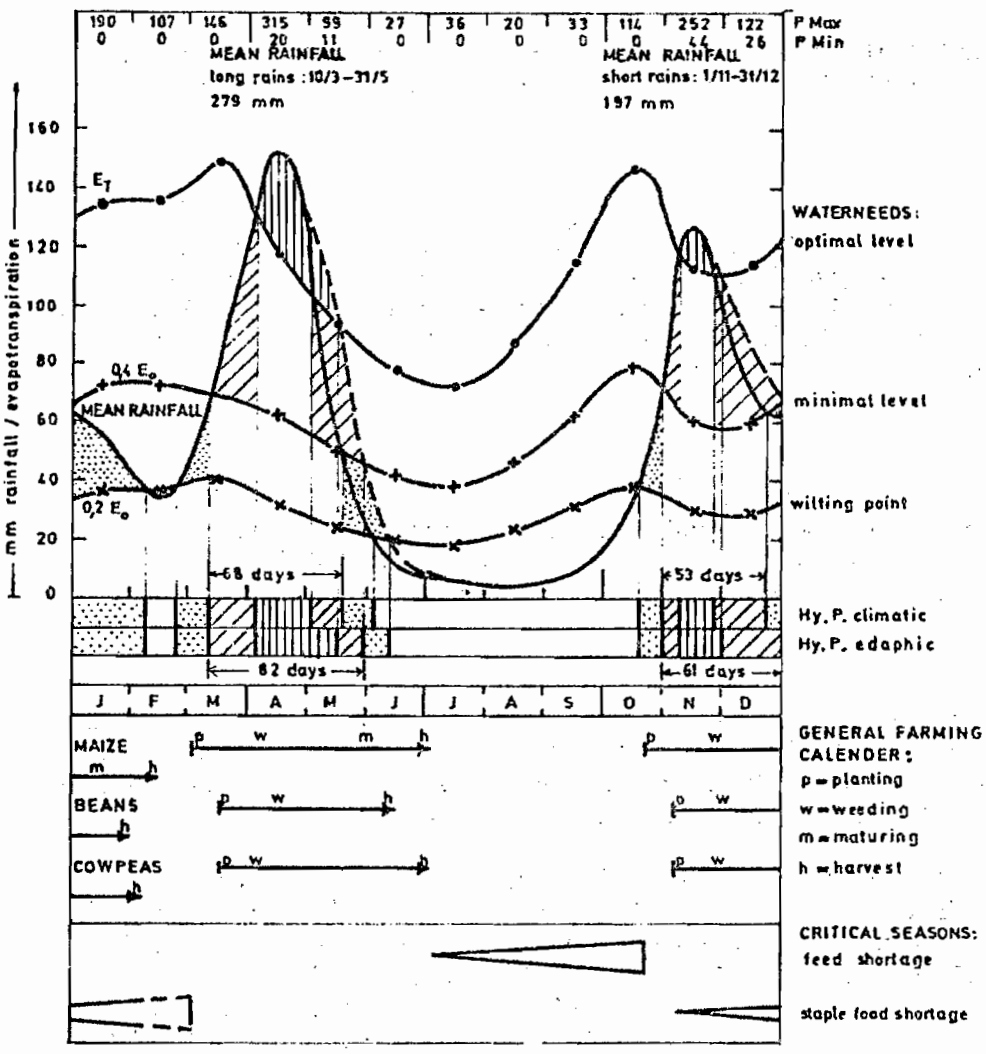
** "Edaphic Hygro period"

Fig.: 1

WATER AVAILABILITY DIAGRAM
monthly data

Location : KATUMANI / MACHAKOS
1° 35' S
37° 14' E
alt.: 1601 m

mean annual rainfall: 647 mm (1970-82)
" " pot. evapotr. 1346 mm



HYGROPERIODS:

arid	P/E_o	<0,2
semiarid	P/E_o	0,2–0,4
sub humid	P/E_o	0,4–0,75
humid	P/E_o	>0,75

Hy. P. climatic = rainfall
Hy. P. edaphic = rainfall + 100 mm soilwatercapacity

DATA SOURCES:
Rainfallrecords 1970—1982 (K.M.D.)
Evaporation Class A Pan data over 7years (J.I.Steward 1981)

5.1.2 Rainfall

The rainfall pattern is biomodal with one distinct dry season from June to October and a less accentuated dry period from December to March.

Rainfall amounts

The mean annual rainfall of 647 mm is split into 279 mm and 197 mm for the longer and the shorter rainy season respectively, while the remaining 171 mm (or 26%) mainly fall between December and March (107 mm).

The small occassional rains during the period June to October have no significance for agriculture and can be considered under "Evaporation Loss".

5.1.3 Evaporation

The potential evapotranspiration (assumed to be 75% of the potential evaporation) with an annual total of 1348 mm is of bimodal pattern as well, with maximal values of 149 mm and 145 mm in the month's proceeding the most important rainfalls (March, October). The annual amplitude is 77 mm or 107% of the lowest amount.

5.1.4 Water Balance

Precipitation exceeds potential evapotranspiration slightly in April and November, but this water surplus is not sufficient to meet the assumed soil water storage capacity of 100 mm. Accordingly there is no run off to be considered on the basis of the monthly data.

5.1.5 Water Availability Periods

The last two columns of the table indicate the monthly ratios P/E_o and E_p/E_o which refer to the water availability classes. To estimate the availability of water periods to the nearest day, graphical smoothing of the monthly rainfall and evaporation amounts is used.

It appears from the diagram (Fig. 1) that rainfall exceeds the value of ET twice an average year; from approx. 6th April to 3 May and from 10th November to 24th November. Assuming that water requirements of most plants are still met with a P/E_o ratio between 0.75 (ET) and 0.4 the water availability period can be estimated to be 68 days during the "long" rains and 53 days during the "short" rains. When the soil water reserves are considered to be available for plant development, (broken line), the subhumid and humid periods are 82 days and 61 days for two rainy seasons.

The points of intersection of the rainfall curve (and/or effective rainfall line) and the 0.4 E_o or 0.2 E_o line, allows to delimitate semi arid and arid periods in the same way.

5.1.6 Climatic Zoning

Using the available date (Rainfall, Evaporation, Temperature) and checking it against the various climatic or agroclimatic classification systems (2,7,8) the site can be related to:

Thornthwaite, (1948): Zone "D" Semi arid climate

Holdridge : "Premontane - Dry Forest" Life Zone

R. Joetzold : "UM4 S+S" : Upper midland transitional
: Zone S+S (sunflow maize zone) with two short growing periods

H.M.H. Braun: Zone "V4" semi arid zone, alt 1500-1800 m marginal agric. potential

F.A.O. : Major climate "2" Moderately cool tropics or tropical highlands with 0-74 days growing period (only the longer period is inventoried).

5.1.7 General Results for Agriculture

5.1.7.1 Limiting climatic factors

The main climatic constraint is low rainfall distributed over rather short periods. Although temperature is not a limiting factor, except to relatively few crops which could be grown under the given moisture conditions, it affects the length of the growing cycle of certain crops and/or reduces the yield.

5.1.7.2 Cropping Periods

With regard to the bimodal rainfall pattern two cropping periods can be considered for varieties with a very short to a short growing cycle.

Perennial varieties must have drought resistance to survive during the arid period from mid June to mid October.

With regard to the short water availability periods, early planting at the beginning of the rainy seasons (mid February, mid October) can be recommended, once the initially required moisture (rainfall of 20-30 m) become available.

5.1.7.2 List of crops grasses and woody species which could be considered under the given climatic conditions. Table 2 (Ref. 7) ICRAF.

Table 2. Agricultural Crops

CROP VARIETY	Growing Cycle No. of days	Altitude Range m	Rainfall (mm) in growing P
GRAIN CROPS			
Maize Dryland composite	75-85	700-1500	240-430
Maize Katumani composite B	85-105	700-1500	260-450
Foxtail millet (Sc. 285)	65-95	800-1800	220-320
Sorghum 158595	75-105	0-1500	200-430
LEGUMINOUS CROPS			
Tepoxy beans	65-80	600-1500	180-300
Cowpeas	70-90	0-1500	200-400
Moth beans	60-90	0-1500	180-400
Pigeon peas (bi-modal)	180-260	0-1500	500-800
OIL SEED CROPS			
Sunflower dwarf	75-85	0-1500	180-330
Rai sodhpur	60-80	800-2000	180-380
TUBER CROPS (perennials)			
Yam bean	90-270	0-1800	500-1500
Buffalo gourds	365	0-1300	180- 500
Maroma bean	365	0-1800	200- 500
Vigna	365	0-1800	250- 600
FIBER CROPS			
Sisal (perennial)	365	0-1800	550- 900

Grasses

Rhodes grass (Chloris gayona) Bona grass (Pannisetum purp., Guinea grass (Panicum max.), Buffel grass (Cenchusciliaris).

Trees and Shrubs

Leucaena leucocephala (N-fixing, mulch, fuel, fodder, marginal in this climate).
Acacia albida (only if ground water table not too deep fuel, fodder).
Prosopis juliflora (fuel, fodder)
Prosopis chilensis (fuel, fodder)
Parkinsonia aculeata (particularly for live fence, bee forage etc.).
Acacia saligna (for soil conservation, emergency fodder, fuel).
Acacia tortilis (for fodder - pollarding regime - fuel, fence, fence poles etc)
Casuarina equistifolia (for shelter/windbreak, poles, N-fixing).
Cassia siamea (may be marginal because of insufficient rain; for fuel, poles)
Azadirachta indica (fuel, poles, insect reppelent (seed+ (leaves).
Terminalia brownii (termite resistent, poles, fuel).

5.2 10-Day Water Budget Analysis

Once the preliminary site survey has been carried out and the project planning proceeds from the diagnosis to the design phase, a more detailed analysis of the water budget is recommended (ref. chap. 3.2, 3.3) Fig. 2 shows a decade analysis of the water budget for the sample site (Katumani Machakos). Rainfall probabilities have been calculated (cummulative distribution method) and included in the diagrams as well as the crop specific water requirement curve for maize (Katumani Composite B). (The graph starts with the month of March to match the rainfall pattern better with the cropping seasons).

5.2.1 Rainfall

Compared to the monthly data graph, the decade data shows a considerable variability of the mean rainfall amounts especially during the short dry season from December to February.

The average onset of the rainy seasons is marked clearly by sharp increases of the rainfall during the last decades of March and October for the "long" and "short" rains respectively.

The 10 day amounts surpassed in 6 out of 10 years (60% probability) remain considerably below the average values, what stresses the fact that the mean values, include high rainfall events with little significance for agriculture.

The reliability of the rains appears to be slightly higher from March to May, than during the "short" rainy season. This is also confirmed by the total rainfall amounts, during the growing periods, which are surpassed in 6 out of 10 years (232 mm against 259 mm mean rainfall for the period 20/3-31/5; 175 mm against 211 mm mean rainfall for the period 20/10-20/12.1.

5.2.2 Evaporation

As the evaporative conditions are much less variable compared to the rainfall regime, it was considered acceptable to derive the decade values of this parameter by graphical interpolation of the monthly data.

The highest evaporative demands occur during periods, when the sun is passing through the zenith, which are preceeding the onsets of the rainy seasons. A third maximum is reached in January together with maximum effective sunshine.

5.2.3 Water availability periods

Using the same method of graphically smoothing the ten days, date to determine the water availability period to the nearest days, the results compared to the ones based on monthly data, are slightly different. The humid and subhumid period (ratio P/E_o 0.4) in the "long rains" is only 62 days instead of 68 days. When soil moisture is considered as well, the "growing period" becomes 70 days only, thus being even 12 days less than on Fig. 1.

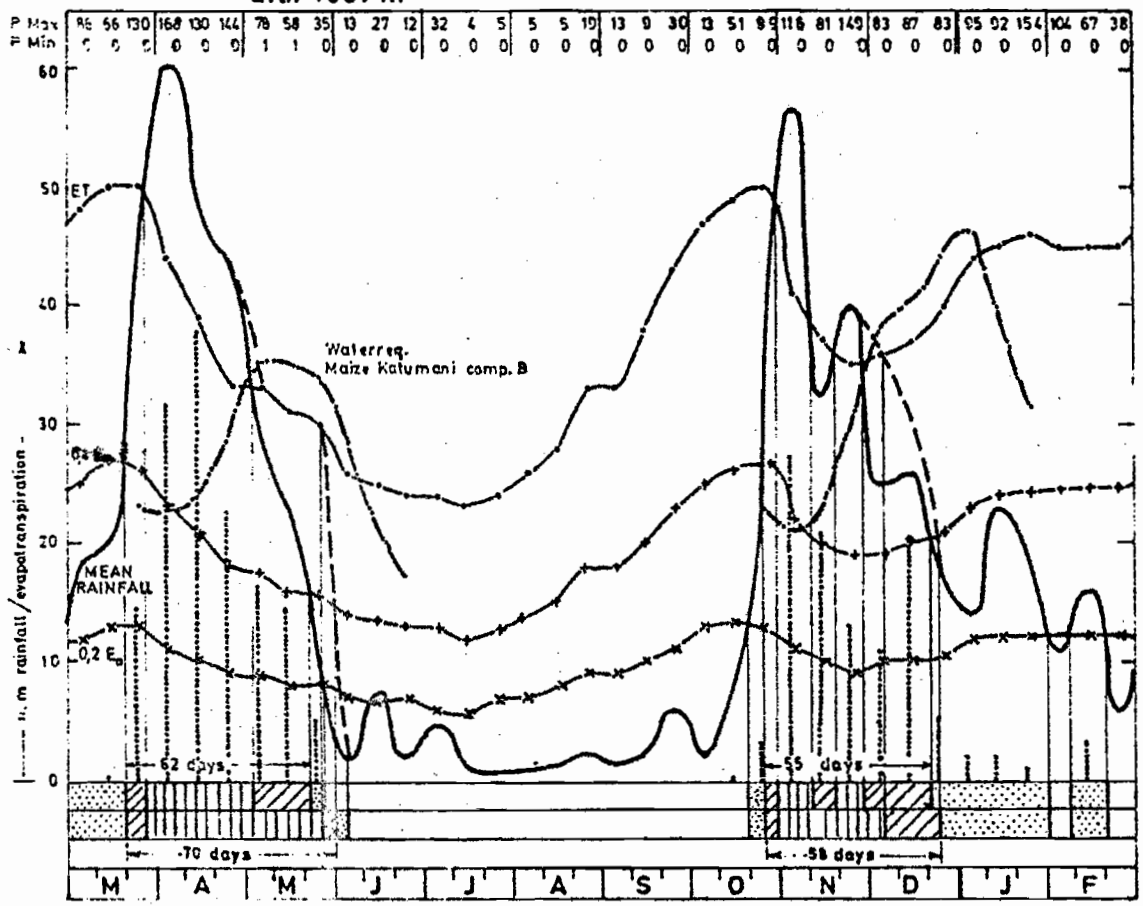
WATER AVAILABILITY DIAGRAM

10 days data

Location: 1° 35' S
37° 14' E
alt.: 1601 m

KATUMANI/MACHAKOS

mean annual rainfall: 647 mm (1970-82)
" " pot.evapotr.: 1346 mm



MEAN RAINFALL per growing period:
20/3 - 31/5 = 259,4 mm
20/10-20/12 = 211,0 mm

DATA SOURCES:
Rainfallrecords 1970-1982 (K.M.D)
Evaporation (E_0) Class A Pan data over 7years (J.I. Steward 1981)

10 days rainfalls means (1970 - 1982)
E_T 0,75 E_0 potential evapotranspiration optimal waterneeds
0,4 E_0 minimal waterneeds
0,2 E_0 wiltingpoint
rainfall surpassed in 6 out of 10years
" + soilwater reserves up to 100 mm max
Hygroperiods
Waterrequ. Maize Katumani comp. B

arid P/E_0 < 0,2
semiarid P/E_0 0,2 - 0,4
subhumid P/E_0 0,4 - 0,75
humid P/E_0 > 0,75

RAINFALL PROBABILITY
amount surpassed in 6 out of 10 years per growing period:
20/3 - 31/5 = 232 mm
20/10 - 20/12 = 175 mm

Hy.P climatic = rainfall
Hy P edaphic = rainfall + 100 mm soilwatercapacity

Fig.: 2

The differences during the "short rains" however are smaller.

When referring to the rainfall amounts which are surpassed in 6 out of 10 years it appears that in 40% of the years no "humid" period will occur at all and that the subhumid period will last for about 34 days only in April/May, and even less in November and December (17 days in November, 3-4 days in December).

5.2.4 Crop Water Requirements

The crop specific water requirements for Katumani composite B maize (live cycle 100 days) were calculated by using the crop coefficient "Kc" (as given by F.A.O. 1) the available information on the potential evaporation and the general wind and humidity regime, (Fig. 3). It appears that, when planted in the last decade of March (initial water requirement met in 6 out of 10 years) the plant will usually be exposed to a moisture deficit as from mid-May or its "mid-season". Yield reductions consequently will be a normal feature. To meet this constraint early planting could be recommended, what however implies a higher failure risk, during the initial period of the plant development.

The "short" rainy season is still much less suitable for this crop variety.

5.2.5 General Results for Agriculture

With regard to the short and unreliable water availability, the agricultural potential of the "sample" site can be classified as "low". As by experience, the ecological equilibrium in such zones is rather vulnerable, the importance has to be stressed, to design land use systems and agricultural practices which:

- Use various agricultural crops with a short life-cycle or plants with a fairly developed draught resistance. (Diversity will decrease the overall crop failure risk).
- Use soil conservation methods, to increase the soil water storage capacity, fight eventual erosion problems and maintain or even improve the soil fertility.
- Aim to decrease potential evaporation by micro climate management (shelterbelts, mulching techniques).
- Include a lifestock component to use the pastoral potential of this climatic zone.

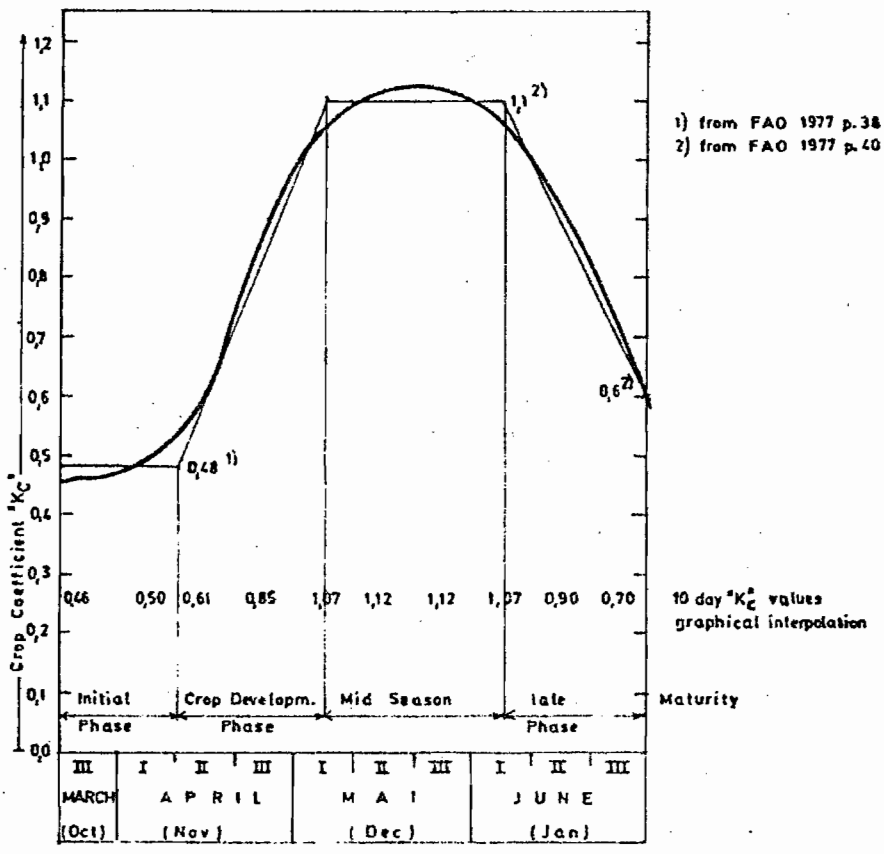
Furthermore it must be recommended to make a detailed survey on the other biophysical parameters such as soil physics, soil chemistry and hydrology as well as on the socio-economic aspects in order to assess long term sustainability of the system.

Fig.:3

CROPSPECIFIC WATERREQUIREMENTASSESSMENT

Example: MAIZE (KATUMANI Comp. B)

GROWING CYCLE	app.	100 days
Initial Phase		20 days
Crop development Phase		25 days
Mid season		30 days
Late season Phase to Maturity		25 days
	total	100 days



1) from FAO 1977 p.38
2) from FAO 1977 p.40

10 day "K_c" values graphical interpolation

	MARCH	APRIL			MAI			JUNE		
E_T	50	44	39	33	33	31	30	26	25	24
K_C	0,46	0,50	0,61	0,85	1,07	1,12	1,12	1,07	0,90	0,70
E_{crop}	23	22	24	28	35	35	34	27	22	17
	OCT	NOV			DEC			JAN		
E_T	50	41	37	35	36	37	39	44	45	46
K_C	0,46	0,50	0,61	0,85	1,07	1,12	1,12	1,07	0,90	0,70
E_{crop}	23	21	23	20	39	41	44	46	40	32

E_T = Potent Evapotranspiration
K_C = Crop Coefficient
E_{crop} = Crop Evapotranspiration

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PART 2: TEMPERATURE AND PLANT DEVELOPMENT

1. INTRODUCTION

Plant development and plant growth is influenced by temperature in many ways. Together with radiation and light, temperature controls to a large extent photosynthesis processes which produce the assimilates, plants use for growth. In general, but within certain limits, the temperature regime determinates the rate of growth and development. There are lower and upper temperature limits beyond which plants cannot grow anymore and are even damaged or killed. Between these thresholds there is a temperature range with optimum living conditions

For many plants, not only the general thermal conditions must be within these thresholds, but also special temperature requirements must be met, such as chilling requirements to initiate flowering, accumulative temperature requirements to pass from one phenological phase to the other, or thermoperiodicity.

Beyond the air temperature, in many cases the soil temperature is of great ecological significance. This applies particularly to trees and tuber crops, but correlations between soil temperatures and early stage growth of cereals are reported as well.

Further, the development of pest and plant diseases depend on thermic conditions, which is frequently another (indirect) effect of a temperature on plant development.

Thus it becomes evident that not only plant development in general, but also the quantity and quality of the economically useful yield is influenced by temperature.

It is therefore very important to know about the temperature requirements of a given plant, to assess its suitability for given climatic conditions.

2. EFFECTS OF EXTREME TEMPERATURE

How favourable moisture, light and soil conditions may be, plant growth will be affected if temperature drops below a minimum or exceeds a maximum value. With regard to the physiological complexity of plants and their growth processes, these temperature thresholds cannot be precisely determined but approximate values are known for many crops and a considerable number of woody plants.

2.1 The Lower Temperature Limits

It is a well known fact that biological processes slow down with decreasing temperature and will reach a zero level once certain limit is reached. Accordingly growth will come to a halt, when temperature drops below the plant specific threshold. In most cases the plants will enter a dormancy period and resume physiological activities when temperatures raises. If however temperatures drop further and reach a point of "no return" permanent damage or death will be the consequence. With regard to the operational range of the protoplasm in living plants the "zero level" of growth corresponds to temperatures near the freezing point. The temperatures where damage occurs however differ considerably from one species to another and from growth stage to growth stage.

For typical temperate region crops (e.g. rye, wheat oats) the minimum temperature limits are fairly low 0° to 5°) and in many cases the "damage" temperatures are as low as -7 to -10° in the germination phase, and -1 to $-3^{o}C$ even when flowering. Crops usually grown in the tropics have minimum "operational" temperatures between 10° and $15^{o}C$. Most of them cannot withstand frost at all, but some are already killed at temperatures as high as $+5^{o}C$. Best evidence of the above is given by the natural change of vegetation parallel to temperature zones, which, in climatic classifications have often been given the names of the prevailing plant cover. With regard to the global distribution of temperatures, this meteorological parameter mainly becomes a limiting factor for agriculture with higher latitudes. In tropical and sub tropical regions lower temperatures are related to higher altitudes.

2.2 The Upper Temperature Limits

As the physiological activity of plant cells increases as temperature raises, the metabolism increases as well. Higher amounts of water, mineral salts, vitamines act. are required. So it is easy to assume that at a certain temperature, the plant will start to suffer from dryness and nutrient stress. As a result plant growth will be reduced and provided the high temperature stress continues, permanent damage or death will occur.

The maximum thresholds for temperate zone plants are approximately between 31° and $37^{o}C$ and those for tropical plants can be as high as 44° to $50^{o}C$.

3. SPECIAL TEMPERATURE REQUIREMENTS

3.1 Chilling requirements and cold treatment

Some plants require low temperatures during certain development stages to allow optimal growth or initiate the passing over to the next phenological phase. (Chilling requirements for initiating flower buds in pyrethrum, cold treatment of germinated seeds and seedlings).

3.2 Accumulated Temperature

The "degree day" concept refers to the dependancy of plant growth upon the amount of heat received. A degree day is the difference between the minimum plant specific threshold temperature and the actual daily mean temperature. Although this concept is subject to some scientific critisism, it is widely used to guide agricultural operations, as in many cases it allows predicting the dates at which particular phenological stages are reached or crops can be planted.

3.3 Thermoperiodicity

The development of certain plants does not or little depend on the degree day, but is largely influenced by the diurnal temperature variation. High day temperatures and low night values are in many cases favourable for crop development (tomatoes, potatoes, tobacco) and yield quality.

4. SOIL TEMPERATURE

Besides air temperature, soil temperatures are of great ecological significance as well. It influences the germination of seed, the functional activity of roots the availability of soil water to plants and the plant mineral nutrient intake. Thus, unfavourable soil temperatures during the growing periods will adversely affect the crops. Low soil temperatures reduce the growth rates and result in low yields, but high temperatures are not desirable either as they also can cause yield reductions and crop degeneration (e.g. potatoes have an optimum soil temperature of 17°, tubers will not develop at all at soil temperatures above 29°C).

As the soil temperature is much more subject to local effects, such as topography, insolation surface structure and colour, it may considerably differ from the air temperature. Therefore it is necessary to pay special attention to it, when making plant suitability assessments.

REFERENCES

1. FAO, 1972. Crop Water Requirements. FAO Irrigation and Drainage Paper No. 24. FAO Rome.

2. Bluethgen and Weischet, 1980. Allgemeine Klimageographie. 4th edition. w.de Gruyter. Berlin/New York

3. WMO, 1973. A study of the agroclimatology of the highlands of East Africa. WMO No. 339. WMO. Geneva.

4. R. Jaetzold, 1981. Klimageographie-Ostafrika Gebrueder Borntraeger, Berlin-Stuttgart.

5. FAO, 1979. Agrometeorological crop monitoring and forecasting. FAO Plant Production and Protection Paper No. 17. FAO. Rome.

6. J.Ian Stewart, 1982. Impact of weather analysis on agricultural production and planning decisions for the semi-arid areas in Kenya. Journal of Applied Meteorology, April 1982, 477-494.

7. R. Jaetzold, 1983. Kenya Farm Management Handbook, Vol. II/A. Ministry of Agriculture, Nairobi.

8. Holdridge, L.R., W.C. Grenke, W.H. Hatheway, T. Liang and J.A. Tosi Jr, 1971. Forest Environments in Tropical Life Zones. Pergamman Press. Oxford/New York.

APPENDIX A-4

GUIDELINES FOR COMPLETION OF THE SOCIOECONOMIC DATASHEET

Worksheet 1.2 on socioeconomic characteristics of the environment of the focal land use system(s) should be completed mainly on the basis of secondary data from existing sources of information, although supplementary consultations with qualified informants in the study area or scientists familiar with the area may be needed to complete some aspects of the datasheet (see Appendix A-1). This appendix gives suggestions for the interpretation of the various information categories in the Worksheet.

HUMAN FACTORS

The first three categories are indicators of the demographic situation within the environment of the focal system(s). Crude *population density* will suffice although, if available, supplementary information on population per unit of cultivable land will be valuable. *Crude population growth rate* for the area, expressed in percentage growth per annum, is self-explanatory. *Sex ratio* within the *working age group* (this varies from country to country from 15-49 to 15-65) can, together with comparative population density, provide a rough indication of population pressure. For example, a high population density coupled with a low male-female ratio in the working age group, would suggest a high rate of male outmigration in search of labour opportunities outside the area, which in turn would suggest a relatively high rate of population pressure. Alternatively, it could indicate proximity to an urban or industrial area of high labour demand; although, the degree of outmigration would still tend to reflect the relative non-availability of productive labour opportunities within the area.

Ethnic composition and *other relevant social differentiations* within the population (e.g. caste, sex roles vis-a-vis farming, etc.) can exert important influences on land use and are, therefore, important to know.

Migration trends refer to general longterm trends (Is the area a source area or a target area for migrants? What is the rate of in or outmigration? Which social groups are migrating? etc.) as well as seasonal migration activities (e.g. in or out migration of part of the agricultural labour force: What seasons? For what purposes?).

Under *settlement history*, a brief general account will suffice. (How long has the area been settled? What phases of settlement have occurred? etc.) *Current settlement pattern* refers to the general patterns of population distribution and residence (i.e. whether dispersed individual farms or small hamlets, small nucleated villages distributed along the roads, large towns or urban concentrations, etc.).

Size of holding refers to the size of the agricultural land management unit; give the average and range of farm sizes within the area, with brief explanatory notes.

Labour utilization pattern refers to the general types of labour used by farms within the area (e.g. family, hired, reciprocal exchange, communal, etc.) and the pattern of utilization (e.g. permanent or seasonal hired labour, seasonal use of migrant labour, etc.).

Land tenure is self-explanatory (see Step 2.3, collum 6 for suggested land tenure categories). Indicate the predominant types of tenure found in the area. Under *land use traditions* what is required is a brief description of major traditional land use types associated with different population groups within the area (e.g. shifting cultivation, smallholder mixed farming, plantation agriculture with tenancy, etc.).

INFRASTRUCTURE

Brief descriptions will suffice of the situation with respect to the nature and adequacy of *roads and transport, agricultural input supply* (are inputs available to small farmers? are they supplied on time?), *processing facilities* for farm and forest products, *storage facilities* for farm commodities, *water supply* within the area, and the availability and quality of *extension services.*

ECONOMY

General information on area *exports* and *imports* can give a useful overview of the economic character of the area, its strengths and weaknesses. Information on *marketing structures* indicates how goods are moved in and out of the area and between producers and consumers within the area.

Information on *agricultural commodity prices* and *agricultural input prices* (for the major commodities and inputs) is important for purposes of rough indicative assessments of the economic viability of existing and alternative farm enterprises. Under *use of agricultural inputs* what is needed is a summary statement of the type and extent of input usage by different farming groups within the area, with brief explanatory notes.

A general statement on the *degree of mechanization* within the area should indicate the typical situation as well as any important deviations from it. Likewise with the *degree of commercialization.* In assessing the *availability of credit* attention should be given to social differences in access to and terms of credit for agricultural or cottage industry purposes.

Under *opportunities for non-farm employment* indicate the main types of non-agricultural employment opportunities (including processing of agricultural products), the general availability of such opportunities, and any social differences in access to these opportunities. Under *important cottage industries* indicate those informal sector activities which are locally important to individual households as well as those which are of general economic significance to the area.

ADDITIONAL NOTES

Feel free to add any notes which shed additional light on socioeconomic aspects of the study area of relevance to the selected land use system(s).

APPENDIX A-5

ECOSYSTEMS ANALYSIS IN D&D APPLICATIONS*

The Rationale

The potential applications for agroforestry technologies often extend beyond the farming system. Based on apparent needs (felt or demonstrated) and on expressed interest, many of the client or target groups are:

1. Rural agricultural populations plagued by failure of existing production systems to satisfy basic needs, as perceived by the policy sector and the people themselves.

2. Populations living in *or* dependent *on* fragile environments plagued by soil and water conservation problems (e.g. problems of quantity, quality, and distribution in surface waters, soil water, ground water; problems of erosion, deposition, nutrient depletion, cementation and other forms of soil degradation).

Given the nature of the problems encountered thus far on-farm and the potential application of agroforestry explicitly for rural development and watershed management purposes, there is often a need for rapid appraisal at the ecosystem level. This is particularly important for diagnosis of watershed problems (including conflicts in land and water use, and regional ecological constraints on target land use systems) and development problems affecting the landless and near landless.

Such a rapid appraisal procedure should be adapted to both immediate needs of the diagnostic and design team in the field and to the information needs for ex ante evaluations (ecosystem analyses) in the pre-project follow-up.

The conceptual approach of ecosystems analysis suitable for use with dynamic non-linear models can be merged with that of farming systems rapid appraisal to identify:

1. problems in land use and eco-systems

2. the probable causes (and/or sources) and

3. the likely outcome of:

   a) extrapolation of current trends

   b) application of alternative technology

   b) application of alternative land use systems.

The ecosystem provides a convenient unit for the consideration of functional interactions between farms or between whole land use systems. The most generally appropriate unit for ecosystem diagnosis and design is the small watershed (≈1-25km^2), although other biophysical or socioeconomic boundaries will be more applicable in some cases.

The incorporation of ecosystem diagnosis as the larger context for farm level diagnosis allows the analysis of farming system/ecosystem interactions (both biophysical and socioeconomic). Once technology is designed it can

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* Contributed by D. Rocheleau

be evaluated for effects on-farm and at the ecosystem level (including local communities and subsets thereof). This approach also accounts for the dynamic character of both the farming systems and the ecosystems in assessments of system sustainability, with and without proposed technologies. The initial diagnosis, like farm level diagnosis, includes trends in settlement, land use, and land tenure, and current demographic trends, as well as trends in the condition of the natural resource base.

This broader spatial and temporal scale of analysis reponds to two important aspects of current agroforestry research and future extension:

1. There is a need to identify and influence farming systems opportunities and limits that reside (or originate) in the next larger systems of which they are a part. A brief look at the next level in the hierarchy can indicate whether the external constraints on farming systems are changeable, and whether the larger system is resilient enough to support such changes if introduced. Such constraints may be ecological or socioeconomic.

   In the case of farming system dependence on opportunities within the larger system (cheap labor, free fuel, abundant water) the sustainability of these resources *and* their availability to the farm household must be considered. The mixed management of "free"goods such as water and fuel with owned land, cattle and equipment, and the combination of family, communal and paid labor in many rural production systems requires a scale of analysis beyond the farm. Changes in farm technology may also effect the larger system and then feed back indirect impacts on the farm household in the form of changing prices, availability, or quality of basic resources (fuel, water, food, shelter, raw materials) or production inputs (agro-chemicals, water, labor, equipment). The result may also be a change in demand for farm products. Both production and sustainability of farming systems are subject to"boomerang" effects from technology change(farm-ecosystem/community-farm).

   Projects geared to specific farming systems or agroforestry production research *per se* would be concerned with ecosystems primarily in this context. Farm - ecosystem interactions are viewed with respect to their eventual impact on the farm.

2. A more explicit emphasis on ecosystem-level diagnosis and design is appropriate for regional development and settlement projects, and for special interest projects for fuelwood production, watershed protection, evironmental rehabilitation or large scale diversification of agricultural and forestry production. All of these serve a broader client group than a particular type of farm household.

In development, settlement and large-scale special purpose schemes there is a need to identify clearly the client group and/or region, the target (now de facto client) group, the target area (or system), and their interactions. This is particularly true for regional scale watershed

and development projects that must reconcile the conflicting needs and demands of several groups and land use systems to meet specific regional or national objectives. Examples include: the rural/urban conflict over land and water use criteria for rural upland watersheds and small farmer risk-aversion and labour minimization vs. increasing national demands for higher production of food and foreign exchange from rural areas.

Description and Analysis of the Human Ecosystem for D&D applications

Whether the project is aimed at a particular farming system, or at a whole ecosystem, the general procedure is the same. The difference will be one of detail and emphasis. The basic tasks are:

1. Definition of boundaries 2. Stratification (sub-division of the ecosystem and some of its components) 3. Description of system structure and function	PREDIAGNOSTIC STAGE (part 1)
4. Identification of problems and potentials and their distribution 5. Elaboration of design specifications for solving problems and realizing potentials (for the ecosystem in general, or by sub-units in projects with an ecosystem focus)	DIAGNOSTIC STAGE (part 2)

Any one or all of these procedures may be used to complete Steps 1.3 and 5.3. 1, 2 and 3 (above) are particularly applicable to Step 1.3, and parts 3 and 4 are most important for Step 5.3. 5 is intended as a supplement for Step 6, to add ecosystem-scale criteria to land use system criteria for technology design. Guidelines are provided below for each task and may be supplemented by information and guidelines from appendices A-8, B-1, B-2, B-6 and B-9.

Prediagnostic Stage

1. Define the Human Ecosystem

The boundaries of the human ecosystem may be defined by various criteria. For the sake of convenience in mapping and analysis the suggested boundary is the watershed (drainage divide) that most closely approximates the socioeconomic environment identified in Step 1.2. See Appendix A-8 for further details on watershed definition and/or description.

This first option may not be appropriate for some cases, particularly in areas where topography and drainage conditions make watershed boundaries less significant. The most obvious alternatives are the land unit(s) or land system(s) identified in Step 1.1 or the corresponding socioeconomic environment unit (Step 1.2). The latter may be political or administrative boundaries, or the area served by a given market. The choice will depend on which boundary is more inclusive and/or distinct, as well as on the emphasis of the project.

Yet another alternative for ecosystem boundaries could be a finite expanse of a vegetation type (such as forest or savanna) or a land use type (such as a contiguous area of pastoralist lands within a larger savanna, or a large logged area within a much larger forest).

Once defined, provide a sketch or map of the ecosystem boundaries.

2. Sub-divide the Human Ecosystem into Functional/Structural Sub-units

This recommended option may be used for pre-diagnostic Step 1.3 or diagnostic Step 5.3. Review the information on land units, land use types and population groups identified in Steps 1.1, 1.2, 2.1 and 2.2. then answer the following questions:

Is there an identifiable spatial organisation of the groups identified in Step 1.2.

Are they associated as groups, or as functional combinations of groups, with any particular land unit(s)?

Is there a characteristic settlement pattern for the area as a whole by sub-area or by group?

Is the population clustered, dispersed, concentrated in one place or along a river or road?

Are activities associated with meeting each basic need (for the households in the ecosystem) relegated to a particular group and/or area?

Based on the responses to these questions and general knowledge about the ecosystem under study, consider the following suggested criteria for ecosystem stratification:

Land use
- type of product
- degree of commercialization
- intensity of use
- level of technology
- land cover

Land tenure
- type of ownership/terms of occupancy
- size of holdings

Group function/occupation
example: farmers
artesans
merchants
wage laborers/farm workers

Ethnic group
example: indigenous farmers
recently-settled pastoralists

Land units
example: hillslope
valley
ridge

Choose from these examples or from other pertinent criteria to

stratify ecosystem. Whenever possible try to combine socioeconomic and biophysical criteria to arrive at the final grouping. The major criterion, for example, may be land use while secondary criteria include both land units and population type or population density.

Three examples are provided to illustrate stratification of ecosystems. In the first case the ecosystem is defined by watershed boundaries, and it is sub-divided geographically (see Fig. 1) into four areas defined by a combination of land units, land use, and population, as follows:

1. town in river valley, densely populated by landless laborers and merchants

2. large cash crop farms on broad terraces and lowhills, sparsely populated by land owners and permanent employees

3. small farms with subsistence and cash crops on foothills, populated by small landowning households

4. forest and shifting cultivation plots on steep slopes, sparsely populated by landless farmers

In the second example the ecosystem is defined by an administrative unit with undulating to flat topography in a broad plain. It is subdivided by land use types which are functionally associated and occur in a repetetive pattern on the landscape (see Figure 2). The sub-divisions are:

1. densely populated town
2. cash crop estates
3. small farms and grazing land populated mostly by households that depend on employment in the estates
4. forest areas held by the estate owners and used for firewood, timber and food collection

In both cases there is a pronounced spatial organisation of land use and production activities. In the first case the pattern is unique within the ecosystem and is formed by 4 contiguous areas. In the second case the pattern occurs on a smaller scale and is repeated throughout the ecosystem. The sub-divisions in the latter case are defined more by land use than by location.

In an ecosystem where there are marked contrasts between ethnic groups, particularly when these transcend differences in land use *per se*, this may be the major criterion for stratification. An example would be an area where recently settled former pastoralists and traditional farmers reside in adjacent lands of simlar characteristics and both engage in semi-commercialized food crop production and cattle raising.

The stratification by ethnic group would be warranted for several reasons: the difference in *how* they perform the activities, their differential impact on the biophysical resource base, the distinctive socioeconomic organisation, the variation in requirements to fulfill basic needs, and the potential for complementary vs. competitive utilization of resources and production of goods and services.

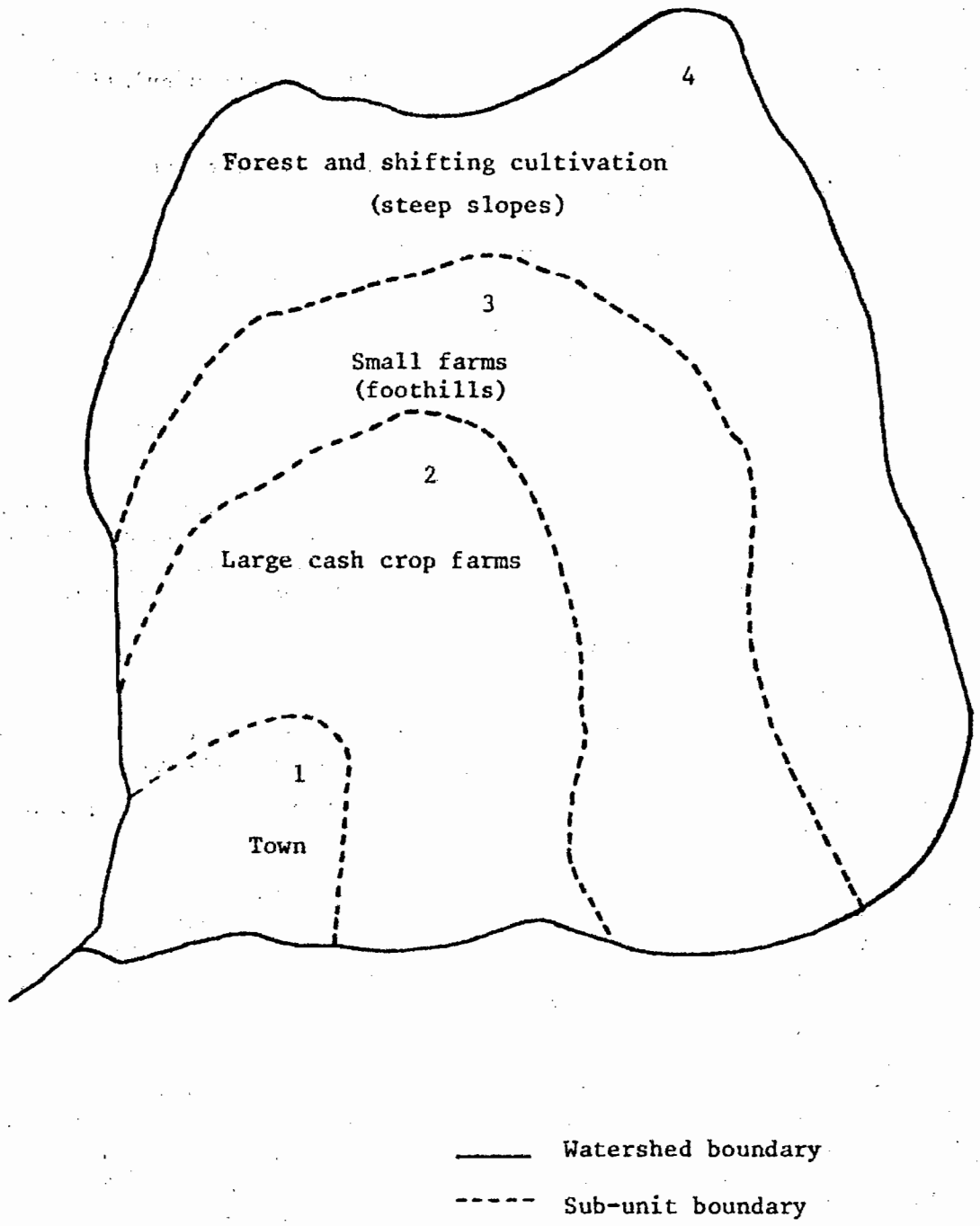

Figure 1

Geographical stratification

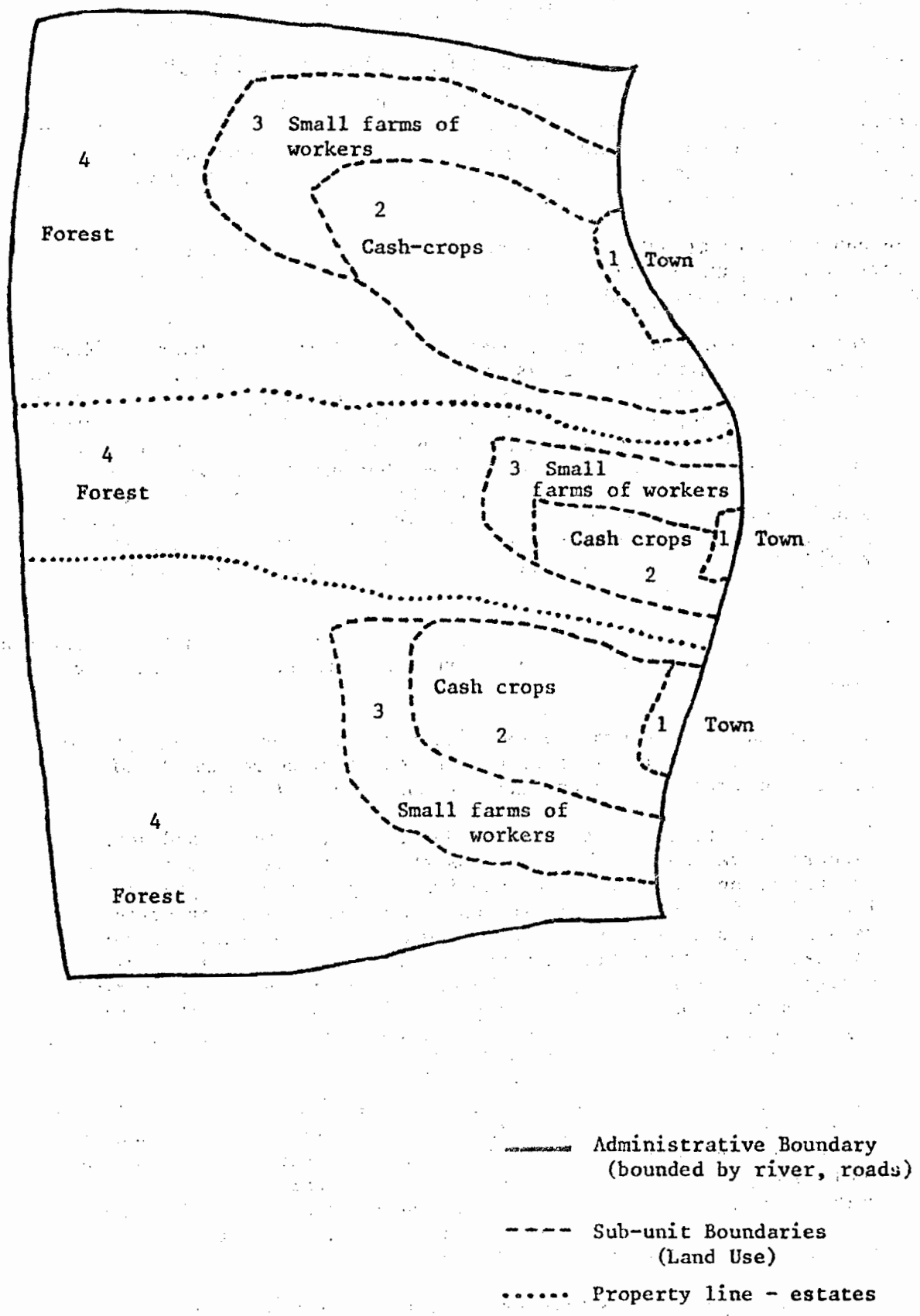

Figure 2

Stratification by Functional Criteria

3. Describe Structural/Functional Attributes of the Human Ecosystem

Guidelines and Checklist for Functional Ecological Description

The ecosystem description by functional attributes (see checklist) can apply to the whole area and its population, or it can distinguish between separate land units, vegetation types, animal populations and human populations. The latter can be sub-divided on the basis of geographical, ethnic, or socioeconomic considerations.

The checklist is almost self-explanatory but some guidelines are provided here, particularly for the subdivision of responses into the more detailed groupings mentioned above.

1. Energy sources are already classified as external or internal (from outside vs. inside the ecosystem) and as free or purchased (no payment vs. labor, material or cash exchange). External free sources include solar radiation, unlimited fuel wood gathered outside the ecosystem, rainfall (which may serve as a multiplier to solar energy in plant production, or which may feed streams that power waterwheels or hydroelectric plants). External purchased sources could include disesel fuel, kerosene or charcoal bought from other areas. Internal purchased energy sources might include a local lignite deposit, or fuelwood (which is really solar-derived) purchased from neighbours by exchange of food.

   Free internal sources could include cattle dung gathered from individual pastures or common land or wood gathered from individual farms or common land.

   Sources, uses and users are identified so as to establish degree of dependence on outside sources and degree of complementarity of production among groups and areas within the ecosystem.

2. The physical resource base is divided into land, water and soil resources available within the ecosystem boundaries. Land can be treated as one Unit or can be subdivided by land units previously identified in Step 2.1. If sub-units are used, the information required should be provided for the whole area and each sub-unit. The land unit description can be provided under land type, area should be reported in ha, and the proportion of land area in different land covers or uses should be reported (if known), or estimated. Suggested categories are forest, bushland, pasture/grassland, perennial crops, annnual crops and flooded paddy.

   Water sources or potential sources are identified as flows (such as streams, springs) or storages (such as water impoundments, natural lakes, groundwater). The method and ease of access are listed (e.g. "well-pump, public, village ctr" or "river, public, 2hrs. average walk"). Amount refers to whether the water supply is limited and/or seasonal. Use should be described as domestic, livestock watering, irrigation, handicrafts/industry or other.

   In the case of a single source used for all of the above, multiple use could be cited, or list the dominant use, then multiple (e.g. irrigation - multiple). Soil resources may be described in general, by land unit or by soil type. The major consideration for this analysis is whether soil depth or condition (erosion, soil degradation) is limiting for all or part of the ecosystem.

3. Primary producers

The vegetation of the area as a whole may be summarized or the specific vegetation types may be listed separately (preferable). For example, unimproved pastures, second growth Acacia woodlands and mixed annual and perennial crops might be entered as the major vegetation types in an ecosystem. The land area covered in each can be estimated and the biomass may be estimated depending upon the focus of the project and the available information. The identification of uses for each vegetation type (e.g. *fuelwood* and *grazing* in second growth woodlands) can be supplemented by an estimate of harvest (for example the volume of firewood harvested or the amount of biomass grazed). An alternative to the latter would be to list the stocking rate and the number of people dependent on this vegetation for firewood. The identification of the users, as such, can be quantitative as above, but it is more important to identify the groups (for example: migrant seasonal laborers, or landless town-dwellers, or landowners or sharecroppers). In the case of plants or plant products that are sold, the use and the users are double. For example, food crops sold by hillslope farmers to valley town-dwellers would be listed as

Use: 1. cash / 2. food

Users: 1. hillslope farmers / 2. valley town-dwellers.

Purchased plant products are described simply by type, amount, use and user. Only the end use and the final user (consumer) are identified. These refer to purchases from outside the system.

4. Secondary producers are animals, whether wild or domestic. Ecologically they are consumers by virtue of their dependence on plants but they are also producers for those higher on the food chain. Animals may be treated as a composite category or they may be sub-divided into groups of major importance to the ecosystem (for example; domestic animals vs. wild game in the savanna; goats, chickens and cows in a farming community). As in the case of plants, the uses and users must be specified in more detail for commercialized products; for example, cattle raised by pastoralists and sold to farmers would be listed as follows:

Use: cash/meat
Users: pastoralists / farmers

5. Consumers usually consist of the human population, which may be subdivided by geographical, ethnic and/or socioeconomic criteria. The total population and that of the sub-groups should be estimated if possible. Labor utilization is described by end product (e.g. basic household or community need(s) satisfied by labor), use (cash, food, water, fuel, shelter, raw materials); the kind of activity; the place *where* the work is done (outside the ecosystem or inside; type of land use unit) and the employer (self, company, community group, farmer/landowner). If the employer is a local farmer or landowner he/she may be identified by sub-group (if previously defined).

6. Investment/Savings

The first category, liquid assets, refers to the amount of cash normally available (total) its relative distribution by sub-groups, and, the main uses to which it is put (also by sub-groups, if different). The infrastructure should be described at the community level and if pertinent by sub-groups. It refers to roads, water works, drainage works, buildings, corrals. More detail may be provided under the headings: type, amount, value ($ or labor invested) providers, uses, and users. Providers and users may often but not always be the same. For example, the government may provide a road for local people to use.

Capital items may be listed if important. Plows, other tools, machinery, vehicles, large stores of agrochemicals would constitute major items. Other forms of savings and investment may or may not already have been listed under other headings. Jewelery, for example may constitute a large proportion of a household's wealth in some cultures and would only be listed as a savings/investment. Cattle might also fulfill a banking function and should be mentioned as such although it is already listed under secondary producers.

7. Handicrafts or manufacturing should be listed if applicable. The activities are identified first, then type and source of raw material, followed by estimated number and group identity of employees, the use of the products (e.g. household use or cash/ornamental) and the users. The users are the persons who sell the products and/or the persons who use them directly. The users may be the artesans who earn cash by selling the items and the tourists who buy them (users: farm wives/ tourists) or the users may be only the artesans' families (users: same household). In a wage/labor situation the user may be the employer *and* the person who buys the product (user: company X/city dwellers outside ecosystem). The information on labor utilization and handicrafts/manufacturing may overlap and should be used jointly to describe labor use and distribution.

Checklist 1. for Ecosystem Description*
Emphasizing Functional Attributes

1. Energy Sources

	type	source	use	users
external				
free, constant				
purchased				
internal				
free				
purchased				

2. Physical resource base (on-site)

	total area	type	cover (% area under different cover, uses)
Land -			

	type	access	amount	use	users
Water -					

	type(s)	% area covered	depth	condition
Soil -				

3. Primary Producers

	area	type	estimated biomass **	yields**	uses	users
Vegetation						

	type	amount	uses	users
Plants/plant products purchased from outside				

---

* Can be used as is, or as a basis for functional diagramming with energy language symbols (See Appendix B-8).

** Option.

4. Secondary producers

	type(s)	no.	uses	yields (optional)	users

animals

	type	amount	uses	users

animals/animal products purchased from outside

5. Consumers

	sub-groups	population	labor utilization end product/use/where/employer

people

6. Investment/Saving

	amount	distribution	uses

Liquid assets($)

	type	amount	value	providers	uses	users

Infrastructure

Major capital items

Other

7. Handicrafts/other industries

Activity	raw material	type/source	people employed	uses	users

Guidelines for Completing Input-Output Checklist (2) for Evaluation of Human Ecosystem Structure and Function

Checklist 2. (see next page) can be completed by answering two questions and coding the answers.

1. Do the households in this group or area import(-) export(+) or sustain themselves (√) with respect to the goods required to fulfill the basic needs or to supply the resources in the list across the top? In addition to noting import, export and self maintenance, is there a deficit (x) or a surplus (*) with respect to the categories listed? It is possible, for example, to import fuel and to still have a deficit. The code for fuel for such an area would be -x, for import and deficit. (See the checklist and the completed sample which follows).

2. What are the sources of imports and the destinations of exports? Each area or group within the ecosystem has a number assigned, including the groups and area outside the ecosystem which are assigned the last number. The cases where export(+) or import (-) are listed should also include the number of the destination or source areas. For example the food in area 1 is imported from within the ecosystem (3) so the food code for area 1 is -3, indicating that it is imported from area 3 in the ecosytem with no notable deficits or surplus in area 1. See legend on sample completed checklist.

The completed form can be used to draw a system diagram (Appendix B-8) or it can serve, as is, to identify the pathways of energy, material, cash and services between the subdivisions of the human ecosystem. An extension of this step, tentative identification of problems and potentials, easily follows from this input-output checklist. Deficits can be viewed as symptoms of problems and surplus as indicators of potential. The incidence of either one can be noted, by subdivision and by need/resources type. For example, in the sample checklist: valley farms/water deficit; hillslope farms/labor surplus; town/cash deficit; valley farms/cash surplus. These subdivisions and topics can be singled out for closer attention during the diagnostic phase.

Checklist 2: Input-Output Checlist for Evaluation of Human Ecosystem Structure and Function

Group or Area		Selected Basic Needs/Resources					
Name*	Number**	Food	Water	Fuel	Raw Materials for Shelter	Raw Materials for Industry	Labor
A	1						
B	2						
C	3						
D	4						
E***	5						

* Group area names should be placed here; letters placed for example only.

** Assign a number to each group for coding purposes on checklist.

*** The last category is always reserved for all the groups or areas *outside* of the ecosystem under consideration.

For an example of completed form see next page.

Completed sample

Input-Output checklist for Evaluation of Human Ecosystem

Group or Area		Selected Basic Needs / Resources						
Name	Number	Food	Water	Fuel	Raw Material for shelter	Raw Material for Industry	Labor	Cash
Hillslope Timber Forest	1	-3	✓	✓	✓	✓	✓/ 3	-5
Hillslope Farms	2	✓/ 3	✓	-1	-1	✓	+*4,5	-x4,5
Town	3	-4,5	-1	-1	-1	-1,4	+*1,4,5	-x5
Valley Farms	4	✓/ 5	-x1	-1	-1	✓	-3	*
Outside	5							

- import
+ export
✓ Self-sustaining
x deficit
* Surplus
✓/ import part, produces part
+* exports, has surplus
* Self-sustaining and has surplus (not export)
x Self-sustaining with deficit
-x imports, still has deficit
+x exports, has deficit within

Diagnostic Stage

4. Identification of Problems, Potentials and Their Distribution

Problems and potentials at the ecosystem level can be identified, described and located by following the sequence listed below:

1. List the symptoms of problems (or potentials) for the ecosystem as a whole and (optional) for the sub-units defined previously by stratification of system. The aggregation of problems by ecosystem units and sub-units is an analytical step that does not necessarily imply new information needs. The general guidelines for problem identification at the pre-diagnostic and diagnostic phase should suffice for information gathering. Determination of problems and potentials at the pre-diagnostic phase can take the structural/functional analyses and Appendix A-2 as points of departure for problem definition. Identification of ecosystem problems and potentials through diagnostic interviews and field observations should follow the guidelines in Appendices B-1, B-2, B-6, B-7 and A-8

2. Identify the apparent causes of the problems or unrealized potentials listed above. Causal or functional diagrams may be used, along with the functional ecosystem description and the input - output checklist, to trace each problem to its source(s). The latter exercise is especially useful if the causes are not very obvious or if they are multiple.

3. Locate causes by source area and/or by ecosystem sub-units. Indicate whether each major problem/potential (in the whole ecosystem and in each subdivision) has its source outside the ecosystem, within the ecosystem as a whole, or within a specific sub-unit(s). To determine the source(s) consider the questions which follow.

   Does the problem (or potential) have a definable cause attributable to a particular source inside or outside of the ecosystem? If so, list the sub-unit and specify the activities or land uses involved.

   If not, is the problem (or potential) based on an overall condition of the ecosystem (natural or otherwise)? If it is based on such a condition, is that condition changeable? (like current land use) or is it an inherent characteristic of the ecosystem (like rainfall)? If changeable, how readily could it be changed?

4. (Option)
   Transfer and code the information from the 3 previous steps onto the problem/potential checklist for ecosystems. It is helpful to complete the checklists for structural/functional description and input-output analysis, prior to this step. A blank checklist with instructions, and a sample completed form are provided for identifying problems/potentials by sub-units affected and by sources.

Checklist for Distribution of Problems/Potentials in Human Ecosystems

Group or Area Affected by Problem/Potential		Basic Needs affected					
Name	Number	Food	Water	Fuel	Shelter	Raw Material for Industry/Handicrafts	Cash
Source(s)							
Source(s)							
Source(s)							
Source(s)							
Source(s)							

On the top line of the first box list the name of the area/group affected, in the next column list the number assigned to it, then list the main problem(s) or potentials) under each basic need and list the number of source area(s) or group(s) on the line under the Problem. Of the problem source is a condition of the whole ecosystem the area/group number is 0. In this case also list L if it is an inherent limit of the ecosystem and list C if it is a temporary or changeable constraint of the whole ecosystem. See the sample completed checklist, with legend for clarification,

5. Elaboration of Design Specifications for Technologies

Based on the nature of the problems or potentials encountered, and the ecosystem (or sub-units) where they occur, specify the performance criteria for new technologies. Label the specifications by the area or sub-unit(s) currently affected and by the area where the technology is to be implemented.

An example is provided to illustrate the application of design specifications in one land use system to solve a problem in another land use system. A rural town is experiencing a fuelwood shortage due to the recent (and rapid) deforestation of nearby hillslope forests by small farmers. It is not feasible to fill the town's fuelwood demand by technology and land use changes within the town itself. An intervention in the forest/farm area is suggested.

The problem symptom, in this case, is felt in the town, the cause resides (at least in part) within the hillslope forest/farm area and the technology specifications apply to the latter. The hillslope farmers' own problems also generate technology specifications for their land use system. They list cash and fodder shortages as major problems. The resulting specifications (or design criteria) for technology in the hillslope forest/farm area include increased fodder production, development of a cash crop or cash-earning activity, and production of fuelwood, if possible, for the town.

