THE AFNETA
Alley Farming Training Manual

Volume 2
Source Book For Alley Farming Research

Alley Farming Research Network for Africa

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Alley Farming Research Network for Africa

About AFNETA

The Alley Farming Network for Tropical Africa (AFNETA) was established in 1989 to promote and coordinate alley farming research and development within the national agricultural research systems (NARS) of the region. Network activities include collaborative research, individual and group training, and information dissemination and exchange.

AFNETA/NARS collaborative research projects are found in 20 different countries and in all major agroecological zones. The main topics of research are screening of multipurpose trees, alley farming management trials, livestock integration in alley farming, and on-farm R & D and socioeconomic investigation. AFNETA collaborates with several other networks, institutions and organisations in the implementation of its programs.

Three international research centers founded AFNETA and now provide technical backstopping: the International Institute of Tropical Agriculture (IITA), the International Livestock Centre for Africa (ILCA), and the International Centre for Research in Agroforestry (ICRAF). IITA, which houses the network's coordination unit, also provides administrative support.

Financial support for coordinating activities has been provided by the International Development Research Cente (IDRC) and the Canadian Agency for International Development (CIDA). Major funding for national research activities has been provided by the International Fund for Agricultural Development (IFAD), with additional support from the Danish International Development Agency (DANIDA). The United States Agency for International Development (USAID) has supported the collaborative research projects at U.S. universities.

Printed at the International Livestock Centre for Africa, Addis Ababa

ISBN 978-131-074-X (Volume 1)
ISBN 978-131-075-8 (Volume 2)

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Preface

Training is one of AFNETA's most important activities. In order to participate fully in AFNETA's collaborative research program, scientists and technicians of national agricultural research institutions require training on the concepts and principles of alley farming as well as on the research methodologies for studying different aspects of the system.

AFNETA employs a train-the-trainer strategy in its training program. Regional training courses are organized at four centers in Africa, in collaboration with national institutions. A core group of trainers from each center has undergone trainer-training to enable them to plan, implement, and evaluate the regional courses. Two regional course, one anglophone, and one francophone, are held each year. In addition, a central training workshop, focusing on a strategically important aspect of alley farming, is held each year at the International Institute of Tropical Agriculture (IITA), Ibadan. It is principally for these training courses that the AFNETA Alley Farming Training Manual has been developed.

This training manual is a collaborative project of the three International Agricultural Centres affiliated to the network: the International Institute of Tropical Agriculture (IITA), the International Livestock Center for Africa (ILCA), and the International Centre for Research in Agroforestry (ICRAF). The manual draws on articles, training materials, and illustrations prepared by scientists and support staff from the three institutions.

The manual has been written with two readerships in mind. First, it is intended for use in AFNETA's training courses, at which African scientists learn how to carry out alley farming research within the framework of AFNETA's collaborative research programs. Most of these scientists have backgrounds in agriculture, forestry, or animal husbandry, and are employed within national research systems.

Secondly, it is intended for any person interested in practicing or experimenting with alley farming. Interest in alley farming is increasing, not only in national research systems, but in non-governmental organizations, development agencies, and among private farmers. Extension agents in many parts of Africa are beginning to be asked to promote the technology. The manual addresses the growing need for readily accessible, technical information on alley farming.

The manual is published in two volumes. Volume 1, the *Core Course in Alley Farming*, has been designed as a basic, six-unit curriculum for short training courses. The Core Course introduces the theory and practice of alley farming, and acquaints the trainee with the major research topics. Volume 2, the *Source Book for Alley Farming Research* is a collection of technical papers for reference and for further study. Each unit and technical paper includes a set of "feedback exercises" as an aide to self-teaching. Those scientists who will go on to conduct field experiments will want to make use of AFNETA's documentation on research guidelines and data collection requirements (available from the Coordination Unit).

In its present form, the manual is presented as a test draft, for use and review in a number of training programs. Any suggestions for improvements from readers are welcome.

Kwesi Atta-Krah

Coordinator, AFNETA
Ibadan, 1992

Acknowledgement

This training manual has been made possible through support and contribution from several institutions and individuals.

AFNETA would like to thank the directors general of IITA, ILCA and ICRAF, who made it possible for their institutions to be involved in the development and production of this manual. We would also like to acknowledge the support and input of Drs. Jim Gulley (IITA), Esther Zulberti (ICRAF), Bansh Tripathi (ILCA) and Michael Smalley (ILCA).

Several scientists from IITA, ILCA and ICRAF prepared technical papers for this manual, and we are grateful to all of them. Our thanks also go to the secretaries and other technical and support staff who contributed in various ways towards the development of this manual. A full list of contributors is given on the following page.

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THE AFNETA
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TECHNICAL PAPER 1

Soil Classification and Charactrization

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1.0 PERFORMANCE OBJECTIVES

Technical Paper 1 is intended to enable you to:

1. Describe the advantages of soil classification and list classification systems used in Africa.

2. Discuss the hierarchy of categories in the Soil Taxonomy classification.

3. Describe the distribution of major soil orders as per the Soil Toxonomy in tropical Africa.

4. Discuss basic features of the FAO/UNESCO and French systems of soil classification and correlate them with the Soil Taxonomy.