The purpose of this exercise is to provide ecosystem-scale inputs to the process of technology design. Criteria from the ecosystem or some of its sub-units are included in the list of design specifications for individual land use systems. The weight or priority eventually assigned to these larger scale criteria will depend on the emphasis of the project and the definition of client and target groups.

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Compressed Sample

Checklist for Distribution of Problems/Potentials in Human Ecosystem

Group or Area		Basic Needs Affected					
Name	Number	Food	Water	Fuel	Shelter	Raw Material for Industry/ Handicrafts	Cash
Town Source(s)	1	Insufficient local staples 2,3 High price of food from outside 5	Water infrastructure damaged by silt 3	Fuelwood shortage 1,4	Timber shortage O,C	Lack of raw material for local or artesans or new indutries 2,3,4	Unemployment 1,2
Valley Farms Source(s)	2	-	Irrigation works damaged by silt 3	-	Timber shortage O,C	Potential for more intensive production of fruits, fibres 1,2	-
Hillslope Farm Source(s)	3	Food shortage, low yields, high price of inputs 3,5	-	-	-	Potential for more intensive production of tree crops for local processing. 1,3	Seasonal unemployment.
Valley Rangeland Source(s)	4	-	Water shortage for cattle O,L	Fuelwood shortage 4 *	-	Potential for intensive use of hides 1,4	Low prices for beef, milk 5
Outside Ecosystem Source(s)	5	-	-	-	-		

O = whole ecosystem
L = limits on whole ecosystem, more or less permanent
C = constraints on whole ecosystem, subject to change
* = Note that the problem may originate in the same group or area that is affected.

APPENDIX A-6

NOTE ON THE ICRAF BASIC NEEDS APPROACH*

As the concept of "basic needs" has been developed and applied in different ways in other contexts, it is important to specify clearly what is meant by this approach as developed for agroforestry purposes by ICRAF. The basic points are as follows:

1. In analyzing land management systems, we have identified the household management unit as a prime focus of D&D attention because this is where most of the land management decisions are made.

2. In our approach to the modeling of household land management systems, we define the subsystems in terms of *outputs*. In other words, the *output subsystem* is defined as the set of all activities, resources and other landuse factors which are involved in generating an output which satisfies one of the major production or land management objectives of the household.

3. In deciding specifically what output categories to consider in defining the major subsystems, it is important to satisfy two requirements:

a) general applicability, and

b) adequate representation of the characteristics of local land use systems

4. To satisfy both requirements and also to facilitate subsequent linkage with categories of agroforestry potentials, a basic needs approach is indicated. The production outputs which may be considered basic to the economic wellbeing of people everywhere are:

- food
- water
- energy
- shelter
- raw materials for local industries
- cash
- savings/investment
- social production

*Contributed by J.B. Raintree

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5. The assumptions which underlie this approach are

   a) that the needs in the above list are basic and univeral, and

   b) that local and regional land use systems are in large part organized so as to satisfy these basic needs.

6. It is important to emphasize that, in espousing this approach, the aim is to insure satisfaction of basic needs but *not* to restrict development efforts to only minimal satisfaction of these needs. Rural development needs *floors*, not ceilings. One implication of this approach is that, once subsistence needs are adequately satisfied, the emphasis shifts to improvements in the cash or savings/investment subsystems.

7. To further clarify this point, in referring to 'basic' needs we mean basic *types* of needs, rather than basic *levels* of need satisfaction. For example, a particular household may be well above the subsistence level in its production of cash but, because of drought or deforestation may have serious problems in meeting its food and fuel requirements. Cash income, which is normally taken as the prime indicator of economic wellbeing, is not always readily convertable into a form which satisfies the other basic needs (e.g. one definition of 'famine' is that there is no food to buy, even if you have the money). For this simple reason, it is necessary to consider the performance of each basic output subsystem separately.

8. Having identified the subsystems in which the problems exist, and having traced the symptoms and antecedent causal factors, analytical aids are then used to model problem etiology and identify agroforestry potentials (see Appendix B-7). For each subsystem the general question is: *Is there anything that trees can do to improve the performance of this subsystem?*

A partial list of the general types of answers which are possible is given below.

POTENTIAL CONTRIBUTION OF TREES TO BASIC NEEDS SUBSYSTEMS

Food Subsystem

a) *Human food* from trees (fruits, nuts, cereal substitutes) at low input levels on marginal land

b) *Livestock feed* from trees (one step down the trophic chain)

c) *Fertilizer* from trees from improving the nutritional status of food and feed crops (through the *addition* of atmospheric nitrogen

to the soil system by leguminous trees, through *improvement of access* to a greater volume of subsoil nutrients by the nutrient recycling action of appropriate trees and also by the *improved availability* of soil nutrients which often accompanies the higher CEC levels associated with the higher organic matter levels and improved physical structure of tropical soils under the influence of appropriate tree canopies)

d) *Soil Conservation* effected by trees in agroforestry intercropping systems has a direct and measurable long term benefit on the production of food crops from the protected fields

e) *Micro-climate amelioration* associated with properly spaced trees (e.g. the "shelterbelt effect") can also have a direct impact on food crop production (e.g. 30% increase in Russian wheat yields attributable to shelterbelts)

Water Sybsystem

a) *Regulation of water delivery* for human consumption, household use, watering of livestock, etc., through reduction of runoff and improvement of interception and storage in infiltration galleries (various watershed management practices involving trees)

b) *Improvement of soil moisture retention* by rainfed cropping systems and pastures (soil structure and microclimatic effects of trees)

c) *Protection of irrigation works* by hedgerows of trees

d) *Prevention/reduction of downstream flood damage* by various watershed management uses of trees

e) *Improved drainage* from waterlogged or saline soils by phreatophytic trees

f) *Increased biomass storage* of water for animal consumption in forage and fodder trees (higher water content of feeds in dry season)

Energy Subsystem

a) *Woodfuels*

   i) firewood
   ii) charcoal

b) *Methanol* (wood alcohol)

c) *Ethanol* (from fermentation of high carbohydrate fruits, e.g. *Prosopis* pods)

d) *Producer gas* from charcoal

e) *Latex* and other combustible saps and resins

f) Other fuels and energy technologies under the general heading of *biomass*

g) Augmentation of *windpower* by jet stream effects of appropriate tree arrangements

Shelter Subsystem

a) *Building materials* for housing

b) *Shade trees* for humans and livestock (and even some heliophobic crops)

c) *Windbreaks* around settlements, fields and pastures

d) *Living fences*

Raw Materials Subsystem

a) *Wood* for a variety of craft uses

b) *Fiber* for weaving industries

c) Ingredients for *medicinal preparations*

d) Etc.

Cash Subsystem

a) *Direct cash* benefits from sale of the above listed products

b) *Indirect cash* benefits of non-tree crop productivity improvements effected by trees (e.g. higher profits from savings in fertilizer costs)

Savings/Investment Subsystem

a) *Addition of a savings/investment enterprise* on farms now lacking one (e.g. growing of high value timber trees for future educational expenses, etc.)

b) *Improvement of existing savings/investment enterprises* by a variety of tree roles (e.g. fodder trees in systems where livestock play the role of "savings on the hoof")

Social Production Subsystem

a) *Production of goods in kind* for social exchange purposes (e.g. fruits, more livestock for ceremonial occassions or marriage needs, etc.)

b) *Increased cash* for social purposes (e.g. political contributions, taxes, gifts, etc.) by means of various productive or service roles of trees.

APPENDIX A-7

GUIDELINES FOR DESCRIPTION OF FORESTRY PRODUCTION SYSTEMS*

In cases where forestry management units in the study area are to be diagnosed, Worksheet 3.1. which is oriented toward the description of household management systems, may not provide an appropriate format for description of forestry objectives, management practices, and locations.

To meet this need, a sample matrix format for description of forestry management systems is given on the following page. Guidelines for completion of the matrix are given in the form of examples in the appropriate boxes.

---

*Contributed by P. von Carlowitz

Type of Forest	Management Type	Management Practices	Main Products/Output	Secondary Products/ Outputs	Location

Type of Forest	Management Type	Management Practices	Main Products/Output	Secondary Products/ Outputs	Location
Indigenous dense, mainly broadleave forest	- Timber Production	Selective logging (min. girth); Plenter-system; Timber Stand Improvement (increase of commercial valuable species); Natural regeneration	Sawn-and Construction timber, peeler logs	Fruits, game, oils fuelwood, charcoal, a.o.	e.g. low populated humid plains or sloping hill/ mountain sites
	- Protection	Minimum logging; maintenance of undergrowth and groundcover	Watershed protection, erosion prevention	Fruits, nuts, game, mushrooms etc.	e.g. Catchment areas, slopes, hill crests
	- Recreation	Minimum logging, nature preservation, improvement of accessability	Recreation, amenity	Soil & Water conservation	usually in gazetted forest areas
Savannah Woodland	Usually extensive low management level	e.g. promotion of valuable fodder trees; lopping or pollarding for fodder production and fuel	Fuel, charcoal, fodder	Prevention of water and wind erosion	Usually in the low populated subhumid, semi-arid or arid plains
Mangrove Forests	Wood production	Selective cutting or clear felling; natural regeneration.	Construction timber (for low-cost housing) poles, fuelwood,	Riverbank preservation	Coastal strips, lower courses of rivers, river mouths
Commercial Man-made Forest	Wood and Timber production	Usually artificial establishment (planting, direct sowing or coppicing for regrowth; usually thinning in intervals; clearfelling on fixed dimension-oriented rotation periods	Sawn and construction timber, other industrial wood (mainly pulpwood, poles, mine timber, wood for chip- or particle boards railway sleepers etc)	Fuelwood, charcoal, fruits, game etc.	Usually government-owned or not settled land

(Cont'd) Communal Forests (mainly man-made)	Mono-or limited multi-output production	Artificial establishment (planting, direct sowing); thinning in intervals, clearfelling on fixed, mainly dimension-oriented rotation periods; preferably coppicing regime, but subject to species	Fuelwood, charcoal, poles	Recreation, protection, fruits etc.	Usually close to settlements
Household (social) Forest (Woodlots)	Mono-or limited multi-output production	Artificial establishment (planting, direct sowing); thinning in intervals, clearfelling on fixed, mainly dimension-oriented rotation periods; preferably coppicing regime, but subject to species. Thinning may be irregular and according to need of wood products.	Fuelwood, charcoal, poles	Protection/shelter	Usually within or next to farm

APPENDIX A-8

WATERSHED EVALUATION GUIDELINES*

Combining Farming System and Ecosystem Analysis in Watersheds

This hybrid approach combines elements of farming system and ecosystem analysis drawing from the work of Antonini *et al* (1975) Brakensiek *et al* (1979), Gil (1979), Hart (1980), Hildebrand (1981), Likens *et al.* (1977) Odum (1971, 1982) and Pereira (1973). Three units of analysis are suggested. The farm household, the small watershed (1-25 km^2) and the regional watershed (1,000-10,000km^2). The first two will be the most commonly used for D & D applications, although regional analyses may later become important for defining feasibility and application domain for proposed technologies. The larger regional watershed analysis is most appropriate where erosion and watershed protection are issues of concern (Hamilton 1983).

The small watershed provides the natural context to combine concerns of regional resource management with local farm production and land use systems. Streams draining the area integrate outputs of water, nutrients sediments, pathogens, and toxins from several farm households. Streams can be monitored later for ecological changes reflecting community-level land use changes. The movement of goods, animals, currency and people across watershed boundaries can be estimated through a combination of field observation, interviews and farm records. Roads, paths and property lines often follow the water divides in rough terrain, thus reinforcing the convenience of this unit of analysis.

The analysis of small watersheds can provide a key to understanding the ecological and economic interaction between given farming systems, related land uses, runoff and erosion. It also clarifies the relationship between the farming system(s) in the small watershed and the larger regional system. The small watershed also provides the link between farm level erosion rates and sedimentation of major rivers and reservoirs.

The guidelines provided below (short and complete forms) may be applied at any one of the three scales. The analysis should normally be conducted in at least two of the three units listed, to identify linked problems and solutions between different levels in the nested hierarchy of watersheds (or other ecosystem units).

---

* Contributed by D. Rocheleau

Guidelines for Watershed/Water Resources Evaluation: Short Form

Inventory and Evaluation of Water Resources*

1. Resource base

   1.1 inherent characteristics

   -- water balance (based on climate, topography, soil, land cover, ground water)

   -- type and location of potential water sources

   1.2 conditions

   -- historical, current, trends (quality, availability, accessibility of water resources, and changes over time)

2. Resource utilization

   2.1 use of resource (list type, amount use, by activity: domestic irrigation etc.)

   -- consumptive (water degraded and/or disposed; includes) substantial evaporation and transpiration increases)

   -- non-consumptive (water returned to source directly or indirectly in usable form)

   -- historical, current use trends by activity (domestic, municipal, irrigation, nursery, cattle, industry)

   2.2 special planned, projected uses?

   2.3 problems, perceived by:

   - clients
   - residents
   - project staff
   - survey team

---

* For interview guidelines see Appendix B-2.

Note area of reference (may be farm, community, land unit, watershed or other ecosystem unit), refer to appropriate map presented in previous sections.

Guidelines for Watershed/Water Resources Evaluation: Complete Form

1. Define Boundary Watershed

   1.1 If pre-defined, identify (watershed *per se*, area influencing dam, etc.)

   1.2 If region is ambiguous (political or project area), take larger watershed which includes *all* of project area, *or* smaller watershed(s) which includes *most* of project area, depending on convenience, institutional constraints, interests.

2. Identify areas of *impact* of major interest (indicate type and location)

   2.1 outside watershed

   2.2 inside watershed

   for: soil loss, water loss, channel erosion, deposition, sedimentation, flooding, waterlogging and water shortage.

3. Define client group

   3.1 Is primary *client* group inside or outside *target* area (i.e. is is local residents or water users downstream?).

   3.2 If it is *outside* area, then identify problems and *needs* of client I, in order to best choose the second client group, within the target area, that will have the most potential for helping to meet group I's needs Now a common interest needs to be found, which requires:

   - better characterization of watershed/ecosystem

   - diagnosis of problems/potentials in target land use system(s)

4. Watershed Description

   4.1 Form

   4.1.1 Size, Shape, Location

   4.1.2 Drainage density and pattern including drainage infrastructure

   4.1.3 Average slope, soil depth

4. Process

4.2.1 Rainfall characteristics and water balance*

- under natural vegetation
- existing

4.2.2 Flow characteristics of surface waters (river regime)

- Average monthly discharge (quantitative data or quality description)
- Stability (describe changes over time if significant)
- Description of flood (with 1. freq 2-3 times/year)
  2. freq 10 times/year)
  - Timing
  - Volume, velocity
  - Debris
  - Colour

4.2.3 Conditions of Channels

- Erosion
- Deposition
- Cover on banks
- Shifting of channels

5. Water Resource Evaluation

5.1 Disposition of water resources

5.1.1 of Surface Water

-- Withdrawal

- Where?
- For?

domestic
municipal
irrigation/nursery
cattle
industrial
other

-- Inpoundment

- where?
- what type? hydroelectric, water supply, both, other

---

* Use any standard method (Holdridge, 1967; Penman, 1963; Thornthwaite, 1957) indicate which method and note vegetation or land cover coefficients used.

- for? (domestic, municipal, cattle, nursery, irrigation, industrial)

-- Contamination

- where?
- what kind? (chemical, biological, physical sediment)
- source: (domestic, municipal, cattle, nursery, irrigation, industrial)
- User: (domestic, municipal, cattle, nursery, irrigation, industrial)

5.1.2 Of Ground Water

-- Withdrawal

- where?
- for? (domestic, municipal, cattle, nursery, irrigation, industrial)

-- Contamination

- where
- what kind? (chemical, biological, physical)
- source? (domestic, municipal, cattle, nursery, irrigation, industrial)
- for? (domestic, municipal, cattle, nursery, irrigation, industrial)

5.1.3 Soil Water

-- Water availability for plant growth by month, for average and critical years, under major land cover type found in watershed (see water balance, 4.2.1)

5.2 Problem Diagnosis (Based on records, observations and interviews*

5.2.1 Hydrology/sedimentation

- are there notable excesses (floods, waterlogging, salinization) or shortage of soil moisture, surface and groundwater?
- where?
- when?
- type damage?
- severity?
- history, changes over time?

---

*See appendix B-2 for interview guidelines. See appendix B-6 for observation guidelines on land management/degradation problems.

- what production activity or landuse system is affected?
- what production activity or landuse system (on or off-farm) may be a contributor.
- cause?
- if floods, are there problems of channel erosion, erosion channel, shifting channel deposits of sediment or deposits of sediment on flooded fields? where? when? severity?

5.2.2 Related land management problems

-- Soil erosion

- are there noticeable erosion features from

  wind?
  water? rill erosion
  gully erosion
  sheet erosion

  mass movement? landslides, landslips

  Give location on map or by land units and land use systems identified in environmental data sheet.

  Give severity

  Note history of occurrence, changes over time

-- Land degradation

- is there noticeable evidence of soil compaction/trampling?
  barren impermeable soil
  terracettes, other

  Give location(s), identify land units, land use systems

  severity

- is there visible or historical evidence of decreasing soil fertility?

  Composition or condition of crops, pastures or second growth vegetation in poor condition (not attributable to climate change/weather), pests/diseases, decreasing yields over time

- is there evidence of other land management problems at the ecosystem scale? (See appendix B-6)

  in general?

  in specific land use systems/land units?

  severity?

  history, trends.

REFERENCES

Antonini G.A., K.C. Ewel and H. Tupper, 1975. Population and Energy: A Systems Analysis of Resource Utilization in the Dominican Republic. University of Florida Press, Gainsville.

Brakensieck, D.L., H. B. Osborn and W. J. Rawls (Coordinators) 1979. Field Manual for Research in Agricultural Hydrology, Agriculture Handbook No. 224, Science and Education Administration, U.S.D.A., U.S.G.P.O. Washtington D.C.

Gil, N. 1979. Watershed Development with Special Reference to Soil and Water Conservation. F.A.O. Soils Bulletin 44, F.A.O. Rome.

Hart, R. 1980. Agroecosystems, CATIE. Turrialba, Costa Rica.

Hamilton, L.S. 1983. Executive Summary, in Forest and Watershed Development and Conservation in Asia and the Pacific, L.S. Hamilton (Ed), Westview Press, Boulder Colorado.

Hildebrand, P. 1981. Combining disciplines in rapid appraisal: the sondeo approach. Agricultural Administration (8), 6.

Likens, G.E., F.H. Bormann, R.S. Pierce, J.S. Eaton, and N.M. Johnson. 1977. Biogeochemistry of a Forested Ecosystem, Springer-Verlag, New York.

Odum, H.T. 1971. Environment, Power and Society, John Wiley and Sons, New York.

1982. Ecological and General Systems, John Wiley and Sons, New York.

Pereira, H.C. 1973. Land Use and Water Resources in Temperate and Tropical Climates, Cambridge University Press, London.

Additional References on the Water Balance

Holdridge, L.R. 1967, Life Zone Ecology, Tropical Science Center, San Jose, Costa Rica.

Penman, H.L. 1963, Vegetation and Hydrology, Commonwealth Agricultural Bureaux, Farnham Royal, England.

Thornthwaite, C.W. and J.R. Mather. 1955. The water Balance, Drexul Inst. Technology, Publ. on Climatology 8,1.

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APPENDIX A-9

LIVESTOCK PRODUCTION SYSTEMS*

Part 1: BIOLOGICAL ASSESSMENT OF LIVESTOCK PRODUCTION SYSTEMS

Various aspects of livestock production and management need to be understood before any reasonable suggestions can be made as to how sustainable production may be improved, and in order to ascertain the likelyhood of acceptance of the suggested measures. The information needs to be gathered from "farming" units (in the broad sense-includes pastoralists) from a broad a range of unit types: e.g. according to size, wealth, social group (e.g. caste), product specialization, etc.

1. Livestock type and numbers.

Each livestock type (e.g. cattle, goat, donkey) should be separated according to sex, broad age group and according to whether they are productive or not (in a biological sense) (e.g. how many mature females calved this year; how many are in milk; proportion of castrated to uncastrated males etc). Age at first breeding is also one important factor in overal productivity (again in a biological sense) - i.e. number of young produced per number of adults.

2. Livestock role

The role and relative importance of each group (e.g. sex, age group) within each livestock type (e.g. cattle, goat) should be determined. Livestock roles can be broken down into those which result in direct products and those which involve indirect benefits to agricultural production:

a) Direct Roles

- Animal products for home consumption
  Food: milk, blood, meat
  Non Food: wool, hair, hides

- Power
  Threshing, lifting of water, transport, ploughing

- Fuel (dung)

- Source of income or barter

  Income: milk, live young for rearing, stock for slaughter, non-food products

  Investment:

  Insurance/stored wealth

- Social
- Religious

---

* Parts 1 and 2 contributed by P.J. Robinson and W. Künzel, respectively

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b) Indirect Roles

e.g. dung production/fertilizer value, ploughing time/rain infiltration, power/release of labour for important production activities.

Average yields (e.g. offspring production rate, milk yields) can give an indication of the extent to which improvements may be achieved through certain ameliorative measures. The times of year when the livestock roles are of greatest importance should also be registered, since these often do not coincide with the periods when the livestock are optimally productive: for instance a high price for milk during the dry season may induce farmers to plan for milk availability at that time even though production is lower; or the sale of sheep/goats for the Muslim Pilgrimage Sacrifice (the date of which falls 10 or 11 days earlier in each solar year) requires over a certain number of years in the 34 year cycle that a large number of stock are kept during the driest and most unproductive part of the year (from a primary production point of view).

Although the assessment of livestock roles and their timing should be as perceived by the stock owners, a separate assessment by the investigator is worthwhile - particularly in the case of indirect roles- as the development of any new appropriate technology or practice may clearly depend on what alternatives there are to present production patterns. Further, the role of livestock in other farming systems should be assessed (e.g. pastoralist-cultivator livestock mediated relationships etc).

3. Feed and Water Sources

A preliminary inventory of the types and origin of feed sources over the year (e.g. pasture, agricultural residues, weeds, browse, gathered fresh grass, stored grass, tree fodder, or fodder crop etc.), should be made for each different categories of livestock: there can be differences in the feeding strategies for different animals - e.g. nutritious rations for ploughing animals. The ownership status of the feed resources should also be ascertained e.g. common, private, rented, exchanged for some product (e.g. dung).

An indication of the fluctuation in availability of fodder (quality and quantity) within the yearly cycle and also between years is desirable in order to explain certain management and production strategies.

Similarly the seasonal availability and location of water for livestock should be noted. Ownership of water resources can also be important. There are labour implications as well from both feed and water considerations.

In the case of nomads and semi nomads, the mapping of livestock movements over the year and their variation between years is important.

4. Other animal production related factors

Information on any other factors which influence animal health and production should be noted - e.g. pests, predators, thieving - if possible with an indication of the degree of influence.

The number of young deaths and the cause of mortality in young and mature animals should also be noted.

5. Management Practices

All significant management practices and their raison d'etre bearing on the following should be noted along with indications of labour requirements and any social specialization of labour (e.g. by sex or age group) for the particular management practice:

- Feed sources:

  e.g. grazing management, fire use, lopping strategies, pasture resting.

- Pests:

  e.g. measures to reduce the incidence of disease, predator control or protection from predators. Strategies for reducing the impact of livestock theft.

- Animal husbandry

  e.g. differential feeding strategies and herding of different animal types, controlled mating (time and type of animal), castration, culling of different types.

- Marketing

  e.g. Time of optimum production vs. demand time and time price differentials, marketing structure (e.g. guaranteed or market price, dealer monopoly, fluctuating product demand), distance to markets and feed opportunities on the way.

Part 2: SOME SOCIAL FACTORS TO CONSIDER WHEN EVALUATING THE PERFORMANCE OF TRADITIONAL LIVESTOCK SYSTEMS

Pastoral societies are known for their intricate network of social and and economic relationships revolving around if not centering on livestock. When considering traditional livestock systems these socioeconomic factors have a profound influence on the economic performance of a livestock orientated, especially pastoral, society.

Onwership and economic use of livestock or land are seldom a clear-cut state of affair but may take many different organizational forms. The number of animals a farmer has standing in front of his house, milks, tends or sells are often absolutely no indication of the number he owns or controls. A team working on the evaluation of a traditional livestock economy will have to take this into consideration.

To clarify the point, consider the example of a Wapare community living in the Western Usambara Mountains/Tanzania. Different tribes will have different systems of regulating the ownership of livestock, but the basic features are similar at least throughout East African Livestock-oriented societies.

Table 1. Wapere Livestock tenure: rights and obligations. (Source: Künzel et al., 1982)

Individually owned cows	These are inherited or bought, with the farmer having the right to dispose of them at will.
Cows received by son from his father	They often stay with the farmer permanently, but can be recalled by the father in times of need. The farmer cares for them and keeps the milk. The father receives all of the calves.
Cows received from friends or relatives	They often stay with the farmer permanently, but can be recalled by the donors in case of need. The farmer cares for them and keeps the milk. When receiving the cow the farmer will also receive a goat as payment for looking after the cow. All the calves will belong to the donor. Or, as another possibility, the farmer will not receive a goat but he will return the first and second calf, while the third belongs to him. This form of lending cows can be initiated by both sides. The donor can ask the farmer to take a cow, or the farmer can ask somebody to lend one. The farmer receiving the cow takes the obligation to help the donor in times of need.
Cows belonging to a wife	She may have received them from her father or her mother. The husband is in complete control of the management of these livestock, but he is not allowed to sell them. The cows and the milk belong to his wife, the calves belong to the wife's father. The woman may also decide to give part of her livestock to her daughters.

A case like this may have several implications for new technology.

For example, those farmers tending a lot of cattle (on overgrazed pasture) may not be interested in improved dairy cows because they don't own their stock. Those who own those cattle may equally not be interested because they would simply loose the benefit - improved milk production of improved cows - in case they give away those cows for social security. The scope for a successful introduction of dairy cows in such a case is much smaller than may appear superficially. The economic function "insufficient grazing ground plus insufficient milk production plus a market for milk products introduction of improved dairy cows" is not

valid here unless the programme is tailored to the varied ownership/ user relations regarding livestock of the target group. The evaluation team would have to record those ownership/user relations, assess their social and economic impact and identify the potentials for development.

How could this be done?

Some Methodological Suggestions

In the *Pre-Diagnostic Phase*, speak with farmers, elders, key informants about social and technical aspects of tending, selling, inheriting and exchanging livestock. Try to assess the complexity of the livestock owner/user system and make a list of the persons involved (father, brother, uncle, wife, etc).

If you are dealing with a clear-cut situation of private livestock ownership, as is often found in cropping-oriented societies, you can start with, and expand on, the question:

- How many cows.....do you own?
  bulls.....
  oxen.....
  calfs.....
  goats.....
  sheep.....
  others.....

If varied forms of ownership exist, forget the question. Apart from farmers not being willing to give you a correct answer they will not be able to do so because you haven't defined what you mean by ownership. The question may now take a form like this:

Go with the farmer to the animals, point at one, and ask.

- Who was the first (second, third) owner of this animal?
- Under what conditions did it come to the present owner?
- Who receives the benefits from it?

Benefit	Person
Milk	
Hides/Meat	
1st offspring	
2nd offspring	
3rd offspring	
drought power	
Others (specify	

- Who can make the following decisions?

Decision	Person
Sale	
Give as loan	
Give as security	
Give for dowry	
Kill for festival	
Kill for meat	
Sale of milk	
Sale of offspring	
Others (specify)	

Even though you ask about the same cow, you may get different answers for each question. Remember that the objective of these questions is to obtain a qualitative, not necessarily quantitative understanding of the situation initially (since quantification might require some years of survey). Repeat the questions with different animals of different farmers till you feel that you have covered the various forms of ownership and user-rights present in the village or area.

The results could be presented in a table listing the ownership versus the user relations. In our example from the Usambara Mountains the following table was produced.

Table 2: The Interrelationships between Ownership of Cows and their Use. The table is based on the question of which benefits a male farmer will get for his nuclear family from the cows to which he has an ownership relation. (Source: Künzel et al. 1982)

USE / COW	MILK	HIDES a.MEAT	DOWRY	ECONOMIC SECURITY	SOCIAL SECURITY
INDIV. OWNED	X	X	X	X	
FROM FATHER	X	X 2)	X		X
FROM FR.or REL.	X				X
OWNED BY WIFE	X 1)	X 3)		X 4)	X
GIVEN TO SON		X 2)	X	X	X
GIVEN TO FR.or REL.		X	X	X	X

1) normally consumed in the household, but the wife may sell it
2) partly used, since shared in the extended family
3) partly used, since shared with wife's parents
4) on borrowed basis only

The question of land tenure is also very important. As is the case for livestock, various owner/user relationships may exist for grazing areas. Those, for example, who can decide on the use of an "unused" grazing area on public land (and who may happily agree to put some form of agroforestry on it) may not be the ones who can protect the area against a direct claim from a fellow villager who wants to use this space for cropping. Once the area is under dispute, encroachment by cattle and fire are not far away. Therefore, it is important to make sure that an area considered for agroforestry measures is not under dispute regarding ownership.

References

Künzel, W., A. Kagi and M. Mdoe. 1982. Implications of traditional cattle-keeping: a case study of social aspects of the traditional livestock economy in two villages in the Western Usambara Mountains, Tanzania. Unpublished report.

APPENDIX A-10

INDICES OF LAND USE INTENSITY*

To assess the intensity of agricultural land use in a particular system the following indices are recommended:

1. CULTIVATION FACTOR

The *cultivation factor* is the number of years-under cultivation as a percentage of the total cultivation/non-cultivation cycle. It is measure of the intensity of arable use of a soil. The cultivation factor R, in percent, is given by

$$R\% = \frac{C}{C + F + L} \times 100$$

Where C = years of cultivation; F = years of fallow; L = years of grass ley or other non-arable use. Thus 3 years of cultivation followed by 10 years of fallow would give an R value of 3/(3 + 10) x 100 = 23%, 4 years of cultivation followed by 2 years of grass ley would give a value of 4/(4 + 2) x 100 = 67%. Double cropping, the taking of two crops in one year, counts only as one year of cultivation. Hence the maximum value of R is 100%, representing continuous cultivation.

Shifting cultivation systems are characterized by R values of less than 30%, semi-permanent cultivation systems by 30-70% and permanent cultivation systems by over 70% (Ruthenberg, 1980; FAO, 1974).

2. CROPPING INDEX

The number of crops harvested in relation to years in the cropping cycle is the *cropping index*, C, expressed as a percentage:

$$C\% = \frac{\text{Number of crops harvested}}{\text{Number of years in the cropping cycle}} \times 100\%$$

For farming systems based on tree and shrub perennial crops the above indices are not applicable.

An additional factor in assessing the intensity of agricultural land use is the level of material inputs to the cropping system. Material inputs refer to seed, fertilizers, pesticides, machinery, etc. They may be described in generalized terms as levels of inputs, or specified in detail.

For generalized descriptive purposed, three *levels of inputs* are suggested:

1. Low input level

   No significant use of purchased inputs such as improved seed, artificial fertilizers, pesticides, or machinery (i.e. traditional farming in developing countries)

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*Contributed by A. Young.

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2) Intermediate input level

Methods practices by farmers who follow the advice of agricultural extension services but who have limited technical knowledge and/or capital resources; inputs adequate to increase yields but not to achieve maximum yields or maximum economic return; e.g. some fertilizers (50-100 kg per hectare, expressed as combined weight of elemental nutrients) and possibly some use of chemical weed or pest control.

3. High input level

Methods based on advance technology and adequate capital resources, which are employed to maximize yields or economic returns; e.g. fertilizers at levels of maximum economic return, chemical weed and pest control at advanced technical levels, mechanized cropping systems.

References

FAO. 1974. Shifting cultivation and soil conservation in Africa. Soils Bull. 24, FAO, Rome.

Ruthenberg, H. 1980. Farming Systems in the Tropics. 3rd edition. Clarenden Press. Oxford.

APPENDIX B-1

ENVIRONMENTAL OBSERVATIONS AT THE DIAGNOSTIC SURVEY STAGE *

1. OBJECTIVES

The objectives of studies of the physical environment at the diagnostic phase, during and after field reconnaissance, are:
to amplify, and where necessary correct, information obtained at the pre-diagnostic phase. This includes discovery of additional sources of information (see below) and amplification of information on relevant aspects of the environmental setting.

To interpret the prediagnostic classification of land units. This is basically a familiarization exercise, although the D&D team may wish to modify somewhat the previous classification. These land units form the environmental basis for further diagnosis and, subsequently, of systems design (See steps 3 and 5)

To assess resource potential and environmental limitations: By field study of the environment and the present land use, and by subsequent comparison with land use requirements (of crops, etc.) and analogous environments elsewhere, a preliminary assessment can be made of the crops, livestock and trees suited to the area, and of its productive potential. At the same time, the negative physical factors which limit productive capacity are appraised. (See Appendix B-9).

To assess adequacy of, and pressures upon, land resources. There may be shortages of cultivable land, grazing land, or woodland. As a consequence of this, there may be corresponding pressures on any of these types of land. Land shortage is a particular type of management problem (see below), but distinctive in its methods of appraisal and its effects (See Appendix B-5).

To assess land management problems. This is the "troubleshooting" step in the diagnostic phase. It is particularly relevant because many of the techniques of agroforestry have a potential to ameliorate land management problems. (See Appendices B-2, B-3, B-6, B-7 and B-8).

To assess the present environmental degradation and degradation hazards. Present degradation refers to adverse effects on resources that have already occurred, e.g. existing soil erosion. Natural hazards refer to the danger of degradation occurring in the future, e.g. the hazard of soil erosion if land pressure forces cultivation of steeper slopes than are presently cultivated.

The difference between limitations and degradation/natural hazards is that limitations are restrictions to productive potential caused by the environment in its natural state, e.g. a short growing season limiting the choice of crops; degradation refers to further lowering of potential caused by adverse impacts of land use on resources, e.g. lowering of soil fertility through continuous arable use. Assessment of degradation hazzards are particularly important to the evaluation of the sustainability of present land use systems. (See Appendices A-7, B-2 and B-6).

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*Contributed by A.Young.

2. SOURCES OF INFORMATION

At the Diagnostic Stage, the amount of information available on the physical environment from the Prediagnostic stage may be greatly augumented, in three ways. First, visits to local research institutes, and in particular to the national Soil Survey and the Meteorological Services Organization, may reveal published and unpublished maps, reports and tables of information which had not previously been identified or obtained. Secondly, much will be learnt from talking to local scientists, particularly in agro-climatology, soil survey, and ecology, to be sought in universities, research institutes and government departments. If possible a soil surveyor and/or an ecologist should accompany the team near the start of the field tour.

But thirdly and most important, there is the information on land-forms, soils and vegetation obtained by field observation. Besides its direct use, this will clarify, and probably lead to revision of, the interpretations previously obtained from air photographs or satellite imagery.

There will be some divergence at this phase between data-collection activities on climate on the one land, and on landforms, soils and vegetation on the other. The climatic data comes primarily from locating and copying records the other environmental information from field study.

The standard methods used in the reconnaissance stage of soil surveys are appropriate: route traverse notes on landforms, soil appearance and vegetation, tied to site records at apparently representative stops. The latter should where possible include a soil pit or other soil exposure (e.g. road cutting).

APPENDIX B-2

INTERVIEW GUIDELINES FOR AGROFORESTRY DIAGNOSIS AND DESIGN*

Farming systems Research and Extension programs and farming systems rapid appraisal methodologies have been developed and tested under diverse conditions within recent years. The widespread application of an integrated farming systems approach has fostered the testing and refinement of several rapid appraisal techniques (Chambers, 1981) including the "sondeo" of Hildeband for FSR/E programs (Hildebrand, 1981), the cropping systems approach developed at IRRI(Zanstra *et al.*, 1981) and the step-wise series of interviews and surveys used by Collinson (1981) in East Africa. Summaries of these methodologies and the related interview techniques are also reviewed in a compendium on Farming Systems Research by Shaner *et al.* (1982). A useful discussion of the art of the informal diagnostic survey is contained in Rhoades (1982). As such, general farming systems applications of diagnostic methods have been discussed and described in the literature and need not be treated here.

To the extent that agroforestry systems D&D differs from the usual farming systems approach it requires some additional guidelines, both on content and methods of interview. The major objectives of agroforestry technology development are:

1. to meet basic needs of client populations
2. to improve the sustainability of production systems
3. to further improve quality or quantity of production where possible, once the first two conditions are satisfied.

The first objective usually refers to the basic needs of the farm household: food, water, fuel, shelter, cash and raw materials for cottage industry (See Appendix A-5). This emphasis introduces a sliding spatial scale to the analysis (and the interviews) ranging from the intra-household level (distribution of labour, responsibilities, and benefits relative to each need) to the ecosystem level (distribution, use, and management of off-farm water, fuel, related land resources, labour and socio-economic and physical infrastructure).

The second objective, by definition, extends the time scale of the diagnosis. To judge system sustainability under existing technologies and proposed alternatives we require some knowledge of past conditions, as well as trends in production rates and the state of the resource base. On this basis we can determine likely trends for the future. The fact that agroforestry deals with combinations of long-lived trees and shrubs, together with annual crops and animal production, also reinforces the need for a longer time frame than that normally applied to farming systems analyses.

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*Contributed by D. Rocheleau

Historical accounts of land use, production, household conditions and ecosystem condition become important tools both for diagnosis of sustainability and production constraints and for feasibility evaluation of proposed solutions. Imagining the futures - possible, with the farmers' help, becomes important for judging technologies that require present investments for relatively long term returns. Sustainability considerations may also require topical emphases on soil, water, and/or labour depending on which resource is, or is likely to become, limiting. In many cases agroforestry technologies are intended as methods for maintenance or rehabilitation of soil and water resources in fragile and/or degraded ecosystems.

The third objective, improved production, does not differ substantially from the usual focus of farming systems analyses and surveys. As such it requires no special guidelines beyond those already referred to in the literature.

Interview guidelines are presented for determining intra-household perceptions of problems and potentials with respect to basic needs, for determining historical trends and exploring futures possible at the farm and ecosystem scales, for describing the interaction between the farming system and the larger ecosystem (including the community), and for diagnostic interviews in soil and water conservation or watershed management projects.

1. GENERAL INTERVIEW GUIDELINES

Intra-household distribution of labour and interests re: basic needs

Problem diagnosis can easily be biased by speaking exclusively to adult males and/or heads of household. For example, in many areas, although men are recognized as farm managers and heads of household, they specialize mainly in cash and food production. It is also necessary to consider the role of women as managers of water, fuel, milk, food supplies, cottage industries and small animal production. Children are often employed in such tasks as well, usually under maternal supervision.

Early on in the interview (perhaps just after a brief overview of the farm's layout and the land use history) the team should determine who is responsible for collecting, producing, purchasing and/or managing each of the end-products identified as basic household needs. Based on the answer, part or all of the team may wish to question the farmer's wife or husband, some of the children, a parent, or other members of the farm household. It is often helpful to let one or two team members split off and converse with other persons while the group stays with the main farm (or unit) manager.

These parallel interviews contribute two types of information:
First, the concerns and opinions of each sub-manager or participant about the activities and needs of greatest import to them; and secondly, verification of data obtained from other informants. Differences between responses to certain common questions asked of all informants

(land use history, trends in yields, trends in environmental conditions and utilization of labour on and off-farm, etc.) can be verified in this fashion, as well as by comparing responses between similar farm households. The first type of information is more uniquely the province of intra-household stratified interviews and should take priority in terms of time and emphasis given in the interviews.

For these supplementary interviews the actual questions to be asked may vary little from the checklist and questions suggested for each basic needs in Appendix B-3. The major differences will be in the range of basic needs discussed and in the format for discussion itself. For example one might walk to the well, river or waterhole (if nearby) with the farmer's wife to discuss a problem of water supply (quality, quantity, transport) or the interview might take place inside the cooking area while food is being prepared, or in a milking area near the house. Conversation about other related concerns of the women such as child-rearing may lead to identification of nutritional or health problems, fuel shortage or household labour shortages. These informants may be invited or requested to tour other parts of the farm premises with the team member(s) if it will help to clarify activities managed by that person in another part of the farm holdings or environs. In the case of cottage industry one or more team members may enter the work area or shop if, for example, there is a separate building for woodworking, weaving or similar activities. Artisans may be interviewed while working. Gathering or collecting sites for raw materials may also be visited, if pertinent.

It should be kept in mind that to the extent the team splits up for part of the interview time, more post-interview discussion will be required for the team to synthesize the results and complete the diagnosis. If only one person can be interviewed, due to logistic, cultural or other constraints, then more attention should be directed toward questions about the concerns and work of other people within the farm household. To the extent possible, interviewers should pose questions that might indicate indirectly whether other household members face problems with respect to each of the basic needs categories. For example time-and-distance questions with respect to fuel and water collection can indicate potential problems in labour utilization within the household. Where such indicators prove positive one can probe further to elicit the second-hand impressions of the farm manager with respect to such activities and related problems. It is, however, always preferable to speak to two or three members of the household where responsibilities and labour are divided.

2. INTERVIEW GUIDELINES FOR EXPANDING THE TIME FRAME OF THE DIAGNOSIS

The rapid appraisal time constraints for the diagnostic process itself do not necessarily limit the time span considered in diagnostic and design interviews. The agroforestry D&D methodology includes a dynamic analysis conducted within a rapid appraisal context.

The back drop for such an analysis fits well into the needs of the interview team. After the introduction at the outset of the farm tour the team can ask the land manager about his/her length of residence in the vicinity and on the present holding. This can be followed by an open question about the history of land use and management on the farm and its immediate surroundings. Further prompting should be directed

toward: land use/farm management changes and the reasons for them; trends in yields and prices of farm products, trends in amount and prices of purchased production inputs and purchased household goods; past problems experienced by the farm household, the responses to them and the eventual outcome; differential impact of past economic or natural stresses on various land use types and on fulfilment of the various basic needs at the household level. Other specific questions may arise based on the responses of the interviewee. Discussion of the current situation may be guided somewhat by this knowledge of the land use history, but the general approach would follow the guidelines normally used for farming systems interviews about present conditions.

Projecting the present conditions and alternative technologies or systems into the future should be presented casually as an exercise in imagination. The potential for this technique will vary with personal and cultural attitudes about the future and planning in general. However, in many cases the farmer may anticipate future problems not yet apparent (and seek solutions to them). Informants may also veto some suggested alternatives based on latent constraints previously unknown to the team. The alternatives should be raised in very general terms leaving the field open for elaboration or other suggestions by the informant. The changing conditions on the farm must be imagined into these technology previews, including the demographic characteristics of the farm household, the condition of the natural resource base on the farm, price changes in farm products and purchases, and changes of all 3 three types in the wider environment of the farm. The informant may anticipate these, but if not some prompting should be provided to explore the impact of such changes on adoptability and performance of suggested technologies.

This same type of exercise could apply if the informant names a constraint that the team judges to be ephemeral or realistically subject to removal. Then the question "what if that were changed?" could be used to postulate an alternative future condition for technology adoptability/performance.

3. INTERVIEW GUIDELINES FOR CHARACTERIZING FARM-ECOSYSTEM INTERACTIONS

The relationship of the farm to the larger ecosystem is important to agroforestry D&D for three reasons:

1. The need to better understand and cope with farming systems opportunities and limits that reside (or originate) in the next larger system of which the farm is a part.

2. The need in many projects (which currently apply a farming systems approach) to serve a broader client group than a particular type of farm household.

3. The need to analyse the combined use of private and public (or otherwise shared) resources in rural agricultural and forest production.

Two major topics of interest can provide focal points for discussion with land managers (unit managers) about the relationship of the land use unit to its surroundings. First, discuss dependence on local off-farm resources for satisfaction of basic needs, especially fuel and water, which

are often collected off-farm but nearby. Cash may also be earned from nearby off-farm work or sales to local consumers. The degree of direct dependence on local off-farm resources can be established by asking about the relative amounts and the importance of the goods secured off-farm. Ask about who owns and uses these resources and about the terms of use, trade, purchase or collection. If possible try to get the farmer's impression as to the future reliability of the quality, quantity and accessibility of these resources.

The second related point is the reliance on local market services for transactions with external sources. Questions about where the household sells its goods, where it makes its purchases and what kind of items are traded, should be directed toward establishing the degree of interdependence between local farms and other land use systems and the degree of interaction with (or dependence on) outside sources of basic household needs.

As a complement to the farm interviews it is advisable to go to public plazas or similar gathering places with one who knows the settlement or town. Visit homes, if necessary, to conduct interviews and visit some businesses or market place locations if possible. Rely on local team members or guides to identify potential informants and request their participation in a discussion. The feasibility of doing this in a park, marketplace or business will vary with the cultural predisposition to talk to strangers under these circumstances and will also vary with the timing of the interview (re: crowding, noise level, presence of potential interviewees, etc.).

Once an introduction has been made, begin by discussing current conditions that relate to local production and livelihood of the inhabitants: the weather, this season's harvest, current prices in the market. Determine the length of time the informant has lived in the area, his/her place of residence, size and type of holdings, if any, and occupation. This should be accomplished if possible with general open-ended questions to avoid placing the informant in a defensive position. Ask more specific (but still open-ended) questions about the availability of food, water, fuel shelter, employment, raw materials, labour, desired "imported" goods, and markets for local products. With respect to these topics, informants may be asked for their opinions on the general case for the community at large, their own case, and how the situation varies by group or location.

If interviews are being conducted in a public place try to stay out of earshot of other groups. Be particularly careful of mixing people of different socio-economic groups if small-group interviews are conducted, especially when treating issues such as employment, markets, and labour. Even among peers it is possible that responses to some questions may be biased by the informant's efforts to maintain his/her image.

A significant part of the information on farm-ecosystem interactions may also come from discussions with other qualified informants such as civil servants, extension agents, health and/or social workers. Reliance on any single agency (such as agricultural extension) should be avoided since this would bias both the content and the conclusions of information on

community needs and problems within the ecosystem. For example, the obstacles to adoption of new technology should also be discussed with public servants concerned with other evaluation criteria.

Some landless people and some who have very small farms and depend primarily on off-farm income should be interviewed, especially if their numbers are large and more so if the ecosystem analysis is being conducted within the context of a rural development project. To determine the condition as well as the current role of these people within the ecosystem, questions should address a wide range of topics: sources of cash and/or materials for fulfillment of basic needs; the degree to which these needs are met; problems or potentials for improvement perceived by the informants; and the degree and type of interaction with local land use systems and the larger system. Note types of activity, location, timing (if seasonal) and exchanges of goods/services/cash.

Ask about time of residence in the area and in their current home. Probe for predisposition to remain in the area and to engage in employment (on or off-farm) related to potential agroforestry technologies or land use changes. Present these alternatives as part of an array of future possibilities so as not to bias reponses. Encourage informants to suggest future alternatives or solutions to current problems, since this gives the team an idea of what people most need, want and are willing to do.

4. INTERVIEW GUIDELINES FOR AF APPLICATIONS TO SOIL AND WATER CONSERVATION OR WATERSHED MANAGEMENT

The rapid appraisal or diagnostic survey offers a vehicle for gathering pertinent qualitative information about the soil, water, vegetation animals and water resources of the region and the local ecosystem(s). Farm families and other residents often have considerable knowledge of the characteristics and behaviour of their environment.

It is advisable that these interviews be conducted by the whole team or at least by two members in order to utilize both social science skills and ecological knowledge.

It is particularly important, for design purposes later on, to diagnose the local perception of the soil and water management problems, as well as the characteristics, magnitude and trends of the problems. Moreover, the will and ability to apply specific conservation practices or technological solutions must be gaged, if possible, particularly with regard to agroforestry substitutes or supplements to standard practices.

Trends in the degradation of water and vegetation can also be identified and described, particularly by elderly residents. This type of information can indicate whether such trends are perceived as "problems," and whether there is a marked relationship to land use and management. This in turn indicates whether agroforestry technologies might be used for rehabilitation or stabilization purposes at the ecosystem scale.

For example, flood frequency and intensity, and its variation with land use over time, may be estimated for ungaged streams for information gained in interviews with reliable informants. This is best accomplished by independent questioning of several people, including 2 or 3 elderly residents who live near regularly observed streams or rivers of interest. Their description of flood crests should be related to recognizable features on or near the stream banks so as to allow location on topographic maps or aerial photographs later on. Other questions about flood frequency and characteristics can also be answered in qualitative terms. It is important to avoid leading questions about the trends involved or the potential relationship to land use.

It is best to broach the subject of the river, it's behaviour and it's history and then to let the informants relate their experiences, observations, impressions in a more or less uninterrupted fashion (if time permits and if informantion is relevant). If the information is not volunteered, some specific questions should be posed regarding the situation during the informant's childhood and young adult years. The answers can be compared later with statements about the current condition and behaviour of the stream. It is usually possible to determine: the highest flood on record or in memory , the relative frequency of lesser flood magnitudes, including before and after specific land use changes of interest, the approximate extent of the mean annual, 5 year and 10 year floodplains, the intensity of channel erosion and changes over time, the relative amounts of sediment transported and deposited in stream or river channels during floods, the existence of seasonal water shortage problems, whether there are apparent effects from upstream land use, and whether residents relate watershed management or land use to stream behaviour, stream water quality, dependability of water sypply or damage to floodplain fields.

The historical development, probable causes and effects of prominent erosion features, such as gullies and landslips, or outcrops exposed by erosion, can also be ascertained in like manner. This is often an easier topic than river regime and watersheds, since farmers are usually more aware of such features and the time frame required for their analysis is relatively short by comparison. After establishing how long the person has lived on the farm it can be determined whether the current features on or near the farm (a large gully for example) pre-date his/her arrival.

The time of appearance and the conditions (land use, management, weather) under which a particular feature occurred may offer clues as to the cause. If he/she does not recognize such a feature as a "problem" per se it may be useful to probe for the reason.

If soil or water conservation programs have been promoted or introduced in the past it is particularly important not to refer directly to erosion control or conservation practices until the farmer has had a chance to indicate his/her attitude towards land condition or specific features. Otherwise results are likely to be biased by "official line" responses known to be the "correct" answers. If the answers seem to be of this type interviewers can probe by asking about the labour and capital requirements for such practices, or by asking about where they have been applied and what have been the results. Also, one may ask if other farmers are implementing the recommended practices, and why (or why not).

The informant or the team may observe that significant effects exist but are felt primarily off-farm. In such a case the persons or groups most directly affected may be identified and interviewed, depending on the importance of soil erosion/land degradation within the context of the project. Such special interviews (on land degradation effects) can determine whether the effects are perceived, how serious they are (and are perceived to be), if those affected relate the problem to land use or to natural causes, if there are discernible historical trends in the occurance and/or magnitude of the effects, and what measures have been taken to combat/correct the problems (by whom, how, at what cost?).

References

Chambers, R. 1981. Rapid Rural appraisal: rationale and repetoire. Public Administration and Development 1: 95-106.

Collinson, M.P. 1981. A low cost approach to understanding small farmers, Agricultural Administration 8(6): 433-450.

Hildebrand, P.E. 1981. Combining disciplines in rapid appraisal: the *sondeo* approach. Agricultural Administration 8(6): 423-432.

Rhoades, R.E. 1982. The art of the informal agricultural survey. International Potato Center. Lima. (mimeo).

Shaner, W.W., P.E. Philipp and W.R. Schmel. 1982. Farming Systems Research and Development. Westview Press. Boulder.

Zandstra, H.G., E.C. Price, J.A. Litsenjer and R.A. Morris. 1981. A methodology for on-farm cropping systems research. IRRI, Los Banos, Philippines.

APPENDIX B-3

SAMPLE DIAGNOSTIC SURVEY FORM

LOCATION _____ DATE _____

FARMER'S NAME _____ INTERVIEWER _____

This survey guide assumes that the representativeness of the farm being surveyed has been more-or-less established by the Prediagnostic Working Group, but section 2 on resource endowment and utilization will assist the D&D Survey Team to accurately classify the farm and decide whether, in fact, the farm is representative of the selected land use system. (This will determine whether or not the interview is to be continued.)

ON ARRIVAL AT THE FARM: Greet the farmer, explain the purpose of the visit and ask him/her to take the team on a quick inspection tour of the farm. During this tour take note of prominent landscape features, general land use pattern and variations in soil type, crop stand, vegetation cover, farm infrastructure, etc.

During this tour initiate enquiries contained in sections 1 and 2 below. On completion of the farm tour and sections 1 and 2, the team should decide whether the farm is representative and whether or not to continue the interview. If the decision is not to continue, thank the farmer for his/her cooperation and depart gracefully.

Try to address specific enquiries to the most knowledgeable/appropriate household member.

1. LAND USE HISTORY

How long has the farmer been living in the area?

How long has he/she been farming this particular land?

What form of land use was practiced at the beginning of the period? What changes in land use have occurred? Why ?

What was the condition of the land at the beginning of this period? What changes in land condition (including vegetation changes, etc.) have occurred in the meantime?

2. RESOURCE ENDOWMENT AND UTILIZATION

2.1 *LAND*

Subdivide the holding in terms of the following land use types, ascertain the approximate area of each, and note any pertinent observations about the quality or quantity of particular land resources. Add other land categories as needed. Find out whether the farmer owns or makes use of other plots outside the immediate farm boundaries and be sure to include them in the survey. Note also the amount, type and quality of water resources on the farm (or, if none, the nature of and distance to off-farm sources). Check land tenure

Land Use Type	Approx. Area	Observations/Notes
rainfed cropland		
irrigated cropland		
pastures		
rough grazing land		
orchards		
woodlot/forest land		
home compound		
_____		
_____		
_____		

Water sources on farmland:

Land tenure:

Additional Notes:

2.2 *LABOUR*

Ascertain the labour resources of the farm in terms of *source* (family, hired, community, etc.), *type* (adult male or female, children, others) engagement in *off-farm activities*, and *availability for farm activities*. Specify numbers in terms of persons and availability in terms of percentage of time available for farm work (or man-days if % is difficult to elicit).

Source and Type		Number	Non-Farm Activities	Availabilty for Farm Work
Family:	adult male			
	adult female			
	children			
Hired:	adult male			
	adult female			
	children			
Other (Specify)				

Additional Notes:

2.3 *OTHER RESOURCES*

Livestock (Specify)	Number	Use or Purpose	Observations/Notes
_____			
_____			
_____			
_____			
_____			
Farm machinery/implements			
_____			
_____			
_____			
_____			
Other resources			
_____			
_____			
_____			
_____			

2.4. *LIMITING RESOURCES*

Having ascertained the resource endowment of the management unit, the team should now try to determine which resources are most limiting for farm production. This step is broken down into two parts dealing with the main *production factors* and *land qualities*.

Production Factors

Which of the following factors constitutes the main limitation to farm production? If there is more than one limiting factor, try to rank them in order of constraint. Probe the farmer's response with such questions as: "If you wanted to increase the production of the farm, which of the following would you need most? Next most?" etc. "For what purposes?"

Rank	Factor	Observations/Notes
____	Land	
____	Labour	
____	Draught animals	
____	Machinery/implements	
____		
____		
____		

Land Quality Limitations

Ascertain, through questions and direct observation, whether there are any qualitative limitations to production for the crops raised on the farm. This is to be done at a very preliminary and general level; more detailed examination of limiting constraints will be carried out as part of the trouble-shooting exercise in section 3. (See Appendix B-9 for further guidelines.).

Climatic Limitations	Observations/Notes
_____	
_____	
_____	

Soil Limitations

_____

_____

_____

Topographic and Other Site Limitations

_____

_____

_____

Additional Notes:

3. PROBLEM IDENTIFICATION IN HOUSEHOLD PRODUCTION SUBSYSTEMS

This is a progressive, trouble-shooting type of exercise. First determine farmers production objectives with respect to each basic needs category, then ascertain what problems there are in meeting these objectives (the symptoms will usually be in the nature of supply shortages), then probe for possible causes of each problem (through a combination of question, direct observations and general discussion). See Appendices B-1 through B-9 for more detailed guidelines on specific diagnostic procedures.

3.1 *FOOD PRODUCTION SUBSYSTEM*

The focus here is on crops and livestock products grown for home consumption, and whatever is involved in growing them.

Production Objectives

Ascertain primary and secondary objectives with respect to the household's strategy for supplying itself with staple foods.

Production	Primary Objective	Secondary Objective
Staple food self-sufficiency	____	____
Supplementary production of staples	____	____
Purchase		
Purchase of most staples	____	____
Supplementary purchase of staples	____	____
Sale		
Sale of food cash crops	____	____
Sale of "surplus" food	____	____

Supply Problems

Seasonal shortages of staples occur:	only in bad years	____
	in most years	____
What season?	even in good years	____

To better understand the supply situation it may be useful fill out the following supply calendar for the main crops and livestock products related to food supply problems. Check discrepancies between times of main consumption, harvest and purchase. (Indicate times in months or seasons).

	Main Times of			
Main Foods	Consumption	Harvest	Purchase	Observations/Notes

Diagnosis of Causal Factors Responsible for Food Supply Problems

Detailed guidelines for the trouble-shooting analysis of possible causal factors involved in the the generation of food supply problems are given in Appendices B-1 through B-9 (see especially B-6). Most of the contributing causes will fall into the following categories. Add other categories and notes as required. Check as applicable and give explanatory notes (why, when, how, etc.).

CROP PRODUCTION

Causal Factors	Explanatory Notes
____ Land shortage	
____ Labour shortage	
____ Draught power	
____ Moisture deficiencies	
____ short growing season	
____ unreliable timing of rains	
____ midseason moisture stress	
____ Poor infiltration of rain	
____ Low water holding capacity	
____ Poor rooting conditions	
____ shallow soils	
____ poor structure/consistency	
____ poor drainage/aeration	
____ Tillage problems	
____ workability	
____ rocks, stones, roots	
____ Soil nutrient deficiencies	
specify:	
evidence:	
____ Soil erosion	
____ gully	
____ sheet	
____ wind	
____ Other hazzards	
____ flooding/waterlogging	
____ salinization	
____ soil toxicities	
____ weeds	
____ crop diseases	
____ insect pests	
____ other pests	
____ theft	
____ Inadequate supply of inputs	
____ Inadequate knowledge or skill	
Other factors:	
____	
____	
____	

LIVESTOCK PRODUCTION

Problem/Causal Factors	Season	Observations/Notes
____ Weight loss or low rate of gain		
____ Low milk production		
High mortality		
____ unweaned animals		
____ adult animals		
____ Low reproduction rate		
____ Land shortage		
____ Labour shortage		
____ Water shortage		
____ Pasture shortage		
____ Browse shortage		
____ Fodder shortage (cut-and-carry materials, etc.)		
____ Poor quality of feeds specify which:		
____ Pasture degradation		
____ Bush encroachment		
Soil erosion		
____ gully		
____ sheet		
____ wind		
____ Fire Hazzard		
____ Inadequate fencing		
____ Inadequate shade		
____ Inadequate veterinary services		
Other factors:		
____		
____		
____		
____		

Measures Taken to Alleviate Problems in the Food Production Subsystem

How does the household cope with supply shortages? What strategies have they got for dealing with crop failure? What measures are taken to reduce or mitigate causal factors and constraints? Are these measures adequate? Probe and discuss until the team feels it has an adequate picture of household strategy with respect to the alleviation or avoidance of food problems.

3.2 *WATER SUPPLY SUBSYSTEM*

Water is not "produced" on the farm in the same way that the other basic needs are produced, but water management practices can affect the overall supply of water on the farm. Problems associated with indirect consumption of water on the farm (e.g. for crop and livestock production) are dealt with in other sections. This section deals with problems involved in the supply of water for direct household consumption.

	Problems/Causal Factors	Observations/Notes
____	Inadequate drinking water	
____	Inadequate water for other uses (bathing, etc.)	
____	Lack of water source on farm	
____	Time & distance to water source	
____	Poor allocation of water resources	
____	Poor watershed management	
____	overgrazing	
____	deforestation	
____	inadequate runoff control	
____	poor infiltration	
____	Lack of drainage and storage infrastructure	
____	High evaporation losses from surface storage facilities	

3.3 *ENERGY SUPPLY SUBSYSTEM*

First ascertain the household's present pattern of energy use by filling out the table below. Then probe for answers to the questions which follow.

	Type of Energy	- Uses - Cooking	Heating	Industry	- Means of Supply - Produce	Collect	Purchase	Adequacy of Supply
____	Firewood							
____	Charcoal							
____	Crop residues							
____	Dung							
____	Kerosene							
____	Gas							
____	Electricity							
	Other							
____								
____								
____								

Location of woodfuel (firewood, charcoal) sources?

How much time is spent in meeting the household's energy requirements?

Is the household using what it considers to be inferior energy sources? Why?

Are supply, time or cash expenses required for meeting energy needs considered to be a problem by the person(s) responsible (usually the women)?

Are energy shortages anticipated in the future?

3.4. *SHELTER SUBSYSTEM*

Shelter in various forms is another basic need (inclusive of the following shelter types and resources). Probe present status and unfulfilled needs.

Shelter Type or Resource	Present Status	Needs
Housing for people		
Housing for livestock		
Stores		
Windbreaks		
Shade		
for people		
for livestock		
for crops		
Fencing		
around cropland		
around grazing land		
for pens, bomas, kraals		
for security purposes		
Delineation/protection		
of boundaries		
of paths		
of catchment areas		
of drainage/irrigation features		
Building materials		
poles		
posts		
saw wood		
other		

3.5 *RAW MATERIALS SUBSYSTEM*

Identify the main cottage industries engaged in by household members whether for home consumption or sale (e.g. handicraft, food processing, carpentry, brick making, etc.). Next, identify the type of source (farm produced or purchased) of the main raw materials and ascertain whether there are supply problems now or any anticipated in the future. Record analysis of the causes of these problems.

Cottage Industry	Raw Material	- Source - Produced	Purchased	Problems/Causes

3.6. *CASH SUPPLY SUBSYSTEM*

Identify the main cash expenditures (household expenses, farm inputs, others) and the main sources of cash income. Note times of cash outflow and inflow (by month or season). Ascertain whether there are any difficulties in raising the cash to meet these expenses. (Identify time discrepancies between cash inflow and outflow and probe for problems.) Trouble-shoot the cash enterprises to identify the causes of these problems. (Some of the causes may have already been identified in the diagnosis of previous subsystems.)

	Expenditures	Time	Problems/Causes
____	Food		
____	Clothing		
____	Fuel		
____	Shelter		
____	Raw Materials		
____	Social expenses		
____	School expenses		
____	Crop inputs		
____	Hired labour		
____	Equipment purchase or rental		
____	Livestock purchase		
____	Veterinary expenses		
	Others		
____			
____			
____			
	Income Sources		
____	Sale of cash crops		
____	Sale of surplus foods		
____	Sale of Livestock		
____	Sale of cottage industry products		
____	Off farm employment		
____	Gifts and remittances		
	Others		
____			
____			
____			
____			

What are the main times during the year when cash becomes a bottleneck?

3.7 *SAVINGS/INVESTMENT SUBSYSTEM*

In addition to maintaining an adequate cash flow throughout the year, most households have savings or investment aspirations (e.g. to send the children to college, buy land, improve the farm, pay bride price or dowry, build a new house, move to town, or simply have something to sell to meet emergency medical expenses). Unfortunately, not all households with genuine savings aspirations have viable savings/investment enterprises. (Livestock serve this function in many systems; high value timber plantings could be another example of a savings/investment enterprise). First determine what savings/investment enterprises there are, if any, and then trouble-shoot them to identify problems and causes. (The lack of any savings/investment enterprise could itself be considered a problem).

___ There is no savings/investment enterprise (check if applicable). Is this perceived as a problem? Why is there no such enterprise?

Existing Savings/Investment Enterprises	Problems/Causes

3.8 *SOCIAL PRODUCTION SUBSYSTEM*

The maintenance of good social relations within the community of immediate relevance to the household is an economic imperative and a basic human need. Many types of "social production", not easily classified under any of the above categories, come under the heading of this general umbrella term for all production activities and expenditures which are undertaken for explicitly social (or political) purposes. In some societies, this amounts to a large proportion of the total labour effort. In all societies, there will be "social expenses" of one sort or another. Rites of passage (birth, marriage, death, ascendency to political office, etc.) are common occasions of often unbelievably high expenditures for social purposes. Identify the major forms of social production and expenditure, the associated problems and (if the problems are significant) the causes of these problems.

Social Production/Expenditure	Problems/Causes

4. *FARMER'S ASSESSMENT OF AGROFORESTRY POTENTIAL*

Probe for farmer's free response to the suggestion that trees might play a role in the solution to some of his problems with questions like:

"What role can a tree/shrub play to solve some of the problems you have?"

"What kind of trees would you plant and where?"

"Why have you not planted them yet?"

Team members may also wish to probe the farmer's response to specific technical suggestions, explained to him/her in the field.

Notes:

APPENDIX B-4

COMMODITY/RESOURCE AVAILABILITY PROFILES*

The occurence of shortages of consumed commodities or production resources will, in many cases, be a seasonal phenonmenon. To assess the occurance and severity of such shortages it is useful to construct an availability profile for the major commodities and/or resources:

- *Food profile:* showing food production, taking into account storage and food consumption over time (for the main products only). A more sophisticated form of food profile could be a nutritional profile.
- *Energy profile:* showing the consumption of energy (particularly woodfules) as well as the supply of energy over time.
- *Cash flow profile:* showing cash inflows and outflows, including loans and debt service, over time.
- *Labour profile:* depicting supply and demand for labour over time
- *Feed profile:* showing the supply of various types of livestock feed in different seasons of the year.

The normal time span for such profiles is a "typical" year, marked off into monthly and/or seasonal divisions, although it may also be useful to look at availability profiles in "bad" years and "good" years.

Traditionally, these profiles have been constructed on the basis of long-term studies providing detailed quantitative data. Although such data would be ideal, in rapid appraisal, where little time and/or data are available, obtaining a rough qualitative picture of the *critical periods* may be all that is possible or necessary.

To obtain a rough qualitative picture of the *peak* as well as the *slack* as well as the slack periods of supply and demand for the above commodities/resources, several options exist:

1) Use data obtained from the existing literature; for example, case studies that have been conducted in the study area already.
2) Use information obtained directly from diagnostic interviews with representative farm management units. This may be best handled by asking questions like: when do you, or would you like to buy additional food or firewood, borrow money, hired additional labour, purchase additional feed or rent additional grazing land?
3) Use indirect inferences obtained by studying the agroclimatic conditions (especially the rainfall pattern - see Appendix A-3) in relation to the cropping calendar and pattern.

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*Contributed by D.A. Hoekstra.

APPENDIX B-5

ASSESSMENT OF THE ADEQUACY OF LAND RESOURCES*

1. General

Shortage of land, with consequent pressure of use upon it, is widespread and fundamental. The pressure of use frequently leads to environmental degradation: soil degradation or erosion, degradation of pasture and browse vegetation, degradation of woody vegetation. Many traditional systems for land management were ecologically stable at low population densities but have become unstable through increasing intensity of use.

Land resources can be considered basically in terms of cropland, grazing land, woodland, land for other uses, and wasteland (the last-named being unproductive and unutilizable land within farm boundaries). An initial question is the extent to which cropland, grazing land and woodland are distinct from each other. Land allocation practices may arise through environmental necessity, e.g. grazing land on swampy valley floors, woodland on rocky hill slopes. Alternatively they may arise for social reasons, e.g. communal tenure rights to grazing and/or woodland, lack of labour to convert one use to another, or simply farming custom. It is clearly relevant to possible agroforestry interventions to assess the situation in this respect.

The following discussion is based on the assumption that the different major kinds of land use are practised on separate land areas. Adjustments must be made for rotation between uses. In all these cases the principle is the same, to compare land requirements with available land. This may be done for sample farms visited, or for a synthesized farm representative of the land management system.

2. Cropland

Requirements. For subsistence food needs, estimate dietary needs for farming family in kilocalories (2500 kcal per adult per day); divide by calorific value of staple food crop(s) to obtain required weight of harvested crop(s); divide by typical yields to obtain required area harvested each year; adjust where relevant for 2 crops per year; and divide by the maximum permissible cultivation factor C, expressed as a fraction, to obtain cropland required for subsistence food needs. (Sources: Allan, 1965; Young, 1976; Young, 1980). E.g. man, wife, one elderly person and 3 children = 4 adult equivalents; dietary requirement 4 x 2500 x 365 =3.65 million kcal/year; growing one crop per year of maize, 3500 kcal/kg, 3.65 million ÷ 3500 =1043 kg maize; typical yield 1000 kg/ha, requires 1.04 ha; maximum acceptable arable use 6 years in 10, C = 60% or 0.6, :. land required for subsistence needs, 1.04 ÷ 0.6 = 1.73 ha.

A more rapid method is simply to obtain a local estimate for the land area required to support one person or an average farming family.

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*Contributed by A. Young

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For cash crops the equivalent procedure is to assume a target income, and adjust successively for price of crop, typical yield, and maximum permissible cultivation intensity under the crop.

Note that the cropland requirements refer to a specified management levels, those which lead to the value for crop yield employed.

Available cropland. If all cultivable land is cultivated (or under short fallows), there is no problem. Otherwise, cultivable land must be estimated. This is conveniently done by selecting critical values of the major limitations to arable use: slope angle, soil depth, soil drainage class. The technique of land capability classification has as its primary purpose the identification of potential arable land (land capability classes I-III), marginal arable (class IV) and non-arable (class V-VIII).

3. Grazing land

Requirements. The starting point is usually the number of livestock units actually present on the farm. Alternately, the needs (for traction, milk, meat, sale, social purposes) may be estimated. Next, the livestock carrying capacity must be estimated; this is the maximum number of livestock units (per hectare or per square kilometre) the land will support, at a given level of management, without degradation of vegetation. Carrying capacity is usually obtained as an estimate based on local experience, since the pasture growth rate and other measurements necessary for an objective estimate are too time-consuming (Condon, 1968). There may be separate carrying capacities and requirements for dry-season grazing land (valley grasslands) and wet-season land.

Available grazing land. All land suited to grazing is probably in such use, and the area can be measured or estimated.

4. Woodland

Requirements. Multiply the population by the annual per capita fuelwood requirement (a figure of one m^3 per person per year is commonly taken). Add an amount for wood requirements other than for fuel. Divide by an estimate of the mean annual increment of existing woodland, as cubic metres per hectare per year, to obtain hectares of woodland required.

Available woodland. As land suited to woodland but not presently under it is not a current resource, the available land is actual area of woodland. In some environments, woodland will also be included as wet-season grazing land.

5. Summary Table

The following table is a proforma for estimating present land use, land requirements, available land, and thus pressure on land resources. Provision for the farmer's perception of land shortage is included.

The ratios between land requirements and land availability, for each major kind of use, will only be very approximately estimated during the diagnostic phase. Nevertheless, even these broad estimates serve to indicate relative land pressures. A requirements: availability ratio of appreciably less than 1.0 indicates no pressure. If the ratio exceeds 2.0, pressure on land may reasonably be considered severe, with the likelihood of degradation of resources.

LAND AVAILABILITY

Areas in hectares , acres , local unit = ha.

1. Present land use

Total farm area

Cultivated

resting:	fallow (natural vegetation)	_____	ha
	productive ( )	_____	ha
grazing:	valley/wetland	_____	ha
	hill/steep slopes	_____	ha
	other	_____	ha
woodland:	natural ( )	_____	ha
	planted ( )	_____	ha
other uses:	1.	_____	ha
	2.	_____	ha
	3.	_____	ha

Notes

2. Land shortage

Is all cultivable land cultivated?

Notes:

Land shortage: grade as shortage exists , severe , and describe.

	Farmer	Survey team	Notes
Cropland			
Grazing land			
Woodland			
Other problems			

Notes

3. Land pressure

A. Cropland: soil rest period

Estimated requirement: Kcal/y
Kg (crop)/y
at (yield) Kg/ha
= ha/y cultivated

Typical rotation (years): cultivated C
resting: fallow = F
productive = L

Cultivation factor R (%) = $\frac{C}{C+F+L} \times 100$

R = %

Crop rotation:

Changes from past (fallow, rotations):

B. Grazing land

Estimated carrying capacity _____ Livestock unit (350 kg) per hectare

		Number		Cattle equivalent
Stock on farm:	cattle		=	
	sheep	÷ 10	=	
	goats	÷ 10	=	
	other	÷	=	_____
	total			

Grazing land (hectares)

Cattle equivalent = _____ Cattle equivalent/ha

Relation between cattle equivalent and 350 kg livestock units:

Notes:

C. Woodland

Woodland area ha
Mean annual increment m^3/ha/y
Annual growth m^3/y
Estimated requirement m^2/y

$\frac{\text{Requirement}}{\text{growth}}$ =

Frequency of cutting (total, coppicing, partial, etc.):

Notes:

Summary: Land availability and pressure

References

Allan, W. 1965. The African husbandman. Oliver and Boyd. London.

Condon, R.W. 1968. Estimation of grazing capacity on arid grazing lands. *In*: Land evaluation (ed. G.A. Stewart), 112-124.

Young, A. 1976. Tropical soils and soil survey. Cambridge Univ. Press. London.

Young, A. 1980. Rest period requirements of tropical and subtropical soils under annual crops. *In*: Land resources for populations of the future. FAO. Rome. 197-268.

APPENDIX B-6

NOTES ON THE ASSESSMENT OF LAND MANAGEMENT PROBLEMS AND DEGRADATION HAZARDS*

1. Land Management Problems

Land management problems are difficulties which originate from interactions between land use and land. Most such problems are specific to one major kind of land use.

Check-lists are given below. These may be used at sample farms during diagnosis. Summaries can subsequently be prepared, separately for each system. Notes on the evidence for existence of a problem should be added. Possible forms of evidence include:

- farmer's statements
- statements by local advisory or research staff
- field observation during tours of farms
- experimental evidence from research stations

The following list of land management problems directs attention to difficulties present in the land use systems, which in some cases may offer opportunities for emelioration through agroforestry techniques.

Crop Production

Moisture deficiency: short growing season
viability/unreliability
moisture stress in crops

Oxygen deficiency (soil drainage)
Nutrient deficiencies (give details, evidence)

Rooting conditions: shallow soils
poor structure/consistence

Tillage problems: rocks/stones
workability
Low soil water holding capacity

Hazards: flooding/waterlogging
salinization
soil toxicities: Al (pH $<$5.0)
other

weeds
crop diseases
insect pests
other pests

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*Contributed by A. Young

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Soil erosion: gully
sheet
wind

Other problems

Livestock production

Pasture shortage: season
Browse shortage: season
Insufficient cut-and-carry materials
Poor quality (nutritive value, palatability) of vegetation
Pasture degradation (nature, evidence)

Fire
Bush enroachment

Soil erosion (on grazing land): gully
sheet
wind

Soil compaction/trampling
Water shortage: season
Inadequate fencing
Inadequate shade
Low milk production
High calf mortality
Other problems

Woodland

Tree species present do not meet needs

Slow growth of required species

Fire
Tree damage by grazing animals
Pests and diseases
Other problems

2. Environmental degradation and degradation hazards

2.1 General

Environmental degradation commonly arises through pressure of land use upon resources. The resource base is lowered, thus exacerbating the pressure. Degradation results from the interaction of the land use practices with natural processes.

The most widespread forms of environmental degradation are:

- soil degradation
- soil erosion
- vegetation degradation: grazing resources
- vegetation degradation: woodland resources

Other forms occur more locally or in special circumstances, e.g. soil salinization, lowering of the groundwater table, augumentation of pest or disease problem.

2.2 Soil degradation

Soil degradation, commonly called lowering of fertility, is a deterioration in the physical, chemical and biological properties of the soil, and thus in its capacity to produce crops. It is a more widespread problem than soil erosion, and probably on a world scale a more serious one. It attracts less attention than erosion, for two reasons: first, it acts slowly, and lacks the sometimes spectacular visible symptoms of erosion; and secondly, it is less easily diagnosed.

In detail, soil degradation may include any or all of the adverse changes given below. There is a considerable degree of interaction between the forms listed, both within and between the three groups. The net effect of soil degradation is manifest in lowered fertility, a reduced capacity to produce crops.

Forms of Soil Degradation

Physical
- decrease in porosity (increase in bulk density)
- degradation of structure, limitations to rooting
- lack of aeration
- decrease in water storage capacity
- surface sealing and crusting

Most forms of physical degradation are caused directly or indirectly by decrease in pore space.

Chemical
- leaching of bases
- loss (leaching, oxidation) of nitrogen
- acidification
- increased fixation of phosphorus
- lowering of cation and anion exchange capacity, and thus if ability to retain nutrients

Biological
- lowering of organic matter content, with consequences for physical and chemical degradation, and resistence to erosion.

Soil degradation may show itself in any of the following ways:

i. Lower crop yields if no fertilizers are added.

ii. A need for larger amounts of fertilizers of crop yields are to be maintained.

iii. A lower response to added fertilizers (caused by nutrient imbalance, micronutrient deficiencies, or the consequences of physical degradation).

It is difficult to obtain firm evidence of soil degradation. A farmer's statement that crop yields are "not what they used to be in former days" could well be true, but falls short of being scientific evidence! The evidence for soil degradation may be identified at three points: soil analyses, crop deficiency symptoms, and crop yields. The basic problem is to know whether the cause is soil degradation, or whether it arises from inherent low fertility. Possible lines of evidence, in order of decreasing precision but increasing likelihood of availability, are:

i. Comparison of records in earlier years and now (crop yields, soil analyses). Whilst ideal, it is very unlikely that such data will be available. Crop yields would need to refer to closely similar management, and soil samples to be from precisely identified locations, as described in earlier agronomic experimental records or soil surveys. In the case of repeated soil analyses, careful attention to use of the same analytical methods would be necessary.

ii. Comparison of land under known lengths of cultivation and under natural vegetation (different lengths of cultivation: crop yields, deficiency symptoms, soil analyses; cultivation compared with natural vegetation: soil analyses). For soil analyses, this technique has been successfully used on a research basis. The land use history is obtained by questioning, composite soil samples taken, and analytical data compared. Deficiency symptons may be visible, whilst for crop yields there are three possibilities: crop cuttings, visible difference in plant health with increasing length of cultivation, or farmers' reports of how rapidly yields decline.

iii. The condition of the crop or soil at the present day as compared with some expected standard (yields, deficiency symptoms, soil morphology and analyses). Crop yields may be so low, or deficiency symptoms apparent, that this can reasonably be attributed to soil degradation. Physical degradation may be apparent to skilled inspection, possibly with sampling for bulk density determination. In principle, analytical data could be compared with that considered typical for the climate and soil type, but such standards are only very approximate; a substantial decline in organic matter content might be indicated by these means.

iv. Opinions of farmers, advisory or research staff (crop yields, soil fertility). For a farmer to blame low yields on decline in soil fertility clearly needs to be treated as a subjective opinion.

2.3 Soil erosion and erosion hazard

There is an interaction between soil erosion and other forms of soil degradation. The onset of erosion commonly results from lowering of the organic matter content, structure and porosity of the soil, as brought about by biological and physical degradation. Conversely, loss of relatively fertile topsoil through erosion lowers soil fertility. Soil conservation is one of the specific areas in which agroforestry techniques may be of benefit. The relevant techniques differ according to whether

the problem is one of gully erosion, sheet erosion, accelerated mass movements, or wind erosion.

Of the evidence and methods of observation, that of direct measurement will rarely if ever be practicable in the diagnostic situation. This leaves two methods, visual assessment and calculation of risk.

i. Visual assessment

The effects of gully erosion are very apparent. Record its severity, and whether present on cropland or, as is often the case, on grazing land, particularly valley floors or lower valley sides. Sheet erosion is a far more widespread phenomenon but less easy to observe. Rills, erosion pedestals around stones, exposed roots, accumulations of sandy soil above obstacles and on gentler ground at the foot of slopes are common signs (for a detailed list see FAO, 1979, pp. 65-66). Accelerated landsliding is a localized feature, found where steep slopes under a humid climate have been deforested; the scars are readily seen. Wind erosion is evidenced by accumulations of sand in the lee obstacles, superficial concentrations of stones, exposed roots, etc. Record the type of erosion observed, the severity of each (subjectively), and the evidence.

ii. Calculation of risk

A range of models are available for calculating the erosion loss, from sheet erosion, to be expected in a specified environment and under given crop cover, management practices and conservation measures. These models are:

- The universal soil loss equation (USLE): complex and requiring considerable data; not likely to be practicable in the diagnostic situation (Wischmeier and Smith, 1978).

- The soil loss estimator for Southern Africa (SLEMSA): intermediate in complexity (Elwell, 1980).

- The FAO soil degradation assessment methods (FAOSDA): includes short-cut methods based on readily obtainable data (FAO, 1979).

The models work on similar principles. Erosion, calculated as soil loss in tonnes per hectare per year, is assumed to be a multiplicative function of factors related to climate (rainfall aggressivity), soil erodibility, slope (angle, sometimes also slope length), the protective cover (vegetation or crops), and conservation practices. There are two steps. First, the soil loss expected to result under the worst possible conditions, namely continuous bare fallow, is calculated. This value is then reduced by a land cover/land use factor related to vegetation cover, crop over, and conservation practices. This allows estimates to be made not only of erosion loss under present conditions but also of the expected reductions in erosion which might result from specified changes in land use and management.

The minimum data required, for calculation of the FAOSDA model, are:

- mean monthly and annual rainfall
- soil type (FAO classification, or converted to it)
- soil texture (generalized classes as per FAO soil map of the world)
- predominant slope angle range
- fractions of land under crops and vegetation (and bare fallow, if any)
- approximate average percentage cover, during rainy season, of crops and of vegetation.

For the more complex models, data are required on rainfall energy (daily totals), soil type erodibility ratings, slope length, and crop and vegetation cover at different periods of the year. The FAOSDA system also includes a similar technique for estimating loss by wind erosion.

Generalized maps purporting to show erosion hazard on a world or continental scale should be treated with much reserve, as there can be large local variations. There is no general agreement at what is an acceptable rate of soil loss. Formerly, target values of either 5 or 12 t/ha/year were aimed at. It was then found that such levels were impracticable to attain in most tropical environments, and reduction to 50 t/ha/year is now often considered acceptable, even although this considerably exceeds the natural rate of soil formation. The erosion severity classes employed by FAO (1979) are: none to slight, $<$10 t/ha/year; moderate, 10-50 t/ha/year, 50-200 t/ha/year; very high, $>$ 200 t/ha/year.

2.4. Vegetation degradation

Whether for pastures or woodlands, it is highly unlikely that quantitative surveys from some earlier date will exist, such as to permit repeat surveys and comparison. The clearest means of judging degradation is to compare the pastures, or woodland, over the majority of a land unit with some part of the unit which has been protected from grazing or cutting pressures. A modification of this approach is to compare land with high and with lower population density. Failing such opportunities for space/time substitution, the present state of the vegetation must be judged against its assumed natural state.

For pasture degradation, symptoms include:

- dominance of unpalatable species
- short/sparse grass where tall/dense grass would be expected
- heavily worn movement tracks of livestock
- bare trampled areas around points of concentration, e.g. watering
- absence/paucity of browse species where they would be expected

- bush encroachment: invasion of pastures by unpalatable shrub and tree species, often thorny
- indirectly, undernourished livestock, particularly cattle and particularly in the late dry season

For woodland degradation, symptoms include:

- lower tree density than would be expected; open canopy where closed would be expected
- absence or paucity of species favoured by users
- absence of trees with straight trunks
- absence or paucity of young trees (regeneration prevented by fire or browsing)
- excessive fire damage to trees
- heavy coppicing, few mature trees and much bushy regrowth.

References

ELWELL, H.A. 1980 Design of safe rotational systems. Dept. of Conservation and Extension, Salisbury, Zimbabwe, 50 pp.

FAO 1979 A provisional methodology for soil degradation assessment. FAO, Rome, 84 pp.

Wischmeier, W.H. and Smith, D.D. 1978 Predicting rainfall erosion losses - a guide to conservation planning. Agric. Handbook 537, U.S. Dept. Agric., Wash. D.C., 58 pp.

APPENDIX B-7

INTRODUCTION TO CAUSAL DIAGRAMMING*

Causal diagramming is an analytical tool used to facilitate understanding of complex causal relationships among variables within a system. In rapid appraisal D&D exercises one of the most valuable pragmatic uses of causal diagramming is to avoid or resolve differences between team members in the interpretation of the causal backgound of a problem. By displaying interrelationships between multiple contributing causes, the technique is helpful in avoiding fruitless discussions about what is "the" cause of a problem, which otherwise might arise between team members with different disciplinary perspectives on the problem.

As a "discovery procedure" for uncovering cause-effect relationships, the usefulness of causal diagramming is in its ability to increase the *clarity* of the team's causal understanding. For this reason, very complex diagrams attempting to describe all causal relationships in the background to a problem should generally be avoided, since "monster" diagrams will tend to be more confusing than clarifying.

The simplest use of causal diagramming is to depict the generative causal relationships responsible for a *single problem*. A set of such diagrams, one for each of the identified problems within the system, would be the result of this approach. However, since individual causal factors may contribute to the generation of more than one problem, interrelationships between seperate diagrams should be shown whenever this will add to the clarity of the teams perception of significant causal relationships. This could be done as a second stage exercise, to bring about the necessary integration of partial diagrams developed in the first stage of the exercise. Perhaps the best strategy is to start with a diagram of the most significant or central problem within the system, and then judiciously expand the diagram as needed to elucidate *significant connections* with other problem complexes. In deciding how to proceed at any stage in the use of causal diagrams, the criterion is always whether or not the contemplated use will add to the clarity of the teams causal understanding of a problem.

Specific Guidelines

Causal diagramming is an art. Like most arts, it improves with practice. There is no single "correct" causal diagram for a given situation, there are only more or less useful ones. Different analysts may come up with slightly different diagrams for the same problem, although if they are working from the same diagnostic data they should generally come up with functionally equivalent causal analyses. The differences will be mainly in the terms used to characterize the various factors involved. Although there are no hard and fast rules for the development of causal diagrams, there are certain conventions which, if observed, will greatly increase the usefulness of the tool.

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* Contributed by J.B. Raintree

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As applied in the D&D context, casual diagramming will be mainly used to analyze the causal background to household supply problems. Optionally, the tool could also be used to assist the team in its understanding of sustainability problems and problems at the ecosystem level, although the use of causal diagrams to analyze problems at the household (or other unit) management level may already depict the important causal aspectes of these other problems. The following conventions are expressed in terms of the analysis of household supply problems. Reference is made to the accompanying examples in Figure 1 to Figure 4.

1. First identify the *problems* to be explained. These are given in the listing of household supply problems in Worksheet 5.1.1

2. Then identify the *causal factors* involved in the generation of each problem. These are given in Worksheet 5.1.2

3. Next, decide on a word or descriptive phrase to describe the problem, and enter this on the *left-hand* side of the paper and draw an oval around it. The convention is to move from effects on the left to causes on the right. Observation of this convention greatly increases the clarity of the diagram and the ease of its interpretation. Since the problem to be explained is the ultimate effect, it is entered at the extreme left side of the paper.

4. Then, decide on words or descriprive phrases for the various causal factors related to the problem and start entering then within ovals to the right of the problem. Do not worry too much about the positioning of the various causal factors at this point. Start with the most significant factors. Leave trivial factors out.

5. Next, examine the various factors and draw arrows between the respective ovals showing cause-effects relationships between different causal factors and between causal factors and problems. Not all causes are equal; some are more distantly related to the problem than others. In analyzing complex systems of causation we are always dealing with cause-effect chains. A "cause" at one position in the chain is an "effect"at the next. The arrows are used to depict the movement from cause to effect. When all of the arrows are drawn in the pattern revealed will contain *causal chains* and, perhaps, also causal *loops*.

6. At this stage what will have been produced is a rough and rather messy first approximation of the final causal diagram. The next step is to clean it up and make any necessary additions and modifications to improve its contistency and clarity. This is done by renaming the causal factors so that the terminology within each oval is consistent with the relationships shown by the arrows coming in and out. Also, the position of the ovals is rearranged so as to display an orderly cause-effect progression from right to left. In other words, the arrows should mainly point in a general leftward direction. Exceptions must be made, of course, in the case of causal loops depicting feedback relationships.

7. At any point from step 4 onwards, it may become apparent that there is a missing term in the cause-effect sequence. This may indicate a causal factor that has been overlooked by the team, or it may merely signify the need to reconceptualize the terminology used to describe the causal factors enclosed within certain ovals. In either case, it may be necessary to add an additional "intermediate" factor between two or more ovals.

Forexample, in Figure 1, "low available moisture" was not in the initial diagram for this problem complex. It was added in the second round of the diagramming process to receive and summarize the effects of several contributing factors (insufficient rainfall, poorly distributed rainfall, low infiltration and high runoff losses, and weed competition). "Poor soil fertility" was included in the first diagramming attempt, along with the contributing causes (low organic matter and low nutrient levels), but "low available nutrients" was added in the second round to integrate the effects of these factors together with nutrient competion from weeds. The double effect of weed competion on both water and nutrients available for crops was not clearly displayed in the first, rather messy diagramming attempt, but became clear after reconceptualization and rearrangement of the diagram.

After this diagrammatic optimization process, the final diagram (Fig. 1) displays a clear progression from the main problem to be explained (poor and unrealiable crops) to the main summary causes (low available moisture, low available nutrients and insect damage) to the various contributing causes. Or, reading from right to left, from contributing causes to proximate causes to the problem. Thus, the diagnostic knowledge of causal factors involved in the generation of the problem has been *organized* into a coherent picture of the problem (i.e. how it arises within the system).

Figure 1 is a partial causal model dealing with only one of the diagnosed problems in a system in the semi-arid zone of Kenya. It depicts causal chains but no causal loops. Figure 2 shows a generalized causal model of an entire national land use problem complex derived from secondary information on Rwanda (ISNAR, 1982). The four main problems to be explained are shown on the left-hand side of the diagram. The causal analysis displayed to the right of the problems reveals both causal chains and loops, depicting the combination of social and biophysical causes and effects underlying the general degradation syndrome affecting land use systems in the country. To give an idea of what a causal diagram adds to an understanding of causal relationships, it may be useful to cite a prose description of the Rwandan problematique:

> Rwandan agriculture is now caught in a process of continuous degradation: overpopulation goes hand in hand with overcropping of fertile lands, the use of more fragile areas around arable lands, shrinking of pastureland, overgrazing, uncontrolled deforestation, etc. Labour productivity is decreasing. Ill-nourished crops grown on improverished soils, moreover, become disease-susceptible. In sum, the country is suffering from deterioration of its plant canopy which includes decreasing biological and genetic diversity, decreasing soil fertility, and soil losses due to erosion (ISNAR, 1982).

This statement, together with addtional descriptive information on the Rwandan problematique, has been transformed into a clear diagrammatic representation (Fig. 2) of *how* the problem is generated.

Using Causal Diagrams to Discover Potential Intervention Points Within the System

At Step 14.2 the D&D team is asked to identify points within the diagnosed system where functional interventions may play a role in removing or reducing constraints on system performance. Figure 1 and Figure 3 illustrate the use of causal diagrams for this purpose. The team simply studies the causal diagram of the problem and for each causal factor or constraint asks itself the question: "Is there anything than can be done at this point in the system to remove or reduce the constraint or otherwise improve system performance?" Ideas for functional interventions will generally be forthcoming if this procedure is followed. The team may then go on to assess how effective the various suggested interventions might be in reducing constraints, alleviating problem-causing syndromes, and ultimately solving the identified problems.

Combining Causal Diagramming with Functional Diagramming

Functional diagramming techniques and uses are discussed at some length in Appendix B-8. Such diagrams may be used independently or as an adjunct to causal diagramming. An example of the latter usage came up in the course of a D&D exercise in the Philippines. In the midst of the diagnostic analysis it became clear that the main problem was a cash flow problem, and that to adequately conceptualize this problem it would be necessary to diagram the in-flow and out-flow of cash within the household system, in addition to the diagramming of causal factors affecting cash flow. Hence, Figure 4, which depicts causal influences by arrows with broken lines and the flow of cash and relevant inputs and outputs by arrows with solid lines.

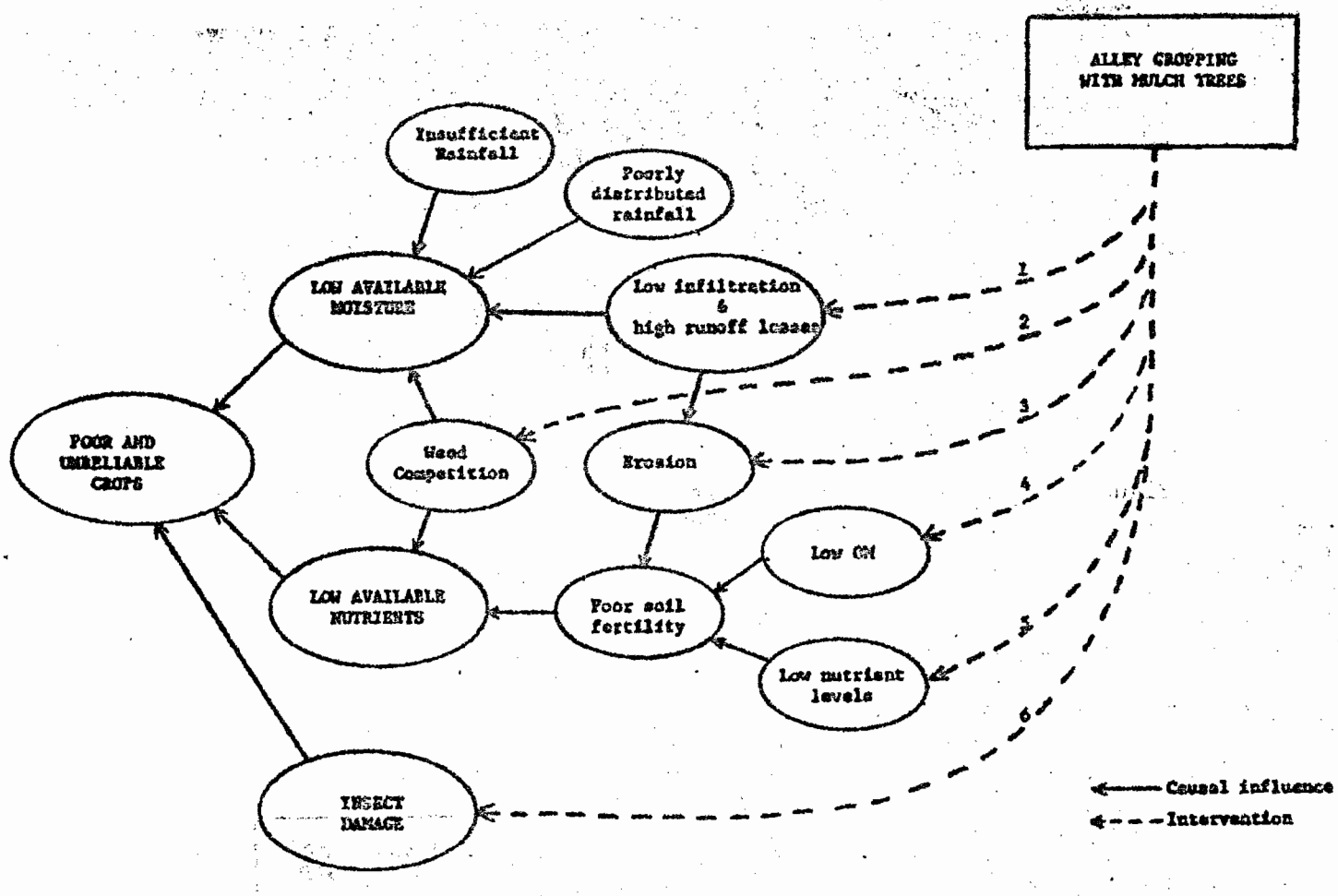
References

ICRAF. 1983. Draft proposal for an agroforestry research project in Tab ngo, Leyte, Philippines. ICRAF. Nairobi.

ISNAR. 1982. Le system national de recherche agricole au Rwanda. The International Service for National Agricultural Research. The Hague.

Raintree, J.B. 1982. A methodology for diagnosis and design of agroforestry land management systems. ICRAF. Nairobi. (mimeo)

Raintree, J.B. 1983. The agroforestry approach to land development: potentials and constraints. Paper presented to the Seminar on Agricultural Research in Rwanda, 5-12 February, 1983. Kigali.



Potential Mulch Trees

N-fixing	Insect-repellent
Leucaena leucocephala	*Adhatoda vasica*
Mimosa scabrella	*Azadirachta indica*
Sesbania bispinosa	*Derris indica*

Potential Interventions

1. Improved infiltration, reduced runoff
2. Weed control with reduced labour
3. Reduced splash and runoff erosion
4. Increased organic matter
5. N-fixation and nutrient pump action of deep penetrating roots
6. Use of insect-repellent mulch species.

Figure 1. Partial causal diagram depicting causes of food problems in a semi-arid zone mixed farming system in Kenya, with suggested technological interventions. (Source: Raintree, 1982)

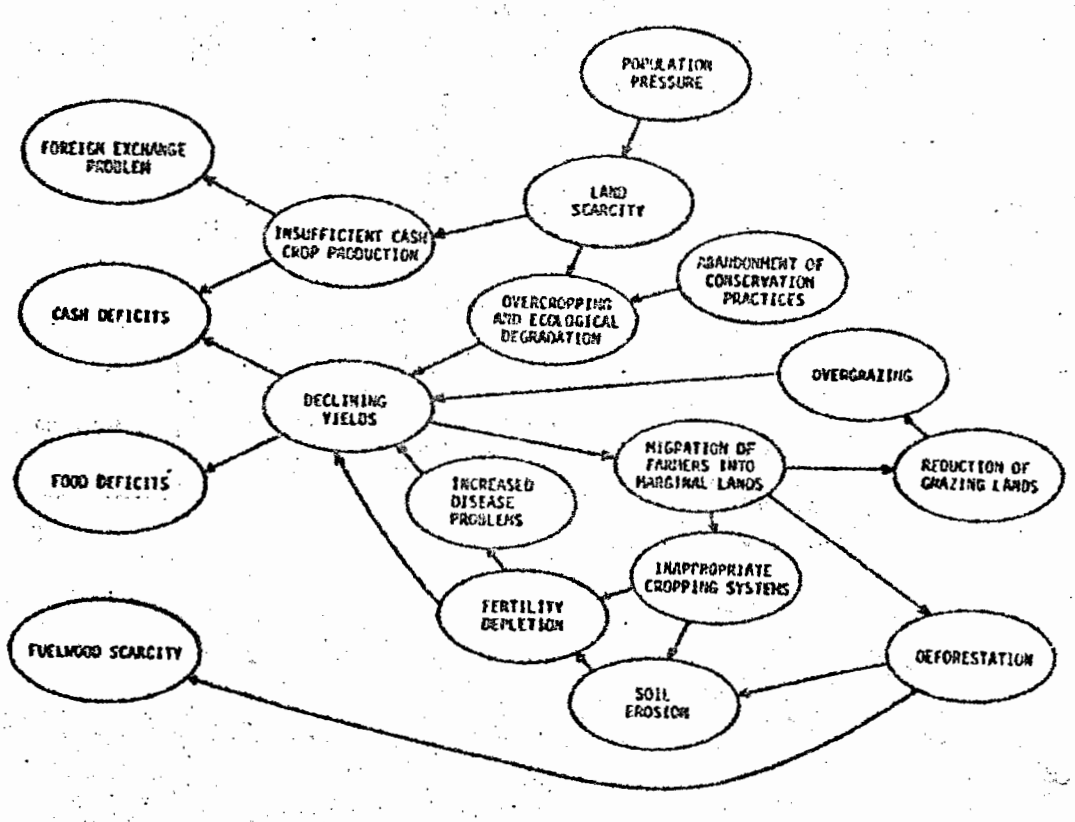


Figure 2. Generalized causal diagram of the Rwandan Problematique (Source: Raintree, 1983)

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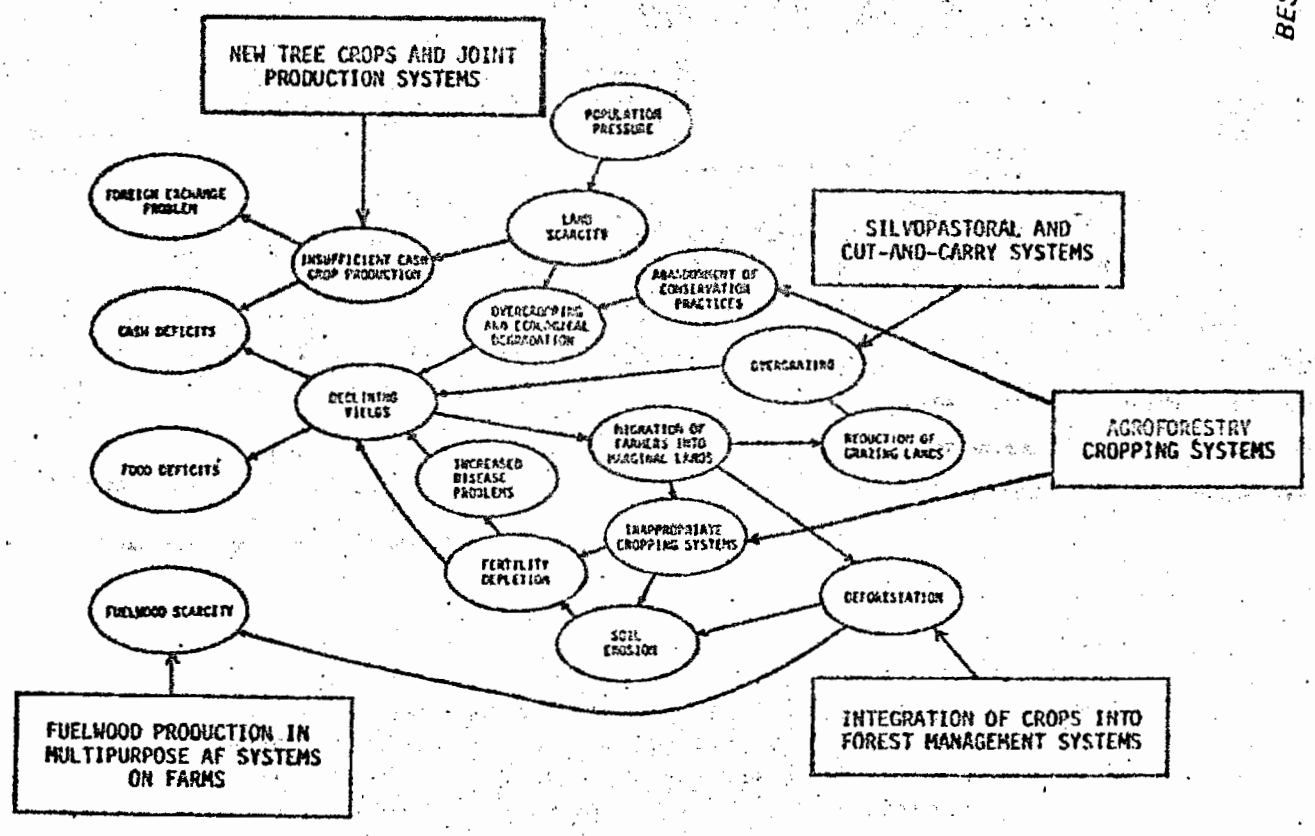

Figure 3. Some possible agroforestry interventions (Source: Raintree, 1983)

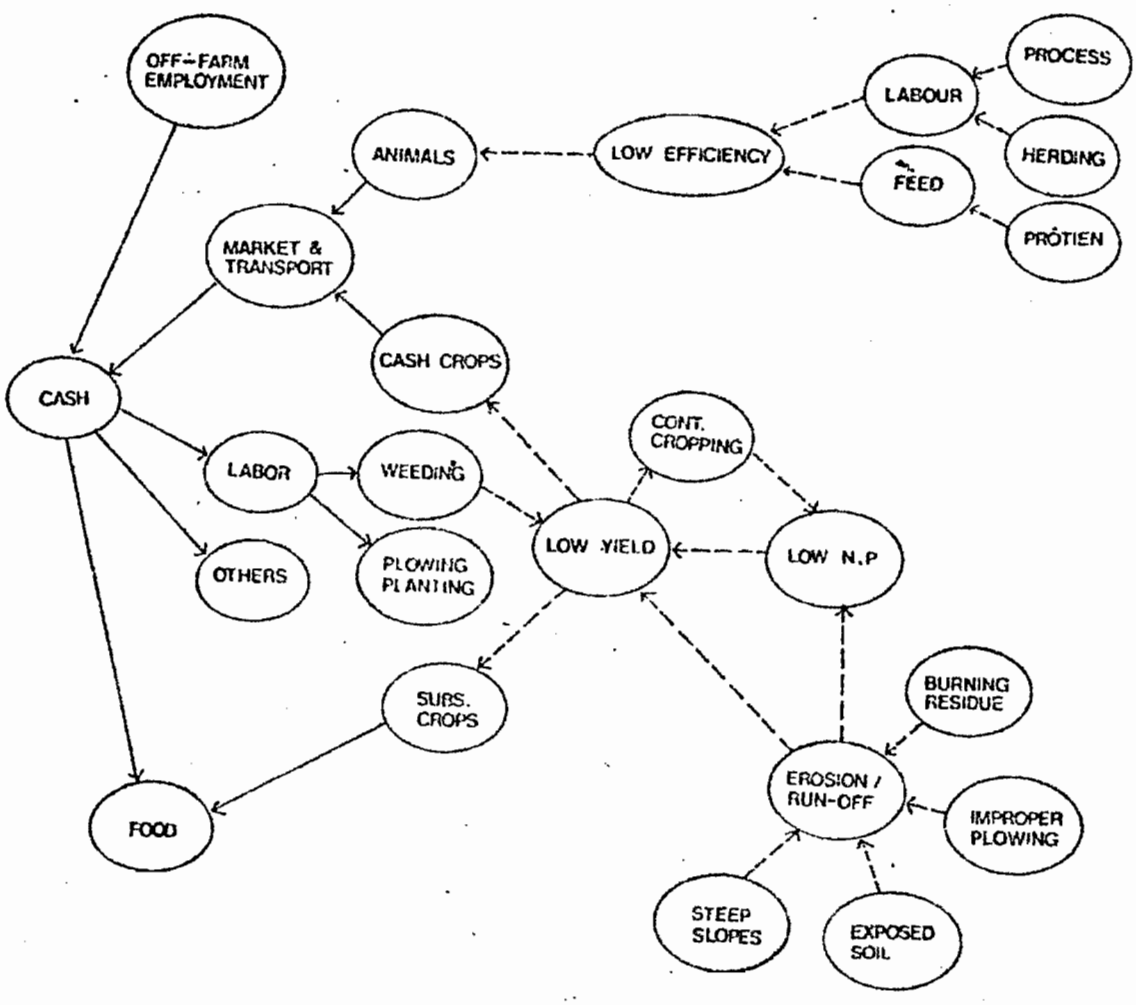

Figure 4. Combined functional-causal diagram.
(Source: ICRAF, 1983)

APPENDIX B-8

INTRODUCTION TO FUNCTIONAL DIAGRAMMING*

Functional diagramming is a useful analytical tool for understanding how a system works. It consists essentially of a diagramatic representation of the structure of the system and the flow of matter, energy and information between the various components of the system. Such diagrams can be used in many ways. For D&D purposes, functional diagrams can be used to describe the organization and dynamic functioning of a land use system and also to trace through the probable effects of proposed interventions in the system. They may be used independently, or as an adjunct to causal diagramming for these purposes.

This appendix consists of two parts:

Part 1. Functional Diagram of a Small Farm

This is an example of the use of functional diagramming based on the kind of information given in Worksheet 6.3. The diagram on the next page represents the transformation of such data into a diagrammatic representation of system structure and function.

Part 2. Functional Diagramming for Ecological Analysis of Farms and Ecosystems

This part discusses the application of a specialized type of functional diagramming based on the use of ecological symbols and modeling conventions. Following an introduction to the use of the techniques, examples are given of functional models of farming systems at different levels of technology.

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*Contributed by D.A. Hoekstra (part 1) and D. Rocheleau (part 2)

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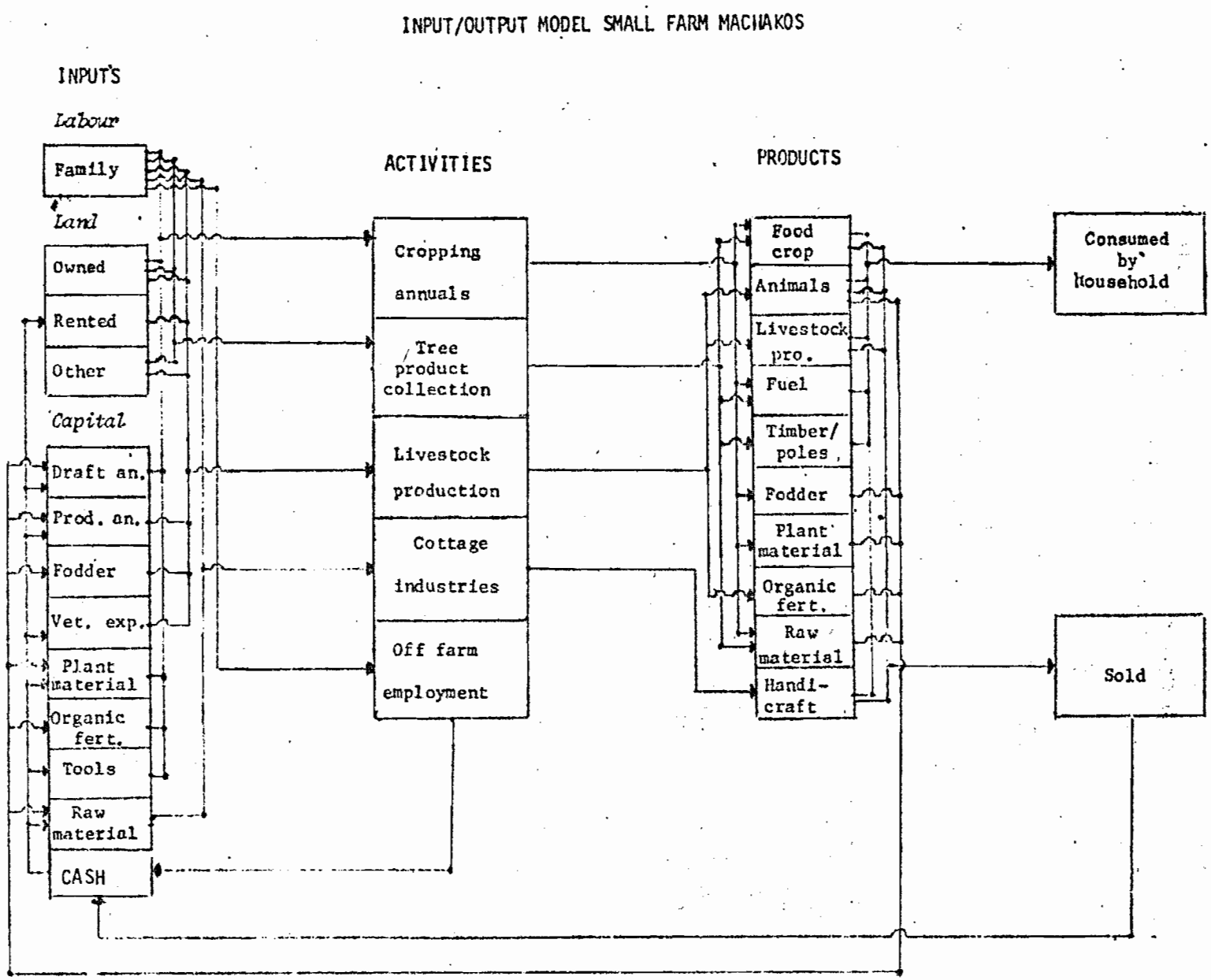
Part I. Functional Diagram of a Small Farm



PART 2

Functional Diagramming for Ecological Analysis of Farms and Ecosystems

Dynamic non-linear system models for cropping system, farm, or ecosystem-level analysis.

The diagramming of dynamic non-linear system models was developed within operations research for fine-tuning of industrial processes. A major feature of this type of model is the inclusion of feedback effects, as loops, that illustrate both positive and negative bommerang effects of changes made in a given variable within the system.

The diagramming method has been modified and adapted for use in urban systems planning (Forrester, 1971) and ecosystems analysis (Patten, 1971; Odum, 1971, 1982), including agroecosystems (Hart, 1980) and land use systems (Antonini, Ewel and Tupper, 1975;Odum *et al* 1976). For detailed instructions and further examples these works should be consulted. For purposes of understanding existing system functions and component interactions in a qualitative manner, the following examples, (with legends and comments) should suffice. Some simple guidelines are provided for comparative use of conceptual models in diagram form. This should allow comparison between existing systems (structure, function, sustainability) and between current conditions and potential alternatives for any given system. In this section only the concepts and diagrams are treated since they are most relevant to the D & D exercise.

The specific diagramming method presented is that developed by H.T. Odum (1971) for use in energy analyses of ecosystems. The diagrams can be used to represent sources, flows, storages (and interactions between them) in terms of energy and/or materials (including money and information if appropriate). Models may depict farming systems, other land use systems or ecosystems. The checklist for farming system components and processes is found in Step 3.3. and the ecosystem checklist is in Appendix A-5.

The examples shown represent a series of land use systems in order of increasing intensity of labor and/or capital investment per unit land and per person supported by the system. More detailed accounts of energy flows and material cycles in such a hierarchy of land use intensity are provided by Leach (1976) and Makhijani and Poole (1975).

The elements included in these models are based on judgements as to which elements of the complex real system are most appropriate for consideration. This will vary depending upon the emphasis of the project (production vs. sustainability, farm vs. ecosystem). In this series nutrient cycling, labor utilization (human and animal labor) and degree of commercialization were emphasized as the main points of comparison. The series, as such, is presented to illustrate different types and complexities of land use and to develop the models in step-wise fashion to arrive at the semi-commercialized systems normally considered in D&D applications.

The first model, (Fig. 1)that of hunting and gathering in a forest, has been fully labelled (Fig. 2) for more accurate illustration and explanation of the method. The symbol legend (Table 1) describes the component symbols used in the diagram, and their function.

The specific sources, storages and flows in the model are identified in the legend below the diagram. The diagram generally depicts energy flows, although many storages and flows could also be expressed as biomass or other materials.

The three external sources are sunlight (S) Rainfall (R) and Nutrients (N). The natural rate of nutrient input (K3) to the available soil nutrients (N1) in the farming system is low, but consistent. The direct input from S,R, and N1 (K1, K2, K4) combine with work done (K5) by the existing plant biomass (V) to produce (K6) more plant biomass, in this case forest plant life. The increment in the total forest biomass (or total energy storage) is determined by subtracting from (K6) detrital losses recycled to soil (K8), respiration and detrital losses from site (K7), plants harvested by forest animals (K9), and plants harvested by the hunters and gatherers (K13).

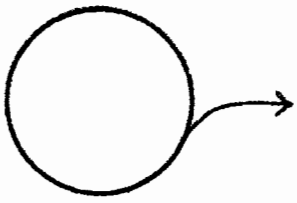
The harvested plants from the forest K9, combined with the metabolic, foraging and reproductive work (K10) done by the animals, provides the net energy input (K11) to the animal population. Outputs include mortality, respiration and waste products (K12) and harvesting of animals by humans (K14).

The human population of hunters and gatherers is maintained by food and fuel gathered (K13) and hunted (K14) and through the energy invested by the people themselves in metabolic, foraging, food processing and reproductive work (K15). The net energy input from these combined flows (K16) is partly balanced by combined losses (K17) from mortality and normal maintenance expenditures. To show the increased mortality and the extra work associated with increasing population in the same area, with the same technology, there is a multiplier on (K17). This indicates that losses will increase exponentially with population increase if the area and technology remains the same.

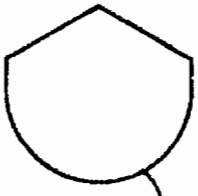
The model of pastoral nomadism shows similar components with different functions. Here the vegetation (mostly grasses and dry-forest trees) is harvested primarily by the animal population (A) and to some extent(firewood) by the human population (H). Human labor is intensified through work in herding (see Fig. 3).

In shifting agriculture (Fig.4) the major differences are in the diversity of vegetation/land use units (VF and VA); in the lack of a strong feed back from vegetation (VA) to the nutrient pool (NA1); and in the labor invested by the population (H) in cultivation. The main source of food is planted vegetation (VA) while fuel, supplemental plant food, and animals (A) are harvested from the forest (VF). The subsequent systems show increasing investments of labor by humans and animals to maintain sedentary agriculture Figs.5-10). The system-wide impacts of using cattle dung and fuelwood trees as energy sources can be compared in Figs. 6 and 7. Trade and cash flows are introduced in Fig. 8 and Figs 9 and 10 show intensification of trade and use of capital intensive inputs.

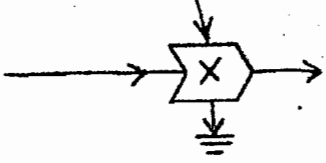
Table 1. Symbols Used in Energetic Models[1] of Ecosystems.



Indicates a constant source (inexhaustible within period of analysis) external to the system; for example solar energy, rainfall or long-term reliable material and cash subsides a given system.

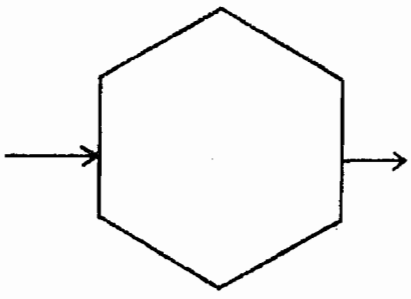


Symbolizes storage, for example: human, animal and plant biomass, water stored in aquifers, soil, lakes, tanks etc.

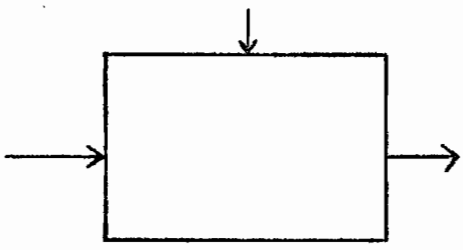


Indicates interaction between two (or more) flows, for example fuelwood and raw food -> meals. Indicates a heat sink, for example heat loss incurred in combustion processes, respiration, condensation.

Production module.
Symbolizes self-sustaining primary production such as photosynthesis (or an analogous process).



Consumer module. Indicates secondary production processes that depend on primary producers and/or other consumer/producers. For example cattle and other herbivores depend on photosynthesizing plants, and man (and other carnivore/omnivores) depends on plants (primary producers) and animals (other consumers involved in secondary production).



Black box, indicating a sub-system or process the internal workings of which are not of interest in the problem at hand. For example, a coffee processing plant in a farming system model.

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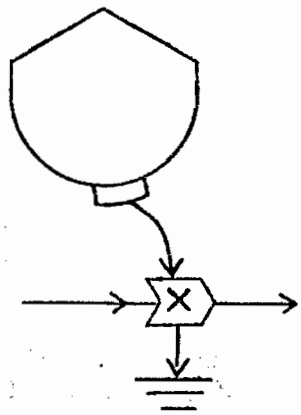
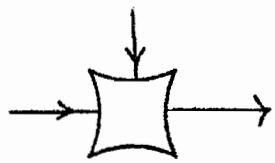
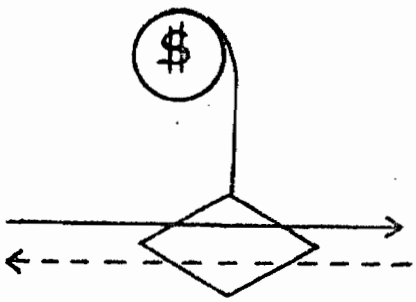
[1] Energy language symbols may be used to show flows, storages and interactions of energy and/or materials, depending on the application.



Sensor on tank. Indicates qualitative *effect* of storage on a flow or on an interaction between flows.



Represents a regulator or switch. Flows can be started or stopped based on the conditions set for the switch's operation. For example *when* soil moisture storage capacity is saturated *then* runoff begins, so the runoff flow is regulated by a switch that responds to soil moisture/soil moisture storage capacity.



Exchange of money for goods, flows in opposite directions, with unit price of goods in circle.

Parts of land use systems, and whole ecosystems can also be described within these same diagrams. Figs. 11 and 12 demonstrate the use of an energy language diagram to depict soil erosion, runoff, stream discharge and sedimentation under alternative land use systems for a watershed with degraded soil. Runoff and erosion rates are determined by interactions of rainfall, soil (volume, type, moisture) and land use. Land use acts as a multiplier and as such changes in land use have a major impact on these rates.

The composite erosion and runoff rates (per ha) for these land use combinations are determined by multiplying known or estimated erosion and runoff rates for each land use type times the % land area covered by each. These are summed to give the composite rates.

The change in land use depicted in figure 12 would have a significant impact on erosion and runoff and subsequently on stream discharge and sedimentation. The energy input (labor) from the population is intensified and redirected so that forest land is maintained, and bush land and cropland are partly converted to agroforestry use. The change is intended to decrease erosion and increase production. The model could be used as a conceptual framework for subsequent estimates and calculations or it could serve as a basis for simulation.

Fig. 13 shows an ecosystem-level model of a rural farming district combining four land uses (in partial rotation) and including two sub-groups in the resident population, one group mainly cash crop farmers and the other group subsistence farmers who make charcoal and sell it for use outside the area. Both groups share public grazing, wood-collecting and water sources. There is a rotation initiated by forest/woodland (LW) clearing (by group X) for food crop land (LF). This land later serves as grazing (LG), part of which returns to forest/woodland through natural succession. There is also a parallel forest clearing (by group Y) for permanent establishment of cash crops.

The sustainability of the ecosystem with current trends can be examined using the diagram and some rough estimates of sources, storages and flows as guides. Sources or sensitive points for problem-solving interventions can also be identified. For more precise estimates or prediction, existing systems with and without new technologies, and alternative land use systems can be diagrammed,then simulated. This last option (simulation) requires some quantitative data or reasonable estimates and the use of a micro-computer (or calculator) to do simultaneous solution of differential equations (see Appendix C-16). It is appropriate for technology or systems feasibility and impact analyses but is not included in the diagnostic phase. The same diagrams developed for diagnostic purposes can,however, be used later in these more elaborate analyses (option).

REFERENCES

Antonini, G.A., K. Ewel and H. Tupper. 1975. Population and Energy: A Systems Analysis of Resource Utilization in the Dominican Republic. University of Florida Press, Gainsville.

Forrester, J. 1971. World Dynamics, MIT Press, Cambridge. Mass.

Hart, R. 1980. Agroecosystems, CATIE, Turrialba, Costa Rica.

Leach, G. 1976. Energy and Food Production, I.P.C. Science and Technology Press Limited, Guilford, Surrey.

Makhijani, A. and A. Poole. 1975. Energy and Agriculture in the Third World, Ballinger Publishing Co. Cambridge, Mass.

Odum, H.T. 1982. Ecological and General Systems, John Wiley and Sons Inc., New York.

Odum, H.T. 1971. Environment, Power and Society. Wiley, New York.

Odum, H.T., M. Brown and R. Costanza. 1976. Developing a steady state for for Man and Land: Energy Procedures for Regional Planning pp. 343-361 in Science for Better Environment. Proceedings of the International Congress on the Human Environment (HESC) Kyoto Asahi Evening news Tokyo. (Reprints available, Centre for Wetlands University of Florida, Gainesville).

Patten, B. 1971. Systems Analysis and Simulation in Ecology, Academic Press, New York and London.