5. Describe the main characteristics of the major soils of tropical Africa.

6. Recall major problems of low-activity clays soils and suggest measures to improve these soils.

7. Explain the Land Capability Classification System.

Technical Paper 1:
Soil Classification and Characterisation

Main Contributors: B.T. Kang, B. Tripathi

1.1 INTRODUCTION

Development of sustainable agricultural systems such as alley farming is an attempt to reduce degradation of natural resources and to find environmentally compatible ways of increasing production and promoting broad-scale development.

Intensification of agriculture on land currently used for traditional farming requires a thorough knowledge of the soil as a resource and attributes of the land. Information on distribution, potential and constraints of major soils is needed, so that the most appropriate soil management systems can be designed. In addition knowledge on land capability and suitability is also essential to determine the best land use for sustained crop production.

This paper reviews current systems used to classify soils and land capabilities. It also provides an introduction to the management requirements of the major soils in the humid and subhumid zones of tropical Africa.

1.2 SOILS AND THEIR CLASSIFICATION

Soil is the thin layer covering the entire earth's surface, except for open water surfaces and rock outcrops. The properties of soil are determined by environmental factors. Five dominant factors are often considered in the development of the various soils: (a) the climate, (b) parent materials (rocks and physical and chemical derivatives of same), (c) relief, (d) organisms (fauna and flora), and (e) the time factor. There are a large number of different soils, reflecting different kinds and degrees of soil forming factors and their combinations.

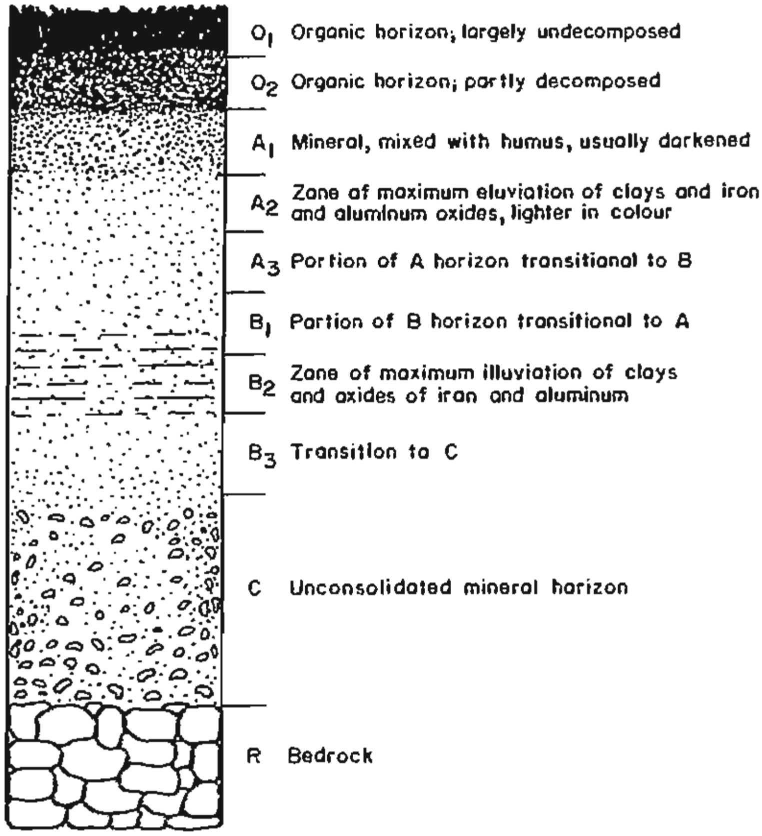

Figure 1. A hypothetical soil profile.

Scientists have developed different systems of soil classification to group soils of similar properties in one class, allowing them to exchange information on soils found in different areas. Soil classification also helps in determining the best possible use and management of soils. Soil classification is however a controversial subject at both national and international levels. There is lack of agreement for a common classification system, because soil scientists do not agree on the characteristics for differentiating and classifying soils.

Although many soil classification systems exist; however, two system are widely used: The USDA Soil Taxonomy and the FAO/UNESCO legend. The French system (ORSTROM) is also commonly used in France and in Francophone Africa.

The classification of soils starts with examination of soil profiles. Morphologically, soils are composed of a series of horizons. Soil horizons are layers of different appearance, thickness, and properties which have arisen by the action of various soil-forming processes. The horizons are normally parallel to the surface. Collectively, the horizons make up what is called the soil profile or soil "pedon". A soil profile is defined as a vertical section of the soil to expose layering. Figure 1 sketches a hypothetical soil profile having all the principal horizons, with a brief description of the characteristics of each horizon. Individual soils have one or more of these horizons. Very young soils may not yet have started the soil horizonization process.

In soil classification, the item to be classified is the soil profile. The classification or study of the entire profile consists of recognising and naming the horizons which make up the profile. In the study of soil profiles, sub-soil horizons are given greater emphasis than surface horizons which are frequently changed by human activity to such an extent that they bear hardly any relationship with genetic process.