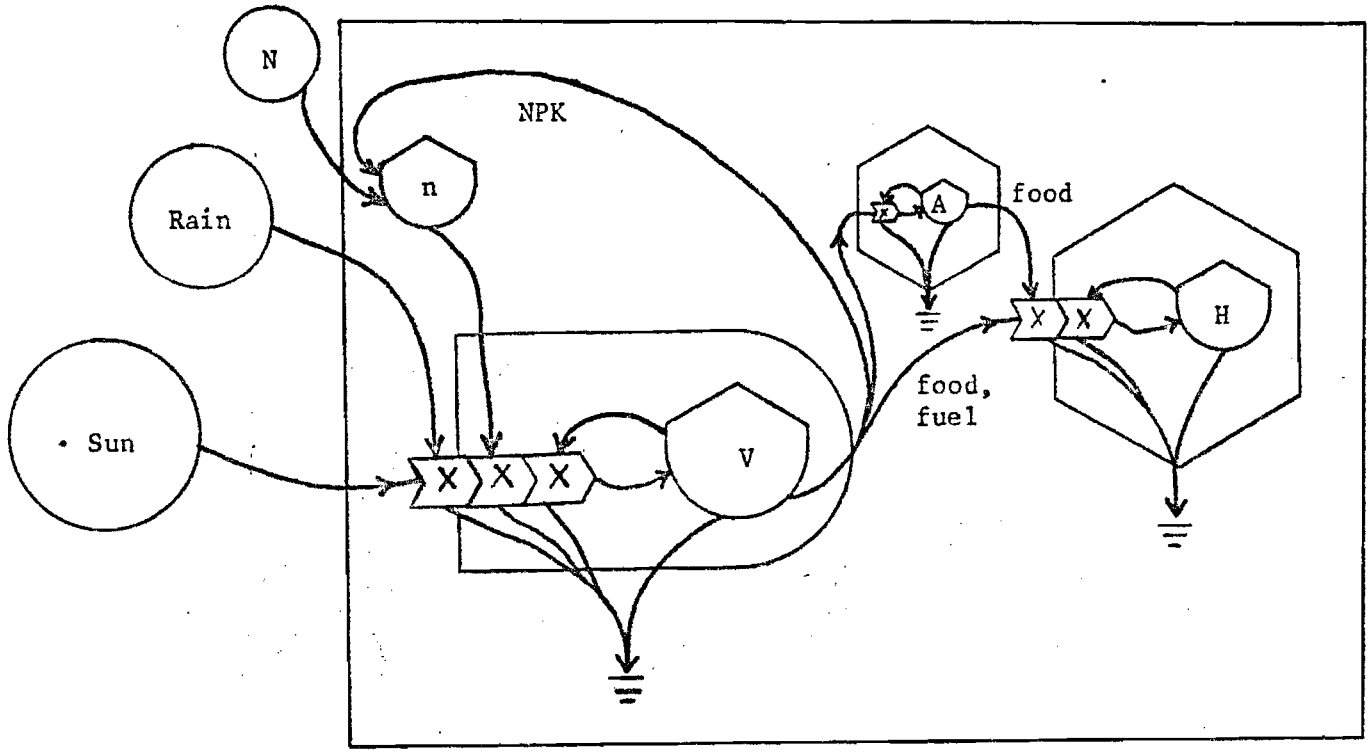


Figure 1

Hunters and Gatherers in the Forest

N = natural input of nutrients

n = nutrient storage in soil

V = vegetation biomass (or energy equivalent)

A = animal biomass (or energy equivalent)

H = human population (or energy equivalent)

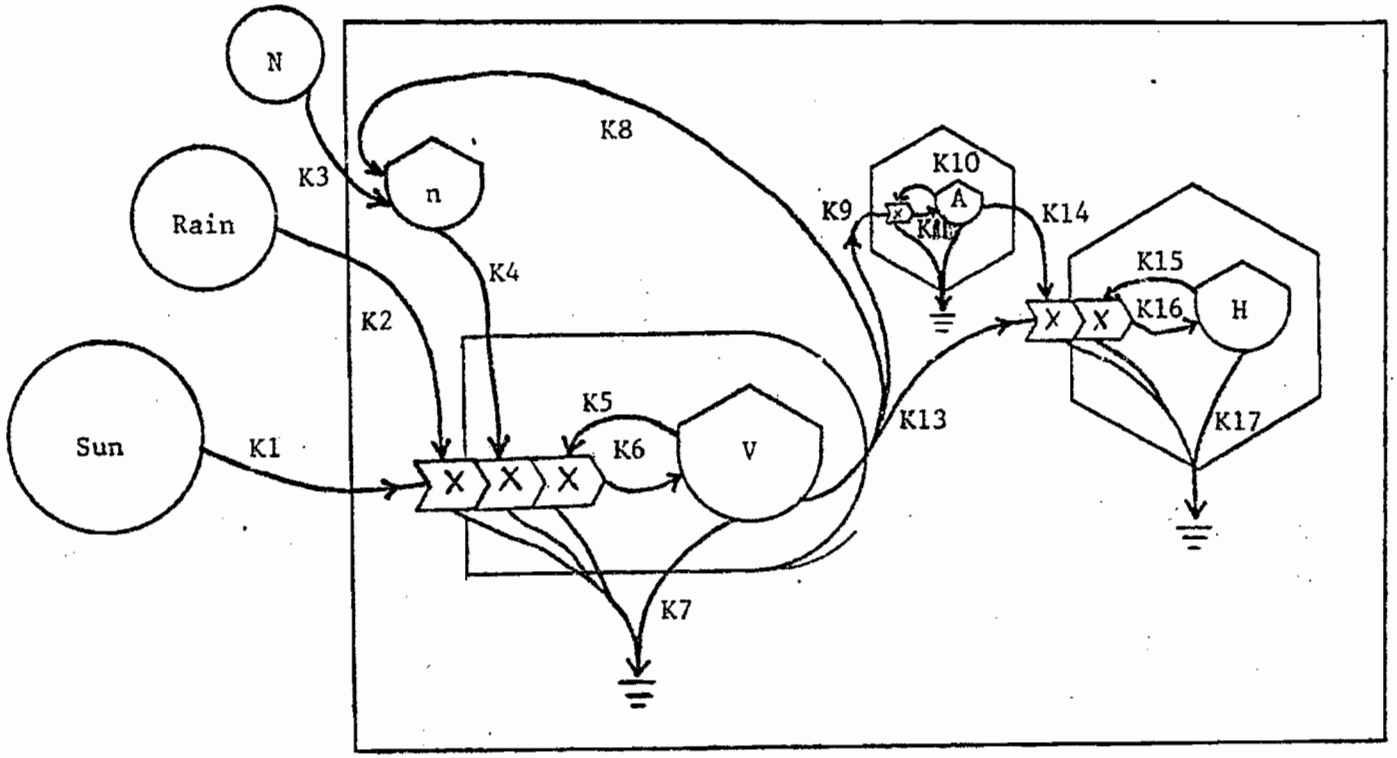


Figure 2.

Hunters and Gatherers in the Forest (Labelled Flows and storages

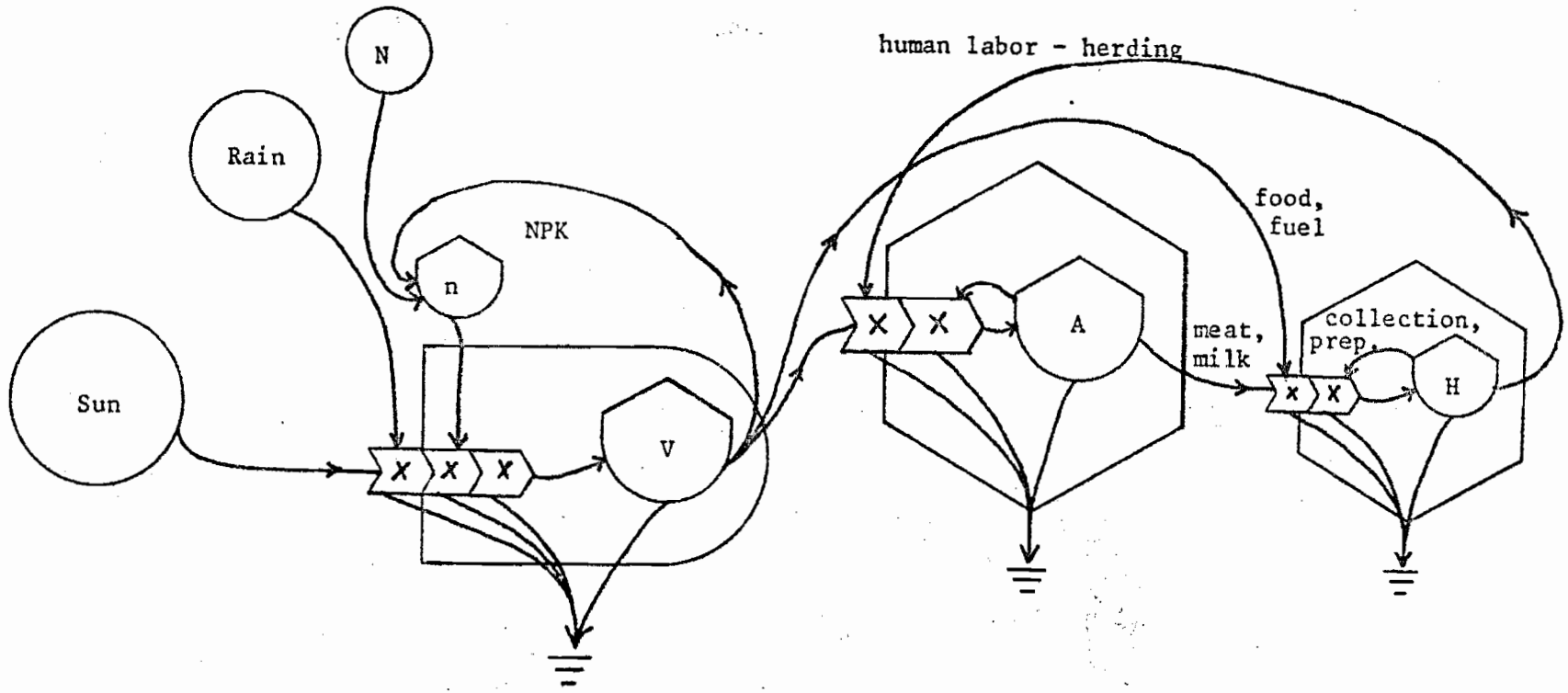


Figure 3. Pastoral Nomadism

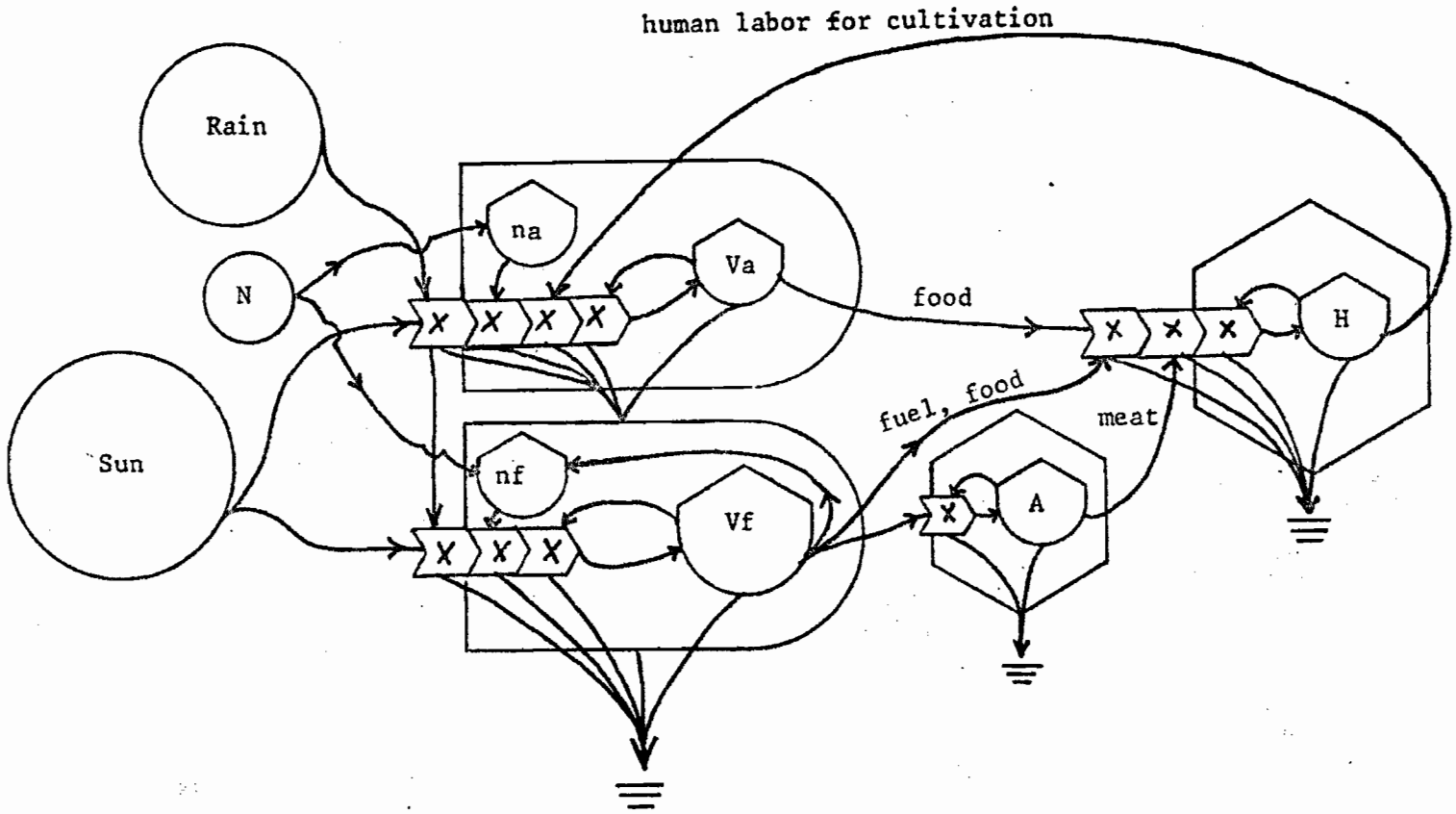


Figure 4. Shifting Agriculture

Va = planted vegetation (biomass or energy)
Vf = forest vegetation (biomass or energy)
na = nutrients in cultivated soil
nf = nutrients in forest soil

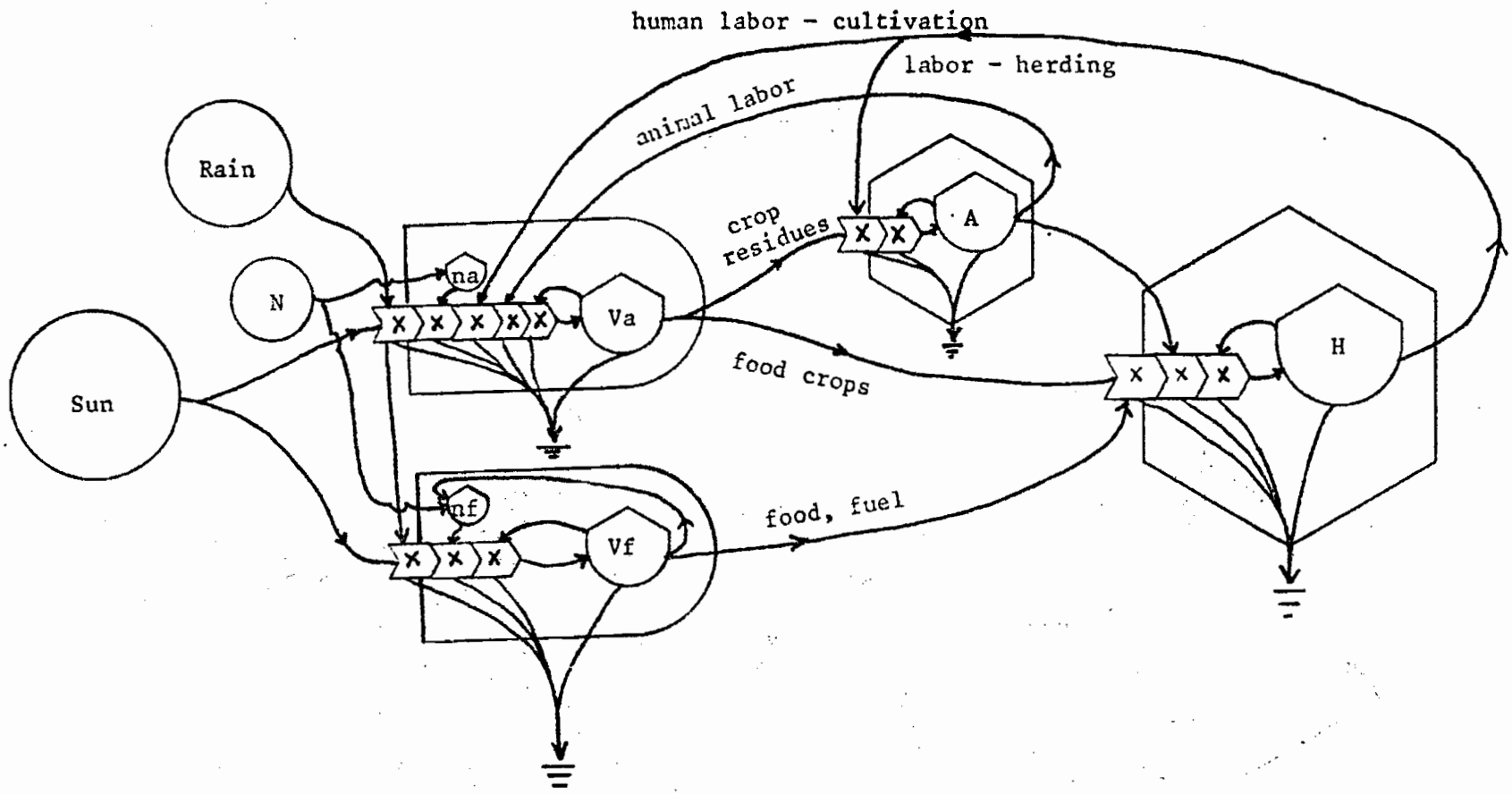


Figure 5.

Sedentary Rainfed Agriculture with Domestic Animals and Supplementary Food Collection in Forest

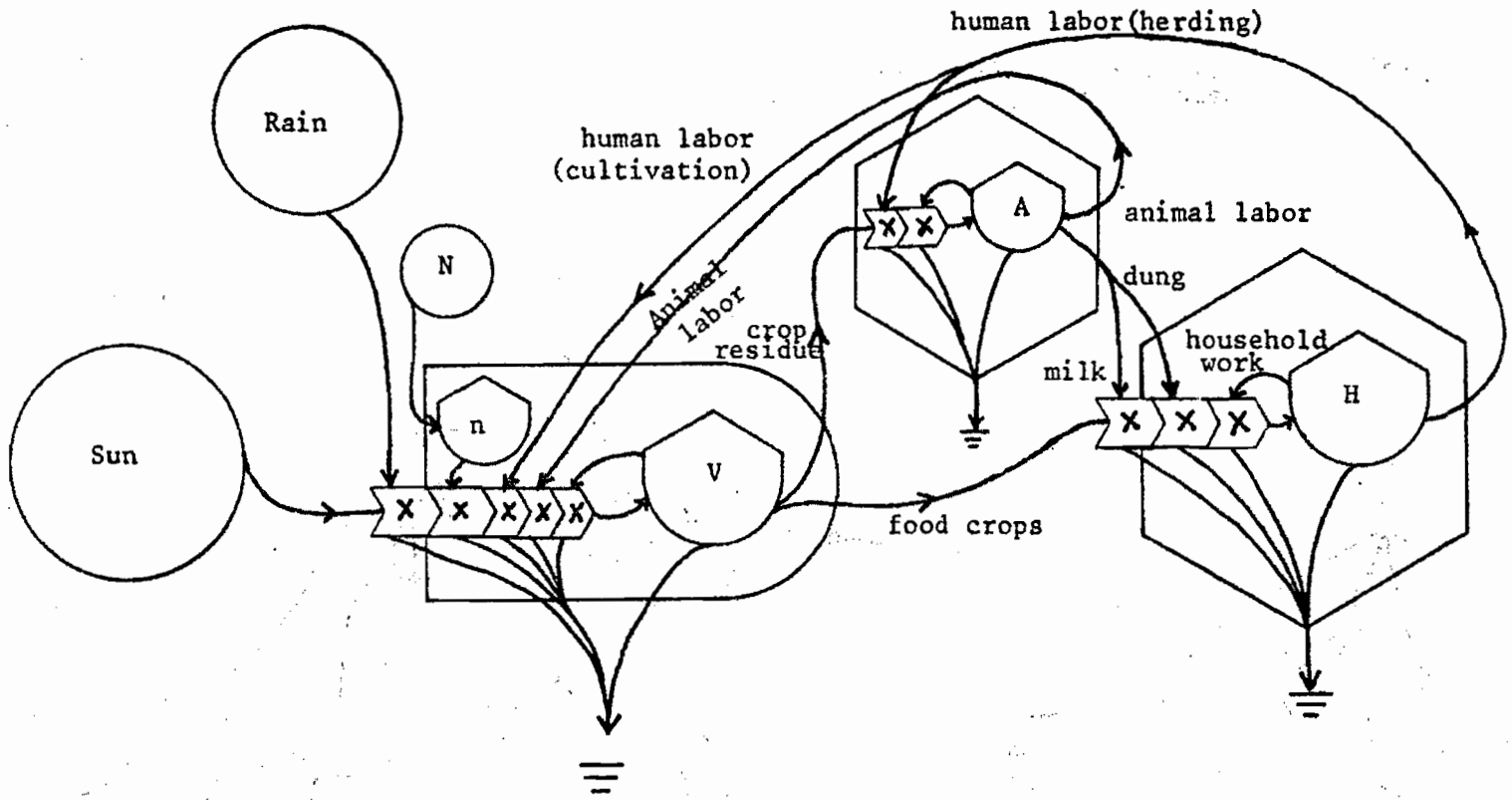


Figure 6

Labor - intensive Agriculture with Use of Cattle Dung for Fuel.

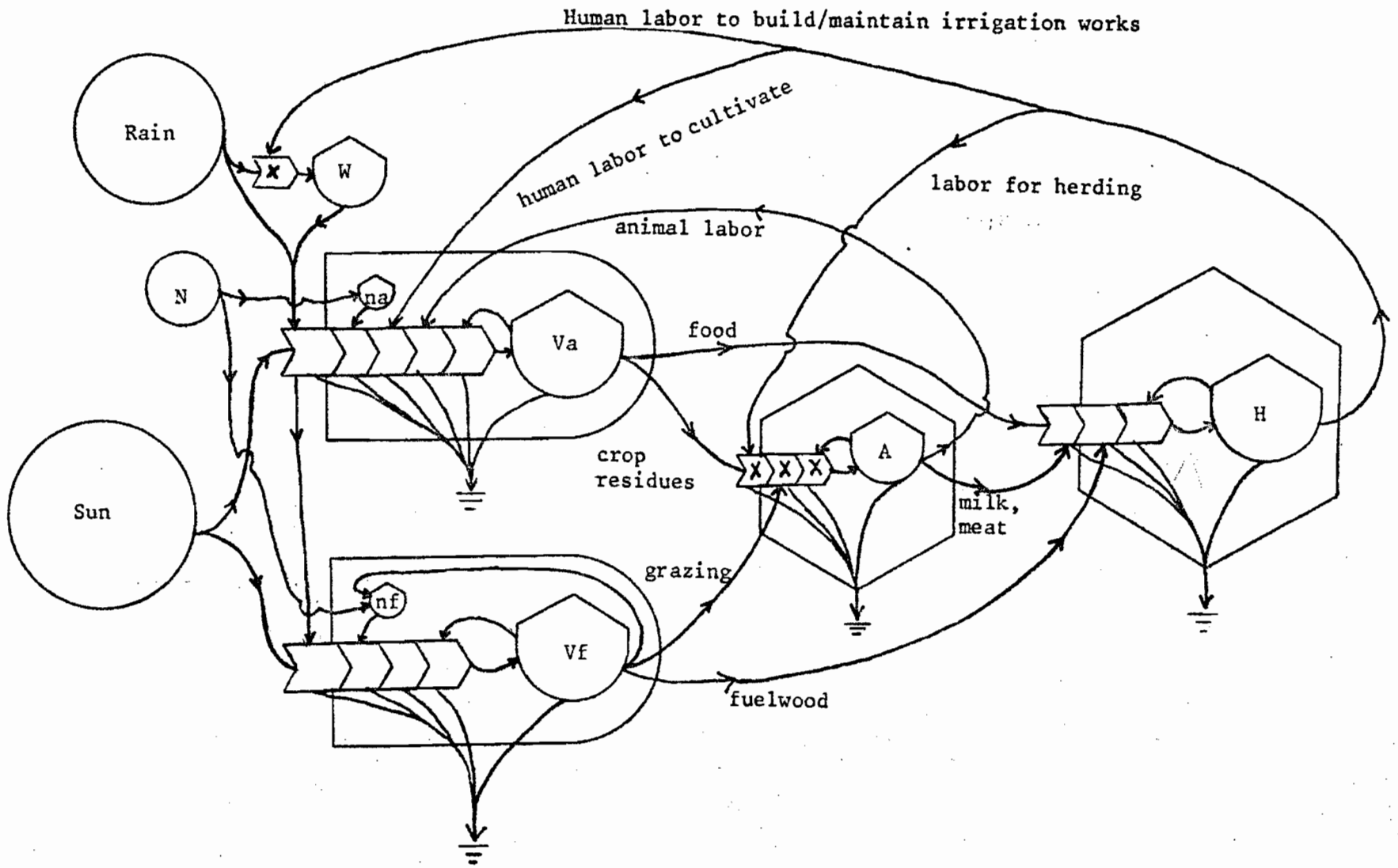


Figure 7.

Labor - intensive, Irrigated Paddy Rice with Fodder Trees/Woodlot.

W = Stored water

Vf= Woodlot/fodder trees

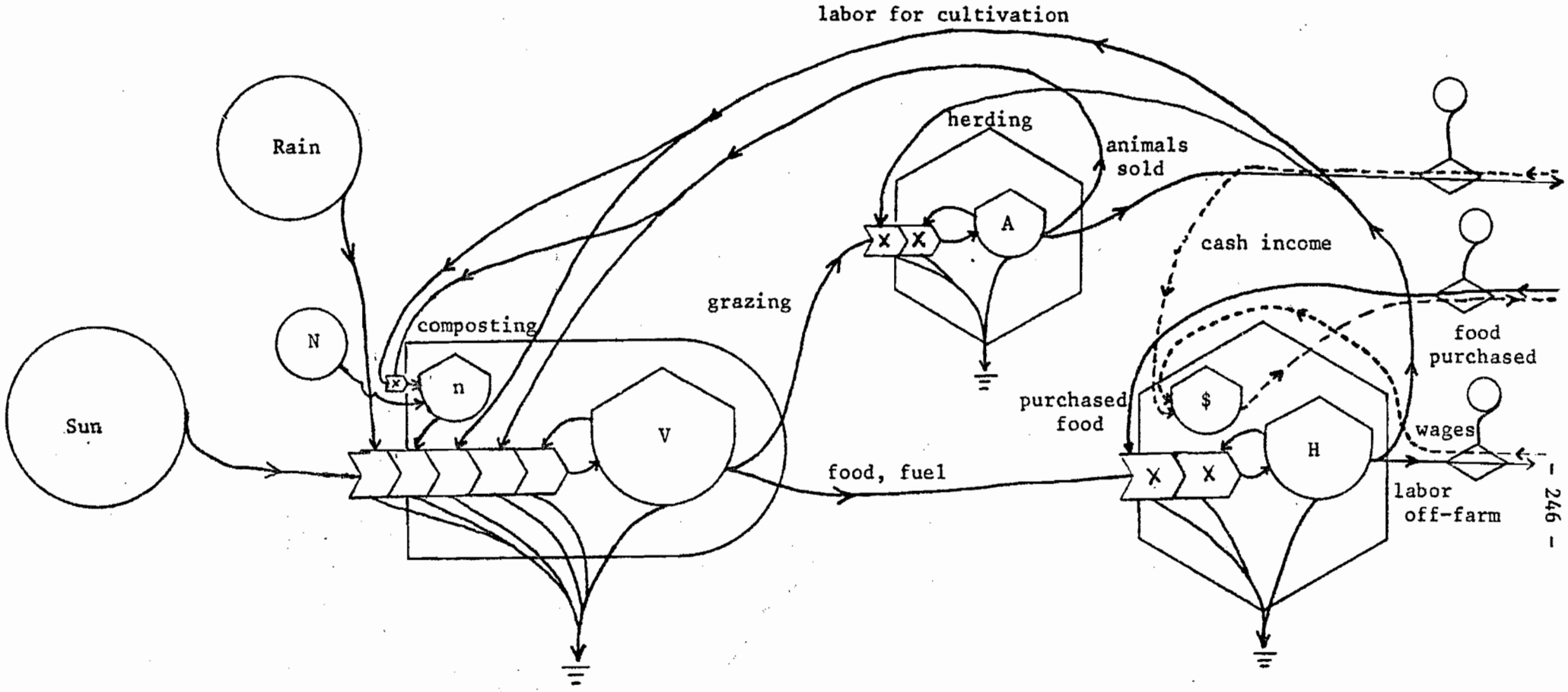


Figure 8.

Mixed Subsistence - Commercial Farm (with sale of animals, labor, purchase of food).

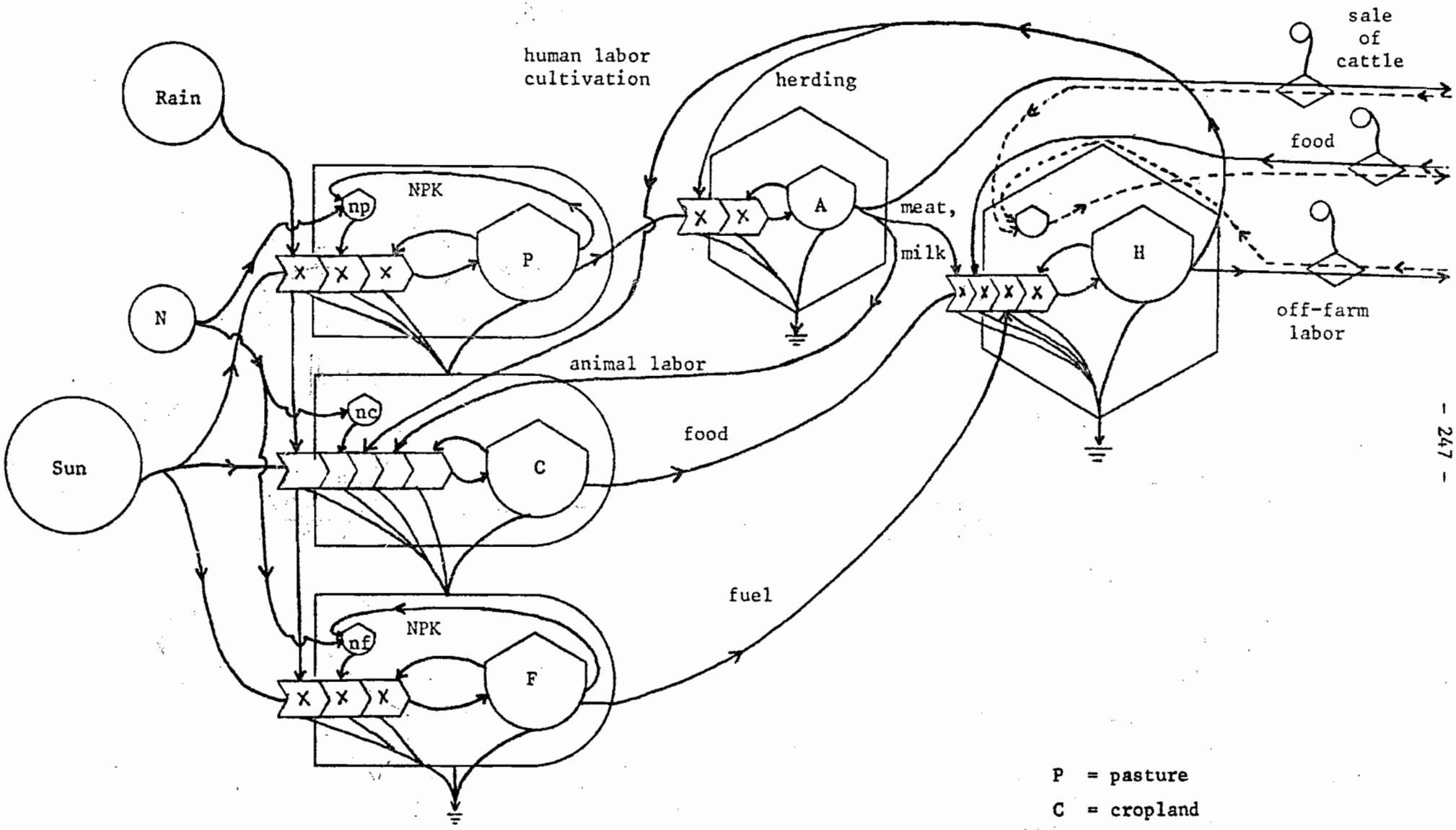


Figure 9.

Mixed Subsistence - Commercial Farm with Three Land Use types.

P = pasture
C = cropland
F = forest/woodlot
np = soil nutrients in pasture
nc = soil nutrients in cropland
nf = soil nutrients in forest/woodlot

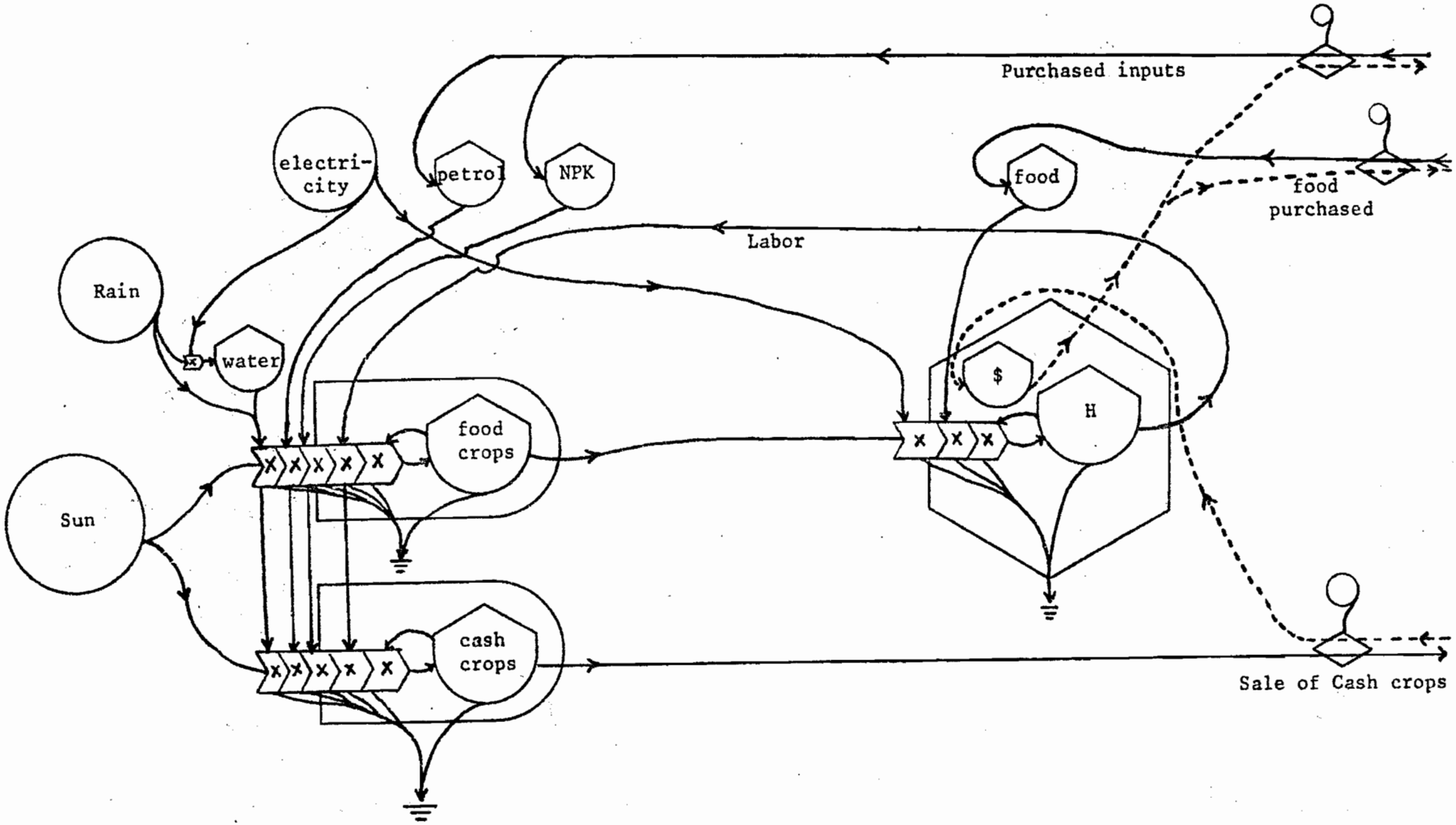


Figure 10.

Commercial Family Farm (with Irrigation, Tractor, Fertilizer and Subsidised Electricity).

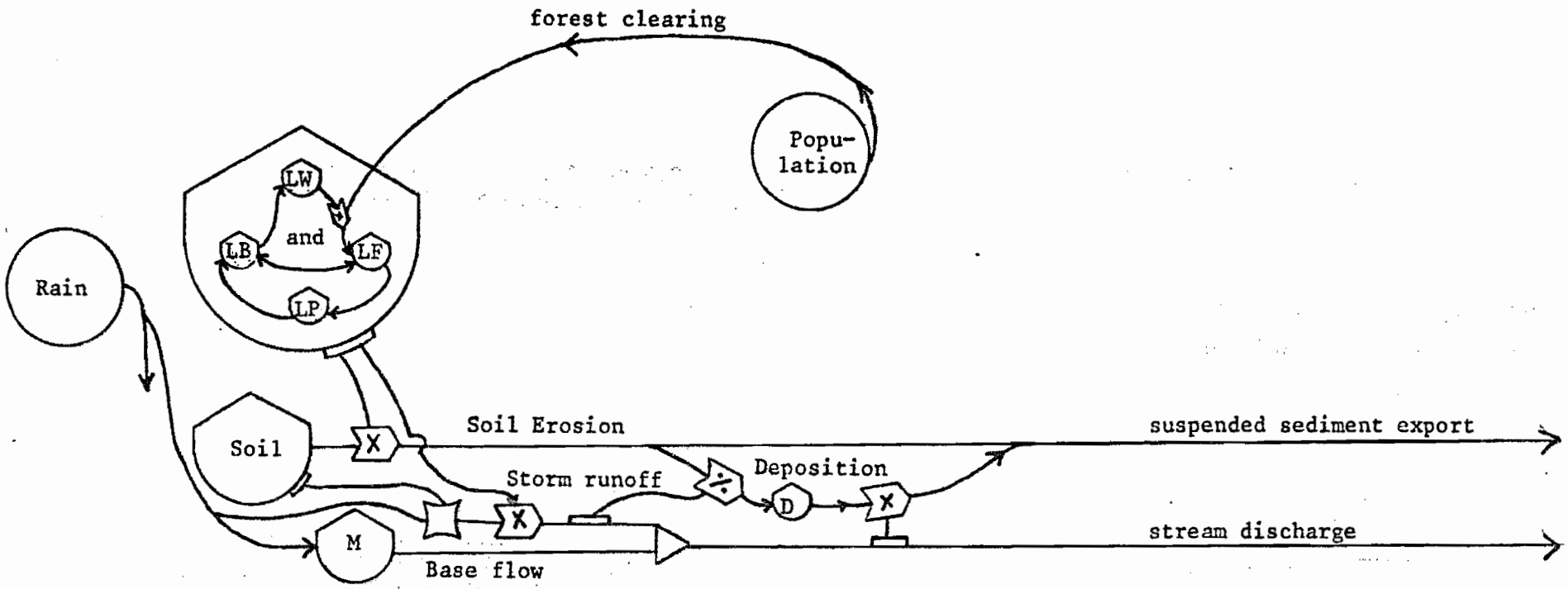


Figure 11.

Small Watershed Model of Land use, Erosion, Runoff and Sedimentation.

R = rainfall, mean annual

S = Soil (wt & Volume)

M = Soil moisture (volume, assumed maximum = 50% soil volume)

L = Land (land use distribution, indicated by type).

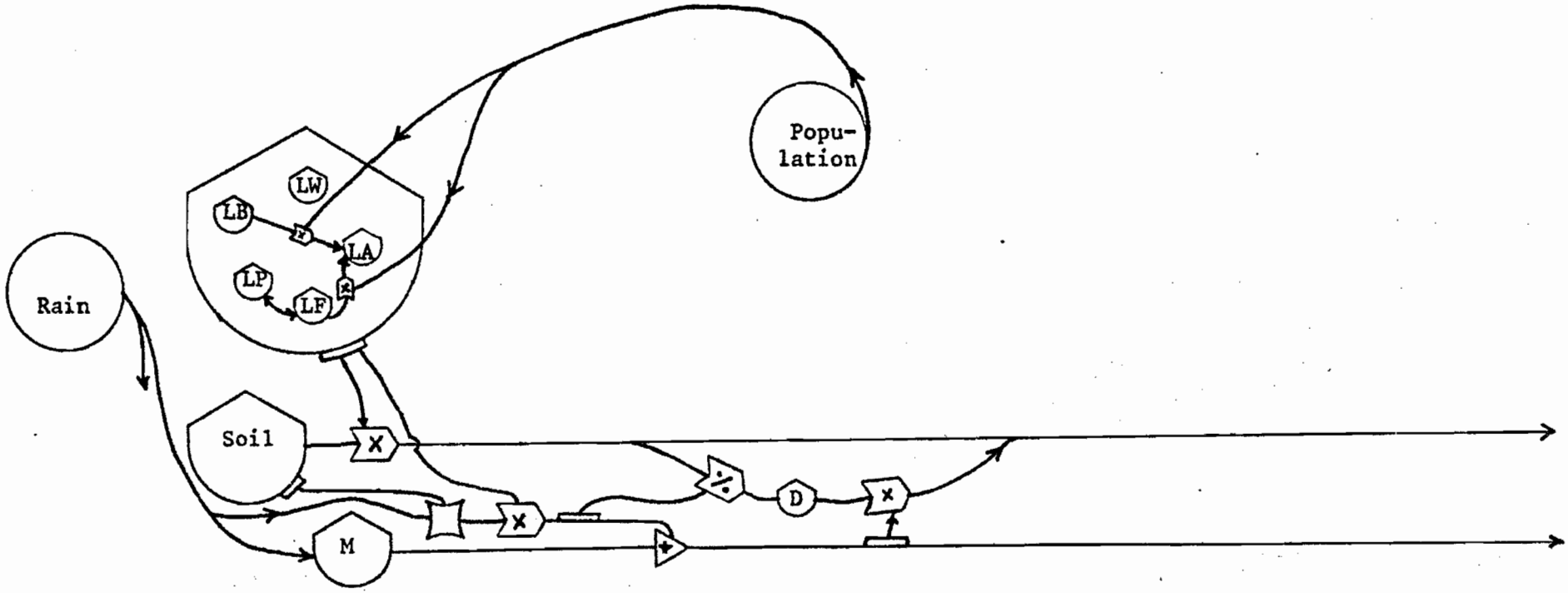
LW = % woodland area

LF = % Food and annual crop area

LP = % Pasture

LB = % Bushland (second growth)

D = Deposits of sediment in stream channel



LA = agroforestry system

All others - same as Figure 11.

Figure 12.

Small watershed with Land use Change (conversion of bushland and some cropland to agroforestry systems, forest clearing stopped).

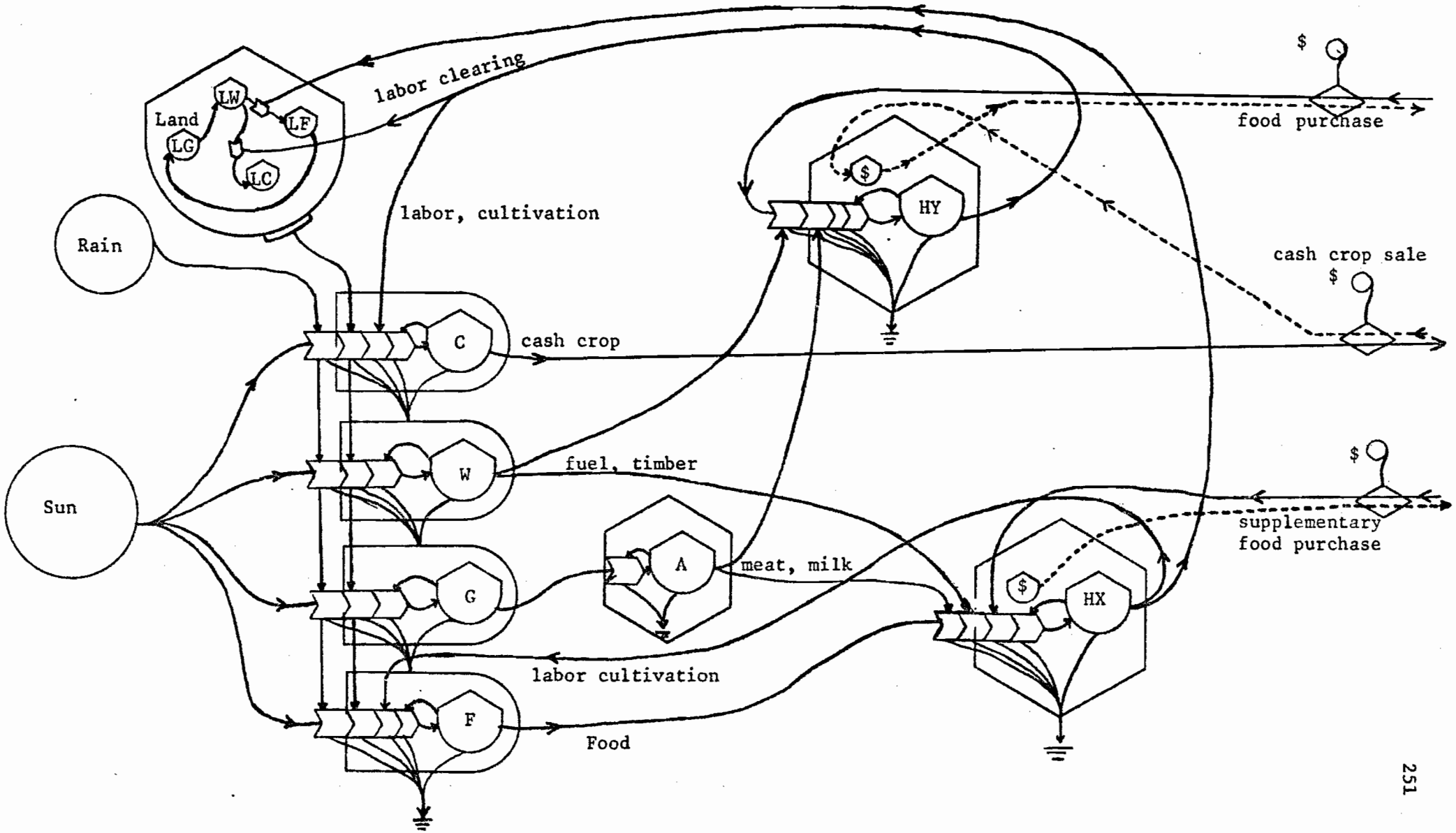


Figure 13.

Ecosystem Model of Rural Farming District

APPENDIX B-9

ASSESSMENT OF RESOURCE POTENTIALS AND LIMITATIONS*

The qualities of the land units which determine productive potential can be reviewed in two ways: positively as resources, or negatively as limitations. Thus deep soil is a resource, shallow soil a limitation. Resources and limitations are always specific to particular kinds of land use. For example, a growing period of 120 days is a resource for maize, but a severe limitation for most perennial crops.

Ways of making the initial identification include:

- Present land use. What crops are currently being grown? What are the other forms of production from the land?
- Agroclimatic and soil suitability. Possible crops and forms of production may be identified by comparison with areas possessing similar environmental conditions, and by reference to tables of crop requirements (see Appendices C-9 and C-12).
- Experience of local agronomists and research stations, data from field trials.
- Market demand. For what products is there an unsatisfied demand, at favourable prices?
- Suggestions by government. Policy may dictate certain objectives, e.g. increased food production, export production.

The second of these methods, agroclimatic and soil suitability, requires that environmental data should be collected in a form similar to, or such as to permit conversion to, data on land use requirements. It is recommended that data should be collected in terms of land qualities, each of which can be measured or estimated in a variety of ways by means of land characteristics. A land quality is a complex attribute of land which affects its suitability for use in a distinctive manner; examples are moisture availability, soil rooting conditions, erosion hazard. A land characteristic is an attribute of land that can be measured or estimated; examples are mean annual rainfall, effective soil depth, slope angle. (For further explanation of land qualities and characteristics, see FAO (1976), FAO (1983), Dent and Young (1981). Requirements for rainfed crop production may be summarized by saying that, for satisfactory growth, crops need suitable temperatures, moisture, oxygen, nutrients, opportunity to develop an adequate root system, and absence of hazards which would hinder growth or damage the crop. There are in full 25 land qualities which can affect suitability for the growth and management of crops, but some of these are of limited appliability, because they affect few crops, are relevant in only few environments, or both. With some combining, the most widely relevant land qualities for rainfed crop production are:

- temperature regime
- moisture regime
- oxygen availability (soil drainage)
- nutrient availability
- rooting conditions
- hazards: climatic, flooding, toxicities, pests and diseases.

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*Contributed by A. Young

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Livestock need feed and drinking water at all seasons of the year, and absence of stresses, pests and diseases. Again with some combining the principal land qualities affecting suitability for livestock production are:

- feed availability (pasture and browse, total and seasonal)
- availability of drinking water (distance, quality, seasonality)
- hazards: climatic stress, vegetation toxicities, pests and diseases.

For forest production there is a clear distinction between utilization of natural forests and forest plantations. For natural forests, the main land quality is clearly the extent, species composition, growth rate and user properties of the trees present. For plantations similar qualities to those for crop production apply. In addition, for both kinds of forest land use, a further land quality of importance is terrain factors affecting management (establishment, maintenance, extraction or felling).

The following is a check-list of the more important land qualities, together with land characteristics which can be employed for their assessment. During the diagnostic phase it will by no means be possible to collect information on all characteristics listed; however, it is often possible for a particular area to assess which are not significant and which are of particular importance.

Land quality	Land Characteristics
A. For rainfed crop production	
1. Temperature regime	- mean and extreme monthly temperatures
2. Moisture availability	- monthly rainfall (means, variability) - monthly evaporation (potential evapotranspiration - soil availability water capacity - soil texture (as an indicator of AWC)
3. Oxygen availability	- soil drainage class - period of waterlogging
4. Nutrient availability	- soil analytical data (N,P,K,CEC, etc.) - soil reaction - crop deficiency symptoms
5. Rooting conditions	- soil effective depth - soil structure/consistence
6. Soil availability	- topsoil texture
7. Flood hazard	- frequency of flooding
8. Climatic hazards	- duration/frequency of frost - frequency/severity of storm damage
9. Excess of salts	- soil analytical data (ECe, ESP, etc.) - visible salt precipitates

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(Cont'd)

Land quality	Land Characteristics
10. Soil toxicities: aluminium	- reaction
other	
11. Pests and diseases:	
affecting crop	- known incidence
affecting stored produce	- " "
12. Soil erosion hazard	- calculated erosion loss - slope angles - soil texture - observed symptoms
13. Soil degradation hazard	- comparison of cultivation intensity with rest period requirement
B. For Livestock Production	
1. Feed availability: pastures, total	- data on composition, biomass, growth rate, palatability and nutritive value of pastures; especially biomass, DCP;
pastures, seasonal	- as above, for least favourable season
2. Water availability	- distance to water, least favourable season - depth to groundwater - salinity
3. Climatic stresses affecting livestock	- monthly temperatures, humidities
4. Pests and diseases affecting livestock	- known incidence, endemic diseases
C. For Forest Production	
1. Timber resources	- species composition, volume, growth rate of existing forests
2. Terrain factors affecting management	- slope angles - swamps, stream density
3. Pests and diseases affecting trees	- incidence
4. Climatic hazards affecting trees	- fire, widthrow, frost

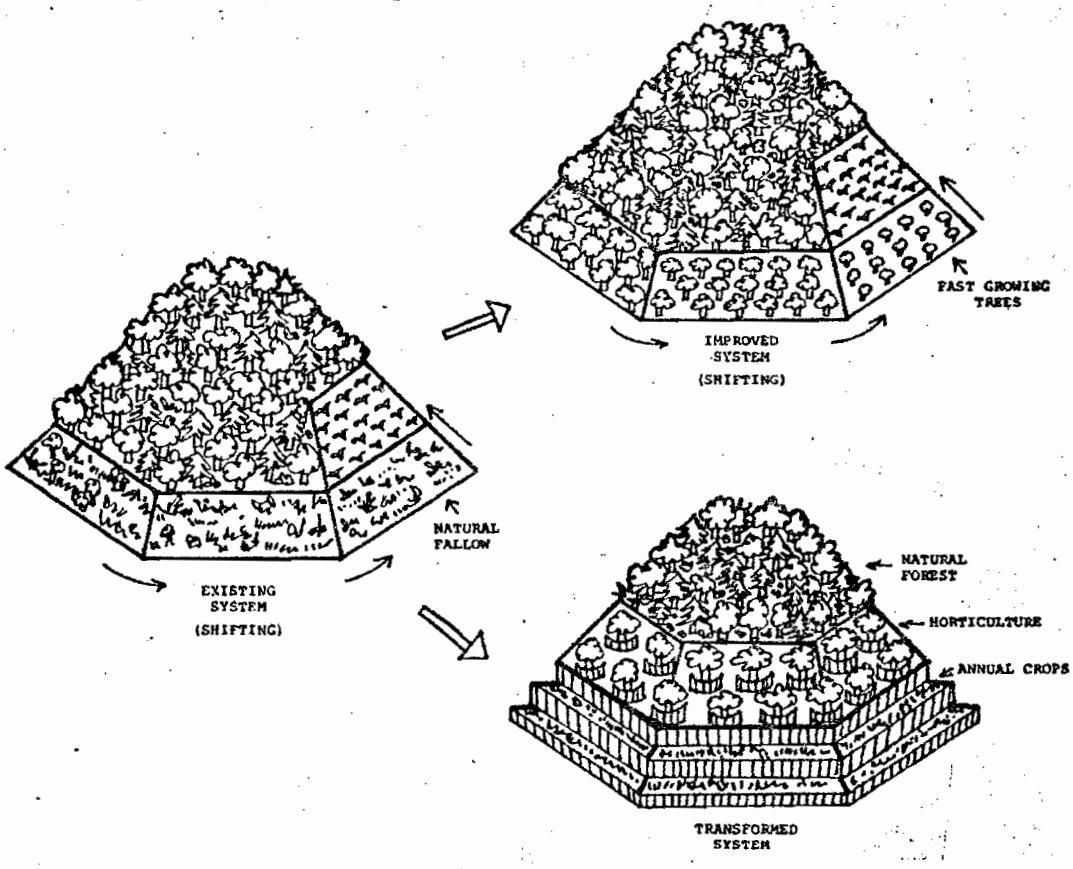
In addition, climatic and soil factors affecting crop production may similarly affect growth of trees.

APPENDIX C-1

IMPROVING vs. TRANSFORMING APPROACHES TO THE DEVELOPMENT OF LAND USE SYSTEMS*

The following example is given to illustrate the difference between an "improving" and a "transforming" approach to the development of a land use system, in this case a system of shifting cultivation in the north eastern hill region of India.

A shifting system is the traditional way of cultivating the land in this region, characterized by cut and burn practices followed by dibbling of various crops in an intimate mixture. Usually shifting to a new site takes place after two years of cultivation, returning to the same site in 3 to 6 years to start the process again. This has led to marked soil erosion and decrease in productivity due to a loss of soil fertility. The existing system can be improved by introducing a fast-growing tree species, which will control some of the problems derived from shifting but will essentially not alter the cultivating method being used. On the other hand, it could be transformed, by introducing a new soil management practice - terracing - and a new spatial distribution of crops. The proposed system - based on terracing the lower 1/3 area and utilizing it for growing field crops, while the next-up 1/3 is dedicated to horti-pastoral crops and the top portion is left with natural forests including fodder and fuel trees - was evolved as a consequence of studies on the soil and crop components. If applied, the transformed agroforestry system would increase the net income four-fold, but the improved system might be more readily adopted.



*Excerpted from F. Torres. 1980. Research objectives in agroforestry: a conceptual approach. *In:* T. Chandler and D. Spurgeon (eds). International Cooperation in Agroforestry. ICRAF. Nairobi.

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APPENDIX C-2

MULTIFUNCTIONAL AGROFORESTRY DESIGNS*

A good agroforestry design should aim at maximizing the *impact* of the technological innovation on the landscape of rural poverty. In general, a good design will score high on three attributes: *productivity*, *sustainability* and *adoptability*. The first two criteria are virtually axiomatic in agroforestry, which almost by definition aims to serve both production and conservation needs. Most farmers, on the other hand, are primarily interested in production and show less interest, if any at all, in technical innovations aimed at conservation objectives. The concept of "sustainability" is a way of operationalizing the conservation objective in terms of the production objective.

The third attribute, adoptability, is equally important to an impact-maximizing design strategy. As nutritionists note, the nutritional value of any food that is not eaten is zero, regardless of its chemical composition. No matter how productive and sustainable it may be, an agroforestry technology will have little impact on the landscape unless it is adopted by a significant percentage of the intended users. Hence, the emphasis on producing genuinely adoptable designs.

One of the main ideas behind the diagnostic or "problem-solving" approach to agroforestry design is the assumption, bourne out by experience, that farmers are more likely to adopt technical innovations which solve *perceived problems* than those which do not. Much of the D&D methodology is aimed at discovering what land management problems are perceived by the farmer as having a high priority for solution. The payoff comes in the increased adoptability of designs which offer solutions to perceived problems.

But what about *unperceived problems*? The D&D team will, in all probability, discover problems which it considers crucial to the productivity or sustainability of the system but which, nevertheless, ramain unperceived or are accorded a low priority in the farmer's thinking. Rather than just "leaving the ignorant farmer to his fate", agroforestry designers would be well advised to regard the farmer's insensivity as an *added design problem* and try to solve it along with the other problems of a more technical nature.

One promising design tactic, which resourceful designers will employ, is to try to find some way of *combining* solutions to unperceived or low-priority problems with those for well-perceived, high-priority problems. In other words, in the case of low-priority conservation problems, to introduce the unwanted conservation function as a *by-product* of the farmer's decision to adopt a new technology for its production benefits. By making use of multipurpose trees and the wide range of spatial and management options, we may take advantage of the enormous

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*Adapted from J.B. Raintree (1983), Strategies for enhancing the adoptability of agroforestry innovations, Agroforestry Systems 1(3): 173-187.

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scope in agroforestry for *multifunctional designs*. The trick is to find out what the "selling points" for agroforestry are, given the farmer's way of thinking, and to package the appropriate technological functions together with other potential functions addressing unperceived problems or potentials of the system.

For example, in its D&D work in Kenya, where erosion is often a severe problem, the ICRAF team has encountered farmers with little or no present interest in erosion contol who appear, nevertheless, very interested in farm plantings of fast-growing fuelwood trees to satisfy household energy needs. By planting hedgerows of coppicing fuelwood tree together with grass in contour strips on sloping cropland at intervals selected for effective erosion control, it is possible to solve both problems with a single, adoptable design. This design tactic, which might be called the "Piggy Back Principle," strives for multifunctional designs which seek to introduce undesired functions "on the back" of desired functions.

The tactic can also be used to address future production problems which the farmer may have difficulty in anticipating. For example, although somewhat rarer than the previously cited case, ICRAF's D&D team has also encountered Kenyan farmers with a definite and present interest in erosion control but no *presently perceived* problem with fuelwood supply. This situation is found in hilly areas where, although the natural woody vegetation cover is diminishing at a rapid rate, deforestation has not yet reached the point where fuelwood is in short supply. By planting a hedgerow design (similar to the previous example) for erosion control purposes in cropland, the farmer will have what amounts to a future fuelwood production system already in place on his farm when eventually the fuelwood shortage does arrive. This is a *preadaptive* application of the principle of multifunctional designs. Given the need and the potential for agroforestry systems which address future as well as present problems, preadaptive designs should be encouraged whenever they can be linked to presently adoptable technologies.

APPENDIX C-3

THE CONCEPT OF AN OPTIMAL PATHWAY OF INTENSIFICATION*

In this age of rapid population growth land use systems are highly dynamic. Tree-based land management systems, by contrast, may take a long time to establish and, once established, may commit the land to a specific form of use which is not lightly changed. Therefore, it is incumbent upon designers of agroforestry systems to give thought to the future and, whenever possible, to strive for designs which incorporate flexibility and scope for gradual intensification to meet the needs of future generations living on the land at substantially higher levels of population density.

That is the positive statement of the design problem. The negative statement is that, unless this aspect of the time dimension in agroforestry design is taken into account before embarking on a research effort to develop the envisaged technology, the technology may be obsolete by the time it is ready for dissemination.

In most cases it is not a simple problem of anticipating and designing for some future state of the system. This is because technologies appropriate to later states of the system, characterized by higher land use and labour intensities, may not be adoptable in the present state of the system, characterized by lower land use and labour intensities. The pivotal factor, in most cases, will be the farmer's perception of acceptable labour intensity at any given point in time.