1.3 THE USDA SOIL TAXONOMY

The Soil Taxonomy developed since the early 1950's is the most comprehensive soil classification system in the world, developed with international cooperation it is sometimes described as the best system so far. However, for use with the soils of the tropics, the system would need continuous improvement.

1.3.1 Hierarchy of Categories in the Soil Taxonomy

There are six levels in the hierarchy of categories: Orders (the highest category), suborders, great groups, subgroups, families and series (the lowest category) (USDA, 1978).

Orders

There are ten orders, differentiated on gross morphological features by the presence or absence of diagnostic horizons or features which show the dominant set of soil-forming processes that have taken place. The ten orders and their major characteristics are shown in Table 1. The occurrence of the major soils in the humid and subhumid tropics is shown in Table 2.

Suborders

It is the next level of generalization. It permits more statements to be made about a given soil. In addition to morphological characteristics other soil properties are used to classify the soil. The suborder focusses on genetic homogeneity like wetness or other climatic factors. There are 47 suborders within the 10 orders. The names of the suborders consist of two syllables. The first connotes the diagnostics properties; the second is the formative element from the soil order name. For example, an Ustalf is an alfisol with an ustic moisture regime (associated with subhumid climates).

Great groups

The great group permits more specific statements about a given soil as it notes the arrangement of the soil horizons. A total of 230 great groups (140 of which occur in the tropics) have been defined for the 47 suborders. The name of a great group consists of the name of the suborder and a prefix suggesting diagnostic properties. For example, a Plinthustalf is an ustalf that has developed plinthite in the profile. Plinthite development is selected as the important property and so forms the prefix for the great group name.

Table 1. Brief descriptions of the ten soil orders according to Soil Taxonomy.

SOIL ORDERS	DESCRIPTION
ALFISOLS -	Soils with a clayey B horizon and exchangeable cation (Ca + Mg + K + Na) saturation greater than 50% calculated from NH_4OAc-CEC at p^H7.
ULTISOLS -	Soils with a clayey B horizon and base saturation less than 50%. They are acidic, leached soils from humid areas of the tropics and subtropics.
OXISOLS -	Oxisols are strongly weathered soils but have very little variation in texture with depth. Some strongly weathered, red, deep, porous oxisols contain large amounts of clay-sized Fe and Al oxides.
VERTISOLS -	Dark clay soils containing large amounts of swelling clay minerals (smectite). The soils crack widely during the dry season and become very sticky in the wet season.
MOLLISOLS -	Prairie soils formed from colluvial materials with dark surface horizon and base saturation greater than 50%, dominating in exchangeable Ca.
INCEPTISOLS -	Young soils with limited profile development. They are mostly formed from colluvial and alluvial materials. Soils derived from volcanic ash are considered a special group of Inceptisols, presently classified under the Andept suborder (also known as Andosols).
ENTISOLS -	Soils with little or no horizon development in the profile. They are mostly derived from alluvial materials.
ARIDISOLS -	Soils of arid region, such as desert soils. Some are saline.
SPODOSOLS -	Soils with a bleached surface layer (A2 horizon) and an alluvial accumulation of sesquioxides and organic matter in the B horizon. These soils are mostly formed under humid conditions and coniferous forest in the temperate region.
HISTOSOLS -	Soils rich in organic matter such as peat and muck.

Table 2. Occurrence of major soils in the Humid and Subhumid Tropics.

Classification (USDA)	Occurrence
1. Alfisols	Savanna and drier forest zones
2. Hydromorphic Soils	Valley bottom of a rolling topography
3. Vertisols	Alluvial plains in savanna
4. Ultisols	Rain forest zone and derived savanna
5. Oxisols	Rain forest and savanna
6. Inceptisols	All regions
7. Andepts (suborder of Inceptisols)	Limited and localized distribution relating to present and past volcanic activities

Subgroups

There are three kinds of subgroups:

1. The typical subgroup which represents the central concept of the great group, for example Typic Paleustalfs.
2. Intergrades are transitional forms to other orders, suborders or great groups, for example Aridic Paleustalfs or Oxic Paleustalfs.
3. Extragrades have some properties which are not representative of the great group but do not indicate transitions, for example, Petrocalcic Paleustalf.

Families

The grouping of soils within families is based on the presence or absence of physical and chemical properties important for plant growth and may not be indicative of any particular process. The properties include particle size distribution and mineralogy beneath the plough layer, temperature regime, and thickness of rooting zone. Typical family names are clayey, kaolinitic, isohyperthermic, etc. There are thousands of families.

Series

The soil series is the lowest category. It is a grouping of soil individuals on the basis of narrowly defined properties, relating to kind and arrangement of horizons; colour, texture, structure, consistence and reaction of horizons; chemical and mineralogical properties of the horizons. The soil series are given local place names following the earlier practice in the old systems in naming soil series. There are tens of thousands of series.