It is now widely acknowledged that traditional farmers are rational producers who economize on the use of resources. Labour economics play an important role in the decision to adopt or reject technical innovations. Historically, agricultural systems have shown a tendency to evolve from extensive to intensive systems of land use. Insofar as extensive systems tend to have lower labour requirements per unit of production than intensive systems, the historical preference for extensive systems can be seen as a rational choice based on the economic use of labour resources. That being the case, what drives this reluctant evolution toward more labour and land use intensive systems?

According to the theory of Boserup (1965), the main driving variable is *population pressure*. Subsistence-oriented farmers, it is argued, economize on the use of labour resources and will tend to resist adoption of more labour intensive technologies as long as less labour intensive means (traditional extensive technologies) remain capable of satisfying their basic needs (including whatever cash or development aspirations they may have). There is an ecological dynamic, however, i.e. environmental degradation resulting from increasing population pressure under traditional technology, which determines that eventually a point will be reached when returns to labour will actually be lower under the traditional extensive technology than under newer, more intensive land management alternatives. When that point is reached it becomes

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*Adapted from J.B. Raintree (1983), Landuse and labour intensity: factors affecting the adoptability of conservation farming practices under conditions of population pressure. Proc. of the Workshop on Conservation Farming, January 17-21, Colombo, Sri Lanka; and Raintree (1983), Strategies for enhancing the adoptability of agroforestry innovations, Agroforestry Systems, 3.

rational for the traditional farmer to adopt the more intensive technology.

What prevents the agroforestry designer from going immediately to high density, intensive designs is the fact that, in the present state of the system, the labour economics of the more intensive technology may compare unfavourably with the traditional, less intensive technology which, as long as it remains ecologically viable, will generally give higher returns to labour. As land becomes scarce and population pressure increases, however, this situation will change. The challenge to agroforestry designers is to take the dynamism of the land use system into account in their designs without contravening the principle of *appropriate labour intensity* at any point in time. It may be futile to try to introduce an excessively labour intensive technology before its time but, on the other hand, a technology designed for the present level of acceptable labour intensity may become rapidly obsolete in a highly dynamic system under population pressure.

What is called for is a phased approach to intensification based on a *succession of technologies* which keeps pace with population growth. This will only be possible if each stage in the succession of technologies meets two requirements:

1. It must be compatible in its labour demands with the prevailing level of acceptable labour intensity per unit of production at each stage in the development of the system. (This means that the labour requirements of the alternative technology should not *grossly exceed* that of the traditional technology at the time of its introduction).

2. It must leave sufficient flexibility and scope, in terms of committed land use, for the *next stage* in the succession. In other words, each stage in the progression of technologies should prepare the ground and leave scope for the succeding stage.

Let us postulate, then, for design purposes, an "optimal pathway of intensification" and see what such a thing might look like for a specific land use system.

An Example from Kenya

Kuria Division in Western Province, Kenya has a current average population density of approximately 148 persons/km^2. Present land use takes the form of an unregulated ley farming system which is not very intensive, but there is a need for fuelwood plantings to meet the requirements of a cottage industry based on the growing and flue-curing of tobacco. With the prevailing relatively low opportunity cost of land, there is no reason *at present* why fuelwood lots of Eucalyptus on non-prime agricultural land within the farms would not be a suitable means to meet fuelwood requirements.

However, with an annual population growth rate of approximately 4%, the population of Kuria Division will double in about 17 years. To the next generation of farmers a conventional fuelwood lot, which competes directly with agriculture for increasingly scarce cropland, might seem a somewhat undesirable form of land use as compared to the alternatives of border plantings or internal hedgerows of tree species and management systems selected for their compatability with crops. One could envisage an appropriate system of hedgerow intercropping or "alley cropping" for joint production of fuelwood as a by-product of an improved food crop production system, but this innovation would perhaps be a bit early for adoption by farmers accustomed to the relatively low labour intensities of the present farming system.

Figure 1 represents one possible design solution which applies the concept of an optimal development pathway for this location. Unfortunately, no data on the actual landuse and labour intensities of the technologies in the proposed succession are available at present to substantiate the hypothesis, but the example may serve to illustrate the general design concept.

The x-axis in Fig. 1 represents some measure of landuse intensity such as Ruthenberg's R-value (See Appendix A-10). The y-axis represents some index of labour intensity. The diagonal line depicts the succession of hypothetically adoptable technologies as population pressure increases.

From a distance, the first stage in the sequence looks like a conventional fuelwood lot, but on closer inspection one notices that the trees involved are a mixture of fast-growing leguminous and other coppicing species selected for their ability to produce not only fuelwood but also high quality mulch and green manure. (Other desirable characteristics would be a deep rooting habit, non-allelopathic interactions with crops, and possibly some insect-repellent properties). As regards spacing, one notices that the trees have been planted at closer than normal in-row spacing and wider between row spacing to allow for the eventuality of intercropping with food crops.

The succession of management practices goes something as follows: In the initial stage the farmer may practice taungya intercropping between the rows of trees in the period following the fuelwood harvest when the hedgerows are re-establishing their canopy. As population pressure advances the system to the next stage of intensification, with an increased demand for food crops to support a denser population, the wood producing cycle is gradually shortened until the farmer is operating what is, in effect, an "alley cropping" or hedgerow mulch farming system with the possibility of a fallow rotation moving around through the subdivisions of the original "woodlot". The purpose of the partial fallow rotation is to increase the production of fuelwood from at least part of this more intensively managed system. Obviously, however, the total fuelwood production will be decreased, but this may be offset by parallel developments in the efficiency of the flue-curing technology.

Eventually, as population pressure forces the next generation of farmers toward even more intensive systems of land use, the fallow rotation is eliminated in favour of permanent "alley cropping". At last, to obtain the final measure of potential productivity from this evolving agroforestry system, the farmers may turn to the vertical dimension and superimpose additional layers of middle and upper-storey food, feed and fuel producing trees on part of the land in a manner analogous to the Javanese "home garden".

We can think of this progression as roughly equivalent to three or four generations of farmers cultivating increasingly smaller sub-divisions of the land. The basic idea is to progressively increase the intensity of land use through a succession of management practices involving acceptable increments in labour intensity. Hopefully, this would buy enough time to implement an effective system of family planning in time to stabilize the population at or below the maximum sustainable carrying capacity of the land with improved technology.

Although each and every land use system must be approached on its own terms, similar applications of the concept of an optimal intensification pathway may assist agroforestry designers to deal effectively with the time dimension in agroforestry design for systems in other parts of the world.

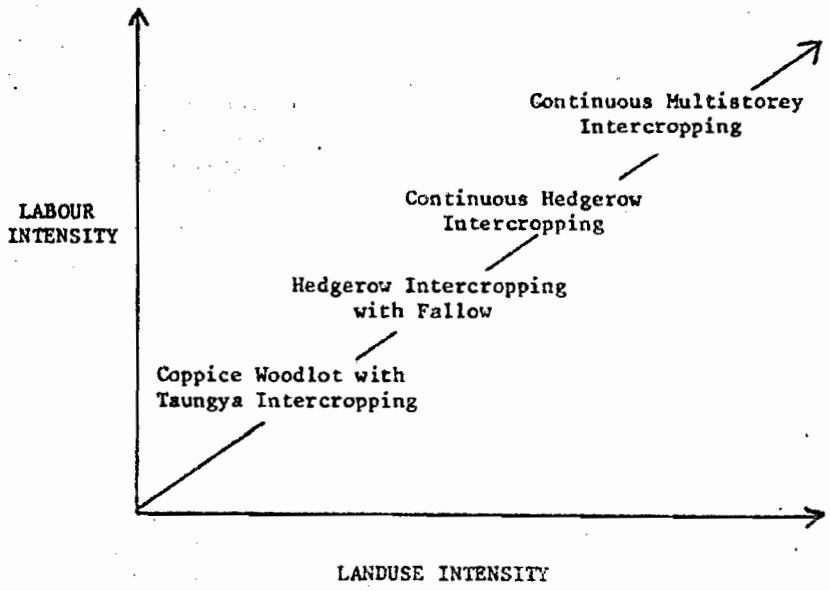

Figure 1. Hypothetical pathway of intensification in an agroforestry system for Kuria Division in Western Kenya.

REFERENCES

Boserup, E. (1965). The Conditions of Agricultural Growth: the economics of agrarian change under population pressure. Aldine. Chicago.

APPENDIX C-4

SCORESHEET FOR EVALUATION OF CANDIDATE TECHNOLOGIES AND DESIGNS*

The scoresheet given here, for optional use in Step 7 and again as part of the Worksheet for Step 9 is intended as a heuristic aid to the evaluation of candidate technologies (of any type) and of overall agroforestry designs. In the first application (Step 7) the scoreheet is intended to be used by the team, if it so desires, to compare and assess the potential benefits of a wide range of candidate technologies (of both an agroforestry and non-agroforestry type), to determine which of them should be included in a design for an improved land use system.

In the second (Step 9) the scoresheet is used to evaluate those technologies which have been included in the design. This will not be simply a repeat of the previous use in that the technologies selected for inclusion in the design will by this point have gone through a process which has given them greater definition and specificity. The use of the scoresheet at this later step is to assist the team to arrive at a consensus on, and give some indication of, its expectations as regards the potential impact of the, now well-defined, technologies on the land use system for which they have been designed. As such, it is part of the overall ex ante evaluation which also attempts to assess the feasibility and potential impact of the design as a whole.

Not too much emphasis should be given to the numbers arrived at in using this scoresheet. The numbers will be representative of the team's ranking of the component technologies in the design and will be generally indicative of relative differences between them on the various dimensions of the evaluation. But the main value of this semi-quantitative procedure is in the *thinking process* which the team is forced to go through in order to arrive at the numbers. To agree on a numerical value for a technology's score on an attribute, the team must discuss and evaluate the technology in some depth. In a sense, once they have been used to arrive at this understanding, the numbers may be thrown away. This applies particularly to the earlier use of the scoresheet to narrow down the list of candidate technologies, although in the later use the numerical scores become part of the documentation of the team's expectations (hypotheses) vis-a-vis the impact of the technologies on the land use system.

In specifying the range of possible scores on the different dimensions of technology evaluation, an effort has been made to allow for differential weighting of the attributes. Thus, any technology which is judged to be capable of solving a supply problem (by whatever specific means) should get a higher rating than one which merely removes one of the constraints contributing to that problem. The difference here is between *ends* and *means*. Hence, the possibility for a higher score for attributes addressing ends than for those addressing means. Obviously, a technology which scores high on all the means would tend also to receive a high score on the ends.

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*Contributed by J.B. Raintree

Specific Guidelines for Use of the Scoresheet

The following comments are concerned with the interpretation of the meaning of the various design attributes.

1. Productivity

1.1 Potential to Solve Household Supply Problems

The distinction between primary and secondary objectives is basic to the rating process. A technology which satisfies primary objectives of the unit manager should get a higher rating that those which satisfy secondary objectives. The decision in which category to classify a given objective is made on the basis of the team's understanding of production objectives derived from the Diagnostic Survey.

Market potential refers to cash crops (including trees and livestock) and is included here because it is important to the evaluation of interventions aimed at improvement of the cash subsystem.

1.2 Potential to Reduce Production Constraints

This is where the team applies the understanding it has derived from causal and functional analyses of the system and the identified technological interventions. "Reduction" of production constraints should be interpreted to include complete removal or by-passing of the constraint. A higher score is possible for technologies which address the most limiting constraint for a given problem than those which merely reduce a contributing constraint.

1.3 Potential to Improve Resource Use

This refers to the potential of a technology to improve the use of presently underutilized biophysical (e.g. soil, climate) and socioeconomic (e.g. labour) resources of the land use system. A higher score is possible for technologies which improve the use of the most limiting resource.

2. Sustainability

2.1 Potential Impact on Future Resources

The evaluation here focuses on the potential to alleviate existing or predicted resource degradation syndromes, as identified in the sustainability analysis (Step 12) or to improve in some way the resource base of the land use system. Differential weighting is given in accordance with the severity of the anticipated resource problem.

2.2 Potential Impact on Future Demand

Does the technology have the potential to fully, or only partially, satisfy the anticipated level of demand under the various scenarios considered in Step 12?

Future market potential is included because it is an important determinant of the sustainability (future economic viability) of interventions aimed at improved cash crop production.

3. Adoptability

Technologies which address priority objectives and perceived needs of the potential adopter are distinquished and weighted accordingly. Scoring on this dimension can vary in accordance with both the level of the farmer's perception of the need (not perceived at all to well perceived) as well as with the potential of the technology to address the need. The score given by the team should take both factors into account.

The next two attributes reflect the degree to which the technology is compatible with the adoption constraints identified in Step 14.4. A negative score is possible since a requirement for non-available resources or a serious interactional constraint can irreconcilably lower or completely block the adoption of a technology. To arrive at a score on these dimensions, the team must assess the degree of the resource constraint and the seriousness of any interactional constraint, i.e. whether these problems could be overcome by some feasible alteration of the system. This may depend on whether certain other technologies within the overall design are adopted. At Step 17.1 the team should also consider whether the *design as a whole* makes feasible demands on available resources and whether there are any constraints that may arise from interactions between the technologies in the design. This assessment may call for modification of the design.

Relative freedom from risk should be assessed in terms of the likelihood and severity of the risk. The potential to yield quick or early benefits will depend not only on the technology, but on what is considered "quick" and how long farmers are willing or able to wait before the benefits start coming. Sometimes a slight modification of the design (e.g. the addition of an herbaceous intercrop) can raise the score dramatically on this dimension of adoptability.

Simplicity of understanding and cultural compatibility are related factors, insofar as technologies which incorporate culturally familiar elements will generally be easier to understand than those which are totally foreign. Nevertheless, the two attributes can be separated and should be scored independently. Compatibility with the local culture can also include such factors as cultural aversion to elements of the technology (e.g. the use and handling of manure, the planting of trees on cropland, etc.).

To rate a technology on the "enthusiasm of response" dimension will require that team members have discussed the idea of the technology with a small representative sample of the intended adopters and gotten an impression of their response to the idea. One should not expect a terribly enthusiastic response to the mere idea of a technology before it has been demonstrated on the ground and farmers have had a chance to understand and evaluate it. What one mainly looks for in the farmer's ex ante response is signs of mild interest or, alternatively, of strong aversion to the technology. Relative differences between technologies may become apparent.

The last two attributes, adoptability by the poor and applicability beyond the study area, may or may not be relevant to the terms of reference for the D&D exercise. The technology design may, if the D&D team so decides, be deliberately system specific, and its applicability beyond the study area be irrelevant to the intentions of the team.

Likewise, specific technologies may not be aimed at the poor, while others are. Still, a technology which scores high on these dimension will be preferable, other things being equal, to one which does not.

Additional Notes

Add other notes as necessary to explain the ratings given.

TECHNOLOGY EVALUATION SCORESHEET

EVALUATION CRITERIA \ CANDIDATE TECHNOLOGIES											
1. PRODUCTIVITY											
1.1 Potential to Solve Household Supply Problems											
Primary Production Objectives											0 to 10 (no potential to full potential)
-											0 to 10 "
-											0 to 10 "
-											0 to 10 "
-											0 to 10 "
-											0 to 10 "
Secondary Production Objectives											
-											0 to 5 "
-											0 to 5 "
-											0 to 5 "
-											0 to 5 "
-											0 to 5 "
-											0 to 5 "
-											0 to 5 (inadequate to adequate)
1.2 Potential to Reduce Production Constraints											
- Most limiting constraint											0 to 5 (no potential to full potential)
- Contributing constraints											0 to 3 "
1.3 Potential to Improve Resource Use											
- Most limiting resource											0 to 5 "
- Other resources											0 to 3 "
2. SUSTAINABILITY											
2.1 Potential Impact on Future Resource Base											
- Solve severe degradation problems											0 to 10 "
- Solve lesser degradation problems											0 to 5 "
- Improve use of source future resources											0 to 5 "
2.2 Potential Impact on Future Demand											
- Satisfy anticipated demand											0 to 10 "
- Future market potential (cash enterprises)											0 to 5 (inadequate to adequate)
3. ADOPTABILITY											
Does the technology address											
- a priority objective?											0 to 10 (No - Yes)
- a perceived need?											0 to 5 "
Will it use only available resources?											-5 to 5 (* see below)
Will it avoid interctional constraints)											-5 to 5 "
Is it risk free?											0 to 5 (No - Yes)
Will it yield quick benefits?											0 to 5 "
Is it simple to understand?											0 to 5 "
Is it compatible with the local culture?											0 to 5 "
Does the idea meet with enthusiastic response from the intended users?											0 to 5 "
Is it adoptable by the poor?											0 to 5 "
Is it widely applicable beyond the study area?											0 to 5 "

NOTES:

* The possibility of a negative score is allowed for here to emphasise the importance of keeping within the limits defined in Step 6.

APPENDIX C-5

CLASSIFICATION OF AGROFORESTRY SYSTEMS*

Agroforestry may be defined as an approach to land use in which woody perennials are deliberately combined on the same land management unit with herbaceous crops and/or animals, either in some form of spatial arrangement or in sequence. The concept of an agroforestry system implies both ecological and economic interactions between the components of the system (Lundgren, 1982).

1. Proposed Classification Scheme

The amplitude of this definition implies that agroforestry systems can be classified according to the types of components included in the combination, the role of the woody component in the system, the type of interaction between the woody component and the other (spatial or temporal), and the way in which the components are arranged in space. Figure 1 illustrates the principles of a classification scheme based on these criteria. The first criterion (component combination) gives the basic high level classification term for the system: silvicultural, agrosilvicultural, silvopastoral, and agrosilvopastoral. The next three criteria (tree role, interaction, arrangement) provide the means for subdivision of agroforestry systems within these broad classes.

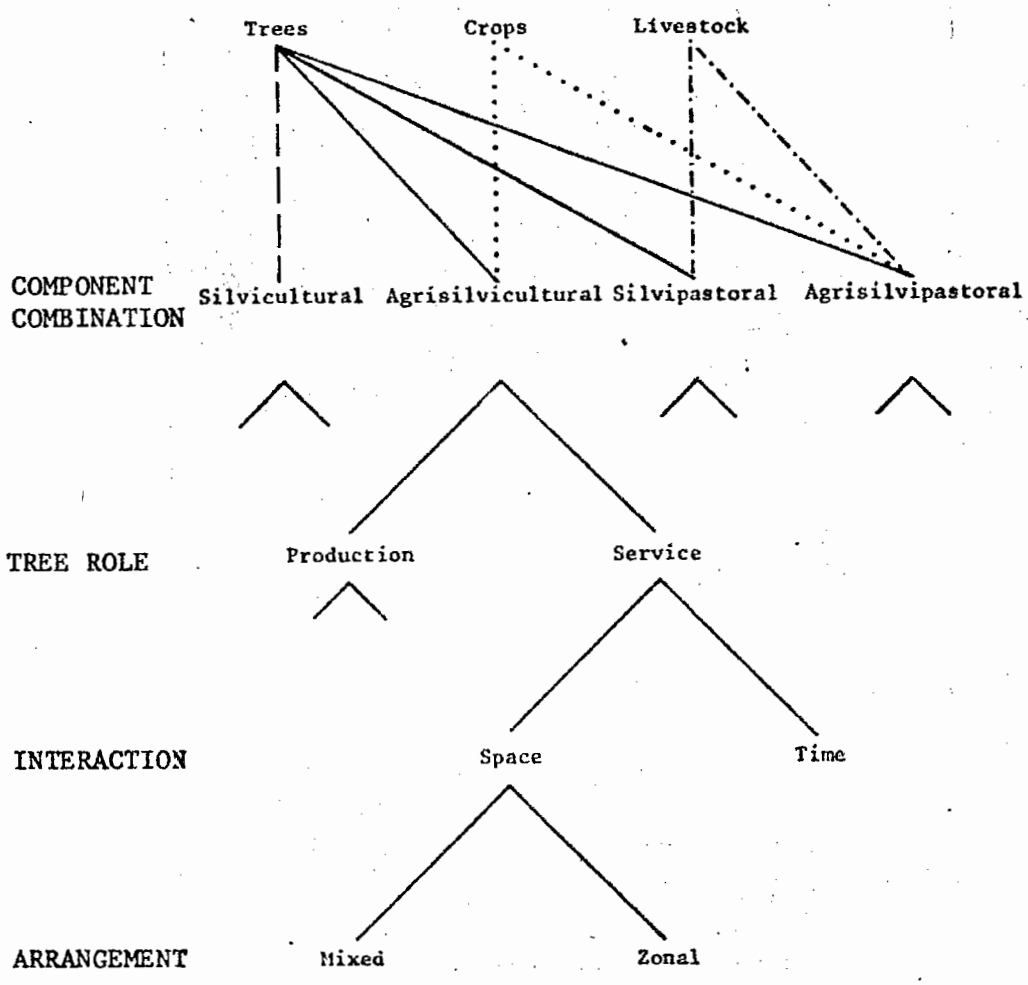

Fig. 1 Classification scheme for agroforestry systems.

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* Adapted from F. Torres, 1983. Agroforestry: Concepts and Practices. *In* D.A. Hoekstra and F.M. Kuguru (eds) Agroforestry Systems for Small-Scale Farmers. ICRAF/BAT. Nairobi.

2. Silvicultural Systems

The inclusion of some kinds of silvicultural systems under the heading of agroforestry may be justified in certain circumstances by virtue of the economic interaction between the silvicultural enterprise and other enterprises on a farm. A farm woodlot, for example, interacts with other enterprises on the farm through competition for land, labour and other resources. A horticultural orchard, by the same token, may also be included under this same category (silvicultural is here interpreted, in the broad sense, as the growing of any kind of woody perennial for any purpose). Figure 2 depicts the concept of a silvicultural system with the example of a woodlot.

System	Tree role			Distribution	
	P	S		M	Z
Fuelwood	✓	✓			✓

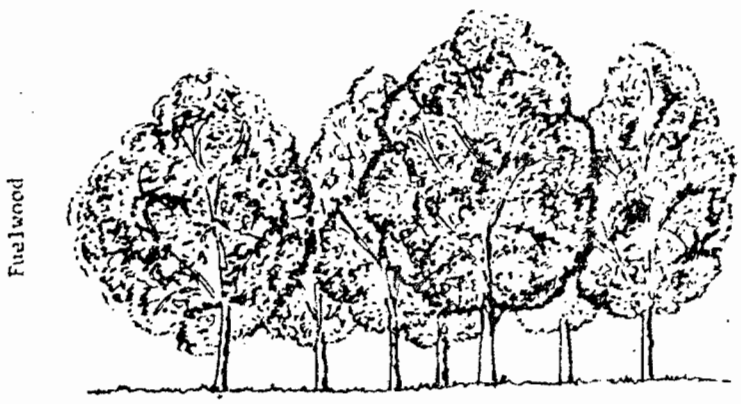

Fig. 2. Silvicultural Systems

3. Agrosilvicultural Systems

Agrosilvicultural systems combine the production of forest or horticultural tree crops, in space or time, with herbaceous crops to fulfill productive or service roles within the land management system. Figure 3 depicts the architecture of some conceptual agroforestry systems of the silvopastoral type.

Systems	Tree role			Interaction			Distribution	
	P	S		T	S		M	Z
Improved fallow	✓	✓		✓				✓
Alley-cropping		✓			✓			✓
Multi-storey	✓				✓		✓	

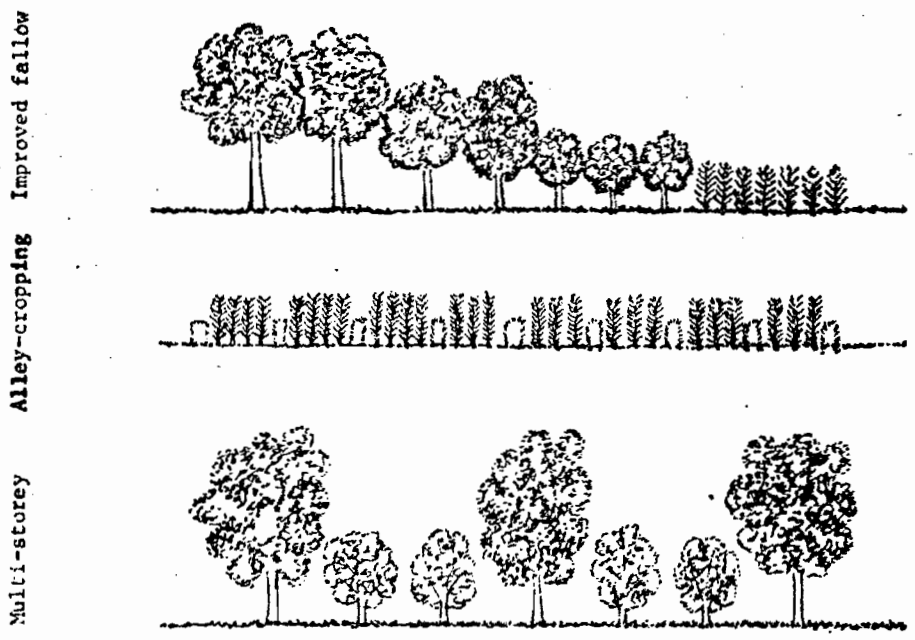

Fig. 3. Agrosilvicultural Systems.

4. Silvopastoral Systems

Silvopastoral systems integrate trees or shrubs with pasture and/or livestock. Figure 4 depicts some conceptual combinations of the silvopastoral type, with their corresponding subclassification.

Systems	Tree role			Interaction			Distribution	
	P	S		T	S		M	Z
Protein bank	✓	✓		✓				✓
Living fences		✓			✓			✓
Tree crop grazing	✓				✓		✓	

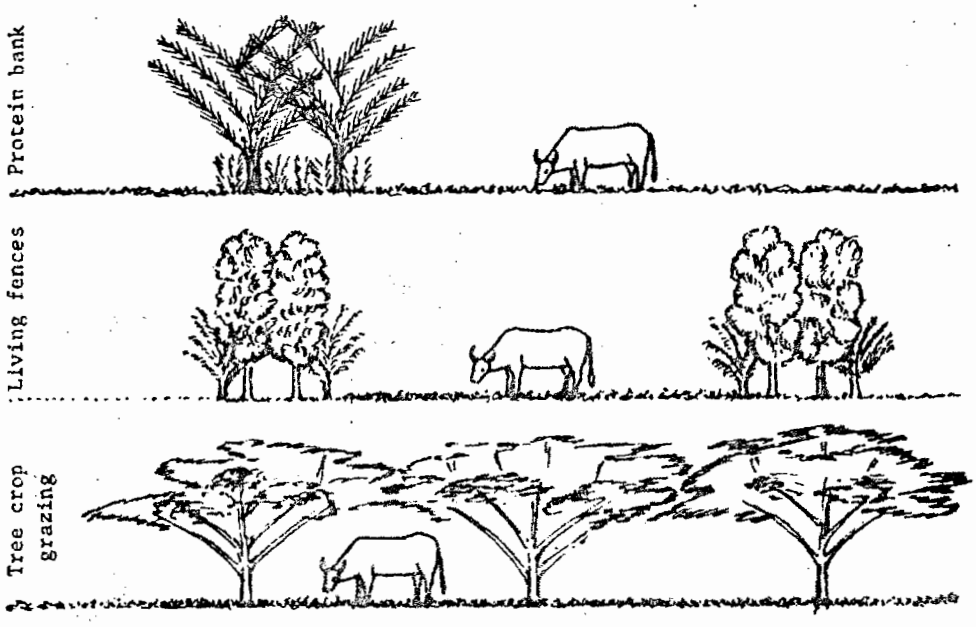

Fig. 4. Silvopastoral Systems

5. Agrosilvopastoral Systems

Agrosilvopastoral systems, as the name implies, combine trees and herbaceous crops with animals and/or pastures. Figure 5 presents some conceptual systems of this type. The first represents a form of integration in time, with silvopastoral phase following an agrosilvicultural phase (to establish the trees, with crops, before replacing the crops with pasture and bringing the animals in). The second represents a complex multistorey system with pigs as one of the major outputs.

Systems	Tree role			Interaction			Distribution	
	P	S		T	S		M	Z
A - S⟶S - P	✓			✓	✓		✓	
Multi-storey	✓				✓		✓	

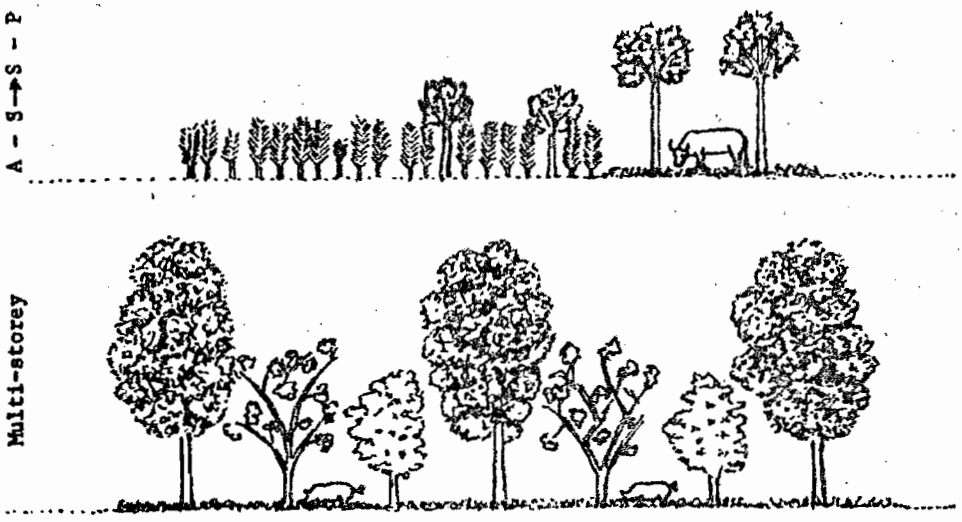

Fig. 5. Agrosilvopastoral Systems.

Figure 6 is a schematic representation of an integrated pig production system developed in Ecuador (Bishop, 1982), which combines the vertical complexity of the second system in Figure 5 with the temporal dynamism of the first, in a highly productive rotation system for smallholders.

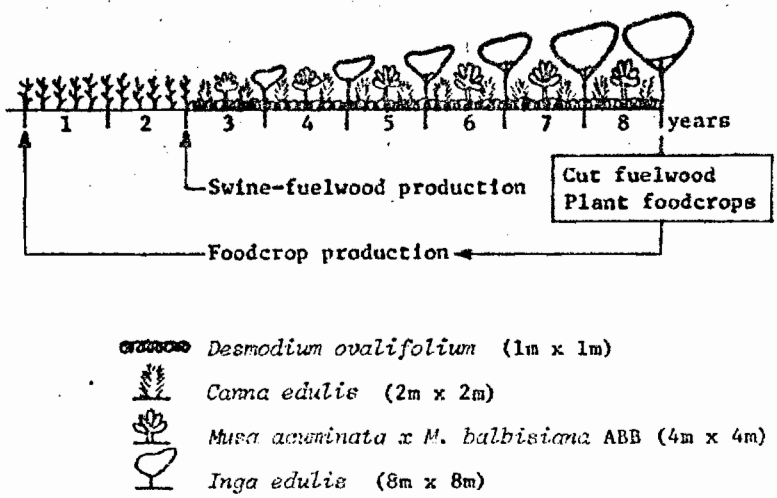

Fig. 6. An integrated pig production system

References

Bishop, J.P. 1982. Agroforestry Systems for the humid tropics east of the Andes. *In*: S.B. Hecht (ed). Amazonia: Agriculture and Land Use Research. CIAT. Cali

Lundgren, B. 1982. Introduction. Agroforestry Systems 1(1): 3-6.

APPENDIX C-6

SOME EXAMPLES OF PROMINENT AGROFORESTRY SYSTEMS AND PRACTICES IN THE DEVELOPING REGIONS OF THE WORLD

The table on the next page presents some preliminary results of ICRAF's ongoing Global Inventory of Agroforestry Systems Project. Examples are given of the most prominent agroforestry systems and practices found in the different regions, based on existing knowledge prior to the commencement of the formal survey phase of the project. A much more complete catalogue and description of existing systems and practices will be forthcoming as the project progresses. The present list may suffice to indicate the *range* of existing agroforestry practices.

---

*Contributed by P.K.R. Nair, Agroforestry Systems Inventory Project Leader.

Some Examples of Prominent Agroforestry Systems and Practices in the Developing Countries

Prominent systems	*Systems and practices in different geographical regions*					
	S.E. Asia	*S. Asia*	*Mediterranean and Middle East*	*Eastern, Central and Humid West Africa*	*Arid and Semi-Arid West Africa*	*American Tropics*
1. Agro-silviculture	1. Commercial trees among crops 2. Fruit/shade trees among crops 3. Live fences 4. Shelterbelts 5. Taungya 6. Shifting cultivation systems 7. Intercropping in plantation crops (rubber, oil palm, coconut)	1. Taungya 2. Plantation crops + arable crops 3. Commercial trees and fruit trees with crops 4. Live fences + shelter belts 5. Various trees on farmlands for productive functions 6. Various forms of shifting cultivation 7. Medicinal plants + agri. species	1. Olive + cereals (on terraces, 'banquettes', 'cuvettes', etc.) 2. Poplars along irrigation canals 3. Trees for sand dune reclamation 4. 'Huertas' – small plots irrigated crops + fruit trees 5. Aromatic, medicinal and fruit trees with crops	1. Taungya 2. Cacao/food crops/forest complex 3. Plantation crops (oil palm/rubber) and root crops complex 4. Coffee + banana 5. Mixed perennial crops 6. Gum arabic + millet 7. Shifting cultivation/bush fallow systems	1. Use of trees on farmlands for protective role (windbreaks, dune fixation) 2. Productive + protective role of trees on farms (*A. albida/Leucaena* + agric. crop systems)	1. Trees in perennial cash crops (coffee, cacao, tea) 2. Trees for organic matter and mulch with annual crops 3. Tree live fences 4. Windbreaks and shelterbelts 5. Trees as support for climbing commercial crops 6. Taungya 7. Shifting cultivation systems
2. Silvo-pastoral	1. Pasture in forest plantation 2. Pasture in secondary forests 3. Commercial trees in pastures 4. Fruit/shade trees in pasture 5. Fodder trees 6. Coconuts + pasture	1. Pasture under trees 2. Plantation crops + cattle grazing 3. Fodder trees and shrubs 4. Fruit trees and commercial trees in pastures	1. Oak forest + grazing 2. Pig breeding and forestry 3. Range land improvement	1. Gum arabic + livestock 2. Plantation crops (coconut/ cashew) + pasture	1. Nomadic/semi-nomadic/ transhuman 2. Sedentary livestock grazing systems/ browsing systems 3. Fodder tree/shrub systems	1. Trees in pasture 2. Pasture in natural regeneration forest 3. Trees lopped for fodder 4. Trees used for browsing
3. Agro-silvo-pastoral	1. Crops and grazing in plantations. 2. Agri. tree crops + grazing in forest plantation 3. Multipurpose trees with crops/animals 4. Integrated farming systems with agric. plantation crops (rubber, coconut, oilpalm)	1. Plantation crops + arable crops + livestock 2. Agric. tree crops + grazing in forest	Range land management	1. Coconuts/other plantation crops + food crops + grazing 2. Coffee + banana + dairying 3. Horticultural complex systems 4. Plough culture complex systems	1. Forestry dominating (forest lands) 2. Agriculture dominating (crop lands) 3. Livestock dominating (crop lands)	1. Agric. plantation crops (coconut, rubber, fruit trees) with crops and pastures
4. Home gardens	Various forms of multispecies combination	1. Multistorey plant canopies in humid regions 2. Arid/semi-arid systems	Mainly in large cities	Various forms	Various forms	Various forms
5. Others	1. Silviculture in mangrove forests 2. Agri-silvi-fishery 3. Trees on bunds in fish breeding ponds 4. Swidden farming 5. Fuelwood agroforestry	1. Mixed perennial cropping 2. Irrigation systems 3. Various site-specific systems 4. Fuelwood systems	1. New system in Morocco (spice plantation for erosion control) 2. Apiculture + forestry 3. Fruit trees in deserts 4. Mushroom cultivation in forest	1. Pastoral systems with corral farming (highland/lowland interactive systems) 2. Mixed perennial cropping	1. Oasis 2. Irrigation systems 3. Various site-specific systems	Mixed perennial cropping

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APPENDIX C-7

LOCATION DECISION MATRIX*

This matrix tool is intended to aid the designers of agroforestry systems to arrive at a decision on the optimum location of particular functional components on the management unit. To facilitate the decision-making process, the following steps are suggested in the use of the tool:

1. First, identify the functions to be addressed by components of the design and list them in the first column of the matrix under functions.

It will be helpful to arrange the list in accordance with the type of function to be performed by the component. Component functions, of trees or other plants, may be subdivided on the basis of whether the component is intended to perform a *productive* or a *service* role within the system. The component will be performing a production role if it produces a harvestable material output. Examples of common tree products include: firewood, charcoal, timber, building poles, craftwood, fodder, fruits, leaf mulch, etc. A service role is defined by the production of an immaterial output or benefit which improves the productivity or sustainability of the system. Examples of service roles performed by woody components include: shade for humans, animals or crops, shelter-belts and windbreaks, boundary demarcations, living fences, erosion control hedges, fertility improving trees, etc.

Some functions may fall in an intermediate category, such as the function of hedgerows in "alley cropping" systems which provide mulch for improved growth of crops grown in the alleys between the hedgerows. This is a harvestable material product, but it is not taken off the field and its role is to perform a service function in the cropping system.

While service functions tend to be location specific (i.e. the efficient performance of the service function requires that the component be grown at a certain location within the cropping system), productive functions are not usually location specific and may be sited almost anywhere within the management unit.

2. Next, across the top row of the matrix list all the possible locations within the management unit where components could be sited.

The identified locations will to a large extent correspond to the location categories given in the Prediagnostic Worksheet 6.1, but may be further subdivided for design purposes. Both existing and potential subdivisions should be identified. For example:

arable land	1 -	contour lines within the cropland
	2 -	waterlogged or unproductive areas within the croplar
	3 -	boundaries

*Adapted from D.A. Hoekstra (1983). The use of economics in agroforestry ICRAF Working Paper No. 2. ICRAF. Nairobi.

grazing land	1 -	general
	2 -	boundaries
home compound	1 -	general
	2 -	boundaries

These are only examples. The location categories and subdivisions used will be specific to the selected system and must be worked out by the team.

3. Next, match the functions to the locations.

This is done by placing an "x" in the appropriate box in the matrix. First locate all site-specific service functions. Once these non-optional sites are marked it will be easier to see what locations remain for the non-site specific production functions. It should not be assumed, however, that service components will use up all of the potential of a location. Service and production components might be combined at a given location by means of appropriate spatial arrangements or managment practices.

In locating production components, the general rule of practice would be to *minimize the opportunity cost of land.* In other words, production components should be located where they will offer the least interference with other enterprises within the existing or proposed management system. This applies particularly to tree components which, if they are not performing a beneficial service role at the site, may compete strongly with other components for land (including all land factors such as light, water, soil nutrients, etc.).

Other factors than the potential alternative uses of land should also be considered, e.g. differences between locations with respect to the ease of labour and management inputs (often a function of distance from the home compound), protection against animal pests or theft, proximity to roads (for ease of harvesting bulky products like timber) or water (if tree components will need watering during the establishment period), etc. To get an appreciation of possible costs and benefits associated with different sites it may be useful to study the existing spatial arrangement of components within the management unit to find out *why* certain components are found in particular locations. This could yield clues to important aspects of the farmer's decision-making.

4. Finally, optimize the overall location plan.

Working through the matrix once will result in a preliminary plan, but this could perhaps be improved by repeating the process one or more times to optimize all factors. Special attention should be given to possibilities for making more efficient use of resources by combining production and service roles at particular sites. Such possibilities, to a large extent, will be determined by technical considerations. For example, a single row windbreak would more or less exclude the possibility of production functions which require the harvesting of the whole tree, but it may leave scope for selective lopping of firewood or production of fruits.

A multiple row windbreak, on the other hand, could possibly allow for the harvesting of whole trees.

The end product of the exercise will be a matrix which links the different component functions and planting sites. If a location has been identified as suitable for several tree functions, multipurpose trees and management programmes may be considered as well as combinations of single-purpose trees. An example of a completed matrix is given below (the numbers in the second row refer to the location subdivisions cited as examples under step 2 above).

Location / Function	arable land			grazing land		home compound	
	1	2	3	1	2	1	2
Shelterbelt						X	
Erosion cont.	X						
Fence					X		
Shade				X		X	
Fuelwood	X	X	X		X		
Fodder		X		X			
Fruits	X					X	X
Mulch	X		X				

APPENDIX C-8

WOODY COMPONENTS OF EXISTING AGROFORESTRY SYSTEMS*

The following tables describe the roles (productive and/or service) performed by prominent woody components of existing agroforestry systems in different regions and ecoclimatic zones of the developing world. This information is the result of documentary searches carried out as part of ICRAF's on-going global Inventory of Agroforestry Systems Project. The information contained in these tables will be continuously updated as the project progresses.

Table 1

Table 1 gives an alphabetical listing of prominent woody species by geographical region. The role of the tree or shrub species in the region is noted in terms of its food, fodder, wood, service or other function. Additional references are given for further information on each species (see references at the end of this appendix). The regions covered are:

Southeast Asia
South Asia (Indian Subcontinent)
North Africa, Mediterranean and Middle East
East and Central Africa (Humid Zone)
West Africa and the Sahel (Semiarid and Arid Zones)
American Tropics

Table 2

Table 2 focuses on prominent leguminous trees and shrubs, the system or practice in which they are used, the major eco-zone and the countries in which these uses have been recorded.

Table 3

Table 3 contains many of the same leguminous species but sorts them according to the predominant type of agroforestry system in which they are found (agrosilvicultural, silvopastoral, agrosilvopastoral), the specific practice involved, the country and the ecological zone in which these uses of the various woody legumes have been reported.

Note: The country information in Tables 2 and 3 is intended to be exemplary rather than definitive. You may well find the same practices in other countries of the same or other geographical regions.

---

*Table 1 contributed by E.C.M. Fernandes. Tables 2 and 3 excerpted from P.K.R. Nair, E.C.M. Fernandes and P.N. Wambugu. 1983. Multipurpose leguminous trees and shrubs for agroforestry. Paper presented to the International Symposium on Nitrogen Fixing Trees in the Tropics. Sept. 19-24. Rio de Janeiro.

Table 1. Functional Roles of Woody Perennials in Existing Agroforestry Systems, by Region.

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SPECIES	FUNCTIONS/USES																																			REMARKS	REFERENCES
	FOOD						FODDER				WOOD						SERVICES								OTHER												
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Implements & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Acacia auriculaeformis											**	**	*			pulp											*					*			48,49,66
Ailanthus altissima											*	*	*		*		*		*																48,
Albizzia falcataria											*		*			pulp			*		*						*	*				*			2,4,49,
Anacardium occidentale	*	*						*											*															Cash crop	53,67
Artocarpus heterophyllus	*	*	*				*	*			*												*												4,
Casuarina equisetifolia											***	**	*	*	*	pulp	***		*	*	"g"						*								48
Durio zibethinus	*	*																																	2,4,45,46
Eugenia aromatica						* (g)																				*								Cloves	45,67
Gliricidia sepium							*			**	*		*	*	*		*	*				*												Toxic to horses	2,48
Haloxylon aphyllum							*				*						*		*	*															48,
Leucaena leucocephala		*	*				*			*	**	**	*		*		*		*		*	*													2,4,46,48,49,66,75
Litsea odorifera																										*									75,
Lychee chinensis	*																																	Cash crop	66,
Magnifera indica	*		*		*			*			*												*							*		*			45
Mangrovea	*										**	**	**	*		pulp			*								*			*				Aquaculture	48
Muntingia calabura	*							*			**			*															*			*			48
Nephelium lappaceum	*			*																															2,4,45,46,75
Parkia speciosa		*																	*			*													2,45,67
Pithecolobium dulce	*			*			*	*		**	*		*				*	*	*		*						*	*				*			46,48,49
P. jaringa		*			*																*					*									45
Psidium guajava	*		*											*																					4,46,

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Table 1. Cont'd

S.E. ASIA

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SPECIES	FUNCTIONS/USES																																	REMARKS	REFERENCES
	FOOD						FODDER				WOOD						SERVICES							OTHER											
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Sea Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Samanea saman	*						*	*					*	*	*						*											*			46,49
Sesbania bispinosa							*				*					pulp	*	*	*		**	*						*	*						48,
Syzigium aqueu	*						*	*			*																								4,46
S. cumini	*						*	*		**	*		*	*			*										*					*			46,48
Thea oleosa				**						**	*		*	*					*											*					16

S. ASIA

Table 1. Cont'd

* FAIR
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*** EXCELLENT

SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER									REMARKS	REFERENCES
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Sea Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Acacia albida							**	*	*	*	*			*					*		*	*					*	*				*			20,27,49,51,73
A. auriculaeformis							*				*	**	*	*		pulp			*		*	*	*				*	*				*			27,48,49
A. mearnsii											*	*							*		*	**					**								27,48,64
A. nilotica							*	*		*	*	*		*						*							*	*		*		*			13,15,18,27,48,64
A. senegal		*					*	*	*	*	*	**	*	*			*		*		*	*						*						Gum arabic	27,48,49,62
A. tortilis							*	*	*	**	**	**	*	*					**	*	*											*			5,13,18,27,47,48,49
Adhatoda vasica											*	*																		*					48,70
Aegle marmelos	*						*			*							*													*					5,27
Ailanthus excelsa							*		*		*						*		*																5,18,27,48
Albizia falcataria							*				*				*	pulp					*														49
A. lebek							*				*		*	*			*		*		*	*					*	*				*			5,27,48,49
A. mollis							**				*		*								*													Fodder tree Nepal	35
Anacardium occidentale	*	*						*		*	*								*				*			*								Cash crop - nut, wine	13,18,53,64,71
Anogeissus latifolia							*				*	**	*	**		pulp											*	*						Sericulture	48
Areca catechu		*											*	*																	**				
Artocarpus heterophyllus	*	*					*						*	*																		*			27,45
Azadirachta indica							*				*		*	*			*					*	*			*	*							Insect repellent	48,64
Balanites aegyptiaca	*		(*)	(*)			*				*		*	*																*					13,80
B. roxburghii	*						*				*		*	*																**				Contraceptive extract	3,
Boehmeria rugulosa							*				*		*	*					*										*						27,
Borassus flabellifer			*	*	*						*		*	*			*		*				*						*		*			Wine	27,64

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S. ASIA

Table 1. Cont'd

* FAIR
** GOOD
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SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER								REMARKS	REFERENCES
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tanning (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other	
Cassia siamea							*	*			*						*					*	*									*		Sandalwood host	5,27,48,73
Casuarina equisetifolia											***	**	*	*			***		*	*							*					*			27,48,64
Celtis australis	*			*			*				*		*						*															Vit. C. fruits	13,27
Ceratonia siliqua	*		*		*			*			*								*		*						*	*		*				Wine	5,7,13,49,79
Cordia dichotoma	*						*				*	*																							5,27
Deria indica							*				*											*							*	*				Insect repellent	48,
Emblica officinalis	*						*	*			*			*								*				*			*	*				Rich vit. C	5,27,48
Erythrina arborescens							*				*			*							*														35
Gliricidia sepium			*				*	*		*	*		*	*			*	*	*		*	*										*		Toxic to horses	5,13,27,39,48,49
Gmelina arborea							*			**	*	*	*																						27,48
Grewia oppositifolia							*				*		*	*					*																27,65
Kydia calycina							*				*	*	*		*																				5,27
Leucaena leucocephala							*		*	*	*	*	*				*		*		*	*													5,8,9,27,40,49,50
Magnifera indica	*							*			*			*																*				Cash crop	18,
Mangroves	*										**	**	*			pulp			*								*			*				Aquaculture	48,
Moringa oleifera	*		*	*			*						*	*																*				Drum stick tree	5,18,27
Morus alba	*						*				*																							Sericulture	5,18,27,35
Parkia roxburghii			*				*				*			*	*				*								*			*		*			27,
Populus ciliata							*				*		*	*	*				*																27,
Prosopis chilensis	*						*	*	*		*		*	*			*	*	*	*	*											*			5,7,10,13,19,48,49, 56,63,
P. cineraria							**	*			*	**	*	*						*	*														5,10,18,19,48,56

Table 1. Cont'd

S. ASIA

* FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER									REMARKS	REFERENCES
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
P. juliflora	*			*			*			*	*	**		*													*	*	*	*				Wine/spirit	5,10,13,18,19,48,56,
Quercus incana							*	*			*		*	*																*					27
Quercus lamellosa							*	*			*		*	*																*					35
Salvadora oleiodes	*			*			*				*	*		*																					5,27
Schima wallichi							*				*		*	**																					35
Sesbania grandiflora	*		*				*	*			*					pulp	*	*	*			**					*	*							5,18,27,48
Syzygium cumini	*									**	*		*	*			**										*					*			18,27,48
Tamarindus indica	*	*	*	*			*	*		*	*	***	*	*							*							*		*		*		Beverage	5,13,27,49
Zizyphus mauritania	*						*	*			*	*		**				*	*								*			*				Sericulture shellac	5,27,48
Z. numularia	*						*	*			*							*	*											*					27,48,70

Table 1. Cont'd

* FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER									REMARKS	REFERENCES
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Acacia aneura							*		*		*		*	*																					49,52
A. ligulata							*		*		*																								52
A. mellifera							*	*		**	**										*							*							49
A. saligna							*				*						*			***								*							48,49
A. seyal							**	**			**		*	*					*	*	*							*							13,38,48,49
A. tortilis							**	**			**	**	*	*					**	*	*											*			13,48,49
Arbutus unedo							**												*																38
Atriplex halimus			*				*												*	*															13,17,26,38,52
Balanites aegyptiaca	*						*				*		*	*																				Beverage	13,38
Cassia sturtii							**		*		*								*		*														49,52
Ceratonia siliqua	*							**		*	*						*		*		*							**		*		*			7,13,49,79
Chenopodium muricoccum				*			**												*																13,38
Elaeagnus angustifolia							*				*		*						*																13,38
Fraxinus oxyphylla							*				*																								38
Gleditsia triacanthos							*	*			*		*						*																38
Haloxylon aphyllum							*				*	*					*		*	**														Xerophye + Halophyte	48
H. persicum							*		*		**	*							*	**															48
Maerua crassifolia							**				*			*																					38
Morus alba	*						*	*																											38
Olea europaea	*			*			*				*																			*	*				13,38

Table 1. Cont'd

* FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER									REMARKS	REFERENCES
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Dac Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Pistachia palaestina		*					*																					*							13,30,52
Prosopis juliflora	*							*		**	***	**	*	*							*				*		*	*	*						13,30,48
Quercus callipenimus							*	*					*	*																					30,52
Q. coccifera							*	*					*	*																					30,52
Q. ilex							*	*					*	*																					30,52
Rhus trilobata	*			*																							*		*						13
Ulmus campestris							*				*						*															*			30
Zizyphus lotus							*				*							*	*	*															30
Z. spina-christii			*				*	*			**							*	*	*															13,17,48

* FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER									REMARKS	REFERENCES
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Acacia albida							*	*	*	*	*		*	*			*		**	*	*	**					*					*			12,15,20,49,58,73,77
A. mellifera							*	*	*	***	*	**									*														23,
A. senegal							*	*	*	*	**	*	*	*					*	*	*						*	**						Gum arable	12,15,23,62
A. seyal							*	*	*	*	*	*							*		*														12,23
A. tortilis							*	*	*	**	**	**	*	*					**	*	*						*			*		*			12,21,23,25,47,48
Adansonia digitata	*		*					*						*													*		*	*	**				12,62,53,76,80
Anacardium occidentale	*	*						*		*	*								*				*			*	*	*						Cash crop	12,53,71
Balanites aegyptiaca	*						*		*		*		*	*																*				Bilharzia control	12,23,80
Borassus aethiopium	*		*										*	*																					12,58,62,80
Butyrospermum parkii	*			*																														Bark for bee-hives	45,80
Cassia sirmea											*		*	*			**		*																48,58,73
Casuarina equisetifolia											***	**	*	*			***		*	*			*				*								12,48.
Catha edulis							*				*		*	*																*	**			Cash crop	12,43
Cordeauxia edulis		*					*												*								*							Drought food	49
Euphorbia tirucalli											*						*	*																	12,23,81
Magnifera indica	*					(*) (C)		*			*																			*		*		Cash crop	25,
Mangroves	*										**	**	*	*													*	*		*				Aquaculture	12,37
Prosopis chilensis	*						*	*	*		*		*	*			*		*	*	*														19,48,63,73
P. juliflora	*							*		*	*	**					*				*														19,48
Rhus tenuinervis	*						*		*		**		*																	*					12,23
Simmondsia chinensis																			*						***					*				Cash crop	29,41
Terminalia brownii							*		*				**	*																*					12.23.25

Table 1. Cont'd

* FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES																																	REMARKS	REFERENCES
	FOOD						FODDER				WOOD						SERVICES								OTHER										
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Zizyphus mauritania	*						*	*			*	*		*				*									*								12,48

Table 1. Cont'd

* FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES																																		REMARKS	REFERENCES
	FOOD						FODDER				WOOD						SERVICES								OTHER											
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Acacia albida							*	*	*	*	*	*	*	*					**	*	*	*					*					*			12,20,49,73,77
A. senegal							*	*	*	*	*	**	*	*					*	*	*						*	**						Gum Arabic	12,23,62
A. seyal							*	*	*	*	*	*							*		*														12,23
A. tortilis							*	*	*	**	**	**	*	*					**	*	*						*			*		*			12,21,23,25,47,48
Balanites aegyptiaca	*		*	*			*	*	*		*		*	*																*					12,23,80
Borassus aethiopium	*		*										*	*																					12,62,80
Cassia siamea											*		*	*			**		*															Toxic to pigs	36,73,
Ceratonia siliqua	*	*						**											*		*							*				*		Coffee Substitute	49,79
Chrysophyllum albidum	*										*		*	**																*					34,54
Cola acuminata		*					*		*																						*			Stimulant-caffeine	34,45,54
Dacryodes edulis	*						*	*																							*				34,54
Elaeis guineensis	*			**									*	*																	**			Wine	34,45,54
Euphorbia balsamifera																	*	*	*																62
E. tirucalli											*						*	*	*																81
Ficus capensis			*				*	*			*																							Bat Roost	11,54
Garcinia kola		*		*									*	**																*					45,54
Gliricidia sepium							*				*		*	*				*	*		*	**												Toxic to horses	1,39
Irvingia gabonensis	*	*				* (c)					*		*	**																*					34,54
Leucaena leucocephala							*	*		*	*	*							*		*	**													8,9,48,49
Mangroves	*										**	**	*	*					*								*	*		*				Aquaculture	48

Table 1. Cont'd

* FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER									REMARKS	REFERENCES
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Parkia biglobosa	*		*	*			*	*													*	*												Beehive location	7,20,45,80
P. speciosa	*		*				*	*											*		*														7,45
Pterocarpus milbredii			*				*						*	*	*																				34,54
Raphia species	*	*											**													*									45
Spondias mombin	*						**						*	*				*	*																34,80
Tamarindus indica	*	*	*				*	*	*	**	**		*	*																**		*		Laxative drink	45,49
Treculia africana	*	*					*	*			*					pulp														*					34,54
Zizyphus mauritania	**						*	*			***	**	*	*				*	*	*							*								48
Z. spina-christi							*	*			**	**	*	*			*	*	*	*															48

Table 1. Cont'd

SPECIES	FUNCTIONS/USES (* FAIR, ** GOOD, *** EXCELLENT)																																	REMARKS	REFERENCES
	FOOD						FODDER				WOOD						SERVICES								OTHER										
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Acacia cyanophylla							*	*			*						*		*	***								*						A.Saligna	48,
Albizia lebek							*				*		*	*	*						*	*						*							49
Alnus acuminata											*		*		*	pulp			**		*													Coffee shade	11,48
A. jorrulensis											*		*		*						*		*										•	Coffee shade	24
Anacardium occidentale	*	*		*				*			*								*				*			*									45,53
Bactris gassipaes	*	*											*	*																				highly nutritious	11,45
Brosimum alicastrum	*	*	*				*	*																											11,45
Calliandra calothyrsus							*				*								**		*	*										*			48,49
Copaifera langadorfii																					*					***				*				Diesel tree	72,
Croton sonderianus																										***								Kerosene tree	47
Elaeis guineensis		*		**									*	*																				Wine	11,45
Erythrina bertero-sna																		*			*														11,
E. poeppigiana																		*			*											*			11,49
Gliricidia sepium							*			**	*		*	*	*			**				**										*		Toxic to horses	48
Guazuma ulmifolia	*						*	*		**	*	*	*	*																				Beverage	48
Inga edulis										**											*														11,49
Inga vera																			*		*													Coffee shade	11,
Larrea species																		*	*						*	*				**				Creosote bush	40,
Leucaena leucocephala		*	*				*	*	*	*	*	*	*				*	*	*		*	**								*					8,9,11,48,49,50
Mangroves	*										**	**	*	*					*								*	*		*				Aquaculture	11,48
Mimosa scabrella											*					pulp			*		*	*										*			48

AMERICAN TROPICS

Table 1. Cont'd

*/ FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER									REMARKS	REFERENCES
	Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other		
Mutingia calabura	*							*			**			*															*			*			46,
Parkinsonia aculeata		*					*	*	*		*	*							*													*			48,
Pithecolobium dulce	*			*			*	*		**							*				*						*	*							11,49
Prosopis alba							*	*			*		*	*			*		*		*														49,56
P. chilensis							*	*			*		*	*					*		*											*			11,48,49,56
P. juliflora	*						*	*		**	**	**	*	*					*		*														10,48,49,56
P. pallida							*	*		**	**	**	*	*					*		*													Beverage	14,48,49,56
Samanea saman	*							*					*	*	*																	*			49,
Simmondsia chinensis																			*						***					*				Whale oil Substitute	29,
Yucca elephantibas													*					*																	11

Table 2. Some leguminous Woody Perennials Currently used in Tropical/Subtropical Agroforestr

SPECIES	SYSTEM/PRACTICE	MAJOR ECO-ZONE	COUNTRIES
Dalbergia sissoo	(SP)* CUT AND CARRY FODDER PROD.	TROPICAL HIGHLANDS	INDIA, NEPAL
Derris indica	(AS)* MULTIPURPOSE TREES ON FARMS	ARID/SEMI-ARID	INDIA
	(SP)* CUT AND CARRY FODDER PROD	" " "	INDIA
Diphysa robinoides	(AS) LIVEFENCES/SHELTERBELTS	HUMID/SUB-HUMID	COSTA RICA
Enterolobium cyclocarpum	(SP) SHADE/BROWSE TREES IN PASTURE	HUMID/SUB-HUMID	COSTA RICA
Erythrina abyssinica	(SP) LIVEFENCES/SHELTERBELTS	TROPICAL HIGHLANDS	ETHIOPIA
	(SP) CUT AND CARRY FODDER PROD.	TROPICAL HIGHLANDS	ETHIOPIA
	(ASP)* CROP/TREE/LIVESTOCK MIX AROUND HOMESTEADS	TROPICAL HIGHLANDS	ETHIOPIA
Erythrina poeppigiana	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	COSTA RICA
		TROPICAL HIGHLANDS	COSTA RICA
Gliricidia sepium	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	BRAZIL, COSTA RICA, PHILIPPINES
	(AS) LIVEFENCES/SHELTERBELTS	HUMID/SUB-HUMID	COSTA RICA, JAVA
	(AS) TREE GARDENS	HUMID/SUB-HUMID	JAVA
	(SP) CUT AND CARRY FODDER PROD.	HUMID/SUB-HUMID	PANAMA
	(ASP) CROP/TREE/LIVESTOCK MIX AROUND HOMESTEADS	HUMID/SUB-HUMID	JAVA
Inga edulis	(ASP) CROP/TREE/LIVESTOCK MIX AROUND HOMESTEADS	HUMID/SUB-HUMID	AMERICAN TROPICS
Inga jinicuil	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	MEXICO
Inga vera	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	PUERTO RICO, WEST INDIES
	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID/SUB-HUMID	WEST INDIES
Lespedeza bicolor	(AS) MULTIPURPOSE SHRUB ON FARMLANDS	HUMID/SUB-HUMID	KOREA
	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID/SUB-HUMID	KOREA
	(SP) CUT AND CARRY FODDER PROD.	" "	"
Leucaena leucocephala	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	NIGERIA, PAPUA N. GUINEA
	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID/SUB-HUMID	PHILIPPINES
	(AS) HEDGEROW (ALLEY) CROPPING	HUMID/SUB-HUMID	NIGERIA
	(SP) CUT AND CARRY FODDER PROD.	" "	PHILIPPINES
	(ASP) WOODY HEDGEROWS FOR BROWSE, MULCH, GREEN MANURE AND SOIL CONSERVATION	" "	PHILIPPINES
Leucaena esculenta	(AS) SHADE FOR COMMERCIAL CROPS	" "	MEXICO
Mimosa scabrella	(AS) MULTIPURPOSE TREES ON FARMLANDS	" "	BRAZIL
		TROPICAL HIGHLANDS	BRAZIL
	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID/SUB-HUMID	
		TROPICAL HIGHLANDS	BRAZIL
Parkia biglobosa	(AS) TREE GARDENS - Multispecies Multipurpose associations	HUMID/SUB-HUMID	CENTRAL AGRICAN REPUB.
Acacia albida	(ASP) CROP/TREE/LIVESTOCK MIX AROUND HOMESTEADS	ARID/SEMI-ARID	ETHIOPIA, NIGER
	(AS) AGROFORESTRY FUELWOOD PROD.	ARID/SEMI-ARID	NIGER, SENEGAL
	(SP) MULTIPURPOSE FODDER TREES	ARID/SEMI-ARID	ETHIOPIA, SENEGAL
Acacia auriculiformis	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID/SUB-HUMID	PAPUA NEW GUINEA
Acacia mearnsii	(AS) AGROFORESTRY FUELWOOD PROD.	TROPICAL HIGHLANDS	JAVA, KENYA
	(AS) MULTIPURPOSE TREES ON FARMLANDS	TROPICAL HIGHLANDS	JAVA
Acacia senegal	(AS) AGROFORESTRY FUELWOOD PROD.	ARID/SEMI-ARID	SUDAN
	(SP) MULTIPURPOSE FODDER TREES	ARID/SEMI-ARID	KENYA, SUDAN
	(SP) SHADE/BROWSE TREES IN PASTURE	ARID/SEMI-ARID	KENYA, SUDAN
Acacia seyal	(AS) AGROFORESTRY FUELWOOD PROD.	ARID/SEMI-ARID	SUDAN, UPPER VOLTA
	(SP) MULTIPURPOSE FODDER TREES	ARID/SEMI-ARID	KENYA, SUDAN
	(SP) SHADE/BROWSE TREES IN PASTURE	ARID/SEMI-ARID	SENEGAL, SUDAN
Acacia tortilis	(AS) AGROFORESTRY FUELWOOD PROD.	ARID/SEMI-ARID	INDIA, KENYA, SUDAN
	(SP) SHADE/BROWSE TREES IN PASTURE	ARID/SEMI ARID	KENYA, SENEGAL, SUDAN
	(SP) MULTIPURPOSE FODDER TREES	ARID/SEMI-ARID	INDIA, KENYA, SUDAN