1.3.2 Distribution of USDA - Classified Soils in the Tropics

According to the USDA Soil Taxonomy, Oxisols are the most abundant soils in the humid and perhumid tropics covering about 35 percent of the land area (Table 3). **Ultisols** are the second most abundant, covering an estimated 28 percent of the region. About half of the Ultisols and 60 percent of the Oxisols are located in humid and perhumid tropical Africa and Asia. In tropical Africa, they are abundant in the eastern Congo basin bordering the lake region; in the forested zones of Sierra Leone; in Ivory Coast; in parts of Liberia; and in the forested coastal strip from Ivory Coast to Cameroon (Figure 2).

The **Alfisols**, which have high to moderate fertility, cover a smaller area of the humid tropics. In west Africa they are found in Ivory Coast, Ghana, Togo, Benin, Nigeria and Cameroon. They are, however, the most abundant soils in Africa's subhumid and semi-arid zones, covering about one third of these regions. The Alfisols are widely distributed in the subhumid and semi-arid tropical regions of Africa, including large areas in western, eastern, central, and southeastern Africa (Figure 2).

Table 3. Geographical distribution of soils in the humid and semi-arid tropics (millions of hectares).

Soil order	Tropical Africa	Tropical Asia	Tropical America	Total	Percent
Humid Tropics[1]					
Oxisols	179	14	332	525	35
Ultisols	69	131	213	413	28
Alfisols	21	15	18	54	4
Others	176	219	103	498	33
Total	445	379	666	1490	100

Contd. Table 3

Soil order	Tropical Africa	Tropical Asia	Tropical America	Total	Percent
Semi-arid Tropics[2]					
Alfisols	466	121	107	694	33
Ultisols	24	20	8	52	1
Others	972	178	198	1348	66
Total	1462	319	313	2094	100

1) Data from NAP (1982).
2) Data adapted from Kampen and Burford (1980). Part of the subhumid tropics is included.

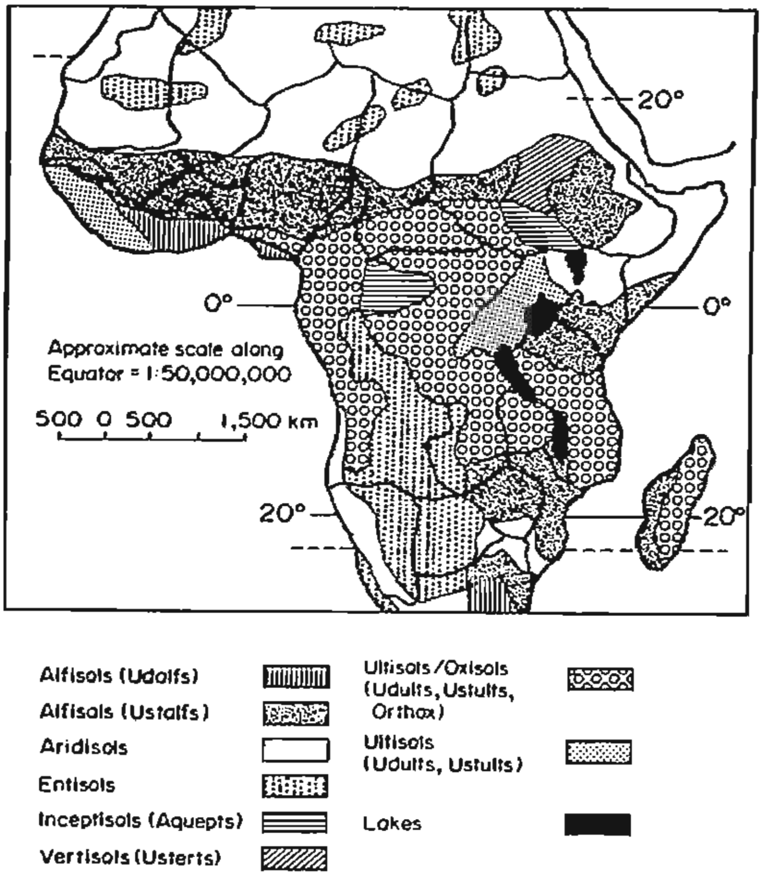

Figure 2. Soils of tropical Africa; according to the USDA soil Taxonomy (adapted from Aubert and Tavernier, 1972).

1.4 THE FAO/UNESCO SYSTEM

The FAO/UNESCO system was devised more as a tool for the preparation of a small-scale soil map of the world than a comprehensive system of soil classification. The map shows only the presence of major soils, being associations of many soils combined in general units. The legend of the soil map of the world lists 106 units classified into 26 groupings. The soil units correspond roughly to great groups from the USDA Soil Taxonomy, while larger main grouping are similar to the USDA soil suborder. Table 4 shows the rough correspondence between the Soil Taxonomy and the FAO/UNESCO system.

In 1986 FAO published a soil map of Africa following the FAO/UNESCO system of soil classification. In this map, all the soils of Africa have been grouped into 10 soil associations (Figure 3). Though it is not very precise, the map provides an overview of the soil resources of the continent of the ten major associations, the desert and shallow soil associations (comprising Yermosols, Xerosols and Luvisols) occupy about one-third of Africa's land area. However, only a part of the area occupied by these associations falls in the tropics.

1.5 THE FRENCH SYSTEM (ORSTROM/INRA)

The so-called French System of classifying soils is based on principles of soil evolution and degree of evolution of soil profiles. It also takes into account humus type, structure, and the degree of hydromorphism. The system was developed by the Office de la recherche scientifique et technique d'outre-mer (ORSTROM, now Institut francais de recherche scientifique pour le developpment en cooperation). Correlations of Soil Taxonomy with INRA French systems are shown in Table 4.

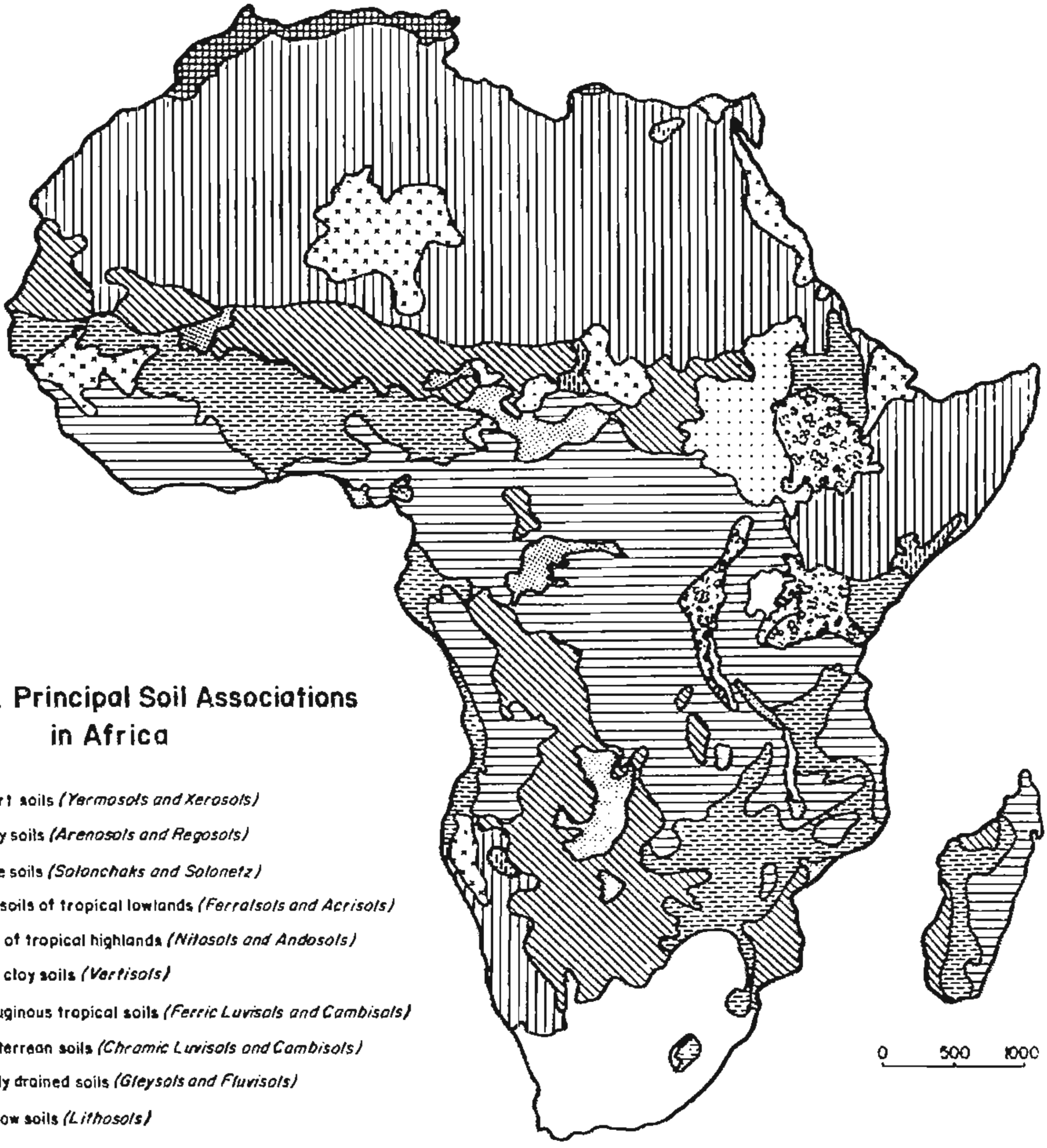

Figure 3. Principal Soil Associations in Africa

- Desert soils *(Yermosols and Xerosols)*
- Sandy soils *(Arenosols and Regosols)*
- Saline soils *(Solonchaks and Solonetz)*
- Acid soils of tropical lowlands *(Ferralsols and Acrisols)*
- Soils of tropical highlands *(Nitosols and Andosols)*
- Dark clay soils *(Vertisols)*
- Ferruginous tropical soils *(Ferric Luvisols and Cambisols)*
- Mediterrean soils *(Chromic Luvisols and Cambisols)*
- Poorly drained soils *(Gleysols and Fluvisols)*
- Shallow soils *(Lithosols)*

Source: FAO Atlas of African Agriculture, 1986

Table 4. Correlation between systems of soil classification: the Soil Taxonomy, FAO/UNESCO legend and the INRA system.