* AS = AGROSILVICULTURE, SP = SILVO-PASTORAL, ASP = AGRO-SILVO-PASTORAL

Table 2. Cont'd

SPECIES	SYSTEM/PRACTICE	MAJOR ECO-ZONE	COUNTRIES
Albizia falcataria	(AS) TREE FARMS	HUMID/SUB-HUMID	PHILIPPINES
Albizia gummifera	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	CAMEROUN
Albizia lebbeck	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	INDIA
		TROPICAL HIGHLANDS	INDIA
	(SP) CUT AND CARRY FODDER PROD.	HUMID/SUB-HUMID	INDIA
Albizia stipulata	(SP) CUT AND CARRY FODDER PROD.	TROPICAL HIGHLANDS	NEPAL
Alnus acuminata	(AS) SHADE FOR COMMERCIAL CROPS	TROPICAL HIGHLANDS	BRAZIL, COSTA RICA
	(SP) SHADE TREES IN PASTURE	TROPICAL HIGHLANDS	AMERICAN TROPICS
Andira inermis	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	BRAZIL, COSTA RICA
Cajanus cajan	(AS) MULTIPURPOSE SHRUB ON FARMLANDS	ARID/SEMI-ARID+HUMID/SUB-HUMID	INDIA
	(AS) LIVEFENCES/SHELTERBELTS	ARID/SEMI-ARID	INDIA
	(AS) AGROFORESTRY FUELWOOD PROD.	ARID/SEMI-ARID	INDIA
Calliandra calothyrsus	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID / SUB-HUMID	JAVA
	(AS) MULTIPURPOSE TREES ON FARMLANDS	HUMID/SUB-HUMID	JAVA
	(ASP) WOODY HEDGEROWS FOR BROWSE, MULCH, GREEN MANURE AND SOIL CONSERVATION	HUMID/SUB-HUMID	INDONESIA
	(SP) CUT AND CARRY FODDER PROD.	HUMID/SUB-HUMID	JAVA
Cassia siamea	(AS) TREE GARDENS-MULTISPECIES. MULTIPURPOSE SPECIES ASS.	HUMID/SUB-HUMID	CAMEROUN
	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID/SUB-HUMID, ARID/SEMI ARID	SUDAN
	(ASP) CROP/TREE/LIVESTOCK MIX AROUND HOMESTEADS	HUMID/SUB-HUMID	NIGERIA
Ceratonia siliqua	(SP) SHADE/BROWSE TREES IN PASTURE	ARID/SEMI-ARID	MIDDLE EAST
Colophospermum mopane	(SP) MULTIPURPOSE FODDER TREES	ARID/SEMI-ARID	ZAMBIA, ZIMBABWE
Parkia clappertoniana	(AS) TREE GARDENS Multispecies, multipurpose	HUMID/SUB-HUMID	NIGERIA
Parkia speciosa	(AS) TREE GARDENS	HUMID/SUB-HUMID	JAVA
Pithecellobium dulce	(AS) LIVEFENCES/SHELTERBELTS	ARID/SEMI-ARID	PHILIPPINES
	(SP) SHADE/BROWSE TREES IN PASTURE	ARID/SEMI-ARID	HAWAII
	(SP) CUT AND CARRY FODDER PROD.	" " "	PHILIPPINES
Prosopis africana	(AS) TREE GARDENS - Multipurpose. Multispecies associations	HUMID/SUB-HUMID	NIGERIA
Prosopis chilensis	(SP) SHADE/BROWSE TREES IN PASTURES	ARID/SEMI-ARID	BOLIVIA, CHILE, PERU
Prosopis cineraria	(AS) MULTIPURPOSE TREES ON FARMLANDS	" " "	INDIA
	(AS) AGROFORESTRY FUELWOOD PROD.	" " "	INDIA
	(SP) CUT AND CARRY FODDER PROD.	" " "	INDIA
	(SP) SHADE/BROWSE TREES IN PASTURES	" " "	INDIA
Prosopis juliflora	(AS) AGROFORESTRY FUELWOOD PROD.	" " "	HAITI
	(SP) SHADE/BROWSE TREES IN PASTURE	" " "	MIDDLE EAST
Prosopis tamarugo	(AS) AGROFORESTRY FUELWOOD PROD.	" " "	CHILE
	(SP) SHADE/BROWSE TREES IN PASTURE	" " "	CHILE
Pterocarpus soyauxii	(AS) TREE GARDENS - Multipurpose Multispecies associations	HUMID/SUB-HUMID	NIGERIA
	(ASP) CROP TREE LIVESTOCK MIX AROUND HOMESTEADS	HUMID/SUB-HUMID	NIGERIA
Samanea saman	(SP) SHADE/BROWSE TREES IN PASTURE	HUMID/SUB-HUMID	AMERICAN TROPICS
	(ASP) TREE/CROP/LIVESTOCK MIX AROUND Homesteads	HUMID/SUB-HUMID	NIGERIA
Sesbania bispinosa	(AS) MULTIPURPOSE TREES ON FARMLANDS	HUMID/SUB-HUMID	INDIA, VIETNAM
	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID/SUB-HUMID	NORTH PAKISTAN
	(SP) CUT AND CARRY FODDER PROD.	HUMID/SUB-HUMID + ARID/SEMI-ARID	INDIA, PAKISTAN
	(ASP) WOODY HEDGEROWS FOR BROWSE, MULCH, GREEN MANURE, + SOIL CONSERVATION	HUMID/SUB-HUMID	INDIA, PAKISTAN, VIETNAM
Sesbania grandiflora	(AS) LIVEFENCES/SHELTERBELTS	HUMID/SUB-HUMID	JAVA

Table 2. Cont'd

SPECIES	SYSTEM/PRACTICE	MAJOR ECO-ZONE	COUNTRIES
Sesbania grandiflora (continued)	(AS) TREE GARDENS	HUMID/SUB-HUMID	JAVA
	(AS) SHADE FOR COMMERCIAL CROPS	" "	MALAYSIA
	(SP) SHADE/BROWSE TREES IN PASTURE	" "	JAVA
	(SP) CUT AND CARRY FODDER PROD.	" "	JAVA
	(ASP) WOODY HEDGEROWS FOR BROWSE MULCH, GREEN MANURE +SOIL CONSERVATION	" "	JAVA
	(ASP) CROP/TREE/LIVESTOCK MIX AROUND HOMESTEADS	" "	JAVA
Tamarindus indica	(AS) MULTIPURPOSE TREES ON FARMLANDS	HUMID/SUB-HUMID	INDIA
Trema orientalis	(AS) SHADE FOR COMMERCIAL CROPS	HUMID/SUB-HUMID	PHILIPPINES
	(AS) AGROFORESTRY FUELWOOD PROD.	HUMID/SUB-HUMID + TROPICAL HIGHLANDS	JAVA

Table 3. Woody Legumes by Agroforestry System and Practice

AGROFORESTRY			LEGUMINOUS SPECIES USED IN		
SYSTEM	PRACTICE	COUNTRIES	ARID/SEMI-ARID AREAS	HUMID/SUBHUMID AREAS	TROPICAL HIGHLANDS AREA
AGROSILVICULTURE	LIVEFENCES/SHELTER BELTS/WINDBREAKS	COSTA RICA		Gliricidia sepium Diphysa robinoides	Gliricidia sepium Erythrina abyssinica
		ETHIOPIA			
		INDIA	Cajanus cajan	-	-
		INDONESIA (Java)	-	Sesbania grandiflora Gliricidia sepium	- -
		PHILIPPINES	Pithecellobium dulce	-	-
	MULTIPURPOSE TREES/SHRUBS ON FARMLANDS	BRAZIL	-	Mimosa scabrella	Mimosa scabrella
		INDIA	Cajanus cajan Derris indica Prosopis cineraria	Cajanus cajan Sesbania bispinosa	-
		JAVA	-	Calliandra calothyrsus	Acacia mearnsii
		KOREA	-	Lespedeza bicolor	-
		NIGER SENEGAL	Acacia albida Acacia senegal	-	-
		VIETNAM	-	Sesbania bispinosa	-
	HEDGEROW (ALLEY CROPPING) WITH FAST GROWING WOODY PERENNIALS	NIGERIA	-	Leucaena leucocephala	-
		INDONESIA (JAVA)	-	Calliandra calothyrsus	-
	TREE GARDENS Multipurpose Multispecies, associations	CAMEROUN	-	Samanea saman Cassia siamea	-
		CENTRAL AFRICAN REPUBLIC	-	Parkia biglobosa Tamarindus indica	-
		NIGERIA		Parkia clappertoniana Prosopis africana Pterocarpus soyauxii	-
	SHADE FOR COMMERCIAL CROPS	NIGERIA PAPUA NEW GUINEA	-	Leucaena leucocephala	-
		PHILIPPINES	-	Gliricidia sepium	Trema orientalis
		BRAZIL COSTA RICA		Andira inermis Inga adulis Inga vera Erythirina poeppigiana	Alnus acuminata Erythrina poeppigiana
		MEXICO	-	Inga jinicuil Leucaena esculenta	-
		MALAYSIA	-	Sesbania grandiflora	-
		PUERTO RICO W. INDIES	- -	Inga vera	-
		CAMEROUN	-	Albizia gummifera	-
		INDIA	-	Albizia lebeck	-
	AGROFORESTRY FUELWOOD PRODUCTION	JAVA	-	Calliandra calothyrsus Trema orientalis	Acacia mearnsii Trema orientalis
		PAPUA NEW GUINEA	-	Acacia auriculiformis	-
		PHILIPPINES		Albizia falcataria Leucaena leucocephala	-
		BRAZIL	-	Mimosa scabrella	-
		PAKISTAN	-	Sesbania bispinosa	-
		W. INDIES	-	Inga vera	-
		SUDAN	Acacia senegal Acacia seyal	-	-
		NIGER	Acacia albida	-	-
		SENEGAL	Acacia albida	-	-
		INDIA	Cajanus cajan Prosopis cineraria		

AGROFORESTRY SYSTEMS	AGROFORESTRY PRACTICE	COUNTRIES	LEGUMINOUS SPECIES USED IN ARID/SEMI-ARID AREAS	HUMID/SUBHUMID AREAS	TROPICAL HIGHLANDS AREA
SILVOPASTORAL	COMMERCIAL/ SHADE/BROWSE/ FRUIT TREES IN PASTURE	INDONESIA (JAVA)	-	Sesbania grandiflora	-
		ZAMBIA	Colophospermum mopane	-	-
		COSTA RICA		Enterolobium cyclocarpum, Samanea saman	Alnus acuminata
		SENEGAL	Acacia senegal		
		SUDAN	Acacia tortilis	-	-
		HAWAII	Pithecellobium dulce	-	-
		MIDDLE EAST	Ceratonia siliqua	-	-
		INDIA	Prosopis cineraria	-	-
		BOLIVIA	Prosopis chilensis	-	-
		CHILE, PERU			
		CHILE	Prosopis tamarugo	-	-
	MULTIPURPOSE FODDER TREES	KENYA	Acacia senegal		
		SUDAN	Acacia seyal		
			Acacia tortilis	-	-
		INDIA	Derris indica	Albizia lebbeck	
			Prosopis cineraria	Dalbergia sissoo	
			Sesbania bispinosa	Sesbania bispinosa	
		ETHIOPIA	Acacia albida	-	Erythrina abyssinica
		PHILIPPINES	Pithecellobium dulce	Leucaena leucocephala	-
		PANAMA	-	Gliricidia sepium	-
		INDONESIA (JAVA)	-	Sesbania grandiflora	-
		KOREA	-	Lespedeza bicolor	-
		NEPAL	-	Dalbergia sissoo	Albizia stipulata
AGRO-SILVO PASTORAL	WOODY HEDGE-ROWS FOR BROWSE, MULCH GREEN MANURE +SOIL CONSER-VATION	INDIA	-	Sesbania bispinosa	
		INDONESIA	-	Calliandra calothyrsus	-
		PHILIPPINES	-	Leucaena leucocephala	-
		INDONESIA (JAVA)	-	Sesbania grandiflora	-
	CROP/TREE/LIVE-STOCK MIX AROUND HOME-STEAD	ETHIOPIA	Acacia albida	-	Erythrina abyssinica
		INDONESIA (JAVA)	-	Gliricidia sepium Parkia speciosa Sesbania grandiflora	-
		NIGERIA		Cassia siamea Pterocarpus soyauxii Samanea saman	

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REFERENCES

1. Agboola, A.A. (1981) "*G. sepium*: a possible means to sustained cropping" in 68 Pg. 141

2. Ahmad, A.M. & Awang, K. (1982) "AF research status and needs in Malaysia" in 61.

3. Amalraj, A.V. & Jayaraman, I. (1979) "*Balanites*: a contraceptive tree from the Indian Desert" in "Int. Tree Crops Journal Vol. 1; No. 2/3 Pg. 204".

4. Ambar, S. (1982) "Overview of the results of traditional AF study in CI-TARUM river basin, West Java" in 61.

5. Arora *et al* (1979) "Plant resources in tropical Agroforestry for Indian Arid and Sub-humid Plains" in 30 Pg. 183-193.

6. Bauer, J. & Sanchez H.H. (1979) "The promotion of AF techniques in semi-humid zones in Honduras" in 69 Pg. 151.

7. Bene *et al* (1977) "Trees, food and people : Land management in the tropics".

8. Blom, P.S. (1981) *Leucaena* : a promising versatile leguminous tree for the tropics" in International Tree Crops Journal, Vol. 1, No. 4 Pg. 221.

9. Brewbaker, J.L. and Hutton, E.M. (1979) "*Leucaena*-versatile tropical tree legume" in 60 Pg. 207-258.

10. Chandler, M. T.(1980) "*Prosopis* - weed or wonder? in 33 Pg. 507.

11. Combe, J. and Budowski, G. (1979) "Classification of Agroforestry techniques" in 69 Pg. 17-47.

12. Dale, I.R. and Greenway, P.J. (1961) "Kenya Trees and Shrubs" (ICRAF for. 21).

13. Duisberg, P.C. and Hay, J.L. (1971) "Economic Botany of arid regions" in 44 Pg. 247-270.

14. Ebenshade, H.W. (1980) "Kiawe: a tree crop in Hawaii" in International Tree Crops Journal Vol. 1, No. 2/3, Pg. 125-130.

15. El Houri Ahmed, A. (1979) "Effects of landuse on soil characteristics in the Sudan" in 31 Pg. 1-11

16. FAO (1978) "China: Forestry Support for Agriculture - Forestry paper No. 12". A review is presented in "Int. Tree Crops Journal, Vol. 1, No. 1, (1980) Pg. 102-104.

17. FAO (1976) "Desert Creep and Range management in the near east". Mission report (Egypt, Syria, Jordan, Sudan, Tunisia, Libya). (ICRAF. An Sci. 1).

18. FAO/SIDA (1981) "Forestry for local community development programme - GCP/INT/347/SWE". Pg. 57-63.

19. Felker, P. (1979) "*Mesquite* : an all purpose leguminous Arid Land Tree" in 60 Pg. 89-125.

20. Felker, P. (1978) "State of the Art : *Acacia albida* as a complementary permanent intercrop with annual crops" (ICRAF. AGRIC. 102).

21. Fernandes, E. (1982) "Structure and composition of *Acacia tortilis* woodland in N. Kenya". Unpublished thesis University of Aberdeen, Scotland.

22. Fletcher, W.A. and Schroeder, C.A. "The Chinese Goosebery (*Actinidia chinensis*) in NZ" (ICRAF - 0193).

23. Fliervoet, E. (1982) "An inventory of trees and shrubs in the northern division of Machakos district, Kenya". Wageningen Agricultural University/ICRAF.

24. Fournier, L.A. (1979) "Alder crops in coffee plantation: Costa Rica". in 69, Pg. 158.

25. Gielen, H. (1982) "Report of an Agroforestry Survey in three villages of Northern Machakos, Kenya". Wageningen Agric. University/ICRAF.

26. Goodin, J.R. (1979) "*Atriplex* as a forage crop for arid lands" in 60, Pg. 133-147.

27. Gupta *et al.* (1979) "Recommendations of the task force to catalogue plant species suited to Agroforestry" in 30 Pg. 247-259.

28. Haller, R.D. (1980) "Agroforestry on the raw material reserve of a cement factory at the Kenya Coast". in 33, Pg. 387.

29. Hogan, le. M. (1979) "Jojoba - a new crop for arid regions" in 60, Pg. 177-185

30. Icar (1979) "Proceedings of the Agroforestry Seminar - May 16-18".

31 ICRAF (1979) "Soils research in AF" Proceedings of an expert consultation (eds. Mongi & Huxley)

32. ICRAF/DSE. (1979) "International Co-op. in AF" Proceedings of an international conference. (eds. Chandler & Spurgeon)

33. ICRAF/University of Nairobi (1980) "Proceedings of the Kenya National Seminar on Agroforestry" (ed. L. Buck).

34. Iyamabo, D.E. (1979) "Ecological aspects of AF in the lowland humid tropics : W. Africa" in 32, Pg. 129-144.

35. Kessler, C.D.J. (1981) "Notes on the raising of some fodder trees for the hills of Nepal" in "Int. Tree Crops Journal Vol. 1, No. 4. Pg. 245.

36. Kio *et al* (1981) "Food crop yield (maize) under Teak and *Cassia siamea* in S.W. Nigeria in 68, Pg. 108-110.

37. Kokwaro, J.O. (1980) "Economic importance and landuse of Kenyan mangroves" in 33, Pg. 377.

38. Le Houérou H.W. (1971) "Africa - the Mediterranean Region" in 70, Pg. 26-36.

39. Lindsay-Falvey, J. (1982) "*G. maculata* : a review" in International Tree Crops Journal Vol. 2, 1 Pg. 1-14.

40. Mabry, .T.J., Hunziker, J.H. and Difeo, D.R. (1977) "Creosote Bush : Biology & Chemistry of *Larrea* in New World Deserts" (ICRAF. BIOL. 3).

41. Madeley, J. (1982) "A bush with a big future" in "Development Forum Vol. X, No. 7 Sept-Oct. 1982".

42. Manandhar, P.K. (1979) "Farm Forestry in mountain ecosystems" in 32, Pg. 69-75.

43. Margetts, E.L. (1967) "Miraa and myrrh in East Africa - clinical notes about *Catha edulis*. (ICRAF 0100).

44. McGinnes. *et al* (1971) "Food, fibre and the arid lands" - Univ. of Arizona Press.

45. Menninger, E.A. (1979) "Edible Nuts of the World" (ICRAF. AGRON. 70).

46. Monsalud, M.R.; Tongacan, A.L.; Lopez, F.R., and Lagrimas, M.Q. (1966). "Edible Wild Plants in Philippine Forests" in "Philippine Journal of Science - 95, 4. (ICRAF - 0265).

47. Munavu, R.M. (1980) "The Potential for Utilisation of some indigeneous Kenyan Trees" in 33, Pg. 473.

48. NAS (1980) "Firewood Crops : Shrub and Tree species production. (ICRAF-ENERGY. 3)

49. NAS (1979) "Tropical Legumes : resources for the future" (ICRAF-AGRON: 32(a))

50. NAS (1977) "*Leucaena* : promising forage and Tree Crop for the Tropics" (ICRAF-FOR 96 (a)).

51. National Acad. of Sciences (1975) "Underexploited Tropical Plants with promising Economic Value".

52. Naveh, A. (1971) "The role of Shrubs and Shrub Ecosystems in present and future Mediterranean Landuse" in 70, Pg. 414.

53. Ohler, J.G. (1979) "Cashew" - Communication 71. Dept of Agricultural Research, Amsterdam (ICRAF-AGRON 3)

54. Okafor, J.C. (1981) "Promising Trees for Agroforestry in Southern Nigeria" in 68, Pg. 103-107.

55. Okafor, J.C. (1980) "Trees for food and fodder in the Savanna areas of Nigeria" in Int. Tree Crops Journal, Vol. 1, No. 2/3. Pg. 131-139.

56. Pedersen, B.O. (1980) "A note on the genus *Prosopis*" in International Tree Crops Journal Vol. 1, No. 2/3, Pg. 113-123.

57. Plucknett, D.L. (1979) "*Cassia* (Cinamonum) - A Tropical essential oil crop" in 60, Pg. 149-166.

58. Poulsen, G. (1979). "AF practise in Tropical Africa" in 32, Pg. 169-176.

59. Raghauan, V & Baruah, N.K. (1958) "Arecannt : India's popular Masticatory history, chemistry and utilisation" (ICRAF 0142)

60. Ritchie, G.A. /ed) (1979) "New Agricultural Crops" AAAS selected Symposium No. 38. (ICRAF. AGRON. 71).

61. SEARCA (1982) "Proceedings of Regional Seminar-Workshop in Agroforestry" Laguna, Oct. 18-22.

62. Seif El Din, A.G. (1980) "Agroforestry practices in dry regions" in 33 Pg. 419.

63. Skerman, P.J. (1977) "Tropical forage legumes" - FAO . (ICRAF. ANM. SCI. 28) Pg. 522.

64. Srimathi,R.A. and Venkatesan, K.R. (1979) "Agroforestry - Plant resources of the Deccan Region" in 30, Pg. 210-219.

65. Srivastava, B.P. (1979) "Ecolocial aspects of AF in mountanious zones : the Himalayan region" in 32, Pg. 53.

66. Sukwong, S. (1982) "AF research status and needs in Thailand", in 61.

67. Terra, G.J.A. "Mixed garden horticulture in Java" (ICRAF 0334)

68. UNU (1981) "Agroforestry in the African Humid Tropics" Proceedings of a Workshop - Ibadan Nigeria. (ed. L.H. MacDonald).

69. UNU/CATIE (1979) Proceedings of Workshop - "Agroforestry systems in Latin America" Turrialba, Costa Rica.

70. USDA for Service (1971) "Wildland Shrubs - Their Biology & utilization". An International Symposium - Utah State University, Logan, Utah (ICRAF.BIOL.4).

71. Warui, C.M. (1980) "Research on Agroforestry at the Coast - Kenya" in 33, Pg. 361.

72. Watkins, G. "Brazil searches for oil producing trees" in "International Tree Crops Journal Vol. 1, No. 1 Pg. 93".

73. Wenner, C.G. (1980) "Trees in erosion and soil conservation" in 33, Pg. 199-234.

74. Whitaker, T.W. & Cutler, C. (1976) "Food Plants in a Mexican market" in "Economic Botany, Vol. 20 No. 1" (ICRAF 0177).

75. Whitmore, T.C. (1980) "Potentially economic species of S.E. Asia forests" in "Int. Tree Crops Journal, Vol. 1, No. 2/3, Pg. 171-180".

76. Wickens, G.E. (1982) "The Baobab : Africa's upside down Tree" preprint from Kew Bulletin Vol. 37, No. 2.

77. Wickens, G.E. "A study of *A. albida*" in "Kew Bulletin, Vol. 23, No. 2 (ICRAF 0170).

78. Wilken, G.C. (1977) "Integrating forest and small scale farm systems in Middle America" in "Agro-Ecosystems 3(4) : 291-302.

79. Winer, N. (1980) "The Potential of the Carob" in "International Tree Crop Journal Vol. 1, 1, Pg. 15-26.

80. Yandji, E. (1981) "Traditional Agroforestry systems in the Central African Republic" in 68, Pg. 52-55.

81. Zeuner, T.H. "An ecological approach to farming : some experiences of the agro-pastoral project Nyabisindu/Rwanda" in 33, Pg. 329.

APPENDIX C-9

CHARACTERISTICS OF SELECTED MULTIPURPOSE TREES AND SHRUBS

The following tables supplement those in Appendix C-8 with more detailed information on the ecological adaptability and management requirements of selected multipurpose trees and shrubs with exceptional potential as components of agroforestry systems. Table 1 contains information on outstanding multipurpose woody perennials in general, while Table 2 focuses in on selected leguminous and other nitrogen fixing trees and shrubs.

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*Table 1 contributed by P.K.R Nair and E.C.M. Fernandes. Table 2 excerpted from Nair, Fernandes and Wambugu. 1983. Multipurpose leguminous trees and shrubs for agroforestry. Paper presented to the International Symposium on Nitrogen Fixing Trees in the Tropics. Sept. 19-24. Rio de Janeiro.

Table 1. SOME CHARACTERISTICS OF A FEW MULTIPURPOSE WOODY PERENNIALS WITH A POTENTIAL AGROFORESTRY ROLE IN VARIOUS ECOLOGICAL ZONES

MAJOR ECOLOGICAL ZONE	SPECIES	ECOLOGICAL ADAPTABILITY				MANAGEMENT ASPECTS			
		ALTITUDE (m.a.s.l.)	RAINFALL RANGE (mm/yr)	MAXIMUM DRY PERIOD (months per year)	SOIL CONDITIONS	ESTABLISHMENT	SEED TREATMENT	CARE	COPPICING ABILITY
ARID/SEMI-ARID	*Acacia albida*	up to 1200 m	300 - 800	6-8	Sandy/silty well drained soils; good tolerance to salinity	Seedlings	Hot water (80 C) & soak for 24 hours	Weeding	poor
	A. senegal	up to 1700 m	200 - 800	8-11	Sandy or well drained soils. Poor tolerance to waterlog ging.	Seedlings	Hot water (80C) & soaking 24 hours	Weeding	good
	Balanites aegyptiaca	up to 1500 m	200 - 1000	6-8	Most sandy/stony soils including black cotton soil.	Seedlings	Stone must be cracked		good
	Parkinsonia aculeata	up to 1300 m	200 - 1000	9	Sandy/gravelly soils. Good tolerance to high alkalinity and salinity. Poor tolerance to waterlogging.	Seedlings, shoot or root cuttings	Scarified & soaked in water 24 hours		
	Prosopis cineraria	up to 1000 m	75 - 850*	8-10	Grows on sandy/rocky soils. Tolerates pH.9.0 and good tolerance to waterlogging and salinity.	Seedlings or root suckers	Scarified & boil-ing water & soak	Good tolerance to weeds	good
	Zizyphus mauritiana	up to 600 m	300 - 2000	8-10	Wide variety of soils. Good tolerance to high alkalinity.	Direct seeding	Seed should be cracked		good
HUMID/SUB-HUMID	*Acacia auriculiformis.*	up to 600 m	1000-1800	6-8	Wide range of soils including Uranium and tin mining spoils pH range 3.0-9.5	Direct seeding or seedlings	Boiling water & soak 24 hours	Weeding	poor
	Calliandra calothyrsus	up to 1500 m	1000-2000	3-4	Wide range of soils. Good tolerance to flooding.	Direct seeding or seedlings	Boiling water soak 24 hours	Good tolerance to weeds	excellent
	Gliricidia sepium	up to 1600	2300	2-3	Does well in moist or dry soils even when very alkaline.	Seedlings or large cuttings	Hot water (80C) & soak 24 hours		good
	Leucaena leucocephala	best be-low 500m	250-1700	5-6	Wide range of soils pH range 5.0-8.0 but poor growth on acid soils. Poor tolerance to flooding	Direct seeding or seedlings	Hot water (80C) & soak 48-72 hours	Weeding	good
	Albizia lebbek	up to 1600 m	500 - 2000	2-3	Grows best on well drained soils. Good tolerance to salinity and salt spray.	Direct seeding/ seedlings/cuttings	Boiling water & soak 24 hours	Weeding	good
	Sesbania grandiflora	up to 800 m	1000-2000	2-3	Wide range of soils. Good tolerance to flooding.	Direct seeding/ seedlings/cuttings	none	little main-tenance	good
TROPICAL HIGHLANDS	*Acacia mearnsii*	up to 1100 m	500 - 1000		Cannot tolerate calcareous soils	Direct seeding	Boiling water & soak 24 hours		
	Ailanthus altissima	up to 2000 m	350-600	8	Most soils - acid or alkaline. Exceptional tolerance to flooding or drought.	Seeds/seedlings/ root cutting		Good tolerance to weeds	
	Alnus acuminata	up to 3200 m	1000 - 3000		Best on well drained alluvial soils but grows on gravels/ sands/clays.	Seedlings	None. Short seed viability	Weeding	good
	Grevillea robusta	up to 2300 m	400 - 2500	6-8	Grows well in most soils. Prefers deep soils. Does not tolerate waterlogging.	Direct seeding or seedlings	none	Good tolerance to weeds	poor
	Prosopis chilensis	up to 2900 m	200 - 700	8-11	Sandy/gravel and even shallow soils. Good tolerance to salinity.	Direct seeding or seedlings	Scarify & soak 24 hours		
	Trema orientalis	up to 2000 m	1000 - 2500		Most soil types. Colonize denuded, fallow or poor soils.	Direct seeding/ cuttings	Refrigerate 2°C for 3-4 months	Good tolerance to weeds	good

* *A reference list for the above species is available from the authors.*

Table 1 Cont'd

* FAIR
** GOOD
*** EXCELLENT

MAJOR ECOLOGICAL ZONE	SPECIES	FUNCTIONS/USES: FOOD						FODDER				WOOD						SERVICES								OTHER								REMARKS
		Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	Windbreak	Live Fences	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Other	Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other	
ARID/SEMI-ARID	*Acacia albida*							*	*	*	*	*	*	*	*					**	*	*	*					*					*		
	A. senegal							*	*	*	*	**	**	*	*					*	*	*						*	**						Gum arabic
	Balanites aegyptiaca	*		*	*			*	*	*		*		*	*																*				
	Parkinsonia aculeata	*						*	*	*		*	*						*	*													*		Sericulture, Shellac
	Prosopis cineraria							**		*		***	**	*	*					*	**														
	Zizyphus mauritiana	*						*	*			*	*		**				*	*		*					*				*				
HUMID/SUB-HUMID	*Acacia auriculiformis*											**	**	*			pulp											*					*		
	Calliandra calothyrsus							*				*								**		*	*										*		
	Gliricidia sepium							*			**	*		*	*	*			**			**											*		Toxic to Horses
	Leucaena leucocephala		*	*				*	*	*	*	*	*	*				*	*	**		*	**	*											
	Albizia lebbeck							**		*	**	*		*		*				*													*		
	Sesbania grandiflora	*		*				*	*			*					pulp	*	*	*			**					*	*						
TROPICAL HIGHLANDS	*Acacia mearnsii*											*	*				pulp			*			**					*** (T)							
	Ailanthus altissima											*	*	*	*			*		**													**		
	Alnus acuminata											*		*	*	*				**		*													Shade over tea + coffee
	Grevillea robusta										**	*		*		*																	*		
	Prosopis chilensis	*						*	*	*		*			*							*													
	Trema orientalis							*	*			*	*	*			pulp			*		*													Shade over tea + cocoa

Table 2. Characteristics and Uses of Nitrogen Fixing Woody Perennials with AF Potential

MAJOR ECOLOGICAL ZONE	SPECIES	ECOLOGICAL ADAPTABILITY: ALTITUDE (m.a.s.l.)	RAINFALL RANGE (mm/yr)	MAXIMUM DRY PERIOD (months per year)	SOIL CONDITIONS	GROWTH FORM	MANAGEMENT ASPECTS: ESTABLISHMENT	SEED TREATMENT	CARE	COPPICING ABILITY	SPECIAL FEATURES
ARID/SEMI-ARID	*Acacia albida*	up to 1200 m	300 - 800	6-8	Sandy/silty well drained soils. Good tolerance to salinity	Tree to 30 m	Seedlings	Hot water (80C) & soak 24 hours	Weedings	poor	leafless in rains
	A. senegal	up to 1700 m	200 - 800	8-11	Sandy/well drained soils. pH 5-8 poor tolerance to waterlogging.	Tree 5 to 15 m	Seedlings	Hot water (80C) & soak 24 hours	Weeding	good	Browse susceptible
	A. tortilis	up to 1500 m	100 - 1000	10-12	Alkaline and sandy soils. Good tolerance to salinity	Tree flat top 4-30 m	Seedlings	Hot water (80C) & soak 24 hours	Weeding	good	Bruchids eat seeds
	Albizia lebbeck	up to 1600 m	500 - 2000	4-5	Prefers drained loams. Good tolerance to salinity.	Tree 20-30 m spreading crown	Direct seeding, root/shoot cuttings	Boiling water & cool & soak 24 hrs	Weeding	good	Browse susceptible
	Cajanus cajan	up to 3000 m	400 - 2500	5-6	Light sandy soils and loams. Poor tolerance to waterlogging.	Shrub, 1-4 m	Direct seeding	None. Use fresh seeds.	Weeding for first 4-6 weeks	good at 0.15 m	Shade intolerant
	Cassia siamea	up to 1200 m	500 - 1000	4-5	Most soils including limestone & laterite Poor tolerance to waterlogging.	Tree 15-20 m. Dense crown	Direct seeding	Hot water (80C) & soak	Weeding for first 2 years	good	Browse susceptible
	Gardenaria edulis	300 - 1000 m	200-500	10-12	Sandy soils. pH 7-8.5; very poor tolerance to frost.	Shrub 1-3 m	Direct seeding	None. Short seed viability (3 mths)		-	frost sensitive
	Pithecellobium dulce	up to 1500 m	400 1600	4-5	Most soils including clay. Good tolerance to salinity and waterlogging.	Tree, 15-20 m	Seedlings or cuttings	None. 6 month seed viability	Very good tolerance to weeds	Very good	Insects eat seeds
	Prosopis chilensis	300 - 2900 m	200 - 600	8-11	Most soils. Good tolerance to salinity	Tree, 8-15 m	Seedlings	Hot water (80C) & soak 24 hours	Weeding in first year	†	frost susceptible
	Prosopis cineraria	up to 1000 m	75 - 850	8-10	Sandy/rocky soils. Tolerates pH 9, salinity and waterlogging.	Tree. 5-9 m Open crown	Seedlings or root suckers	Scarified & boiling water & soak	Good tolerance to weeds	good	tolerates slight frost

* FAIR
** GOOD
*** EXCELLENT

SPECIES	FUNCTIONS/USES: FOOD: Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/Condiment (C)	FODDER: Leaves	Fruits/Pods/Seeds	Shoots	Bee Forage	WOOD: Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Saw Timber	Others	SERVICES: Windbreak	Live Fence	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Others	MISCELLANEOUS: Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other	OTHER REMARKS
Acacia albida							**	*			*		*	*					**		**	**					(T) *					*		Combines well with agric. crops
A. senegal		*					**	**			***	**							**	*	*							***	**	*				Yields Gum arabic
A. tortilis							**	**	*	**	***	**	**	**					**	**	*											*		Widely used for livestock pens. Termite resistant
Albizia lebbeck							**		*	**	**		*		**				**		**	*						*				*		fast growing
Cajanus cajan		**	**				*	**	*		*								**		***							*				*		agriculture/shellac
Cassia siamea							*	*	*		***				**		**		**			**												very toxic to pigs
Gardenaria edulis		***		**	**		**						*						*		*						(D) *							Subsistence food
Pithecellobium dulce	*			*			**	**		**	*		*		*		*	**			*						(T) *	*				*		pressecake makes good stock feed
Prosopis chilensis		*					*	*		*	*		**	*					**		*													high biomass yielder
P. cineraria							**	**		*	***	**	*	*					**	**	**													combines well with agric. species

Table 2. Cont'd

MAJOR ECOLOGICAL ZONE	SPECIES	ECOLOGICAL ADAPTABILITY: ALTITUDE (m.a.s.l.)	RAINFALL RANGE (mm/yr)	MAXIMUM DRY PERIOD (months per year)	SOIL CONDITIONS	GROWTH FORM	MANAGEMENT ASPECTS: ESTABLISHMENT	SEED TREATMENT	CARE	COPPICING ABILITY	SPECIAL FEATURES
TROPICAL HIGHLANDS	*Acacia mearnsii*	up to 2000 m	500-1200	4-6	Wide range except calcareous soils	Tree to 25 m	Direct seeding	Immerse in boiling water	good tolerance to weeds	poor	mod. frost tolerant
	Albizia stipulata	2000 - 3000 m	500-2500	3-5	Well adapted to infertile and shallow soils	Tree 15-20 m	Seedlings, root/shoot cuttings	None	weeding	good	Highlands - Nepal
	Alnus acuminata	1200-3200 m	1000-3000	3-5	Well drained loams and loamy sands. Also on gravelly and clayey soils	Tree 15-40 m	Seedlings or root cuttings	None. 2-3 weeks seed viability	weeding	good	Actinomycete Frankia sp.
	A. nepalensis	300-3000 m	500-2500	3-5	Wide range. Best on alluvial loams and loamy sands.	Tree 30-40 m	Seedlings/cuttings	None	good tolerance to weeds	fair	shade tolerant
	Casuarina oligodon	up to 2300 m	700-4000	6-8	Most soil types	Tree 20-35 m	Seedlings	Ant repellant	weeding	?	mod. frost tolerant
	Erythrina poeppigiana	up to 2000 m	1000-3000	3-5	Most soils; dry to wet	Tree 10-15 m	Seedlings/cuttings	?	?	good	-
	Gleditsia triacanthos	up to 1500 m	500-2500	6-8	Most soils; acid to alkaline, sandy to clay	Tree to 45 m flat topped	Seedlings/cuttings	Immerse in hot water (80°C)	good tolerance to weeds	good	frost tolerant
	Inga jinicuil	up to 1400 m	500-3000	5-6	Most soils including limestone	Tree 10-20 m	Seedlings	short seed viability	?	good	termite susceptible
	Lespedeza bicolor	up to 2000 m	500-2500	3-5	Most types including infertile rocky soils	Shrub 2-3 m	Direct seeding or seedlings	None	good tolerance to weeds	good	Korean species
	Trema orientalis	up to 2000 m	1000-3000	3-4	Wide range including denuded infertile soils	Tree 10-15 m	Seedlings/cuttings	Refrigerate 2°C for 3-4 months	good tolerance to weeds	good	shade intolerant

* FAIR
** GOOD
*** EXCELLENT

FUNCTIONS/USES

SPECIES	FOOD: Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/Condiment (C)	FODDER: Leaves	Fruit/Pods/Seeds	Shoots	Bee Forage	WOOD: Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	SERVICES: Windbreak	Live Fence	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Others	MISCELLANEOUS: Wraps	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other	OTHER REMARKS
Acacia mearnsii											***	**				pulp			***		**	***					(T) ***							combines well with agric. species
Albizia stipulata							***														**	**						*				**		coffee/tea shade
Alnus acuminata											**		**	**	*	pulp			***		**	*												pasture trees
Alnus nepalensis							*				*			**					***		**											*		outgrows and suppresses most weeds
Casuarina oligodon											***	**	**				***		**		*													common fuelwood in Papua New Guinea
Erythrina poeppigiana							**							*				**	**		**	**	*											coffee shade
Gleditsia triacanthos	*						**	**			**		**	**	*		**		**													*		could become a weed
Inga jinicuil											*		**						**		***	**												coffee shade
Lespedeza bicolor							**			**	**								***		**	**												nurse/fallow species
Trema orientalis							**				**	**	**			pulp			**		?													cacao/coffee shade

MAJOR ECOLOGICAL ZONE	SPECIES	ECOLOGICAL ADAPTABILITY: ALTITUDE (m.a.s.l.)	RAINFALL RANGE (mm/yr)	MAXIMUM DRY PERIOD (months per year)	SOIL CONDITIONS	GROWTH FORM	MANAGEMENT ASPECTS: ESTABLISHMENT	SEED TREATMENT	CARE	COPPICING ABILITY	SPECIAL FEATURES
HUMID/SUB-HUMID	*Acacia auriculiformis*	up to 600 m	1000 - 1800	6-8	Wide range including Uranium and tin mining spoils. pH 3-9	Tree, 30 m	Direct seeding or seedlings	Boiling water & soak for 24 hours	Weeding	poor	shallow roots
	Calliandra calothyrsus	up to 1500 m	1000 - 2000	3-4	Wide range of soils. Very good tolerance to flooding	Shrub, 5-10 m	Direct seeding or seedlings	Boiling water & soak 24 hours	Good tolerance to weeds	excellent	1-2 year rotations
	Casuarina equisetifolia	up to 1500 m	200 - 5000	6-8	Most soils except clay. Tolerant to salinity and waterlogging	Tree, 30-50 m	Seedlings	Ant repellant on seed	Weeding	poor	N-fixing Actinomycete
	Derris indica	up to 1200 m	500 - 2500	4-6	Most soils including limestone. Very good tolerance to salinity	Tree, 5-8 m Deciduous	Direct seeding/ cuttings	None	Good tolerance to weeds	good	shade tolerant
	Gliricidia sepium	up to 1600 m	2300	2-3	Moist or dry soils even when very alkaline	Tree, 5-10 m Open crown	Seedlings or large cuttings	Hot water (80C) & soak 24 hours	?	good	Deciduous
	Leucaena leucocephala	best below 500m	250 - 1700	3-5	Poor growth on acid soils (pH 5). Poor tolerance to waterlogging	Shrub/tree, 5-20 m	Direct seeding or seedlings	Hot water (80C) & soak 48-72 hours	Weeding	good	frost sensitive
	Albizia scabrella	up to 2400 m	1000 - 2000	?	Most well drained soils. Poor tolerance to waterlogging	Shrub/tree 10-12 m	Direct seeding	?	?	?	3-4 year rotations
	Tamarindus indica	up to 1000 m	600 - 2500	5-6	Wide range of soils	Tree, 30-40 m Spreading crown	Seedlings	Feed pods to cattle	Good tolerance to weeds	?	shallow roots
	Sesbania bispinosa	up to 1700 m	550 - 1100	5-6	Most soils. Very good tolerance to alkalinity, salinity and waterlogging	Shrub like, 4 m	Direct seeding	None	Very good tolerance to weeds	-	An annual
	Sesbania grandiflora	up to 800 m	1000 - 2000	2-3	Wide range of soils. Good tolerance to waterlogging	Tree, 10 m	Direct seeding/ seedlings/cuttings	None	Little maintenance	good	frost sensitive

* FAIR
** GOOD
*** EXCELLENT

MAJOR ECOLOGICAL ZONE	SPECIES	FUNCTIONS/USES: FOOD: Fruits/Pods	Nuts/Seeds	Vegetable	Oils/Fats	Starch	Spices (S)/ Condiment (C)	FODDER: Leaves	Fruits/Pods/Seeds	Shoots	Bee Forage	WOOD: Fuel Wood	Charcoal	Building Material	Wood for Utensils & Tools	Sawn Timber	Others	SERVICES: Windbreak	Live Fence	Soil Conservation	Dune Fixing	N Fixing	Organic Manure	Mulch	Others	MISCELLANEOUS: Waxes	Essential Oils	Tannins (T) Dyes (D)	Gums	Fibres	Medicinal/Drugs	Cultural, Ritual Social	Ornamental	Other	OTHER REMARKS
HUMID/SUB-HUMID	*Acacia auriculiformis*											**	**				pulp			**		**						(T) *	*				**		outgrows Imperata cylindrica
	Calliandra calothyrsus							**			*	**								**		**	**										*		combines well with agric. species
	Casuarina equisetifolia											***	***	**	**		pulp	***		**	**	*						(T) *							fire sensitive
	Derris indica							**				**			*					**	**	*					*			*	*				insecticide properties
	Gliricidia sepium							**			**	**						**	***	**		*	**												coffee/cocoa shade
	Leucaena leucocephala							***		**	**	**	**	*			pulp	**		**		**	***												combines well with agric. species
	Albizia scabrella											**					pulp		**			*	**										**		coffee shade
	Tamarindus indica	*							**						**	**						**							*				**		pasture shade
	Sesbania bispinosa							**				*					pulp	*		**		**	**								**				combines well with agric. species
	Sesbania grandiflora	*		**				**	**			*					pulp	**		**		**	***					(T) *	*		*				combines well with agric. species

APPENDIX C-10

BIBLIOGRAPHIC SOURCES OF LISTS OF MULTIPURPOSE TREES AND SHRUBS*

The table on the following page gives a master list of sources which list and describe multipurpose woody species of potential significance to agroforestry. Detailed bibliographic information follows the table.

This information supplements the lists of specific trees and shrubs and their characteristics given in Appendices C-8 and C-9. Such information may be helpful to agroforestry designers in selecting woody species for inclusion in designs for improved land management systems, but the reader is cautioned that such lists can never give a full inventory of potential agroforestry species for a given location. They may serve to call attention to some of the most outstanding exotics or native species whose potentials might otherwise be overlooked, but there may be other trees and shrubs of purely local significance which agroforestry designers may be well advised to consider.

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* Contributed by Jeff Burley, Commonwealth Forestry Institute

SOURCES OF LISTS OF MULTIPURPOSE SPECIES

Authors	Date	Scope	No. of genera or species
Bauer	(1982)	Eight site types in Honduras	30 species 21 genera
Camacho	(1981)	Costa Rica	68 species
FAO/IBRD	(1978)	Nepal	91 species
Koivisto	(1979)	Asia-Pacific region	5 genera trees 4 genera bamboos 2 agric. industrial woody spp. 13 potential untested spp.
Laurie	(1974)	African savannahs	
		Subdesert	10 species, 6 genera
		Dry tropical	9 species, 6 genera
		Semi humid tropical	19 species, 6 genera
		Humid and equatorial	13 species, 7 genera
Fenton et. al.	(1977)	Lowland tropical hardwoods	23 species 14 genera
Adams et al.	(1978)	Arid and saline	45 indigenous tree species 53 introduced tree species 65 indigenous } shrubs and cover 24 introduced } shrubs and cover
FAO/IBPGR	(1980)	Arid and semi-arid	13 species, 4 genera
von Maydell	(1981)	Sahel	116 species
Delwaulle	(1979)	Dry tropical Africa	63 species, 43 genera
Goor & Barney	(1976)	Arid	53 species
Brewbaker et.al	(1981)	Tropical legumes in AF	26 species, 12 genera
Vergara	(1980)		
NAS	(1980)	Global firewood	60 species selected list
Burley	(1980)		650 source list
Boland and Turnbull	(1981)		111 species and genera
Lavoie	(1981)	Energy biomass	31 genera, 288 species
Webb et al.	(1979)	Global multipurpose	180 species
Edwards	(1983)	Malawi multipurpose	66 species and/or genera
Barrow	(1983)	Kenya multipurpose	57 species
Owino	(1983)	Kenya nitrogen fixing and multipurpose	55 species, 4 genera
NAS	(1982)	Sahel	54 species
Lessard and Chouinard	(1980)	Bamboos	43 species, Malaysia 22 species, Indonesia Many species, A-P region
Varmah and Pant	(1981)		Many species, India
Le Houerou	(1980)	Browse species, North Africa	34 species
Johnson	(1983)	Palms	4 species domesticated 19 species incipient domesticat:
IDRC	(1979)	Rattans	
Whitmore	(1980)	Many groups and purpose	Various species for Asia countr:
Halliday&Nakao	(1982)	Legumes	1000 species
Brewbaker and Styles	(1982)	Nitrogen-fixing trees	43 species "A" list 50 species "B" list
Okafor	(1980)	Food and fodder, Nigeria	51 species
Kessler	(1981)	Fodder, Nepal	24 species

REFERENCES

ADAMS, R., ADAMS, M., WILLENS, A. and WILLENS, A. (1978). Dry lands: man and plants. Architectural Press, London, England, 152pp.

ALLEN, O.N. and ALLEN, E.K. (1981). The Leguminosae. A source book of characteristics, uses and nodulation. Univ. Wisconsin Press, Madison, USA, 812p.

ANON. (1981). Proceedings of the U.S. strategy conference on biological diversity. US Dept of State Publ. 9262, Washington, DC, USA, 126p.

ANON. (1982). Editorial: What is agroforestry? Agroforestry Systems 1(1), 7-12.

BARNES, R.D. and BURLEY, J. (1982). Vegetative propagation in the improvement of tropical forest trees. Pap. 8th Long Ashton Symp., "Improvement of vegetatively propagated plants", Long Ashton Res. Stn., Bristol, England, 28p.

BARNES, R.D., BURLEY, J., GIBSON, G.L. and GARCIA de LEON, J.P. (1982). Genotype-environment interactions in tropical pines and their effects on the structure of breeding populations. Abstr. in; Proc. IUFRO Jt. Mtg. Wkg. Parties on Genetics about breeding strategies including multiclonal varieties. Lower Saxony For. Res. Inst., Escherode, Germany, 220-1.

BAUER, J. (1982). Especies con potencial para la reforestacion en Honduras; resumenes. Corp. Hond. Des. For., Tegucigalpa, Honduras, 42p.

BELDT, R. van den and HUXLEY, P. (eds.) (1982). Institutions studying nitrogen fixing trees. Pap. NFTA 82-06, Resource Documents, Bellagio Meeting, Nitrogen Fixing Tree Association, Hawaii, USA, 10p.

BENGE, M.D. (1982). Selected tree seed sources in Australia, India, Holland and the United States. ST/FNR Tech. Series No. 1, USAID, Washington, DC, USA, 224p.

BOLAND, D.J. and TURNBULL, J.W. (1981). Selection of Australian trees other than eucalypts for trials as fuelwood species in developing countries. Australian Forestry, 44 (4) 235-46.

BONGA, J.M. and DURZAN, D.J. (eds.) (1982). Tissue culture in forestry. Martinus Nijhoff/Dr. W. Junk Publishers, The Hague, Netherlands, 420p.

BREWBAKER, J.L. (1978). Application of augmented design in field crop experiments. Mimeo. Univ. Hawaii, USA, 4p.

BREWBAKER, J.L. (1982). Systematics, self-incompatibility, breeding systems and genetic environment of Leucaena species. Pap. NFTA Leucaena Workshop, Singapore, 15p.

BREWBAKER, J.L. (1983). Guide to the systematics of the genus Leucaena Benth. Allertonia 3 (in press).

BREWBAKER, J.L., BELT, R. van den, and MACDICKEN, K. (1981). Nitrogen-fixing tree resources: potentials and limitations Pap. conf. Biological Nitrogen Fixation, CIAT, Cali, Colombia, 13p.

BREWBAKER, J.L. and STYLES, B.T. (eds.) (1982). Economically important nitrogen fixing tree species ("A" and "B" lists). Pap. NFTA 82-04A and B, Resource Documents, Bellagio Meeting, Nitrogen Fixing Tree Association, Hawaii, USA, 7 and 2p.

BROWN, C.L. (ed.) (1981). Application of tissue culture technology to production of woody biomass. International Energy Agency Rept. NE 1981:18, National Swedish Board for Energy Source Development, Stockholm, Sweden, 23p.

BURDON, R.D. (1982). The roles and optimal place of vegetative propagation in tree breeding strategies. In: Proc. IUFRO Jt. Mtg. Wkg. Parties on Genetics about breeding strategies including multiclonal varieties. Lower Saxony For. Res. Inst., Escherode, Germany, 66-83.

BURKHART, A. (1976). A monograph of the genus Prosopis (Leguminosae subfam. Mimosoideae. J. Arnold Abor. 57 (3), 219-49.

BURLEY, J. (1980a). Selection of species for fuelwood plantations. Commonw. For. Rev. 59 (2), 133-47.

BURLEY, J. (1980b). Choice of tree species and possibility of genetic improvement for smallholder and community forests. Commonw. For. Rev. 59 (3), 311-26.

BURLEY, J. and KEMP, R.H. (1972). International tropical provenance trials and genotype-environment interactions. Invited Pap. IUFRO/SABRAO Wksp. Applications of Quantitative Genetics in Forestry, Tokyo, Japan. Pap. B - 2 (1), 11p.

BURLEY, J. and KEMP, R.H. (1973). Centralised planning and international cooperation in the introduction and improvement of tropical tree species. Commonw. For. Rev. 52 (4), 335-43.

BURLEY, J. and NAMKOONG, G. (1980). Conservation of forest genetic resources. Invited Pap. Eleventh Commonw. For. Conf., Trinidad. Commonw. For. Inst., Oxford, England, 25p.

BURLEY, J. and STYLES, B.T. (eds.) (1976). Tropical trees: variation, breeding and conservation. Academic Press, London, England, 243p.

BURLEY, J. and WOOD, P.J. (1976). A manual on species and provenance research with particular reference to the tropics. Trop. For. Pap. No. 10, Commonw. For. Inst., Oxford, England, 226p.

BURLEY, J. and WOOD, P.J. (1983). Development of curricula for community forestry. Pap. 12th Session, FAO Adv. Comm. Forestry Education, Nairobi, Kenya, 7p.

BEST AVAILABLE COPY

CAMACHO, M.P. (1981). Ensayos de adaptabilidad y rendimiento de especies forestales en Costa Rica. Inst. Tecnol. de Costa Rica, Cartago, Costa Rica, 287p.

CFI. (1980). Unit of Tropical Silviculture activities 1970-1980. Commonw. For. Inst., Oxford, England, 64p.

DELWAULLE, J.-C. (1979). Plantations forestières en Afrique tropicale sèche. Techniques et espèces à utiliser. Bois For. Trop. No. 188, 3-30.

DOUGLAS, J.S. (1972). Tree crops for food, forage and cash. World Crops Part 1. 15-19 (Jan/Feb) and Part 2. 86-89, 97 (Mar/Apr).

DRANSFIELD. J. (1981). The biology of Asiatic rattans in relation to the rattan trade and conservation. In: The biological aspects of rare plant conservation (Synge, H., ed.), John Wiley, Chichester, England, 179-86.

DREGNE. H. (1980). Study on financing the U.N. Plan of Action to Combat Desertification. Report of the Secretary General, July 17th. of U.N. Assembly, New York, USA.

DUKE, J.A. (1981). Handbook of legumes of world economic importance. Plenum Press, New York and London, 345p.

ECKHOLM, E. (1978). Disappearing species: the social challenge. Worldwatch Paper No. 22, 38p.

FAO. (1973-82). Forest genetic resources information, Issues 1-11, FAO, Rome, Italy.

FAO. (1974). Proposals for a global programme for improved use of forest genetic resources. FAO. Pap. FO: MISC/74/15, FAO, Rome, 34p.

FAO. (1975). Forest tree seed directory. FAO, Rome, Italy, 283p.

FAO. (1977). Report of the Fourth Session of the FAO Panel of Experts on Forest Gene Resources. FAO, Rome, Italy, 75p.

FAO. (1979). Eucalypts for planting. FAO Forestry Series No. 11, Rome, Italy, 677p.

FAO. (1981a). Tropical forest resources assessment project (GEMS): Tropical Africa, Tropical Asia, Tropical America (4 vols.) FAO/UNEP (Rome).

FAO. (1981b). Map of the fuelwood situation in the developing countries. Supplement to Unasylva, FAO, Rome, Italy.

FAO. (1981c). FAO/IBPGR project on genetic resources of arboreal fuelwood species for the improvement of rural living. Forest Genetic Resources Information No. 10, FAO, Rome, Italy, 31-3.

FAO. (1982). Provisional lists of institutions engaged in forestry and forest products research. FO: MISC 82/10, FAO, Rome Italy, 90p.

FAO/IBPGR. (1980). Genetic resources of tree species in arid and semi-arid areas. A survey for the improvement of rural living in Latin America, Africa, India and Southwest Asia. FAO, Rome, Italy, 118p.

FAO/IBRD. (1978). Nepal Community Forestry Development Project. Preparation Report. FAO/World Bank Cooperative Programme, Rome, Italy.

FAO/UNEP. (1981). Report on the FAO/UNEP expert consultation on in situ conservation of forest genetic resources. FAO, Rome, Italy, 34p.

FEDERER, W.T. and RAGHAVARAO, D. (1975). On augmented designs. Biometrics 31, 29-35.

FENTON, R., ROPER, R.E. and WATT, G.R. (1977). Lowland tropical hardwoods: an annotated bibliography of selected species with plantation potential. External Aid Div., Min, Foreign Affairs, Wellington, New Zealand.

GOODIN, J.R. and McKELL, C.M. (1971). Shrub productivity - a reappraisal of arid lands. In: McGinnies, W.G. et al. (eds.), Food, fiber and the arid lands. Univ. Arizona Press, Tucson, Arizona, USA, 235-46.

GOOR, A.Y. and BARNEY, C.W. (1976). Forest tree planting in arid zones. 2nd ed., Ronald Press, New York, USA, 504p.

GRAINGER, A. (1980). The state of the world's tropical rain forests. The Ecologist, 10, 6-54.

GREATHOUSE, T.E. (1982). Tree seed and other plant materials aspects of USAID-supported reforestation projects. US Agency for International Development, Washington, DC, USA, 27p.

GREAVES, A. (1978). Descriptions of seed sources and collections for provenances of Pinus caribaea. CFI Trop. For. Pap. No. 12, Commonw. For. Inst., Oxford, England, 98p.

GREAVES, A. (1979). Descriptions of seed sources and collections for provenances of Pinus oocarpa. CFI Trop. For. Pap. No. 13, Commonw. For. Inst., Oxford, England, 144p.

GUNN, C.R. (ed.) (1982). Directory. The Bean Bag, Plant Taxn. Lab., USDA, Beltsville, Md., USA, 399 members.

HALLIDAY, J. and NAKAO, P.L. (eds.) (1982). Masterlist of woody species under consideration as nitrogen-fixing trees. Pap. NFTA 82-03, Resource Documents, Bellagio Meeting, Nitrogen Fixing Tree Association, Hawaii, USA, 8p.

HAN, H, QIQUAN, S. (1981). Advances in plant cell and tissue culture in China. Advances in Agronomy, 34, 1-13.

HAWKES, J.G. (1980). Group genetic resources field collection manual. IBPGR and EUCARPIA, Dept of Plant Biol., Univ. Birmingham, England, 37p.

ICRAF. (1979). Agroforestry defined. Newsletter 1(1), ICRAF, Nairobi, Kenya, 4.

ICRAF. (1983). INFO/DOC. ICRAF; an interactive, user friendly, agroforestry information request service. ICRAF, Nairobi, Kenya, 4p.

IDRC. (1979). Rattan: a report of a workshop held in Singapore, 4-6 June, 1979. Rept. No. IDRC-155e. IDRC, Ottawa, Canada, 76p.

International Society of Horticulture Science. (1972). Horticultural research international. Directory of horticltural research institutes and their activities in 54 countries. Centre for Agric. Publ. and Doc., Wageningen, Netherlands, 537p.

ISTA. (1976). International Rules for Seed Testing. Seed Sci. Technol. 4, 3-49, with Annexes, 51-177 (and amendments in 1977 and 1980 published by ISTA in 1981, 54p).

ISTA. (1982). Survey of equipment and supplies for seed testing. Intl. Seed Test. Assoc., Zurich, Switzerland, 77p.

IUCN, UNEP and WWF. (1978). Sourcebook for a world conservation strategy; thretened higher plants. General Assembly Pap. GA 78/10, IUCN, Morges, Switzerland, 5 addenda, various paginations.

IUFRO. (1982). IUFRO's new structure. IUFRO News 36 (2/1982), 20p.

IVORY, M.H. (1983). Plant health legislation and forest trees. Annex, ICRAF/IBPGR/CFI/NAS planning workshop on multipurpose tree germplasm, Washington, DC, USA, 8p.

JOHNSON, D.V. (1983). Multipurpose palm germplasm. Annex ICRAF/IBPGR/CFI/NAS planning workshop on multipurpose tree germplasm, Washington, DC, USA, 50p.

JONES, N. and BURLEY, J. (1973). Seed certification, provenance nomenclature and genetic history in forestry. Silvae Genetica 22(3), 53-8.

JOSHI, N.J. (1982). Regional paper (Indian sub-continent). Pap. ICRAF/DSE Intl. Wksp. "Professional education in agroforestry", Nairobi, Kenya, 37p.

KAHN, R.P. (1977). Plant quarantine principles, methodology and suggested approaches. In: Plant health and quarantine in international transfer of genetic stocks (Hewitt, W.B. and Chirapa, L., eds.), CRC Press, Cleveland, USA, 289-307.

KAHN, R.P. (1978). International exchange of genetic stocks. In: Propagation of higher plants through tissue culture; a bridge between research and application (Hughes, K.W. et al., eds.) CONF-7804111, US Dept. Energy, Washnington, DC, USA, 233-45.

KAHN, R.P. (1979a). A concept of pest risk analysis. EPPO Bull. 9(1), 119-30.

KAHN, R.P. (1979b). Tissue culture applications for plant quarantine. In: Practical tissue culture applications. Academic Press, London, England, 186-201.

KAHN, R.P. (1981). Trees as vectors of spiroplasmas and mycoplasma and rickettsia-like organisms. In: Mycoplasma diseases of trees and shrubs, Academic Press, London, England, 281-97.

KAHN, R.P. (1982). The host as a vector: exclusion as a control. In: Pathogens, vectors and plant diseases. Academic Press, London, England, 123-49.