FAO/UNESCO	Soil Taxonomy*	INRA System
Acrisols	Ultisols	Sols Lessive
Andosols	Andepts	Andosols
Arenosols	Psamments	Sols mineraux bruts
Cambisols	Tropepts	Sols bruns eutrophes tropicaux
Ferralsols	Oxisols (Latosols)	Sols Ferraltique
Fluvisols	Fluvents (Alluvial soils)	Sols mineraux bruts
Gleysols	Aquepts and Aquents (Aquic great groups of Entisols, Inceptisols)	Sols a gley peu profond peu humiferes
Histosols	Histosols	Sols hydromorphes organiques
Lithosols	Lithic subgroups	Lithosols
Luvisols	Alfisols	Sols lessives modaux
Nitosols	Tropics, Rhodic great groups of Alfisols and Ultisols	
Podzols	Spodosols	Podsols
Regosols	Orthents, Psamments	Sols mineraux bruts d'apport; eolien ou volcanique; sols peu evolves regosolique d'erosion etc.
Vertisols	Vertisols	Vertisols

*() = Name in old USDA system.

1.6 CHARACTERISTICS OF THE MAJOR SOILS OF THE TROPICAL AFRICA

The main characteristics of the soil orders were summarized briefly in Table 1. The following sections provide additional information on the properties and management of the most important soils in the humid and subhumid zones of tropical Africa.

Alfisols

The Alfisols are less leached and have lower acidity than Ultisols and Oxisols, but they exhibit high base saturation and their fertility is low to moderate. The Alfisols and associated soils support a wide variety of cereal crops (maize, rice, sorghum, millet), root and tuber crops (yam, cassava, cocoyam, sweet potato), and grain legumes (soybean, cowpeas, groundnuts, pigeon peas, chick peas).

Distribution of the Alfisols, Ultisols, and Oxisols is shown in the Soil Taxonomy map (Figure 2). Examples of chemical characteristics of Alfisols and Ultisols from Nigeria are given in Table 5 and Figure 4.

The productivity of the Alfisols is limited mainly by their physical characteristics:

- They have low structural stability and are susceptible to surface crusting, soil compaction and erosion.
- They have low water retention capacity and are subject to drought (Lal, 1974, Kang and Juo, 1983).
- Deficiencies of N and P are common while deficiencies of K, Mg, S, Fe, and Zn occur under intensive cultivation (Kang and Fox, 1981; Cottenie et al., 1981).
- Because of their low buffering capacity, Alfisols acidify rapidly under continuous cultivation, particularly with the use of high rates of nitrogenous fertilizers (Kang and Juo, 1983).

Figure 4 illustrates some of the chemical properties of an Alfisols profile from Southwest Nigeria, where the soil is slightly acidic with high base saturation even in the lower soil horizons.

Benefits from N, P, and K application for continuous crop production on the Alfisols have been well documented. With intensive cropping, N is the primary limiting nutrient, followed by P. Potassium is generally needed with long-term continuous cropping, particularly on soils derived from sedimentary rocks. The Alfisols and associated soils have low P-fixation and high residual effects from applied P. In addition, mycorrhiza symbiosis is common and effective on these soils particularly with root crops, resulting in a low P requirement for crop production.

Continuous cultivation and fertilizer application can significantly affect the properties of Alfisols and associated soils. Cropping, and in particular fertilizer application, reduces soil p^H, soil organic matter, and extractable cations. Lowering of soil p^H on the Alfisols can result in increased toxic levels of Al and Mn (Kang and Spain, 1986).

Table 5. Selected chemical characteristics of surface soils (0-15 cm) of Alfisols and Ultisols collected under natural vegetation from southern Nigeria.

pH-H_2O	Org.C (%)	Exchangeable Cations Ca	Mg	K	Total Acidity	ECEC	Bray-P (μg/g)
		me/100g					
Alfisols							
Egbeda soil (Oxic Paleustalf), Ibadan (Derived from basement complex rocks)							
6.4	1.82	3.80	1.63	0.27	0.04	5.78	7.35
Alagba soil (Oxic Paleustalf), Ikenne (Derived from sedimentary materials)							
6.1	1.82	3.90	1.87	0.14	0.12	6.07	8.40
Ultisols							
Nkpologu soil (Oxic Paleustult), Nsukka							
4.5	1.02	0.40	0.32	0.08	1.44	2.32	9.10
Onne Soil (Typic Paleudult), Onne							
4.3	1.04	0.26	0.09	0.07	2.08	2.50	141.0

*This soil derived from marine sediments has high Bray extractable P level.