KEMP, R.H. (1976). Seed procurement for species and provenance research. In: A manual on species and provenance research with particular reference to the tropics, (Burley, J. and Wood, P.J., eds.), CFI Trop. For. Pap. No. 10, Commonw. For. Inst., Oxford, England, 32-48.

KEMP, R.H., BURLEY, J., KEIDING, H. and NIKLES, D.G. (1972). International cooperation in the exploration, conservation and development of tropical and sub-tropical forest gene resources. Pap. 7th World For. Congr., Argentina, 7 CFM/C: V/4, 16p.

KESSLER, C.D.J. (1981). Notes on the raising of some fodder trees for the hills of Nepal. Intl. Tree Crops J. 1, 245-72.

KING, M.W. and ROBERTS, E.H. (1979). The storage of recalcitrant seeds - achievements and possible approaches. IBPGR Secretariat, FAO, Rome, Italy, 96p.

KING, R.C. (1972). A dictionary of genetics. Oxford Univ. Press, London, 2nd ed., 337p.

KOIVISTO, H.K. (1979). Appropriate species selection for forestry plantations. In: Proc. Regional Seminar "Application of Appropriate Technology in Forestry and Forest Industries", ADB, Manila, Philippines, 170-260.

KRIEK, W. (1970). Report to the Government of Uganda on performance of indigenous and exotic trees in species trials. FAO Rept. TA2826, Rome, Italy, 148p.

LANLY, J.P. (1982). Tropical forestry resources. FAO For. Pap. No. 30, FAO, Rome, Italy, 106p.

LAURIE, M.V. (1974). Tree planting practices in African savannas. FAO For. Dev. Pap. No. 19, Rome, Italy, 185p.

LAVOIE, G. (ed.) (1981). Inventory of species and cultivars potentially valuable for forest biomass production. Intl. Energy Agency Rept. NE 1981: 17, National Swedish Board for Energy Source Development, Stockholm, Sweden, 43p.

LEAKEY, R.R.B., LAST, F.T. and LONGMAN, K.A. (1982). Domestication of tropical trees: an approach securing future productivity and diversity in managed ecosystems. Commonw. For. Rev. 61(1), 33-42.

LE HOUÉROU, H.N. (1979). Le rôle des arbres et arbustes dans les pâturages sahéliens. In: Le rôle des arbres au Sahel. Rept. No. IDRC-158f, IDRC, Ottawa, Canada, 19-32p.

LE HOUÉROU, H.N. (1980). Browse in Northern Africa. Pap. Intl. Symp. Browse in Africa, Intl. Livestock Centre for Africa, Addis Ababa, Ethiopia, 31p.

LESSARD, G. and CHOUINARD, A. (1980). Bamboo research in Asia. Rept. No. IDRC-195e, IDRC, Ottawa, Canada, 228p.

LUCAS, G. and SYNGE, H. (1981). The assessment and conservation of threatened plants around the world. In: The Biological aspects of rare plant conservation (Synge, H., ed.), John Wiley and Sons, Ltd., Chichester, England, 3-18.

LUNDGREN, B. (1982). The use of agroforestry to improve the productivity of converted tropical land. Rept. US Congr. Office of Technology Assessment, Washington, DC, USA, 82p.

MAYDELL, H.-J. von. (1981). Baumund Straucharten der Sahelzone unter besonderer Berücksichtigung ihrer Nutzungsmöglichkeiten. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GMBH, Eschborn/TS, Germany, 526p.

McKELL, C.M. (1975). Shrubs - a neglected resource of arid lands. Science 187, 803-9.

NAMKOONG, G., BARNES, R.D. and BURLEY, J. (1980). A philosophical review of breeding strategies for tropical forest trees. Trop. For. Pap., Commonw. For. Inst., Oxford, England, 67p.

NAS. (1977). Leucaena - promising forage and tree crop for the tropics. US National Academy of Sciences, Washington, DC, USA, 115p.

NAS. (1978). Conservation of germplasm resources - an imperative. National Academy of Sciences, Washington, DC, USA, 118p.

NAS. (1980). Firewood crops: shrub and tree species for energy production. National Academy of Sciences, Washington, DC, USA, 237p.

National Commission on Agriculture. (1976). Report 9, Forestry. Min. Agric. Irrig., Delhi, India, 457p.

NRC. (1982). Priorities in biotechnology research for international development. National Academy Press, Washington, DC, USA, 261p.

OAKES, A.J. (1982). Leucaena bibliography. Econ. Bot. Lab., USDA, Beltsville, Md., USA, 1308 refs.

OECD. (1974). OECD scheme for the control of forest reproductive material moving in international trade. Organization for Economic Cooperation and Development, Paris, France, 21p.

OKAFOR, J. (1980). Trees for food and fodder in the savannah areas of Nigeria. Intl. Tree Crops J. 1, 131-41.

OWINO, F. (1983). Inventory, growth evaluation and improvement of N-fixing indigenous trees for Kenya. Project proposal, NAS Research Grants Committee, Washington, DC, USA, 7.

PALMBERG, C. (1981). Progress in the global programme for improved use of forest genetic resources. Forest Gnetic Resource Information No. 10, FAO, Rome, Italy, 5-16p.

POLHILL, R.M. and RAVEN, P.N. (eds.) (1981). Advances in Legume Systematics. Proc. Intl. legume conf. Kew, 1978. Royal Botanic Gardens, Kew England, 2 vols.

PRANCE, G.T. and ELIAS, T.S. (1976). Extinction is for ever. New York Bot. Gard., New York, USA, 437p.

PRYOR, L.D. (1981). Australian endangered species: eucalyptus. Austral. Natl. Parks and Wildlife Serv., Canberra, Australia, 139p.

PRYOR, L.D. and JOHNSON, L.A.S. (1971). A classification of the eucalypts. Austral. Nat. Univ., Canberra, Australia, 102p.

RADWANSKI, S.A. (1981). Multiple land utilization in the tropics: an integrated approach with proposals for an international neem tree research development program. In: Schmutterer et al. (eds.) Natural pesticides from the neem tree (Azadirachta indica A. Juss.). Proc. 1st Intl. Neem Conf, Rottach-Egern, Germany, June, 1980. German Agency for Technical Cooperation, Eschborn, Germany, 267-77p.

REGAL, P.J. (1982). Pollination by wind and animals: ecology of geographic patterns. Ann. Rev. Ecol. Syst. 13, 497-524.

ROCHE, L. (1975). The methodology of conservation of forest genetic resources. FAO Pap. FO: MISC/75/8, FAO, Rome, Italy, 127p.

SASTRAPRADJA, S. and BRENAN, J.P. (1982). Arboreta and herbaria with major collections of nitrogen fixing tree species. Pap. NFTA 82-07, Resource Documents, Bellagio Meeting, Nitrogen Fixing Tree Association, Hawaii, USA, 4p.

SEPASAT. (1982). Royal Botanic Gardens, Kew (with the support of OXFAM) survey of economic plants for arid and semi-arid tropics, SEPASAT. Royal Botanic Gardens, Kew, England, 2p.

SKERMAN, P.J. (1977). Tropical forage legumes. FAO Plant Production and Protection Series No. 2. FAO, Rome, Italy, 609p.

SOLBRIG, O.T., BAWA, K., CARMAN, N.J. et al. (1977). Patterns of variation. In: Mesquite; its biology in two desert scrub ecosystems (Simpson, B.B., ed.), US/IBP Synthesis Series No. 4, Dowden, Hutchinson and Ross, 449-60p.

SOMMER, A. (1976). Attempts at an assessment of the world's tropical forests. Unasylva 28 (112-13), 5-25.

STAPLETON, C. (1982). Bamboo in East Nepal: preliminary findings (Dec 1981 - June 1982). (Restricted Rept.) For. Res. Inform. Centre, Dept. For., Kathmandu, Nepal, 59p.

STERN, W.L. (1978). Index Xylariorum. Institutional wood collections of the world. 2. Taxon 27(2/3), 233-69.

STEWART, P.J. (1981). Forestry, agriculture and land husbandry. Commonw. For. Rev. 60 (1), 29-34.

STREETS, R.J. (1962). Exotic forest trees in the British Commonwealth. Clarendon Press, Oxford, 765p.

SYNGE, H. (ed.) (1981). The biological aspects of rare plant conservation. J. Wiley and Sons, Chichester, England, 558p.

SYNGE, H. and TOWNSEND, H. (eds.) (1979). Survival or extinction. Bentham-Moxon Trust, Royal Botanic Gardens, Kew, England, 250p.

THOMPSON, P.A. (1979). Preservation of plant resources in gene banks within botanic gardens. In: Survival or extinction (Synge, H. and Townsend, H., eds.) Bentham-Moxon Trust, Royal Botanic Gardens, Kew, England, 179-84p.

TURNBULL, J.W. (1982). Eucalypts in China. Aust. For. 44, 222-34.

TURNBULL, J.M. (1983). Tree seed supply - a critical factor for the success of agroforestry projects. Annex, ICRAF/IBPGR/CFI/NAS planning workshop on multipurpose tree germplasm, Washington, DC, USA, 17p.

UN. (1978). UN Conference on Desertification: Round-Up, Plan of Action, and Resolutions, United Nations, New York, USA.

UNESCO. (1973). Conservation of natural areas and the genetic material they contain. Rept. Expert Panel MAB Project 8, UNESCO, Paris, France, 64p.

USDA. (1974). Seeds of woody plants in the United States. Agric. Handb. 450, For. Serv., USDA, Washington, DC, USA, 883p.

VARMAH, J.C., and PANT, M.M. (1981). Production and utilization of bamboos. Indian Forester 107(8), 465-76.

VERGARA, N.T. (ed.) (1982). New directions in agroforestry: the potential of tropical legume trees. Selection of legume trees for agroforestry. Wkg. Gp. Agroforestry, Environ. Policy Inst., East-West Center, Honolulu, Hawaii, USA, 28p.

WATERWORTH, H.E. and WHITE, G.A. (1982). Plant introduction and quarantine: the need for both. Plant Disease 66, 87-90.

WATTLE RESEARCH INSTITUTE. (1982). Report for 1981-82 (Thirty-fifth year). Wattle Research Insitute, Univ. Natal, Pietermaritzburg, S. Africa, 138p.

WEBB, D.B., WOOD, P.J. and SMITH, J.P. (1980). A guide to species selection for tropical plantations. Trop. For. Pap. No. 15., Commonw. For. Inst., Oxford, England, 342p.

WHITMORE, T.C. (1980). Potentially economic species of southeast Asian forests. Intl. Tree Crops J. 1, 171-81.

WILKINS, C.P., BENGOCHEA, T. and DODDS, J.H. (1982). The use of in vitro methods for plant genetic conservation". Outlook on Agriculture, 11, 67-72.

WILLIAMS. J.T. and DAMANIA, A.B. (1981). Directory of germplasm collections. 5 Industrial crops. I. Cacao, coconut, pepper, sugarcane and tea. IBPGR, Rome Italy, 50p.

WITHERS, L.A. (1980). Tissue culture storage for genetic conservation. IBPGR Tech. Rept. AGP: IBPGR/80/8, Rome, Italy, 91p.

WOOD, P.J. and BURLEY, J. (1980). Ex situ conservation stands. Pap. IUFRO Symp. Wksp. genetic improvement and productivity of fast-growing tree species. Aguas de Sao Pedro, Sao Paulo, Brazil, 8p.

WOOD, P.J., BURLEY, J. and GRAINGER, A. (1982). Technologies and technology systems for reforestation of degraded tropical lands. Rept. US Congr. Office of Technology Assessment, Washington, DC, USA, 114p.

WORLD BANK. (1978). Forestry: sector policy paper. World Bank, Washington, DC, USA, 68p.

WORLD BANK and FAO. (1981). Forestry research needs in developing countries - time for reappraisal? Spec. Pap. 17th IUFRO Congr., Kyoto, Japan, 56p.

WRIGHT, J.W. (1976). Introduction to forest genetics. Academic Press, New York, USA, 463p.

APPENDIX C-11

ADDITIONAL CHARACTERISTICS OF WOODY PLANTS TO BE CONSIDERED IN CHOOSING SPECIES FOR AGROFORESTRY SYSTEMS*

In choosing trees and shrubs for inclusion in designs for improved land use systems, a large number of factors must be considered. Not only must the chosen species fulfill the functional requirements of the system, i.e. for specific production or service functions, but the characteristics of candidate species should be considered, not only from the technical standpoint, but also with a view toward assessment of management and socioeconomic characteristics. The following table provides a checklist of some of the more important considerations involved in the detailed evaluation and selection of woody agroforestry components. These start with an appraisal of germplasm characteristics (1), continue with aspects of propagation (2), planting-out (3), the "juvenile" phase of growth (4), mature growth (5) and senescence and re-planting (6).

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*Excerpted from P.A. Huxley. Some characteristics of trees to be considered in agroforestry. Poster paper presented at ICRAF's Consultative Meeting on Plant Research and Agroforestry, 8-15 April, 1981. In: P.A. Huxley (ed). Plant Research in Agroforestry. (In press)

SOME CHARACTERISTICS OF TREES

1. GERMPLASM

Technical	Managerial	Socio-Economic
(a) Is this species outbreeding and germplasm therefore heterozygous?	1. Does a mixture of genotypes matter? 2. Is germplasm easily and cheaply available? and through what sources (plant quarantine etc?)	Can the land-user collect and/or distribute his own seed? Or does he have to buy it?
(b) Are there seed viability problems? (If so does it pay and are there facilities to investigate?)	Will someone have to carry out seed testing?	Can a farmer easily store seed? Does this put up the cost of seed?
(c) Are there seed dormancy problems? (if so does it pay and are there facilities to investigate?)	Is any special equipment or technology required to break seed dormancies?	Does this hinder adoption through direct-planting technologies?
(d) Are seeds (etc.) commonly attacked by pests/diseaes	Are special storage facilities or conditions required?	Will this be a major hindrance to issuing farmers with seed?
(e) Are there specific seed-borne diseases?	1. Is any special treatment of the seed required? 2. Will the land-user have to watch out to eradicate (or treat) young seedlings?	Will the land-user need special help or advice? & will this be costly?
(f) If tree seeds are not the best or most convenient method of propagating, then do any of the above questions relate to other types of materials that might be used?	Especially viability of cutting budding or grafting materials.	Does the farmer already have experience in say, using cuttings? (and see next section)

2. PROPAGATION

Technical	Managerial	Socio-economic
(a) What methods of propagating are available (See 1f above) - seeds/cuttings/budding and grafting/tissue culture etc.	1. What facilities are there for establishing nurseries and distributing plants? 2. What types of nursery are best? (central, thro' village schools etc. etc.) 3. What skills/labour/materials are there for setting up nurseries and distributing plants?	1. What are the relative advantages of direct-planting versus nurseries? 2. What propagating method best suits the land-user? 3. What will the costs be if using different methods?
(b) What are the specific environmental requirements for germinating seeds and/or rooting cuttings etc, and for early seedling growth?	Are the facilities, labour and skills available?	Will the land-user easily understand the requirements?
(c) Are there requirements for seed innoculation (Rhizobium, Mycorrhirhizae)	Will this be done on farm or for issued seeds?	
(d) Are there specific pests and diseases in the nursery phase?	Are special procedures involving materials and skills required?	Will the land-user suffer severely from a failure to control these properly?
(e) What is the likely (and optimum) duration of the nursery phase.	Can the nurseries supply plants a) when the farmer wants them b) for as long as he wants there is sufficient quantity and c) of a type which will survive the distribution and planting systems.	1. What are the costs? 2. What are the costs of maintaining unsold/undistributed plants?

3. PLANTING OUT

Technical	Managerial	Socio-economic
(a) What are the soil/environmental conditions needed? (best season? Are there special soil conservation requirements in this phase?)	What site preparation problems are there?	How does it fit in with labour availability and other family needs?
(b) What is the optimum plant size (and condition) at planting out? (see also 2e)	Are proper handling facilities available, and the necessary skills?	Can the necessary care be given?
(c) Is shelter/support required for the young plant?	What is the easiest to arrange (what local materials are available?)	Will the farmer bother? Can he afford it? Will he maintain it and finally remove it?
(d) Do the young plants need watering, fertilizing or mulching?	Can it be provided?	What is the cost and likelihood of the land-user adopting these procedures?
(e) Are pests/diseases/weeds likely to be a problem (and animals/birds)	Are special chemicals or protective methods needed?	What cost? How does it fit with labour requirements and available skills?

4. JUVENILE PHASE

	Technical	Managerial	Socio-economic
(a)	1. What is the morphology and early growing habit of the species? 2. How does it respond to training/ pruning and what growth responses are there for buds of different kinds?	1. Does this affect crops growing nearby what are the tree/crop interactions? 2. What training is possible and desirable? 3. Are training skills available?	Will the land-user understand what is required? What are the costs of training versus not training?
(b)	Is the species slow or fast-growing in its early stages? (see also 4a above)	If slow-growing will this increase the burden of management operations?	Will a slow-growing species be acceptable, however useful and productive later?
(c)	What are the rooting characteristics of this tree species?	1. How does this affect management practices (watering, weeding fertilizing)? 2. Does early, deep-rooting characteristic affect associated crops and what are the tree/crop interactions at this level? see 4a(1) 3. Will this affect choice of site (see 3a)	Is the land-user prepared to allocate a special site to the trees (if needed)?
(d)	Is the tree palatable? What is the need for animal protection?	1. Are there any effects on animal production of restricting their browsing? 2. Are people, methods etc.available for animal protection measures?	1. What are the land-users habits with regard to his (or others) browsing animals? 2. What is the cost of protecting the trees from animals?
(e)	What are the plants' requirements and responses to shade/shelter, watering, fertilizing, weeding?	Are materials, labour and skills available?	1. What are the cost/benefits? 2. What are the likelihood of adoption of these techniques? and what will happen if they are not done?
(f)	What is the duration of the time to flowering/fruiting (is the species being grown for fruits?)	What management procedures can be adopted to induce early flowering? (see 4a)	How does this affect incentives to plant?
(g)	How susceptible is this tree species to pests and diseases?	What materials and skills are required?	Will a failure to control these end in disaster?
(h)	What is the phenology of this species - how does this effect the associated crop plants?	Will this time-of-planting and/or other management factors related to the associated agricultural crop?	

5. MATURE GROWTH PHASE AND PERIOD OF MATURITY

	Technical	Managerial	Socio-economic
(a)	1. What is the morphology and branching habit? 2. What is the phenology? - shoot dormancies and growth regulations - leaf flush/leaf-fall sequences - flowering and fruiting cycles - general source-sink relationships.	1. Are skills/labour available to deal with with training/pruning 2. What are the tree/crop interactions implicit in the trees morphology/ phenology	1. Any land-user preferences? 2. What effects on the land-user environment?
(b)	Competitiveness (from 5(a) above)	What timing of (possible) operations to control this?	1. What does the land-user see as his needs to "control" the trees? 2. What are the cost/benefits of doing so?
(c)	Harvestability (single, terminal harvest/sequential harvests?)	How does this fit into the pattern of farming operations?	How does this fit into social requirements? Market opportunities?
(d)	Needs for weed control	1. Is necessary labour/equipment available? 2. How does this fit in with weed control timing and methods for the agricultural crop?	1. What methods are best suited? 2. Will the land-user adopt? 3. What is cost/benefit?
(e)	Soil management and soil conservation	1. Is necessary labour/equipment available? 2. How does this fit in with weed control timing and methods for the agricultural crop?	1. Does the land-user perceive a need? 2. Will the land-user adopt? 3. What is cost/benefit?
(f)	Pests/diseases	1. Is necessary labour/equipment available? 2. How does this fit in with weed control timing and methods for the agricultural crops? 3. Can advice be obtained?	1. Does the land-user perceive a need? 2. Will the land-user adopt? 3. What is cost/benefit? 4. Will there be a disaster if he neglects?
(g)	Biennial bearing? (for fruiting crops)	Are the necessary skills available to obviate this?	Does this affect the land-user/ markets.

6. SENESCENCE AND RE-PLANTING PREPARATIONS

	Technical	Managerial	Socio-economic
(a)	What is likely time of onset of ageing/senesence	What decisions have to be taken on how to remove trees?	How will the land-user perceive the need to remove trees?
(b)	Duration of this phase and effects?	On associated agricultural crops and farm management?	1. On productivity? 2. Need for credit/help? or alternative sources of income?
(c)	Final harvest sequence/tree removal	Effects on adjacent crops and on soil	Alternative choices of how to dispose
(d)	Pests/diseases associated with cutting down trees (including general and specific re-plant problems)	Knowledge of what to look for available?	Willingness to take care?
(e)	Land preparation for replanting	1. Place in whole farming programme 2. Availability of labour	1. Costs? 2. Any social implications?
(f)	Crop/soil management in transition period	Availability of labour etc. especially for soil conservation in this period.	1. Willingness to adopt? 2. Any extra costs?

APPENDIX C-12

POTENTIAL AGRICULTURAL AND HORTICULTURAL CROPS*

To round out the lists of potential components in agroforestry systems, this appendix presents a list of well-known agricultural and horticultural crops along with a chart showing their range of ecological adaptability. The list is by no means exhaustive, but it may serve to stimulate thinking about possible components for inclusion in agroforestry systems. This appendix supplements the lists of woody perennials given in Appendices C-8 and C-9.

General grouping of the selected crops according to their adaptability to different ecological regions in the tropics

LOWLANDS (UP TO 500 m)			MEDIUM ELEVATION (500-1200 m)			HIGHLANDS (ABOVE 1200 m)		
[1]PERHUMID - SUBHUMID	[2]SEMIHUMID - SEMIARID	[3]SUBARID - PERARID	[1]PERHUMID - SUBHUMID	[2]SEMIHUMID - SEMIARID	[3]SUBARID - PERARID	[1]PERHUMID - SUBHUMID	[2]SEMIHUMID - SEMIARID	[3]SUBARID - PERARID
Arecanut	Arecanut	Cowpea	Arecanut	Arecanut	Cowpea	Banana	Banana	Cowpea
Arrowroot	Banana	Finger millet	Arrowroot	Banana	Finger millet	Cardamom	Cassava	Finger millet
Banana	Cassava	Groundnut	Banana	Cashew	Groundnut	Cinchona	Castor	Groundnut
Breadfruit	Castor	Mung bean	Breadfruit	Cassava	Mung bean	Coffee	Cinchona	Mung bean
Cacao	Cinnamon	Pearl millet	Clove	Castor	Pearl millet	Pyrethrum	Coffee	Pearl millet
Clove	Clove	Pigeon pea	Coffee-Robusta	Cinnamon	Pigeon pea	Yam	Cowpea	Pigeon pea
Coconut	Coconut	Sesame	Ginger	Cowpea	Sesame		Finger millet	Sorghum
Ginger	Cowpea	Sorghum	Papaya	Finger millet	Sorghum		Maize	Sweet potato
Oil palm	Finger millet	Sweet potato	Passion fruit	Ginger	Sweet potato		Mung bean	
Papaya	Ginger		Pepper	Groundnut			Passion fruit	
Pepper	Groundnut		Pineapple	Kapok			Pearl millet	
Pineapple	Kapok		Rubber	Maize			Pigeon pea	
Rubber	Maize		Taro	Mung bean			Pineapple	
Taro	Mung bean		Turmeric	Papaya			Potato	
Turmeric	Papaya		Yam	Passion fruit			Pyrethrum	
Yam	Pearl millet			Pearl millet			Soya bean	
	Pigeon pea			Pigeon pea			Sweet potato	
	Pineapple			Pineapple			Yam	
	Sesame			Sesame				
	Sisal			Sisal				
	Sorghum			Sorghum				
	Soya bean			Soya bean				
	Sweet potato			Sweet potato				
	Taro			Taro				
	Turmeric			Turmeric				
	Yam			Yam				

[1]PERHUMID - SUBHUMID: areas with 0-4 dry months and more than 1200 mm rain per year

[2]SEMIHUMID - SEMIARID: areas with 5-8 dry months and 500-1200 mm rain per year

[3]SUBARID - PERARID: areas with more than 9 dry months and less than 500 mm rain per year

A month is considered 'dry' when the potential evapotranspiration is more than the precipitation received during the month.

*Excerpted from P.K.R. Nair. 1980. Agroforestry Species: A Crop Sheets Manual. ICRAF. Nairobi.

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APPENDIX C-13

PLANT ARRANGEMENT CONSIDERATIONS*

Considerations involved in making a preliminary decision on the *location* of the various woody components of the design are discussed in Appendix C-7. It is quite another matter, however, to decide on the actual *arrangement* of the plant components within the identified locations. The first thing to decide is whether the different plants should be grown in combination or separately. This will depend primarily on the nature of the interactions between the plants, i.e. whether generally adverse, neutral or beneficial.

Two basic spatial possibilities exist: *mixed* or *zonal* cropping (figs. 1 and 2). Generally speaking, when the interactions are on the whole adverse the plants should probably be separated. If, however, the interactions are generally beneficial, the plants may be combined in space. Mixed systems tend to maximise interaction between plants, while zonal systems tend to reduce interaction or make it possible to regulate the interaction more effectively. Sole cropping is regarded as an extreme form of zonal cropping in which interaction is reduced to what occurs at the field boundaries.

In choosing between mixed and zonal cropping systems the following factors should be considered.

Mixed Cropping

There are, undoubtedly, cases where mixed cropping of woody perennial species and short-lived herbaceous agricultural crops will be found to give improved yields per unit land area compared with sole cropping. Such systems will often improve soil or microclimatic conditions, or provide a mix or products in a special arrangement that suits the farmer. However, improved yield responses cannot be considered a normal generalization, particularly as in their adult phases most woody perennials can be considered "agressor species" (Trenbath, 1976).

However, each case must be considered on its own merits, taking account of both beneficial and adverse interactional effects as well as management options for shifting the balance in a favorable direction. In some cases, even if the land equivalent ratio is found to be less than unity (indicating the biological potential for higher yields if the components are grown separately), there may be excellent socioeconomic or environmental reasons for mixed cropping, such as higher returns to labour or more sustained yields over the long term.

Examples of mixed agroforestry systems include interspersed trees on pastures and multistorey combinations of trees, herbaceous plants and livestock (see Appendix C-5).

Zonal Cropping

In zonal agroforestry arrangements the extent of plant-to-plant interaction will depend on the species involved, the overall size of the land management

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*Contributed by P.A. Huxley and J.B. Raintree

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unit, and the size, shape and arrangement of zones within it. Plant interactions of the same kind as are found in mixed cropping systems will occur at the interface between zones containing different plant species, but at a reduced level and with the possibility of greater management control than in the more intimately mixed associations.

Zonal agroforestry systems are likely to simplify management procedures because each zonally arranged component can be dealt with largely as a sole-cropping enterprise within the system. At the same time, transfer of beneficial materials (e.g. litter or lopped mulch material) from one zone to another can be easily managed. Properly managed zonal systems might, in some situations, offer the same environmental benefits as mixed systems, with fewer management problems.

"Alley cropping" (Wilson and Kang, 1980) is one example of a promising zonal approach in which field crops are planted between rows of closely-spaced, nutrient-cycling (usually N-fixing) trees or shrubs which are kept pruned during the cropping season to control shading and provide green manure and mulch material to benefit the associated crops. During the dry season, the deep-rooting, vigorously coppicing trees may be managed for additional crops of firewood, fodder, live stakes for pole crops, etc. (Fig. 3). On steeply sloping land, the woody hedgerows may be planted on the contour at appropriate intervals to add a measure of erosion control to the cropping system (Fig. 4).

Windbreaks, living fences and protein banks adjacent to pasture (see Appendix C-5) are other examples of zonal agroforestry systems in which the spatial arrangement of zonally segregated plant associations plays an important role in achieving management objectives. Note that, within a given zone, plant associations might follow either a sole crop, mixed, or micro-zonal pattern.

The Time Dimension

The various components of agroforestry systems can be combined or separated in time as well as space (Fig. 5). Planted fallows, for example, represent a way to reap the soil-improving benefits of certain trees without the competitive effects on crops by associating them with crops sequentially in time, rather than simultaneously in space. Another example is the establishment of fodder trees in an agrosilvicultural system with crops and waiting until the trees are well established before replacing the crops with pasture and letting animals into what has now been transformed into a silvopastoral system (see Fig. 5 in Appendix C-5). Quite complex and efficient systems of rotation involving a phased sequence of mixed or zonally patterned plant and animal associations are possible (see Fig. 6 in Appendix C-5). Further aspects of the time dimension in agroforestry designs are discussed in Appendix C-3.

References

Huxley, P.A. 1980. Agroforestry research: the value of existing data appraisal. *In*: T. Chandler and D. Spurgeon (eds). International Cooperation in Agroforestry. ICRAF. Nairobi.

References (Cont'd)

Nair, P.K.R. 1980a. Agroforestry research: a retrospective and prospective appraisal. *In*: Chandler and Spurgeon (see above).

Nair, P.K.R. 1980b. Agroforestry Species: A Crop Sheets Manual. ICRAF. Nairobi.

Raintree, J.B. 1983. Preliminary diagnosis of land use problems and agroforestry potentials in northern Mbere Division, Embu District, Kenya. ICRAF Working Paper No.1 ICRAF. Nairobi.

Trenbath, B.R. 1976. Plant interactions in mixed communities. *In*: Multiple Cropping. ASA Special Publication No. 27. Madison.

Wilson, G.F. and B.T. Kang. 1980. Development of stable and productive biological cropping systems for the humid tropics. *In*: B. Stonehouse (ed). Biological Husbandry: A Scientific Approach to Organic Farming. Butterworth. London.

Wilson, G.F. and J.B. Raintree. 1980. The leucaena-maize-yam alley cropping system. IITA. Ibadan. (mimeo).

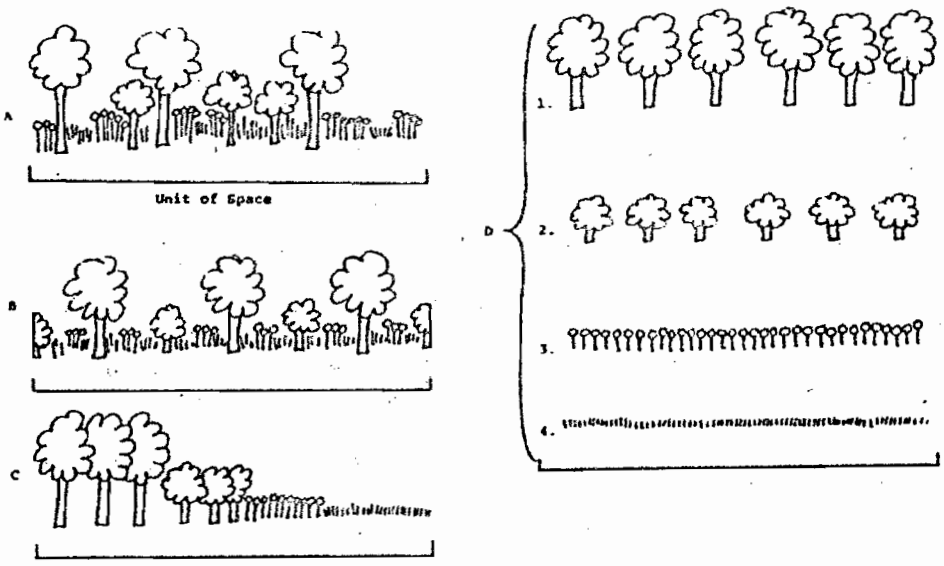

Fig. 1. Diagrammatic representation of the ways in which vegetation can be arranged per unit of space. A) Natural distribution or 'random' mixed cropping. B) Regulated but still mixed or 'microzonal'. C) Zonal in plots, stips or corridors. D) Sole cropping. Source: Huxley (1980)

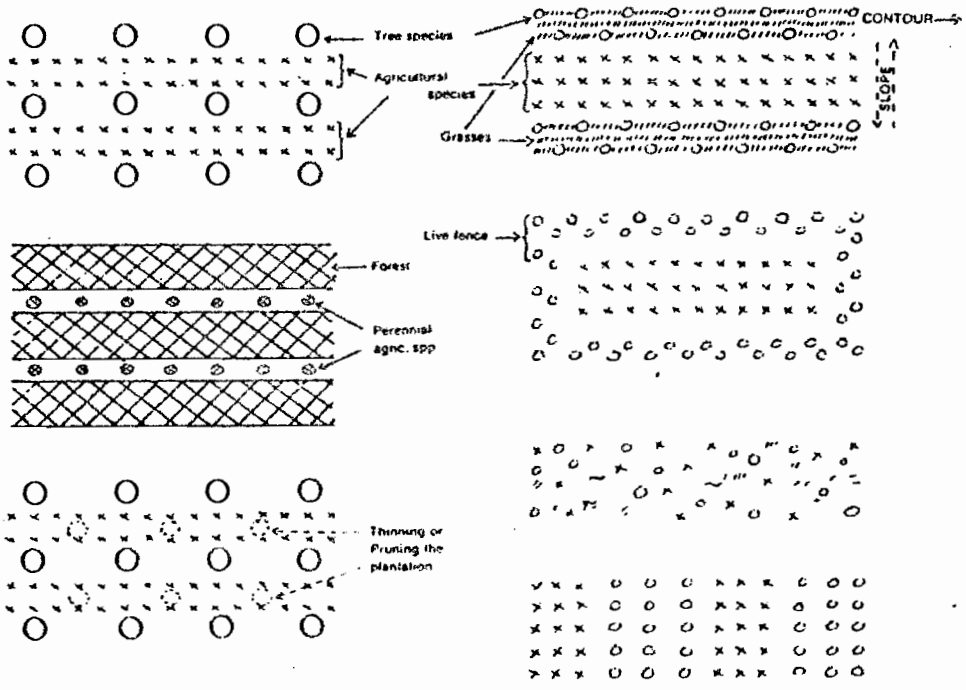

Fig. 2. Some patterns of admixture of species in agroforestry. (Distances not to scale) Source: Nair (1980b)

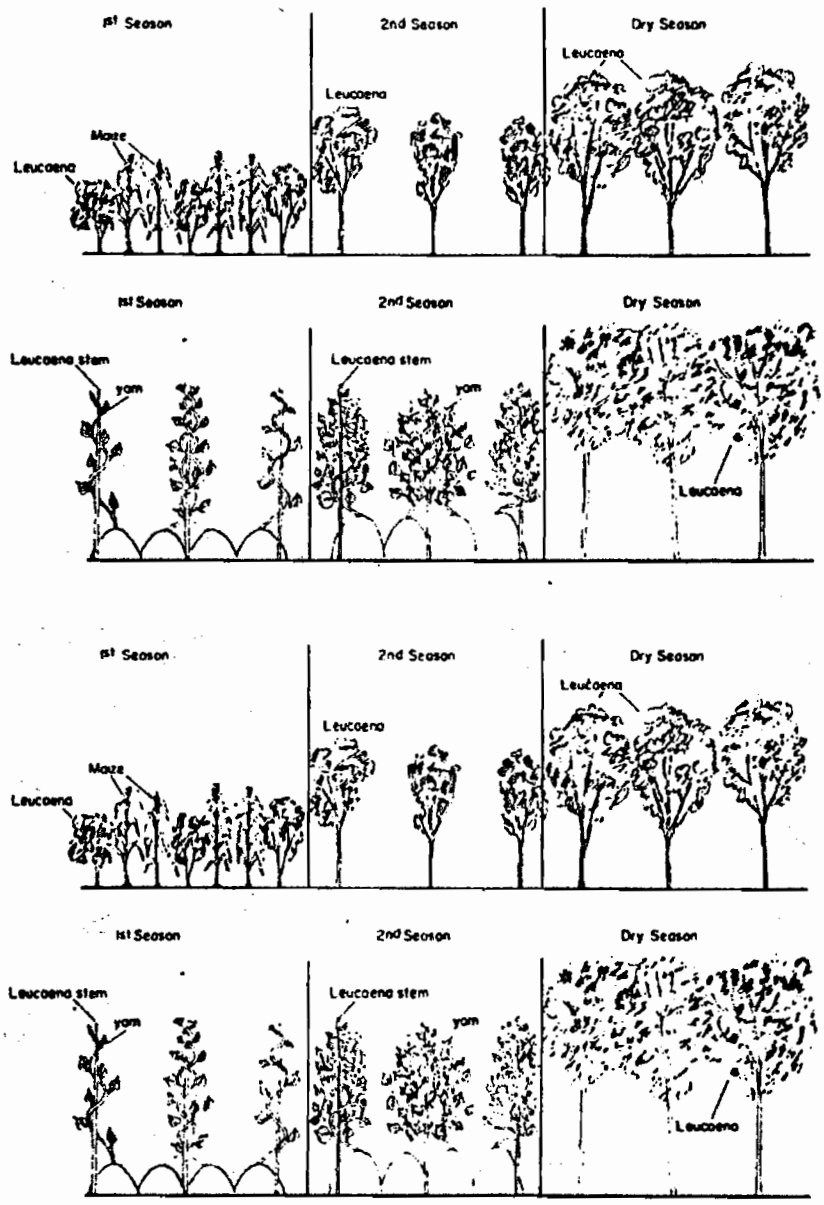

Figure 3. The leucaena-maize-yam alley cropping system developed by Wilson at IITA. (Source: Wilson and Raintree, 1980)

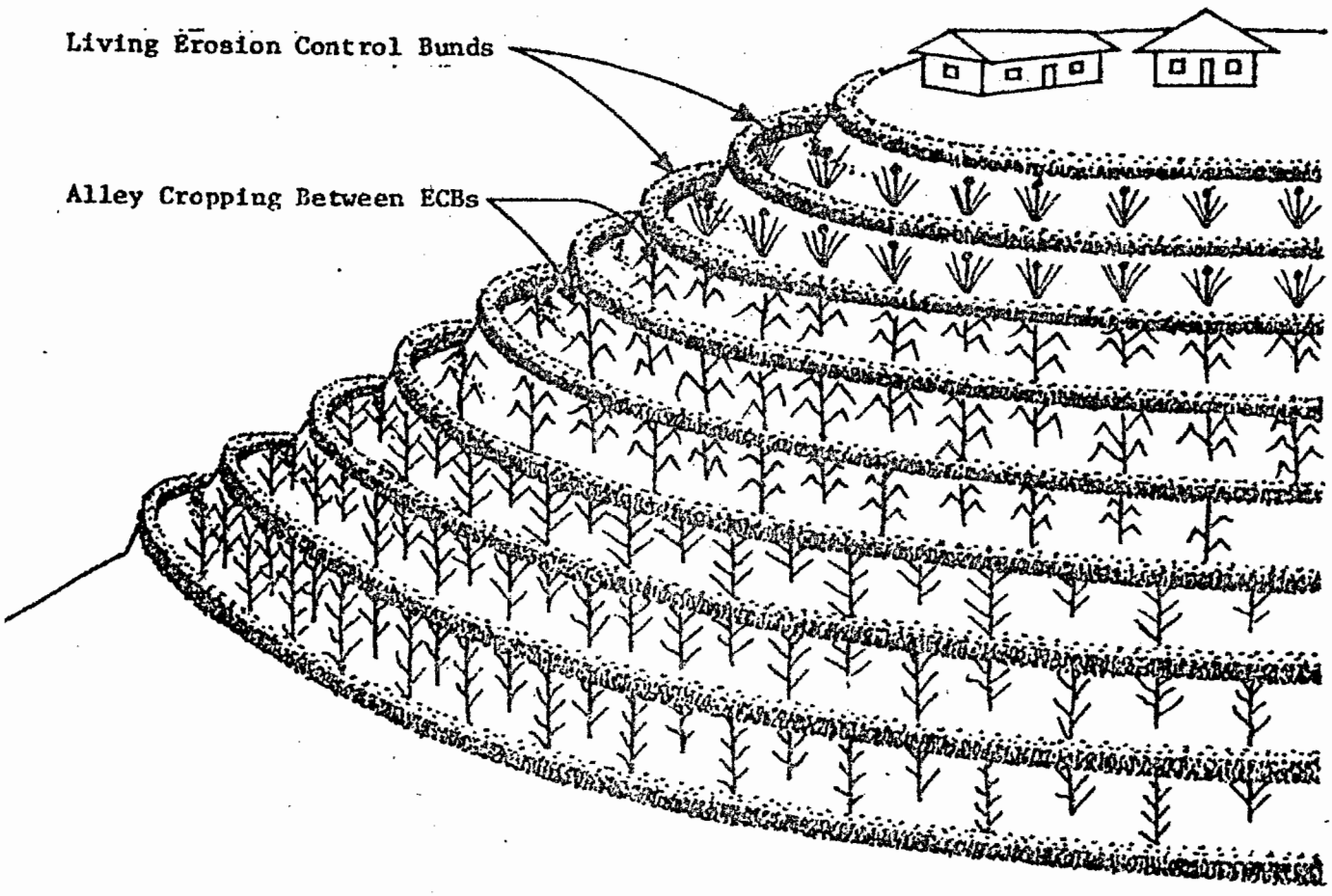

Figure 4. A hillside alley cropping system (Source: Raintree, 1983)

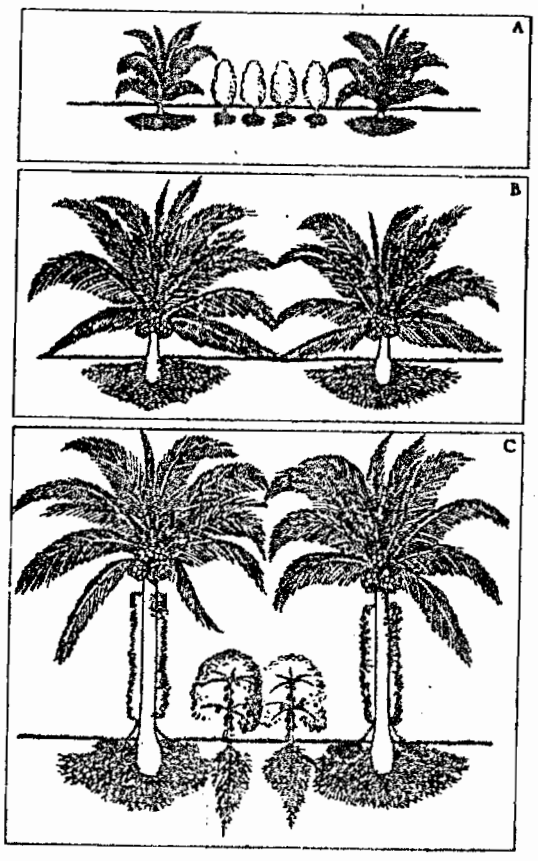

Fig. 5: Schematic presentation of the growth phases of coconut palm indicating possibilities for crop combinations (Nair, 1979)

A. Early phase, up to about 8 years: canopy develops gradually, much scope for intercropping

B. Middle phase, about 8-25 years: greater ground covered by canopy, little scope for intercropping

C. Later phase, after about 25 years: increased scope for intercropping. A multistoreyed combination of coconut, black pepper and cacao is depicted

(Source: Nair, 1980a)

APPENDIX C-14

NOTES ON THE MICROCLIMATIC EFFECTS AND DESIGN OF SHELTERBELTS*

1. INTRODUCTION

For a long time the artificial protection against wind has been one of the most noteworthy of man's efforts to improve the local climate. Especially in windy climates wind breaking hedges, rows of trees, as well as fences of non-living materials have been used to provide protection not only for human dwellings and livestock but also for agricultural purposes.

A distinction is made between damage caused by storms and by winds blowing continuously for long periods. Storm damage, caused by the high wind speeds, has to be considered as an isolated weather phenomenum which will not be discussed further.

Winds which are moderate to strong but which blow continuously as in coastal areas, on high plateaus or on mountain tops can have direct and indirect injuricus effects on plants.

Direct effects are often obvious from deformation of the physical appearance of the plants (inclination of trees or partial wind-ward defoliation). The indirect effects concern mainly the water balance of plants by placing too heavy demands on these, however the water content and other properties of the soil will also be affected. With increasing intensity of cultivation, soil erosion which may occur in dry areas represents another negative effect of wind.

In order to minimize these effects by artificial wind protection, extensive research on this subject has been carried out in many countries, under different climates and by various methods. Therefore only the most important results will be mentioned.

2. MICROCLIMATIC EFFECTS OF SHELTERBELTS

Trees, hedges and rows of bushes by altering the surface roughness, may modify the wind field next to the ground. Depending on the shape of the obstacle not only aerodynamic changes will occur but also other characteristics of the microclimate may be affected.

The classification of the influence of a shelterbelt on these other microclimatic parameters as favourable or unfavourable, will depend entirely on the local conditions. For example a low wind-speed is usually advantageous for the water balance of the soil, but not in wet areas, and not when ripe but still moist crops must dry at harvest time, where increased evaporation would be desirable.

2.1 AERODYNAMIC EFFECTS OF SHELTERBELTS

A shelterbelt orientated at a right angle to the prevailing wind, reduces wind velocity on both windward and the leeward sides. The extent to which a single shelterbelt can reduce the windspeed depends on:

- the height, the length, and the width of the shelter
- the permeability of the shelter
- the windspeed
- the cross sectional shape of the belt.

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*Contributed by T. Darnhofer with P.J. Robinson.

The protective effect is always a function of the distance from the shelterbelt.

The following figure (1) illustrates the shelter effect of shelterbelts of various permeabilities, for winds blowing at right angle to them (after Nagli 1946).

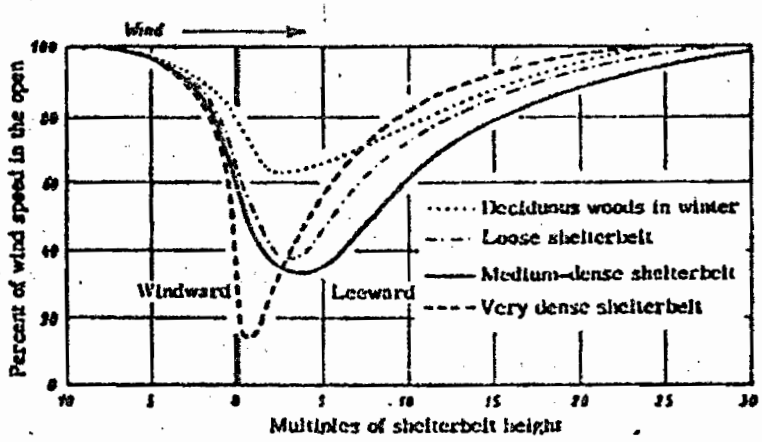


Fig. 1 The effect of a shelterbelt as a function of its permeability.

In all cases the protective effect is substantially greater downwind than upward. Investigations have shown that the effect in depth is approximately proportional to the height "h" of the shelterbelt and the windspeed "v". Distances "x" in front of the shelterbelt (-) or (+) are therefore expressed in units of "h". A 10% reduction in the wind velocity is obtained at a distance of 20 times the tree height to the lee (x=+20h) and three times the tree height to the windward (x=-3h). The lower the permeability of the barrier, the greater the amount of shelter immediately behind it, but the amount of effect is less. Together with the shape of the cross section of the shelterbelt, the density will have an influence on the development of turbulences behind the belt which can be harmful to the plants.

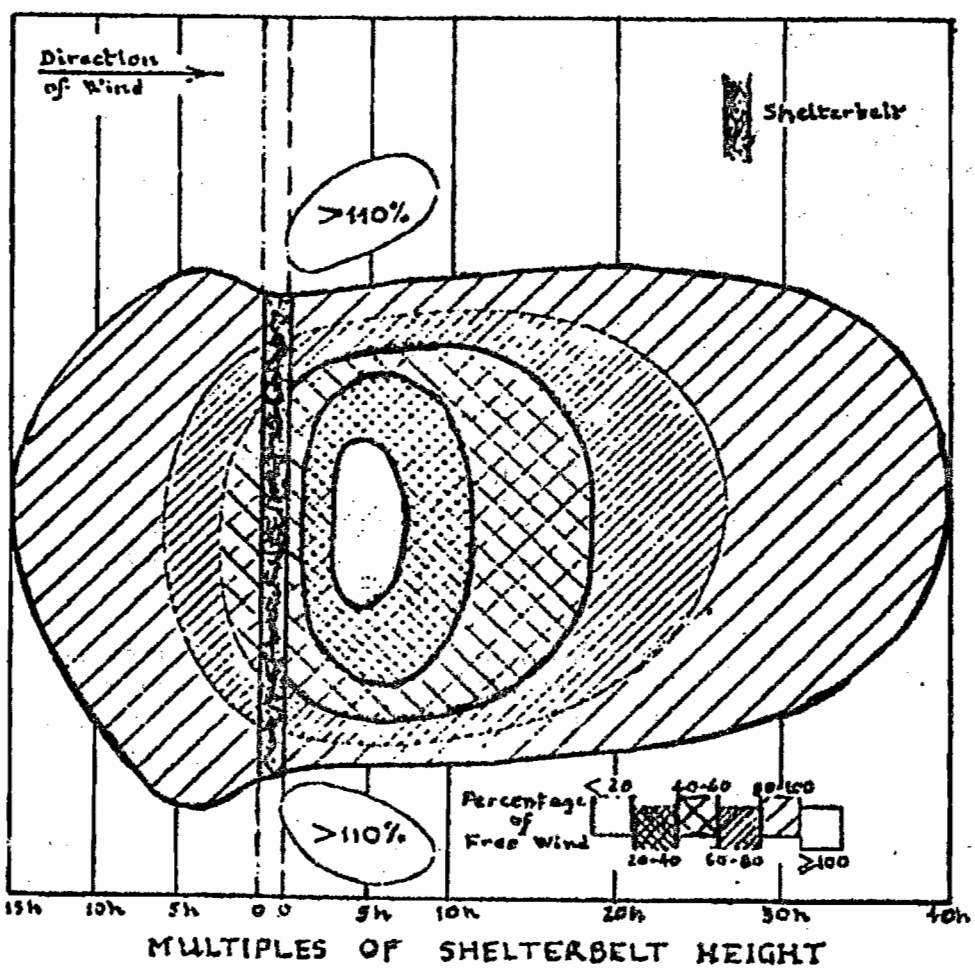
According to different authors (Jensen 1954, Blenk 1956, Gloyne 1954) the most favourable practical results are obtained with a permeability of 40% to 50% as shown by the following table.

Windspeed as % of that in the open	Belt density in %	Distance in "h"
80%	30%	12 h
80%	50%	27 h
80%	100%	15 h

Wind tunnel experiments (v. Eimern 1957) have shown that the shape and the arrangement of gaps in the shelter are without significance; however when permeability is variable it is better if it increases from below upward. The extent to which areas experience different windspeeds in the lee of a shelterbelt depends also on its length. It has been found (Caborn 1957) that a length 12 times the height of the windbreak is required to obtain maximum shelter effect in the centre of the protected area when winds are perpendicular to the barrier. To obtain the full potential of protection with winds varying in direction the length of the shelterbelt would have to be increased. However, the permeability of the windbreak is likely to change with winds blowing from different angles, thus again having an influence on the shelter effects.

A double effect of any single shelterbelt can be recognised; trunks branches or leaves reduce wind velocity by friction, but at the same time the cross section of the stream narrows as the air enters the shelterbelt and this increase the speed. It therefore appears that the braking effect is delayed and greater windspeeds may be experienced to the lee of the gaps in and close to the belt.

Figure 2 shows the spatial distribution of windspeeds in the vicinity of a shelterbelt, as percentage of the speed in the open.



2.2. SOLAR RADIATION

The radiation balance is modified by the shadows created by the shelterbelt. The loss of incoming global radiation depends on the orientation of the barrier as well as on the seaon but is restricted to the immediate vicinity of the trees. Measurements by Dirmhirm (1953) have shown global radiation to be about 95% of undisturbed radiation at a distance of 2 h of the shelterbelt.

2.3 TEMPERATURE

As the temperature depends on various factors such as the radiation properties of the soil and the vegetation, thermal conductivity heat capacity and wetness of the ground, evaporation, air humidity and wind, it is very difficult to attribute one or the other effect qualitatively and quantitatively to changes in the temperature patterns near shelterbelts.

Under windy conditions soil and air temperatures are generally reported (Caborn 1957, Marshall 1967, etc.) to be higher in sheltered sites during daytime and lower at night times. Although the mean temperature might not be significantly different in the field of influence of a shelterbelt compared to the open, the change in the diurnal variation can affect plant growth considerably. An evaluation of the effects of temperature changes will largely depend on plant physiological characteristics.

2.4 PRECIPITATION

Atmospheric precipitation over a large area cannot be expected to be altered by shelterbelts in terms of the over all amount, but together with aerodynamic and other microclimatic effects the local distribution can be changed.

2.4.1 Rainfall

Some mention that the lower air speed in the field of influence of a shelterbelt favours atmospheric precipitation thus improving the water balance. Various measurements have shown that the rainfall distribution at a shelterbelt depends to a large extent on the type of rainfall (heavy or light rains) and on the wind during the rainfall. While light raindrops will preferentially drop in the zone of minimum wind velocity around the barrier, the distribution of heavy rains will not be modified significantly except with strong winds and this again will depend on the wind direction.

Depending on the amount of rainfall, the size of droplets and the wind-speed, the interception by the tree and/or shrub canopy will modify the water balance within the area of influence of the shelterbelt.

2.4.2 Solid precipitation

As any light particle suspended in the air will tend to be deposited in the zone of minimum windspeed, snow and sand will accumulate near windbreaks. In many regions this effect is used for protection of roads

against snow and sand drifts. (Snow deposits will of course change the water balance and other microclimatic parameters considerably).

2.4.3 Dew

Since windspeed is reduced by shelterbelts, air humidity is reported to be higher, and as the radiation balance is modified an influence on the dewfall can be expected. Measurements have actually shown considerable increases (up to 300%) of dewfall in the lee or shelterbelts at a distance of 2 to 3 times the barrier height, when winds were moderate. Whether the quantities of dew, estimated to be an order of magnitude smaller than potential evaporation, can contribute substantially to the water balance, is a subject of some controversy (Monteith 1973, Rosenberg 1974).

2.5 EVAPORATION

Physically the evaporation process (E) can be divided into a radiation (E_r) and a ventilation (E_v) fraction (G. Hofmann 1955).

$$E = E_r + E_v$$

This shows the close relation between evaporation and wind, given similar radiation conditions. The reduction in evaporation is often considered to be one of the most important results of shelterbelts. Early measurements with Piche evaporimeters (Bates 1911) have indicated reductions in the evaporation of up to 60% of its open air value at windspeeds of 6.5 m/s. Measurements of tank evaporation, which is more representative in terms of potential evaporation, have found reduction in evaporation averaging less than 5% (Staple and Lehane 1955). Evaporation has been found to be only slightly affected when windspeeds are low and soils are dry (Alisov 1956). Due to increased daytime temperatures even an increase in evaporation (compared to the open) was reported in an extreme case (Kolasew 1941).

3. EFFECTS ON YIELD

An evaluation of the influence on crop yield caused by an artificial wind protection system will have to take into consideration not only the rather complex effects of a shelterbelt on the micro-climate but also:

- root competition in the vicinity of the shelterbelt
- the sensitivity of the crop plants to mechanical stress (investigations by Russel 1979 have shown that mechanical stress caused by wind can influence plant development)
- the complex effects of shelterbelts on plant development and plant deseases caused by insects, birds and other wind and soilborn pests.

Therefore the over-all effect on a crop yield will vary according to the prevalence of strong winds, rainfall distribution, temperature regime and the kind of crops, as well as the structure and design of the shelterbelt itself.

However, shelterbelts are usually considered to be beneficial to plant growth particularly in areas of strong winds and in areas where erosion or moisture due to snow trapping are important factors. With reference to the above, indications on the overall beneficial effects of shelterbelts vary greatly:

- 60% to 7% increase of alfalfa yield in South Dakota (Bates 1944)
- 30% increase of wheat yield in the USSR (Goverkiantz 1935)
- 7% to 18% increase on various crops in Denmark (Jansen 1954)

Fournier d'Albe (1958) considers 20% as a reasonable average for a yield increase, resulting from shelterbelt effects in areas with strong winds. .However, all these investigations have been made in temperate climate zones and transfer of these results to tropical zones is subject to reservations. A review by Stoeckler (1965) classifies the response of various crops to shelterbelts into three groups:

Low response:	Drought hardy grains, maize varieties grown under dry farming conditions
Medium response:	Rice, fodder crops as alfalfa, lupine clover, wheat
High response:	Garden crops, tobacco, tea

4. EFFECTS ON SOIL EROSION

4.1 WIND EROSION

Wind can transport sand and other solid particles not only along the ground, but can lift and transport them away provided its speed is high enough and the particles are small enough. Especially in intensively cultivated areas, serious losses of fertile top-soil through wind erosion have been observed during the dry seasons. As shelterbelts reduce windspeed they necessarily will alleviate the wind erosion problem. For instance Iizuka (1950) reported that a windbreak that provided a 39% reduction of windspeed at a distance x = 10 h showed only 0.1% sand movement in comparison with that in the open; at a distance x = 20 h sand movement was reduced to 18%. It has to be mentioned that in certain regions shelterbelts are mainly designed and established to protect against soil erosion and thus to help maintain soil fertility and long term yields.

4.2. WATER EROSION

Besides the wind, water is the other factor primarily responsible for the erosion process. In this respect trees and shelterbelts can reduce:

- splash erosion by reducing the size and the energy of raindrops in their immediate vicinity
- flowing water erosion on slopes by decreasing the drainage speed and by increasing the infiltration
- solifluction, by stabilizing slopes mechanically through their roots and by improving at the same time the waterbalance.

Shelterbelts established on slopes therefore will have to follow contourlines rather than be oriented in accordance with the prevailing winds.

5. SHELTERBELT PATTERNS

In the previous chapters reference was always made to single windbreaks. Bigger areas however are protected by a number of successive shelterbelts. Windbreaks established at equal distances one behind the other, thus increasing the roughness of the land, have been shown by experience, to have a substantially more favourable effect than might be expected from individual belts (Kaiser 1959) but this effect does not extend very far leeward of the shelterbelt system.

A much more favourable design is that of a network of shelterbelts perpendicular to each other in which the orientation of the belts is important only if the ground is not level. In this case the shelte effect is more uniform, at least near the centre of the network. Fig 3. illustrates an arrangement proposed by M. Woelfle (1938) which has proven its value in the Upper Rhone Valley.

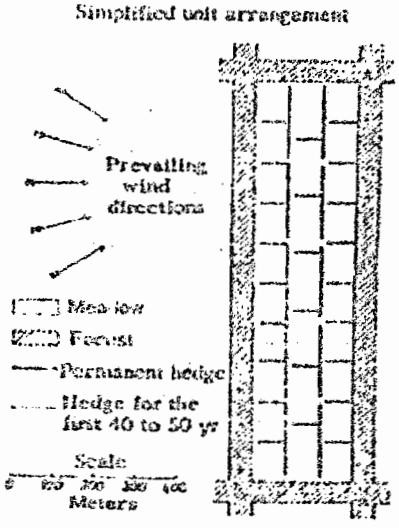


Fig. 3. Wind protection on the Woelfle plan

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The hatched strip shows the network, consisting of a mixed stand 50 m wide and 15 m high. The area inside is subdivided by hedges 5 m high, that can perform secondary functions such as fencing of cattle and production of firewood.

For practical purposes, it would be useful to know about the optimum distance between two or more shelterbelts or about the best size of a network patterned shelter system, but it is not possible to give generally valid specifications. Too many factors are involved, such as the nature of the shelterbelt, frequently distribution of wind directions and speeds, topography of the area, local features etc. It also would be impossible to devise experiments such that local results would yield general conclusions.

6. CONSIDERATIONS FOR SHELTERBELT DESIGN

When approaching the complicated task of designing an effective shelterbelt, it should be known *what* is supposed to be protected and improved. It is only then that research for an answer on *how* this can be achieved will be successful. Furthermore protection against wind should not be understood merely as a wind problem but also as a problem of modifying the environment. Thus it becomes associated with many ecological factors which have to be considered when planning an effective shelterbelt system. Although the general principles of choosing productive components and management practices can be applied, there is no substitute for a thorough site specific design effort at each individual site. In the following, an attempt is made to list the most important considerations to be taken into account:

6.1 PHYSICAL FEATURES

6.1.1 Climatology

With reference to Sec. 2 it is evident that prior to a wind-break design exercise a thorough climatological survey of the area under consideration should ideally be carried out.

This should include:

- the natural distribution in time and space of wind speed and directions as a function of the general wind regime
- The rainfall distribution in time and its quantity
- Indications on the other climatological parameters such as temperature, air and soil moisture, radiation and evaporation

In many cases, where detailed data is not available, this will require measurements on the site, well in advance. Once the preliminary climatic survey achieved and a shelterbelt design is proposed, an assessment of how it may modify the microclimate should be made. However, to which the extent the climatological assessment can be carried out and be justified, will depend largely on economic considerations.

6.1.2 Topography

If the ground is not flat it will be necessary to carry out a survey of the topography of the area.

6.1.3 Soils

An inventory of the soil types is required for an assessment of soil moisture, fertility and erosion problems, as well as the selection of tree species and agricultural crop plants.

6.1.4 Hydrology

Knowledge of surface and groundwater conditions will prove to be useful particularly in wet areas but also in order to estimate availability of water for plant growth.

6.2 ECOLOGICAL CONSIDERATIONS

6.2.1 Preliminary Considerations

As indicated above, prior to the design of a shelterbelt system it has to be decided what is going to be protected:

- Human settlements: In windy areas most of the human habitations are protected against wind by fences made either out of dead or living materials. These fences are often not considered as shelterbelts but their integration in a wind protection system is worth considering.

- Livestock: Shelterbelts can improve stock farming by providing shade, shelter against wind, increased fodder production and fencing. The choice of the animals, cattle, sheep or goats and their number can affect the design patterns of a shelterbelt system.

- Agricultural crops: In most cases shelterbelts are established to improve the growing conditions of agricultural crops, in order to increase the yield. The characteristics of the agricultural crops which are intended to be grown under the protection of a shelterbelt, should be known in as much detail as possible. Their size, the growing periods, their sensitivity, to the various climatic factors, will have to be taken into account in the design of the shelterbelt. Eventually biological interactions (pollinating insects, insect and bird pests, root competition etc.) will help to choose appropriate tree and hedge species.