Ultisols and Oxisols

The Oxisols and especially the Ultisols are acidic, with low base saturation (Figure 4). Both soil orders commonly have multiple nutrient deficiencies (N, P, K, Ca and Zn), as shown by Kang and Juo (1983). Oxisols are highly weathered and leached, while Ultisols are susceptible to erosion and compaction. The poor productivity of these soils is due to their low capacity to provide nutrients to crops as well as their Al and Mn toxicity. Soils have medium to high P fixation. Chemical characteristics of some Nigerian Ultisols are given in Table 5.

The Ultisols and Oxisols support a lesser variety of food crops than Alfisols, being more suitable for tree crop production. Crops that do well on the Ultisols and Oxisols include some cereal crops (e.g., rice), root and tuber crops (cassava, yam, cocoyam, sweet potato), grain legumes (cowpeas, groundnuts). Plantains and bananas also do well. In traditional system, maize is grown only on newly cleared and burnt plots.

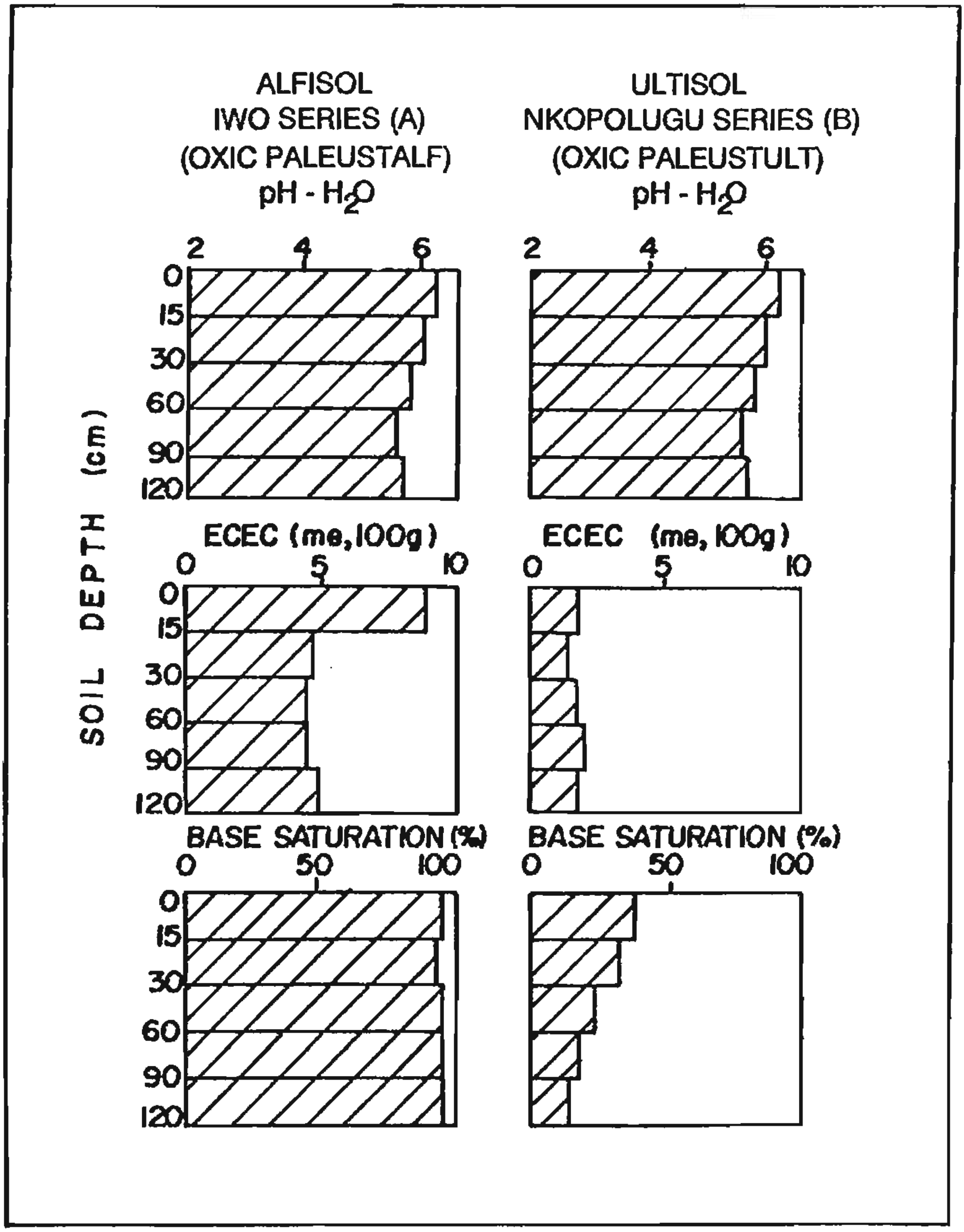

Figure 4. Soil pH, effective cation exchange capacity (ECEC), and degree of base saturation of selected Alfisol and Ultisol profiles under natural forest vegetation from southwestern Nigeria. (Kang and vandenBeldt, 1990).