Planning of the Shelterbelt

Based on the results of the physical survey and the site specific considerations, the design of the shelterbelt system can be approached by finding appropriate answers to the following questions:

Which Pattern will meet the requirements best?

- a simple windbreak
- a system of several successive shelterbelts
- a network system either with or without secondary hedge rows.
- does the topographic, site specific situation impose particular orientations or patterns%

What will be the most appropriate spacing distance between the windbreaks?

This will depend in particular on:

- the height of crops to be protected
- the height of the shelterbelt
- the degree of protection required (e.g. as a function of the wind speed in the open).
- the permeability of the shelterbelt

Choice of tree species for the shelterbelt

- Depending on the height and the width, good shelterbelts often need two or three layers of trees, incorporating different tree species chosen for their combined ability to meet the defined requirements of wind firmness and permeability.
- It is obvious that the species considered must be able to grow under site specific climatic conditions.
- Attention must be paid to the vegetative seasonal cycles of the species chosen (if not species with permanent foliage), to coincide with those of the agricultural crop to be protected, as permeability is strongly dependent on this. In the same respect, one should know that with some tree species the penetrability is a function of the windspeed.

Referring to the general productivity requirements and the site specific situation, "multipurpose" trees and hedges will be advantageous.

Favourable characteristic would include the ability to:

- grow fast
- improve soil fertility
- provide human food
- provide fodder
- produce fuelwood or timber

The negative effects, such as fungi, bird and insect pests have to be considered, and an effort should be made to reduce them as much as possible.

It is certainly true that the "perfect" shelterbelt tree, meeting *all* requirements does not exist, but it must be the aim to incorporate a maximum of properties considered beneficial.

6.3 MANAGEMENT

It is evident that a shelterbelt system is supposed to be a permanent feature of the land use system or at least on the land for a rather long period. Therefore the design exercise should include appropriate management proposals.

Considerations in the initial phase include:

- the preparation of the land
- the planting of the trees and hedges (direct sowing or transplanting)
- provisions to assure the growth of the young plants (including eventual replacement)
- an economic but adapted land use until the shelter has reached its normal size.

Once the shelterbelt has reached its optimal shape provisions have to be made to maintain its shape and its shelter effects (thinning out and replanting in rotations, pruning etc.). As a well designed windbreak, will not only provide shelter but will produce, this production as well has to be taken into account in the management strategy.

7. CONCLUSIONS

It is evident that a shelterbelt system, by virtue of its components and aims, can be considered a type of agroforestry landuse system. Therefore it appears to be logical to apply agroforestry principles and methodologies to any problems concerning artificial protection against wind. Accordingly the request for a shelterbelt design should only be the result of a problem oriented diagnostic approach to the specific land use system. With reference to the complexity of the matter, this will normally require inputs from a multidisciplinary team of specialists throughout the different phases, from the preliminary diagnosis right through to the evaluation of an implemented system.

REFERENCES

1. Alisov, B.P. 1956. Method and results of microclimatic investigations of 1949 in shelterbelt zones of the Voronezh region. *Voprosy Geografii* 23: 209-217 USSR.

2. Bates, C.G. 1911. Windbreaks, their influence and value. *USDA Forest Service Bulletin.* 11.86.

3. Bates, C.G. 1944. "The windbreak as a farm asset". *USDA Farmer Bulletin.* No. 1405

4. Blenk, H. and H. Triens, 1956. Stromungtechnische Beitrage zum Windschutz. *Grundlagen d. Landtech.* 8, I u II. VDI Verl.

5. Gaborn, J.M. 1957. Shelterbelts and Microclimate. *Forestry Comm. Bull.* 29 - Edinburgh.

6. Chang, Jen-Hu. 1968. *Climate and Agriculture.* Chicago Aldine Publ. Comp.

7. Dirmhirn, I. 1953. Zur Strahlungsminderung an Windschutz-streifen. *Wetter u. Leben 5.* Oesterr. Ges. f. Met. Vienna.

8. Eimern, J. van 1957. Uber die Veranderlichkeit der Windschutzwirkung einer Doppelbaumreiher bei verschiendenen meteorologischen Bedingungen. *Ber. DWD* No. 32. 1-27 Frankfurt FRG

9. Fournier D'Albe, E.M. 1958. The Modifications of Microclimates. *Climatology UNESCO.*

10. Geiger, R. 1961. *The Climates Near the Ground.* 4th Edition (Translation from the German edition). Harvard University Press, Cambridge Mass.

11. Gevorkiantz and P.O. Rudolf, 1935. Possibilities of shelterbelt planting in the plain region, shelterbelt experience in other lands. *U.S. Forest.*

12. Gloyne, R.W. 1955. Effect of a Windbreak on the speed and direction of wind. *Meteorological Magazine* 84: 272-81 U.K.

13. Itzuka, H. 1950. Wind erosion; prevention by windbreak. *Bulletin 45. Exp. Stat. Neguro* Tokyo.

14. Jensen, M. 1954. Shelter effect. *The Danish Tech. Press.* Kopenhagen.

15. Hofmann, G. 1956. Verdunstung und Tau, als Glieder des Warmehaushalts *Planta 47,* FRG.

16. Hogg, W.H. and A.R. Carter, 1962. Shelter screens at Luddington, 1957-1959. *Experimental Horticulture 7.* U.K.

17. Kaiser, H. 1959. Beitrage Zum Problem der Luftstromung in Windschultz Systemen. *Met. Rundschau 12.* Verlag Gebr. BORNTRAEGER Berlin.

18. Kolasew, F.E. 1941. Ways of suppressing evaporation of soil moisture. *Coll. of papers on physical aspects of agronomy 3/67.*

19. Naegli, W. 1946. Untersuchungen uber die Windverhaltnisse im Bereich von Windschutzstreifen. *Mitteilungen der Schw. Anst. f.d. Forstl. Versuchswesen* 24.

20. Russel, G. and J. Grace 1978. The effect of windspeed on the growth of grass. *Journal of Applied Ecology.*

21. Staple, W.J. and J.J. Lehane 1955. Weather Conditions influencing wheat yields in tanks and plots. *Canadian Journal of Agric. Science* 34.

22. Stoeckeler, J.H. 1965. The design of shelterbelts in relation to crop yield improvement. *World Crops* 17.

23. Woelfle, M. 1938. Windschutzanlagen. *Forstw. C. 60.* FRG.

APPENDIX C-15

EX ANTE ECONOMIC EVALUATION

1. INTRODUCTION

To give a detailed account of the why and how of economic analysis of candidate A.F. systems/technologies may be a bit too ambitious for an appendix. Fortunately it is not necessary, because most of what applies to the economic analysis of other land use systems applies equally to A.F. and has been well documented. Appropriate references in this content are Gittinger's "Economic Analysis of Agricultural Projects" (1982.) and F.A.O's "Economic Analysis of Forestry Projects" (1979).

The purpose of this appendix is, therefore, to give broad guidelines on this subject matter, which would help make the aforementioned text-books more accessible to analysts who want to carry out ex ante economic analysis of candidate A.F. systems/technologies.

2. WHY AND HOW

An ex-ante economic analysis of candidate A.F. systems/technologies is carried out to influence the technology design so as to get some sort of assurance that the proposed A.F. system/technology is feasible and beneficial.

The methods and procedures are contained in what is usually referred to as *project analysis*, which has *financial* and *economic* aspects.

Financial aspects of project preparation and analysis deal with projecting and evaluating the effects of an intervention on the various project participants, i.e. farmers, project agencies, national treasury.

The economic aspects, on the other hand, deal with evaluating the use of scarce resources required for the intervention from a society's point of view.

Although usually hampered by lack of data, it is still useful to attempt some of these analyses at this early stage of technology development. It would be unrealistic, however, to conduct the analysis in the same amount of detail for research projects as for preparation and analyses of development projects. As a rough rule of thumb it is suggested that technologies whose main beneficiaries are individuals should be subjected to the *financial* type of analysis, while technologies whose main objective is conservation/sustainability of whole areas which society as a whole will benefit in the future, should be subjected to the *economic* type of analysis.

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*Contributed by D.A. Hoekstra.

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Because ICRAF's D&D exercises have, so far, mainly resulted in research proposals of A.F. technologies directly benefiting individuals, emphasis in this appendix has been put on the financial aspects of project analysis in which the farmer's view point is central.

3. EVALUATION OF CANDIDATE A.F. SYSTEMS/TECHNOLOGIES FROM A FARMER'S POINT OF VIEW

To evaluate whether or not a candidate technology will become feasible and beneficiary to the farmers, it is important to look into the following questions:-

i) Is the technology making the best use of the farm's resources?

ii) Is the technology feasible, given the farm's labour availability (amount, seasonal distribution, management skills)?

iii) Is the technology feasible, given the farm's available capital resources (own as well as borrowing potential)?

iv) What are the risks involved with the introduction of the technology?

The following step wise approach is suggested to find answers to these questions.

Step 1. *Determine the type of inputs and outputs required for the introduction of the technology and plot them on a time scale.*

Step 2. *Quantify these inputs and outputs in physical terms on a per unit area basis.*

Labour inputs should be broken down by activity (establishment, maintenance, harvesting), type (adult male or female, children) and likely source (family, hired, community).

Material inputs may be broken down in type (planting material, fertilizers, agricultural chemicals, water, tools veterinary services, fodder, equipment, breeding stock etc) and source (farm produced, purchased or hired, other sources).

Step 3. *Determine the likely scale at which the technology will be introduced into a farming system.*

To find an answer to this question a farm planning exercise has to be conducted, which requires step 4 (labour analysis) and step 5 (cash flow analysis) to be carried out simultaneously.

To get a first approximation of the level at which an A.F. technology may be introduced it is useful to clearly understand the purpose of the technology. Many *service* oriented ones are site specific and therefore self explanatory in terms of scale (acreage), e.g. shelterbelts, fencing, grazing area improvement, conservation measures in the cropland etc.

Scaling of technologies which are more *product* oriented, requires information on whether the product will be used to satisfy household requirements and/or will be produced for cash sale.

If the farmer's only objective, is to satisfy the household needs, the analyst has to obtain an estimate of the physical quantity required e.g. annual fuelwood requirements for cooking. The scale of the technology can then be computed by dividing such annual quantities by the per unit area production.

If the farmer intends to sell all or part of the products for cash, a first approximation of scale depends on the analyst's judgement of the marketing potentials and relative profitability of the technology in comparison with other cash generating farm activities.

In practice such a scaling exercise may become more complicated because of the often multipurpose nature of agroforestry technology, i.e. trees combine productive and sustainability (service) functions. Another factor to consider in such a scaling exercise is whether or not other non-agroforestry technologies are being considered to satisfy the same need.

The end result of this first attempt at scaling the A.F. technology into the farming system will be referred to as *the plan* in step 4 and 5.

Step 4. *Subject the plan to a labour analysis.*

A.F. technologies may be grouped into 2 categories for this analysis:-

i) Those which intend to replace an existing land use system/farm activity.

ii) Those which are complimentary in terms of land utilized.

The labour analysis of the first group may be started on a *partial basis*, by comparing amount, type and timing of labour between the new A.F. technology and the existing technologies/activities. In case little difference is found in labour utilization, no further analysis is required. When there are substantial labour savings, or alternatively, increased labour demands, present/potential use of such labour should be examined If there is no use for the saved labour (on or off-farm), or if additional labour can be hired relatively easy, the analysis may be completed by indicating either the amount of labour saved or the amount of labour which has to be hired.

If the labour saved by the introduction of the new technology can be utilized (on or off-farm) the analyst should indicate how and when (see also cost benefit analysis). If the extra labour for the introduction of the technology cannot be hired the analyst has a number of options (not mutually exclusive).

i) Check if a gradual phasing of the technology into the system would alleviate the labour constraints (important when establishment labour requirements are high).

ii) Reduce the scale at which the technology was originally conceived (step 3). This may be realistic when the technology's produce is mainly for sale. In case most of the produce is for home consumption or the technology performs an essential service function it may be less feasible.

iii) Indicate the change(s) in composition/management of existing activities (on or off-farm) in order to provide the necessary labour. Such an exercise would require a whole farm labour budget.

iv) Ask technicians to redesign the technology.

With the second group of technologies, complimentary in terms of land use, the analyst needs a *whole farm* labour budget of the present farming system, to judge whether or not labour for this activity is available. If not, the 4 options as spelled out in the previous paragraphs apply.

Step 5. *Subject the plan to a cash flow analysis.*

To determine whether or not the plan is feasible from a financial point of view, it is important to check whether or not the hired labour requirements (step 4) and the material inputs (step 2) can in fact be financed by the resources available to the farmer.

Such an analysis requires first of all information on the market prices of all cash inputs and the outputs sold.

Once these have been obtained, a cash cost profile of the technology can be computed by multiplying quantities of purchased/hired inputs by their market prices.

This cash cost profile has to be complimented with the cash benefit profile, by multiplying sold outputs by their price.

A similar procedure as in the previously explained labour analysis can then be followed to determine whether sufficient cash is raised within the whole farm system or *credit* facilities are available at the right time so as to be able to purchase the necessary inputs. If this is not the case, the analyst has again the same 4 options i.e. phasing, scaling, altering existing farm plan or ask for a redesign of the technology.

Step 6. *Cost benefit or farm investment analysis.*

This analysis is carried out to determine whether or not a new or improved technology leads to a better use of farm resources.

The *with* and *without* project comparison is commonly used for such an analysis.

The analysis may be *partial* or *whole farm* in nature. The great advantage of the whole farm approach, is that it does not require the analyst to compute opportunity prices for his own farm resources, because the combined opportunity returns of such resources are the production value minus the cost of all non farm resources in the *without* project situation. If the use of own farm resources in the *with* project situation is in fact larger than in the *without* situation, i.e. using previously idle resources, the opportunity cost of such resources is implicitly priced at zero, since no income is forgone. The analyst should insure however that a farmer is prepared to put these previously idle resources to productive use.

The disadvantage of the whole farm approach is that the analyst is required to work out a whole farm plan for the *with* project situation, which is a rather time consuming activity, even though a computerised technique like linear programming may be used.

For the benefit of those analysts who prefer to use partial budgeting but realise that the introduction of the technology requires re-allocation of farm resources in the *with* project situation (see step 4 and 5) some guidelines are provided with regard to valuation of those resources and outputs according to the *opportunity cost principle*.

Valuation of inputs

Because the *with* and *without* comparison aims at determining the incremental net benefits, the analyst needs not to value those inputs which remain the same in the *with* and *without* situation. Because many A.F. technologies are in fact alternative uses of land, there is no need to incorporate land cost into the comparison since it would be cancelled out. If the *with* technology situation does in fact require more land than the *without* situation the cost of such land is determined by its contribution to production in the *without* situation. In case such additional land was not utilized previously, it would be equal to zero. If it was utilized, its cost would be the per unit area total production value minus all cost except land cost. In case the additional land has to be rented, the rent paid is used to value the land.

Valuation of incremental or saved *labour* also depends on its potential for other uses. If there were no alternative use, including off-farm employment, opportunity cost would be equal to zero. If the saved/incremental labour would be used at the expense of off-farm employment the opportunity cost of labour would be the net wage received. If the saved/incremental labour would be withdrawn from alternative agricultural activities, the opportunity cost of labour would be the production value of the alternative use minus all costs except labour divided by the total amount of labour units used. To avoid elaborate calculations analysts often use 50-75% of the going market price

of labour as opportunity cost of family labour in the off season and 125% of the market price in the peak season. Additional hired labour is valued at the market price.

Valuation of outputs

Market prices may be used for all outputs sold, but the opportunity price principle should be used for those outputs which are consumed on the farm.

For those outputs consumed by the family, for which a local market does exist, the market price may be used as the appropriate opportunity price on condition that the farmers do have cash to buy them. If not, which may be frequently the case, or if the local market in fact does not ensure a proper supply throughout the year, the opportunity price will have to be put substantially above the market price.

Certain outputs of A.F. technologies are achieved by saving inputs necessary to obtain a certain quantity of a commodity e.g. fuelwood planting for home consumption to replace fuelwood collection. Other outputs of A.F. technologies come indirectly through the non-tree component in the system, e.g. sustained yields of annual crops through conservation oriented technologies; improved performance of cattle by providing shade in grazing land, etc.

A special category of outputs are intermediate products like fodder. If there is a ready market, accessible to the farmer, market prices may be used or computed on the basis of for example nutrients content. However in most instances it would be more appropriate not to value such inputs at this intermediate stage, but to measure their contribution in terms of livestock production.

Once costs and benefits have been determined, the analyst can undertake a cost benefit analysis using *discounting* principles to value future costs and benefits. A number of measures of *technology worth* have been developed to judge the viability of new technologies.

i) *Present value costs (P.V.C.)*, which is the discounted value of all yearly costs. This measure is used to compare alternative technologies/systems which have the same benefits but a different cost structure, also referred to as *least cost analysis*. A technology is viable, if at the chosen discount rate, the discounted costs are lower in the *with* than *without* situation.

ii) *Net present value or worth (N.P.V.)*, which is the discounted value of all yearly benefits minus costs. This measure is used to compare alternative technologies/systems with different flows of costs and benefits. It is usually expressed per unit of land. However, in case the analyst is quite sure about the scarcity (opportunity cost) of some of the other

production factors, e.g. labour, it is also possible to express the net present value (N.P.V.) per unit of labour or any other factor (note that in such case the opportunity cost of labour should not be included in the cost flow). A technology is viable, if at a chosen discount rate, the N.P.V. of the *with* is higher than the N.P.V. of the *without*. If the incremental approach is taken the N.P.V. should be larger than zero.

iii) *Net benefit increase (N.B.I.)*, which is the present value of the incremental net benefits after financing with the project, divided by the present value of the net benefits after financing without the project, expressed in percentage terms. This measure is used whenever the farm's own capital inputs are low.

iv) *Internal rate of returns (I.R.R.)*, which is the discount rate at which the incremental N.P.V. = 0. This measure is also used to compare alternative technologies/systems with different flows of costs and benefits. However it is less usefull when the net benefit flow has no negative value or when the rate is higher than 50% or when comparing mutually exclusive alternatives.

Step 7. *Sensitivity analysis*

This analysis deals with risk and uncertainty, i.e. what will happen to the attractiveness of the technology (expressed in one of the aforementioned measures) if some of the assumptions with regard to quantities, prices, timing or discount rates change. No doubt this analysis is very important at the technology development stage since it tests the robusness of the candidate technology.

The techniques for the sensitivity analysis is simply re-calculating the measure of *technology worth* under the revised assumption(s).

A very useful variant of this analysis is the *switching value* or *break even point*. Such as analysis answers the question, how much an element would have to change before the technology would no longer meet the minimum level of acceptability as indicated by one of the measures of *technology worth*.

4. EVALUATION OF CANDIDATE A.F. TECHNOLOGIES/SYSTEMS FROM A SOCIETAL POINT OF VIEW

Looking at A.F. technologies/systems from the point of view of the use of scarce resources and the objectives of society as a whole requires a second look at:-

i) The type of benefits and costs to be considered.

ii) The valuation of benefits and costs.

In the financial type of analysis only those benefits and costs are considered which are received/bourne by the one from whose point of view the analysis is conducted. Only by doing a financial analysis for different project participants will it be possible to obtain a picture of all *direct* costs and benefits. For example a financial

analysis of a taungya system may be conducted both from the forestry service's point of view as well as from the farmer's point of view. In the forestry analysis, labour provided free of charge by the farmers to establish, maintain and harvest the forest trees, as well as the agriculture produce belonging to the farmers need not to be considered in the "with" project situation. In the farmer's analysis on the other hand, the labour provided free of charge to the forestry service are part of the cost of producing the agricultural crops, while forest products are not considered. In an economic analysis all direct costs and benefits are considered irrespective as to who will be the beneficiaries or who will be responsible for the costs.

Besides considering all direct costs and benefits, economic analysis also tries to incorporate all *secondary* costs and benefits as well as the *intangible* costs and benefits.

Secondary costs and benefits may be viewed as costs and benefits which arise outside the project, but are a result of the project. Of particular importance with regard to agroforestry are so called *technological spillover* or *technological externalities* in the form of positive or negative environmental impacts. An example of a positive environmental impact are soil and water conservation in the upper parts of a watershed benefitting the lower regions. An example of a potential negative environmental impact is an increase in birds harmful to crops. Most of these secondary cost and benefits. Analysts may however find it difficult to make appropriate quantitative estimates.

Intangible costs and benefits are often related to specific government policies other than increasing the *gross national income*, e.g. creation of employment, income redistribution. Such objectives usually become part of a so-called *social cost benefit* analysis.

Quantification and valuation of such costs and benefits is rather difficult and most analysts therefore apply a *least cost* analysis. *Multi criteria* methods may also be used to analyse candidate technologies.

Valuation of all costs and benefits for an economic evaluation is based on the value of inputs and outputs in alternative uses in the society, i.e. *shadow pricing*. Financial prices are the starting point for revaluation of inputs and outputs for the economic analysis. Adjustments should be made for transfer payments (subsidies, taxes), price of foreign exchange and price distortions caused by government policies.

References

FAO. 1979. Economic Analyses of Forestry Projects. FAO. Rome

Gittinger, J.P. 1982. Economic Analysis of Agricultural Projects. Johns Hopkins University Press. Baltimore.

Hoekstra, D.A. 1983. The Use of Economics in Agroforestry. Working Paper No. 2. ICRAF. Nairobi.

APPENDIX D-1

EXPERIMENTAL APPROACHES*

Once we have evaluated the systems we are dealing with, and have identified problems that require investigation, how do we set about formulating a research programme? Clearly there is a vast accumulation of working material which forms the basis for thinking about the management of land under any kind of plant or plant/animal associations. However, not all of it is in a form appropriate to the extended time frame and complex spatial arrangements which we find in agroforestry systems. A new set of sound field research tactics needs to be worked out if resources are not to be squandered.

It may be possible to utilize existing woody plant stands and associations (survey and simulation techniques), and this might be an advantage. Otherwise field experiments will start with newly-planted woody species, bearing in mind that it may take many years before these reach their mature phase (conventional fully-randomized or randomised block designs, or systematic designs may be useful here). What has been barely-explored to date is the relative cost/effectiveness of these different approaches with regard to agroforestry.

1. EXPERIMENTS WITH EXISTING VEGETATION

Multivariate Techniques

One interesting approach which is now being tried is that of "simulation" (Oldeman, 1978), and the method is particularly appropriate to transforming forested areas with multi-layered canopies. With the aid of transects, and by describing the architecture and age structures of the vegetation, opportunities are identified for replacing specific components with more productive ones. Sampling of existing mature trees or stands, around which appropriate agricultural crops can be introduced, can be used with appropriate multivariate analysis techniques to look at the crop-environment interactions. Ecologists have been using such methods for many decades to discover facts about the association of different plant species in natural stands.

Modification can be made to existing plant associations so as to obtain more relevant data if this is required. For example, where there is an existing stand of a multi-purpose tree species small plots of agricultural crops could be sown around it so as to obtain information about the interactions between the two kinds of plants. Indeed, this technique could be combined with that of using simple systematic designs (for the agricultural crop) so as to obtain even more information

2. EXPERIMENTS WITH NEWLY ESTABLISHED PLANTS

The Heuristic Approach

In the first place it is possible, of course, to put together past experience with trees and agricultural crops and lay down what might be termed "suck-it-and-see" trials of possible agroforestry systems. Such a

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*Adapted from P.A. Huxley. 1980. The need for agroforestry and special considerations regarding field research; and P.A. Huxley. 1980. Experimental work with trees and shrubs for use in agroforestry systems. (in-house working papers) ICRAF. Nairobi. (mimeo)

speculative approach has in the past, undoubtedly helped in the development of agriculture and forestry, and intuitive jumps by clever and experienced people are not to be despised. Experiments of this type may be useful in initial explorations leading to the development of prototype agroforestry systems based on "notional technologies". Under certain circumstances experimental trials of such systems might be carried out on farmer's fields to obtain crucial early feedback on the farmers' perception and evaluation of the new technology. In this connection, one should not overlook the opportunity to benefit from the farmers' suggestions on how the technology might be modified so as to fit better into his farming system. Such feedback, received early in the development of a new technology, can help make more cost-effective use of limited research resources. If, however, the notional technology or prototype agroforestry system is too undeveloped to take out on farm trials (see Step 19 for a discussion of relevant decision criteria), then one might begin with heuristic "observation trials" undertaken under research station conditions. While the heuristic approach to development and study of prototype "technology packages" may be useful, it will always be necessary to undertake other experiments of a more systematic and controlled nature. Some possible approaches to this complementary kind of research are evaluated below.

Randomized Block Designs

Conventional designs for field experiments, e.g. randomized block lay-outs, are robust, easily laid out and not too difficult to manage. They can, however, take up a very large amount of space if the plots are unduely enlarged, as they must be to accommodate a mixed crop of woody and herbeceous species. Furthermore, the proportion of space actually occupied by experimental plants will be quite small with tree crops, even if only single guard rows are used externally and shared between plots internally; for example, only about 56% with 36 12-tree plots arranged in a block 6 x 6, diminishing to 21% for single tree plots in the same lay-out. With double guard rows a 36-plot block with 9 plants per plot will utilize only 32% of the total area of the experiment.

To avoid bias the lateral light profile at the edge of plots should be no different from the vertical profile in the middle of them. To achieve this in mixed cropping experiments conducted at different plant spacings a guard area roughly equal in width to the height of the canopy may be needed. And, if this is found necessary, the conventional designs become even more wasteful of space.

Finally, if the number of experimental variables and the levels of each in factorially arranged experiments are not kept within bounds the number of treatments soon becomes unmanageable. For example, an experiment with only four spacing treatments, three levels of N, three levels of P and two species (leaving out all other management treatments) will, fully factorialized, involve 72 treatments. In mixed cropping experiments this situation is made more acute as plant population and plant arrangement are such important variables because they can markedly affect the interactions between the plant species. And with plants of such diverse form and stature, as one finds in agroforestry, this is accentuated so that it is not difficult to propose a very large number of treatments during the process of considering what to put into any agroforestry field experiment.

Systematic Designs

Studies involving plant spacing can be very satisfactorily dealt with by using systematic designs (Bleasdale, 1967) and these have been in common use now for vegetable and tree crops, forage investigations and, more recently, for forestry trials and tropical agricultural tree crops. They lend themselves also to the study of spacing effects in mixed cropping (Huxley and Maingu, 1978). Systematic designs take up remarkably little space and can waste relatively little area in guards. They are, however, not robust, they are difficult to lay out and to maintain and, used with out-breeding species sown from seed, the plant-to-plant variability can be hard to handle. Finally, without adequate replication of whole designs oriented differently a full statistical treatment of the data often cannot be satisfactorily achieved.

Despite these adverse features systematic designs lend themselves to early trials in which tree and crop espacements can be tested over a wide range of levels. From the results a more critical selection of spacing treatments can be made, and combined with other experimental variables, in order to set down a conventional design which will be much more compact than otherwise would be the case.

3. CHOOSING AN APPROPRIATE EXPERIMENTAL APPROACH

There is no doubt that all these are useful field methods but just which need to be used in any particular set of agroforestry circumstances has to be given careful thought, depending on the objectives of a particular experiment and the phase of the investigation which has been reached. Because of the time scales and costs involved in agroforestry research there is certainly a need to set limited objectives.

Table 1 outlines the different phases and stages of a research programme for studying plants for agroforestry systems and indicates the type of field approach which might be suitable for each. Both mature and juvenile phases of trees need to be taken into account.

PHASING OF EXPERIMENTATION

The following table sets out a possible sequence of types of experiments which is based on a logical, step-wise set of objectives. In each case the type of experimental layout would be different. There is, of course, no reason why the experiments should not overlap in real time although, as each depends on obtaining information from the previous one, a too-hasty jump from one to the next might not always be prudent.

The time at which separate experimentation on the "crop" and "woody" components becomes unnecessary needs careful thought. In the table above the incorporation of an annual crop component could be introduced in Type D experiments in the sense that it is a "management treatment". On the other hand, if sufficient is still not known about the tree species there could well be a case for continuing to learn more about it in experiments where it is grown on its own. This might well apply, for example, in the case of multipurpose tree species.

The reason for splitting up experimental work into the sections given above is not just one of logically proceeding from one level of investigation to another but, also, for ecomony of effort. For example, in looking at a species which has not been examined in any detail before, or which is a species recently introduced, there is an obvious need to understand the behaviour of the plant in response to seasonal changes in the environment. This needs no more than critical observations on single specimens and, therefore, need take up little time and space. More can be learned about the physiological reactions of the plants if some simple "management" treatments are also applied at the same time (lopping or pruning, irrigation, fertilizer treatment etc. i.e. Type B experiments).

To evaluate the growth potential per unit area of land plants of the same species have to be grown associated as a "crop" and the various combinations of plant populations and plant arrangement must be investigated together with selected management treatments. This is Stage 2.

If animals are to be part of a possible final system then a parallel programme of work is required at this stage in looking at animal production factor, of course.

As agroforestry is dealing with *multiple* land use it is the interactions between the components which interest us most and it is the study of these, in highly-selected arrangements and combinations of treatments formulated from the previous two stages of work, that will form the most important part of "designing" new, or modifying existing, agroforestry systems. The final evaluation of these is obviously a long-term task. These are programme stages 3 and 4, respectively.

Where the information from the early type of experiments (types A, B & C) has not yet been obtained it might well be unwise to specify for experimental layouts exactly what species are to be used but, instead, give some indications of the arguments for using indigenous or exotic species. Also some indications of the size range and habit of the species proposed - particularly as the more complex experimenta will be difficult to run where species have very different statures and are in the same or adjacent plots. Similarly, unless type D experiments have already been carried out on the woody species grown alone any recommendations about spacing in the mixed cropping scheme may not be very soundly based. Especially, when one considers that spacing depends on so many factors, e.g. the size of the individual species concerned, whether one is dealing with the juvenile or adult phases of growth, the effects of management treatments such as lopping etc. and so on, and so on.

Until something is known about the growth of the species when it is *not* grown in a mixture then it seems somewhat hazardous to pick on just one or two spacings when it is.

References

Bleasedale, J.K.A. 1967. Systematic designs for spacing experiments. Expl. Agric. 3:73-85.

Huxley, P.A. and Z. Maingu. 1978. Use of a systematic spacing design as an aid to the study of intercropping: some general considerations. Expl. Agric. 14:49-56.

Oldeman, R.A.A. 1978. Blueprints for a new tropical agroforestry tradition. Proc. of the 50th Tropische Landbouwdag. Dept. Agric. Res. Royal Tropical Institute. Amsterdam.

Table 1. Different Stages of field research on plants in agroforestry ststems.

	OBJECTIVE	TYPE OF EXPERIMENT	TYPE OF LAYOUT	TIME SCALE
Stage 1	A. Determine if the plant species are adapted and select those which establish and grow well	Screening trials for: a) establishment and b) adaptation - providing minimum managment such as fertilizer for the planting hole and/or minimum irrigation at planting.	Replications of: well spaced- plants and close-placed plants (hedgerows)	5-6 years
Stage 1	B. To determine species phenology and the influence of management on growth of the single plant	Single-tree plots, fully randomized and plants subjected to a range of different simple management treatments	Fully randomized	5 - 6 years
Stage 1	C. Appraisal of environment-related factors which affect growth and yield of different species growing in natural or suitably-modified associations	Survey of plant associations and environmental characteristics on a seasonal basis	Multivariate techniques	Over 1 - 3 years
Stage 2	D. Management trials on plots containing groups of plants of any one species a) without animals so as to optimize productivity and b) with animals, if appropriate i.e. if the species have a browse function and so as to investigate the plant-animal	These would be especially to establish the interaction of spacing and management treatments (note that feeding trials with animals kept separately could be carried out if sufficient material is available from this type of experiment or any of the proceeding ones)	a) Parallel row designs or factorial experiments with fixed/variable interrow populations b) Randomized blocks with plots arranged to facilitate grazing or very simple systematic designs for farmer evaluation trials	All these trials might be laid out so as to investigate the juvenile phase (1 - 5 years) or the adult phase (6 years onwards) separately

	OBJECTIVE	TYPE OF EXPERIMENT	TYPE OF LAYOUT	TIME SCALE
Stage 3	E. To test under full-scale trials a selection of viable alternative components or sub-systems based on the information from proceeding experiments A-D - also to include economic assessement such as labour, costs, etc. etc.	Large plot investigations using only highly selected treatment combinations	Randomized block layouts with or without internal guards and with provision for thinning of the woody component/s	1 - 15 years
Stage 4	F. Evaluation of complete systems	Large area investigation to appraise a combination of technical, ecological, social and economic factors	Replication difficult	Very long term

APPENDIX D-2

EXAMPLE OF RESEARCH PLANS DEVELOPED FROM A D&D APPLICATION IN KENYA*

The material contained in this appendix is excerpted from a project proposal based on a D&D application undertaken by ICRAF's Collaborative and Special Projects Programme (COSPRO) in cooperation with the institutions named below. It is included in this volume in order to give a concrete idea of the type of output that can be expected from D&D applications.

It should be noted that the level of planning detail contained in this example was achieved in stages. The initial 'rapid appraisal' application of D&D procedures by a multidisciplinary field team resulted in a general outline of the needed research. The text excerpted here was produced by a small working group in the pre-project followup stage. The detailed plot layout design included at the end of the text was developed at the beginning of the project implementation stage. Further refinements of the technology designs and project plans are occurring continuously as the project progresses.

The section of the project proposal reproduced here does not contain the full description of the project area and the diagnostic results, as contained in the original. It also does not contain the details of project planning that are specific to the institutions involved. It begins, instead, with the design specifications for appropriate technology (output of Step 6) in order to explain the design context for the research plans which follow. The text has been adapted slightly to fit the format of this Appendix.

1. APPROPRIATE TECHNOLOGIES

1.1 Design Specifications

The following *functional* design specifications were derived from the diagnosis of the Kakuyuni farming system.

Improve productivity of the crop production system

i) Maintain or improve soil organic matter
ii) Improve soil nutrient status
iii) Reduce erosion and water run off
iv) Remove labour bottlenecks at field preparation and weeding time
v) Improve pest and disease management

Improve productivity of the livestock production system

i) Improve quantity and quality of fodder
ii) Improve seasonal distribution of fodder
iii) Improve drinking water availability
iv) Reduce labour requirements of feeding
v) Improve veterinary service

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*Adapted from a proposal for a Research Project to Develop Agroforestry Systems for the Semi-Arid Areas of Machakos District, Kenya. Prepared by the Kenya Agricultural Research Institute in cooperation with ICRAF, the National Dryland Research Station at Katumani, and the Machakos Integrated Development Programme (MIDP).

Improve cash balance of the farm

i) decrease (future) cash outflow
   - reduce need to buy food
   - reduce need to buy building materials
   - reduce need to buy raw materials for on-farm cottage industries
   - reduce need to buy agricultural inputs

ii) increase cash inflow
   - improve productivity of crop and livestock production
   - improve raw materials supply for on-farm cottage industries

iii) improve seasonal distribution of cash

These functional design specifications have to be accomplished within the following (future) *farm resource restrictions:*

Large farms

i) Ample land resources
ii) Insufficient labour resources
iii) Low level of capital

Small farms

i) Insufficient land resources
   - no grazing areas on some farms
ii) Insufficient labour resources
   - part-time engaged in off-farm activities
iii) Low level of capital
   - no draught animal power on some farms

1.2 Non-Agroforestry Alternatives

Improving the service infrastructure as well as creating off-farm employment opportunities were not explicitly mentioned in the design specifications but there should not be any doubt that these areas need attention in order to raise the general standard of living of the farmers.

Some of the previously mentioned design specifications are also difficult to achieve by means of agroforestry, e.g. improve crop pest and disease management, reduce storage losses, improve drinking water availability for livestock, improve veterinary services.

The Kenyan institutions responsible for project implementation are, in fact, already pursuing some of these objectives with non-agroforestry technologies, e.g. improve storage facility structures, construct dams to collect and store water, etc.

All the other design specifications may be accomplished with agroforestry as well as non-agroforestry technology. In some cases these may be mutually exclusive while others may complement each other.

It is difficult, however, to say at this stage whether the agroforestry alternatives are superior to the non-agroforestry alternatives. The results of the non-agroforestry experiments/developments at present being conducted by the implementing institutions should therefore be carefully compared with the results of the agroforestry experiments. Some of the non-agroforestry experiments/demonstrations are: use of artificial fertilizers and crop rotation to improve/restore soil fertility, soil conservation works, etc.

1.3 Agroforestry Technologies

1.3.1 Hedgerows with or without an upper storey of fuelwood or fruit trees in the cropland ('alley cropping')

The main purpose of the hedgerows would be to improve the productivity of the crop production system which, in turn, would reduce the cash outflow from the smaller farms while the cash inflow of the larger farmers would be increased.

Lopping the hedges, 15 cm above ground, would take place twice a year, two to three weeks before land preparation and planting. The branches would be spread in the alleys in between the hedges and the woody components would be removed just before ploughing and to be used as fuelwood (in a similar way as the traditional pigeon pea stems). The remaining, already decomposing, leaves and small twigs would be ploughed into the soil.

Such a system aims at improving the soil nutrient status, maintaining soil organic matter, controlling erosion (by reduced runoff) and making better use of land, labour and draft animal resources.

An *ex ante* economic analysis of such a land use system was conducted (Hoekstra, 1983) on the following assumptions:

i) between-row spacing is 2 meters
ii) row width 1 meter
iii) production starts after about 18 months (after transplanting)
iv) total dry matter production m^{-1} year $^{-1}$ is 0.9 kg.
v) 60% of the dry matter is leafy mulch and 40% woody stems
vi) organic N in the leafy material in 3.75 percent
vii) a mixture of maize and beans is grown in the alleys (traditional cropping pattern)
viii) 1 kg of organic N results in 13.5 kg of additional maize, while the bean production remains the same (yield per unit area doubles)

The analysis indicated that the addition of nutrients to the maize and beans in the alley as well as the fuelwood output would result in a better use of the land, labour and draught animal resources as compared to the traditional maize beans mixture:

	Hedgerows	Traditional
N.P.V.* hectare $^{-1}$ year $^{-1}$	1,286	631
N.P.V.* man-day^{-1}	15.2	8.6
N.P.V.* draught power unit^{-1}	1,459	435

* at 12%

The potential addition of organic matter by the leafy mulch and the roots of both the maize/beans mixture and the hedgerow is estimated at 1,630 kg hectare $^{-1}$ year $^{-1}$, which is computed as follows:

Above ground biomass production of 2 crops of maize and beans occupying 0.5 hectare is about 6,400 kg year $^{-1}$ (harvest index 0.4), while the above ground biomass of the remaining 0.5 hectare of hedgerows is 4,500 kg year $^{-1}$. The percentage of roots is estimated at 25% of the above ground biomass production while the conversion factor of root dry matter to organic matter is estimated at 0.4, i.e. added organic matter 1,090 kg hectare^{-1} year $^{-1}$. The annual quantity of leafy mulch added to the soil is 2,700 kg and the conversion factor of leafy mulch to dry matter to organic matter is estimated at 0.2, i.e. added organic matter 540 kg hectare $^{-1}$ year $^{-1}$.

The loss in organic matter due to cropping depends on the organic matter content of the soil. Assuming a 1% soil organic matter content (common for soils in semi-arid regions under natural conditions) the loss is estimated at 1,500 kg hectare $^{-1}$ year $^{-1}$, while, if the soil organic matter content has already been lowered, because of cultivation, to about 0.5%, the loss would be 750 kg hectare $^{-1}$ year $^{-1}$.

The computation of the annual loss is based on the following assumptions: top soil depth 0.2 m, specific gravity soil 1,500 kg/m^3 and a coefficient of decomposition under cultivation (k_c) of 0.05.

It may, therefore, be concluded that the hedgerow system will prevent a future decline in the organic matter status of the soil; however, it is unlikely that it would be able to raise it significantly in the short run.

The following tree/shrub species were identified for the hedgerows:

Leucaena leucocephala, Combretum sp., Erythrina sp., Cassia siamea

The addition of a top storey of fuelwood trees is meant to decrease present and future labour requirements to collect fuelwood or to prevent a future cash outflow. The trees would be coppiced on a regular basis. The following tree species were identified for this purpose:

Azadirachta indica, Jacaranda mimosifolia, Cassia siamea

The addition of a top storey of fruit trees aims at increasing the farm's cash inflow as well as to improve the seasonal distribution of cash.

The following tree species were identified for this purpose:

Carica papaya (pawpaw), Zizyphus mauritiana (Bertree)

1.3.2 Fodder/browse tree/shrubs in the grazing areas

The purpose of these trees would be to improve the quantity, quality and the seasonal distribution of fodder on the farm. This, in turn, will increase the farmer's cash income.

This system is more appropriate for the larger than for the smaller farms, since the latter may only have very small grazing areas left (see 1.3.3 for small farm design).

Establishment of the trees will be a major problem because of the existing free grazing system. Trees will therefore require protection in the initial years. Making use of the existing thorny bush vegetation may be considered, i.e. heaping dead thorn bushes around the seedlings, or planting the seedlings within the area covered by thornbush.

Pod-producing trees with a fairly light canopy to allow grass or shrub growth underneath should be given priority.

The following species were identified:

Prosopis pallida, Acacia albida, Zizyphus sp., Balanites aegyptiaca

1.3.3 Cut and carry fodder systems in the grazing land or farm boundaries with or without an upper storey of fuelwood, timber, poles and/or craftwood trees

The purpose of such system is also to improve quantity and quality as well as seasonal distribution of fodder, especially on the smaller farms. Such a system will also contribute to lowering the labour inputs required per A.U. as compared to the existing practice of herding a small number of animals.

Tree species identified for this purpose are:

Prosopis pallida, Leucaena leucocephala, Acacia saligna, Stylosanthes scabra

The addition of an upper storey of fuelwood trees serves a similar purpose as in the hedgerow system explained earlier (see 1.3.1).

The addition of an upper storey of timber/pole trees and/or craftwood trees aims at reducing (future) cash expenditures for building materials and on-farm cottage industries.

The following species were identified for these purposes:

Craftwood : *Brachyleana hutchinsii, Dalbergia melanoxylon*
timber/poles : *Terminalea brownii, Casuarina equisetifolia, Agave (sisal)*

1.3.4. Living fences around the grazing land with or without an upper storey of fuelwood trees

The purpose of this fence is to reduce the labour input requirements of the free grazing system on the larger farms as well as to reduce the need for cash expenditures on fencing materials.

Two species were identified for this purpose:

Parkinsonia aculeata, Commiphora africana

The addition of an upper storey of fuelwood trees serves a similar purpose as in the hedgerow systems (see 1.3.1).

1.3.5 Windbreak around the home compound

The purpose of this system is, in the first instance, to protect the buildings inside the home compound from damage by wind and so reduce the need for cash expenditure. The use of fruit trees for this purpose would help to increase the farm's cash inflow as well as the seasonal distribution of the inflow.

Mangifera indica is proposed for this purpose.

A hedgerow with some of the previously identified species may be added as an understorey.

6.3.6 Fruit trees in the home compound

These trees would provide the necessary shade and improve the cash inflow as well as its seasonal distribution.

Mangifera indica is proposed for this purpose.

2. RESEARCH PROGRAMME

2.1 On-Farm versus On-Station Research

Five factors were considered to determine whether research on these candidate technologies should be carried out on farm and/or on station.

Readiness of proposed technology:

The principles of living fences and boundary planting are more or less known in the area, however tree planting in the grazing land to provide animal fodder, the hedgerow system in the cropland and the windbreak around the homestead are relatively unknown to the farmers, although some are known in other parts of Kenya. The proposed tree species and management practices are not well known nor tested in the area, perhaps with the exception of the mango trees proposed for the windbreak and the home compound.

Farmers/extension officers attitude towards on farm trials:

M.I.D.P. in its program in the Kakuyuni catchment started introducing some trees. Farmers appear to be very keen to plant trees, often even without knowing their useful purposes, with the possible exception of tree planting in the cropland itself.

Riskiness of the proposed technology:

The positive effects as well as the feasibility of establishing a hedgerow system in the cropland are still relatively uncertain, while at the same time the introduction of these hedgerows may result in a reduction of the arable land and therefore in the production of basic food crops. The risks imposed by the other candidate technologies are considerably lower since the opportunity cost of the land used (production forgone) is low. Care should be taken, however, with regard to the introduction of trees in the grazing areas which may have the potential of becoming a weed (*Prosopis, Leucaena?*).

Need for the candidate agroforestry technology to be exposed to different environmental conditions:

Because the recommendation domain for the proposed candidate agroforestry technologies is limited to part of agroclimatic zone 5, some of the differences in rainfall conditions have been eliminated, reducing the need to test the technologies at many different sites. However soil conditions in this zone differ considerably, requiring the testing of the technologies on different sites. The soil types found in the project area offer this opportunity.

Need for the candidate technology to be exposed to real farming systems conditions:

Due to the absence of free grazing conditions on the Research Station, establishment trials (especially protective measures) in the grazing area and living fence trials have to be conducted on farm. Similarly, windbreak trials have to suit the specific farm conditions and are therefore best conducted on farm. Furthermore, farmer evaluation of all the technologies is essential.

A summary of the weighing of these 5 factors for the candidate agroforestry technologies in the study area is presented below.

Table 2.1.1 *Weighing of on farm/on station research factors*

Technology	Readiness	Attitude	Riskiness	Need for env. Exposure	Need for farm sys exp.
3.1	L	L	H	M	H
3.2	L-M	H	M	M	H
3.3	L-M	H	L	M	H
3.4	M	H	L	M	H
3.5	M	H	L	L-M	H
3.6	M	H	L	L-M	M

L = Low M = Medium H = High

Based on a simultaneous weighing of these factors it is recommended to conduct simultaneous on farm/on station research for the following technologies 1.3.2 - 1.3.4, sequential on station/on farm research for 1.3.1 and on farm research only for 1.3.5 and 1.3.6 (see also 2.2).

2.2 Research Required on Candidate Agroforestry Technologies

2.2.1 Hedgerows in the cropland with or without an upper storey

Purpose : see 1.3.1.

Variable factors

a) species
b) establishment methods
c) spacing in and between rows
d) cutting height and frequency
e) rate of application of mulch
f) time of application

Parameters to be monitored

a) labour inputs for establishment, maintenance and harvesting
b) survival rates and growth
c) yield of mulch
d) resistance to termites
e) rate of decomposition
f) nutrient content of mulch
g) soil nutrient status and moisture balance
h) erosion
i) weed development (including labour requirements)
k) crop yields

The addition of an upper storey will add the following variable factors:

a) species
b) in-row spacing
c) harvesting frequency and method

As a result, the following additional parameters have to be measured:

a) labour inputs, establishment, maintenance and harvesting
b) yield (including fruiting season for fruit trees)
c) yield adjacent crops

Type of research

On-Station

Species selection (elimination, survival/vigor phenology) establishment methods and management practices required in the first years of this land use system. Suitability of species will not only depend on growth performance in general but also on the suitability of the leafy components to improve soil nutrient status, water holding capabity and O.M status of the soil. To analyse these aspects a series of independent mulching trials will be carried out, using different tree leaves. Such experiments will have to be complemented by soil and leaf analysis. This on-station research will continue over the entire life of the project.

On-Farm

Testing of some of the best species and establishment methods developed on station in the previous year of the project (researcher managed, inputs and evaluation jointly by farmers and researchers).

2.2.2 Fodder/browse trees/shrubs in the grazing land

Purpose : see 1.3.2.

Variable factors

a) species
b) spacing
c) establishment methods

Parameters to be monitored

a) labour inputs for establishment, maintenance (harvested by animals)
b) survival rates and growth (termite resistance)
c) fodder yield
d) seasonality fodder production
e) palatability of fodder
f) nutritive value of fodder
g) additional products (fuelwood and nectare production)
h) vegetation growth underneath the trees

Type of research

On-Station

Species selection and establishment trials including nutrient analysis and palatability analysis. The screening trials and analysis will take place during the entire project life.

On-Farm

Species selection trials and establishment trials simultaneous with on station research during the entire life of the project. Management trials of the 'best bet' species and establishment methods in the last two years of the project (researcher managed, inputs supplied jointly by farmer and researcher).

2.2.3 Cut and carry fodder in the grazing land and farm boundary with or without upper storey

Purpose : see 1.3.3

Variable factors

a) species
b) establishment methods
c) spacing
d) harvest management

Parameters to be monitored

a) labour inputs for establishment, maintenance and harvesting
b) survival and growth (termite resistance)
c) yield of different products
d) quality fodder, timber, poles or craftwood
e) nectar production

Type of research

On-Station, On-Farm as in 2.2.3

2.2.4. Living fences around the grazing areas with or without a top storey

Purpose : see 1.3.4.

Variable factors

a) species
b) establishment methods
c) in-row spacing
d) trimming frequency

Parameters to be monitored

a) labour inputs establishment, maintenance
b) survival rates and growth (termite resistance)
c) additional products (including nectar production)

Type of research

On-Station

Species selection and establishment trials

On-farm

Species selection and establishment trials simultaneously with the on-station research. Both research activities will last for the entire project life (researcher managed, inputs and evaluation jointly by farmers and researchers).

The addition of an upper storey may be treated in the same way as the hedgerows in the cropland.

2.2.5 Windbreak around the home compound

Purpose : see 1.3.5

Variable factors

a) variety/cultivars of mango
b) in row spacing
c) tree management

Parameters to be monitored

a) labour inputs for establishment, maintenance
b) survival rates and growth (termite resistance)
c) wind speeds
d) additional products (including nectar production)

Type of research

On-Farm only

Selection of variety, in row spacing (researcher managed, inputs and evaluation jointly by farmers and researchers).

2.2.6 Fruit trees in the home compound

Purpose : see 1.3.6

Variable factors

a) variety/cultivars

Parameters to be monitored

a) labour inputs for establishment and maintenance
b) Survival rate and growth (termite resistance)
c) additional products (including nectar production)

Type of research

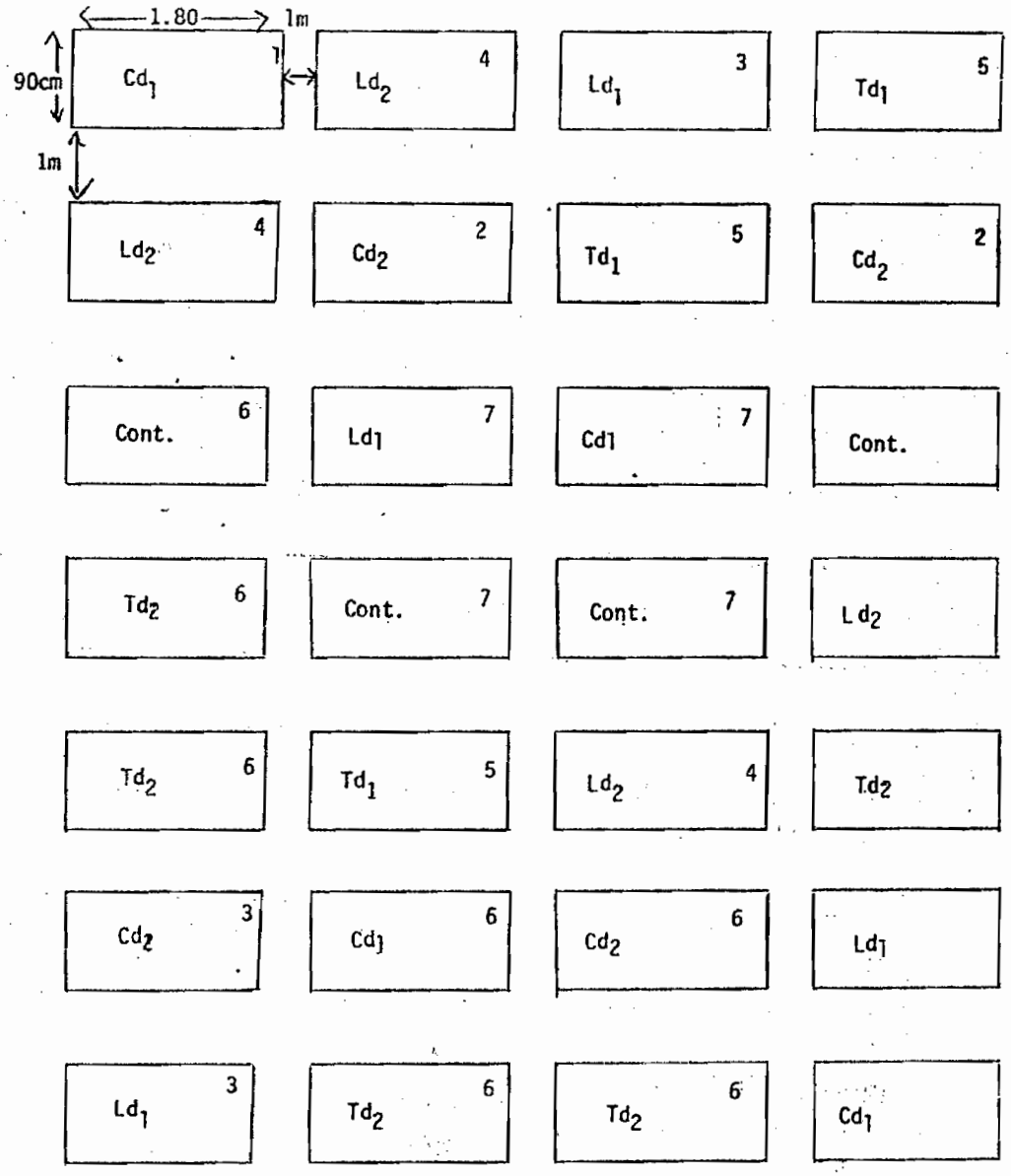
On-Farm only

Selection of variety (researcher managed, inputs and evaluation jointly by farmers and researchers).

2.3 Experimental Designs

The following experimental layouts have been designed for on-station experimentation on the hedgerow/mulch farming system (1.3.1)

MAIZE MULCH/GREEN MANURE TRIAL



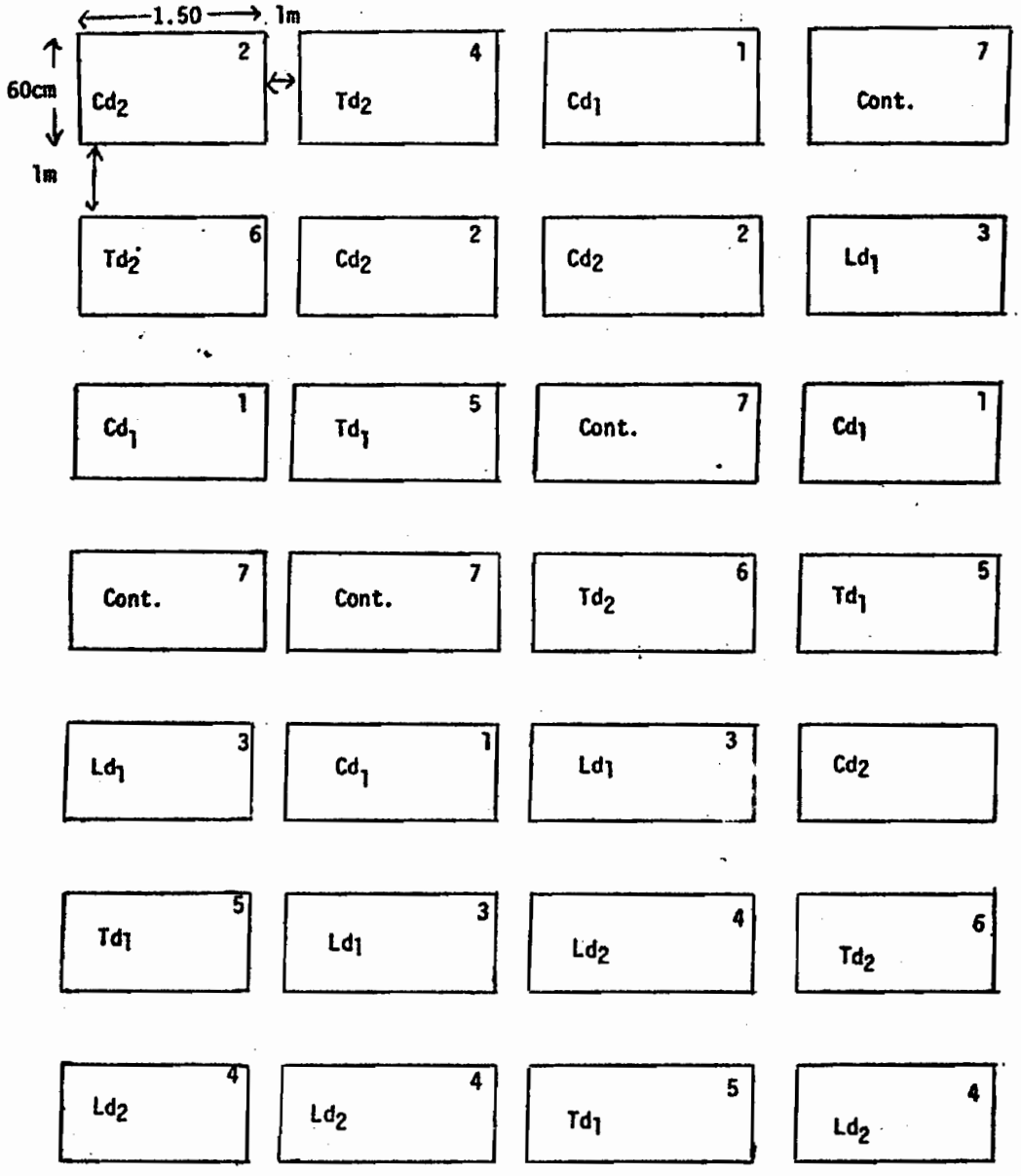
Treatment Combinations

1. Cd_1 - Cassia siamea @ 1 kg/m^2
2. Cd_2 - " " @ 2 kg/m^2
3. Ld_1 - Leucaena leucocephala @ 1 kg/m^2
4. Ld_2 - " " @ 2 kg/m^2
5. Td_1 - Terminalia brownii @ 1 kg/m^2
6. Td_2 - " " @ 2 kg/m^2
7. Cont. control (maize only, no mulch applied!)

Total amount of mulch required Leucaena) Cassia) 19.44 kg of each Terminalia) (fresh weight)

Each plot will have 1 row of maize in the centre, in row spacing 30 cm (6 plants).

BEANS MULCH/GREEN ORGANIC MANURE TRIAL



Treatment Combinations

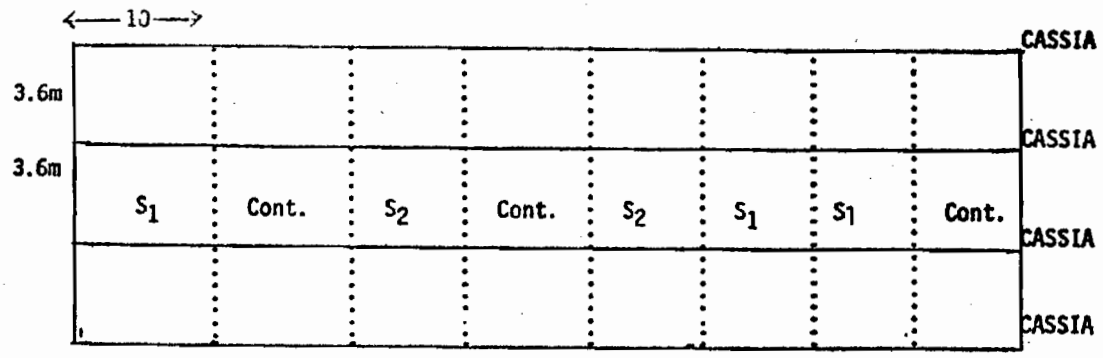
1. Ld_1 - Leucaena leucocephala @ 1 Kg/M^2
2. Ld_2 - " " @ 2 Kg/m^2
3. Cd_1 - Cassia siamea @ 1 Kg/m^2
4. Cd_2 - " " @ 2 kg/m^2
5. Td_1 - Terminalia @ 1 kg/m^2
6. Td_2 - " @ 2 kg/m^2
7. C - Control @

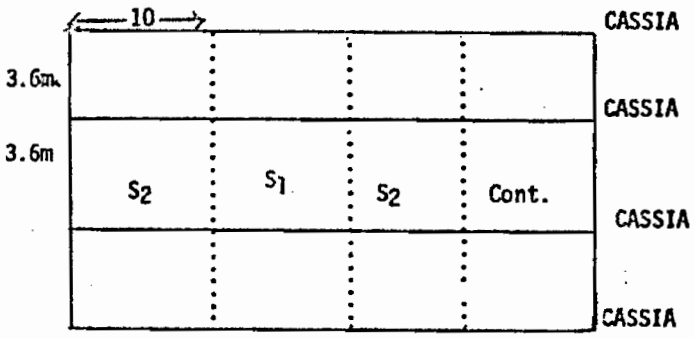
Total amount of mulch required/10.80 kg of each! (fresh weight)

Each plot will have 1 row of beans spaced 15 cm apart (10 plants)

Note: This experimental design and the proceeding one are designed to provide information only on relative differences between treatments. An experiment with larger plots will be conducted in the second phase of experimentation to obtain yield data on the most promising treatments.

HEDGEROW TRIAL





TREATMENTS

S_1 - Cassia siamea in furrows at 0.25m spacing

S_2 - " " in holes at 1m spacing

Cont. (Control) (Maize only)

Three rows of maize are planted between each 2 rows of Cassia (90cm between rows). In the control plots, each cassia row is replaced by a maize.

REFERENCES

Hoekstra, D.A. 1983. *Leucaena leucocephala* hedgerows intercropped with maize and beans: an *ex ante* analysis of a candidate agroforestry land use system for the semi-arid areas in Machakos District. Working Paper No. 3. ICRAF, Nairobi.