In many early studies, acid soils in the humid tropics were limed to neutral p^H, with generally poor results due to nutrient imbalance. Following the finding in the 1950s that acid soils contain more exchangeable Al^3+ than H^+, primary consideration has been given to removal of toxic factors which limit plant growth. Research on acid soils in West Africa has confirmed these findings. Low lime rates are needed to reduce toxic levels of Al^3+ and application of 0.5 to 1.0 tons of lime per hectare was found to be adequate for highly acid soils (IITA, 1984). These soils are usually deficient in P as well. Rock phosphates can be used on unlimed acid soils as an inexpensive and efficient way of supplying P to acid-tolerant crops.

1.7 MANAGEMENT OF LOW-ACTIVITY CLAYS (LAC) SOILS)

For purpose of management, the majority of the upland soils in the humid and subhumid tropics is grouped as low activity clays (LAC) soils. A LAC soils has a low effective cation exchange capacity (ECEC) of $\leq$ 16 meq/100 g clay in the subsoil (Juo and Adams, 1986). The LAC soils are predominantly Alfisols, Ultisols, Oxisols, and associated soils. Vast areas of the rainfed uplands in the humid and subhumid tropics currently used for traditional food crop production are dominated by these "fragile" soils. Observations have shown that the majority of the LAC soils in West Africa have an especially low ECEC of $<$ 8 meq. As the clay fraction of these soils are composed mainly of kaolinite, halloysite, and oxides of Fe and Al, the soil ECEC depends mainly on the soil organic matter level, which controls nutrient absorption and release.

1.7.1 Problems in Fertility Management of LAC Soils

One of the major problems associated with extended cultivation of LAC soils is the maintenance of favorable soil physical conditions and the control of soil erosion. Significant changes in soil chemical and biological properties also occur following forest or bush fallow clearing and cropping. Soil organic matter declines sharply during the first few years under cropping and the effect is more pronounced with intensive continuous cropping.

The loss of organic matter and acidification resulted in a decrease in the effective cation exchange capacity (ECEC) and the loss of Ca and Mg (Kang and Juo, 1983). The arbitrary application of exotic, high -input food crop production technologies on these fragile soils therefore often leads to rapid chemical, physical, and biological degradation of the soil.

Although soil fertility problems on the LAC soils can be corrected by liming and appropriate fertilization, socioeconomic constraints often limit the application of these crop production technologies in many areas of tropical Africa. Currently, sub-Saharan Africa's per capita and per hectare fertilizer use is very low compared with that of other regions. There is a need to develop integrated soil fertility management systems for the region based on better utilization of local nutrient sources. Such systems should be supplemented with external inputs wherever that is feasible and affordable.

For sustained crop production in addition to adequate supply of plant nutrients, the LAC soils also require continuous addition of organic matter.

1.7.2 Integrated Nutrient Management Options

Integrated soil fertility management for LAC soils can be achieved by various methods including:

- promoting maximum recycling and more efficient use of nutrients from plant residues,
- increasing contribution of biological nitrogen fixation,
- improving efficiency of use of mineral nitrogen fertilizers and local sources of phosphate fertilizers,
- using organic residues to reduce soil acidity problems, and
- using acid-tolerant cultivars.

Use of low levels of chemical inputs in combination with fallowing and agroforestry systems has shown varying degrees of success. Fallowing and addition of organic mulches may correct chemical soil degradation resulting from continuous cultivation; at the same time, it may also increase efficiency of fertilizer use.

Crop residue management and seed bed preparation methods can play an important role in sustaining the productivity of these soils for crop production. This can be achieved in reduced tillage systems through the use of crop residue mulches, *in situ* mulches from cover crops, and/or hedgerow prunings from alley farming. The presence of adequate amounts of mulch cover helps maintain high soil nutrient status and high biological activity. Mulch also protects the soil against high temperatures, soil erosion, and run-off, thereby preventing the breakdown of soil structure and the resultant soil compaction and decreased permeability. Furthermore, mulching increases soil moisture retention and reduces runoff and soil erosion (Lal, 1974; Kang and Juo, 1986).

Results of long-term field experiments carried out on Alfisols have also shown that with judicious fertilizer use and crop rotation, high and sustained crop yields can be obtained (Kang and Juo, 1986). Similar principles also apply for managing the Ultisols/Oxisols. For sustained crop production, the Ultisols and Oxisols additionally require judicious liming (IITA, 1984; Nicholaides et al., 1984).

1.7.3 Performance of Woody Species on Alfisols and Ultisols/Oxisols

The integration of food crops and forages with multi-purpose tree species (MPTs) in agroforestry and alley farming systems have received much attention in recent years as an alternative, low chemical input management possibility for LAC soils. However, little information is available on the soil requirements for growing the MPTs.

As with crops, the capacities of MPTs for biomass production and nutrient recycling are affected by soil and climatic conditions. Under the same climatic regime, growth and biomass production of MPTs is expected to be higher on the more productive Alfisols than on the less productive Ultisols/Oxisols. Additions of nutrients may be needed for good growth of MPTs.

MPTs for alley farming such as *Leucaena leucocephala* and *Gliricidia sepium* do well on non-acid or slightly acid Alfisols. Both species perform poorly on acid soils. On the low p^H soils, MPTs such as *Acioa barteri, Calliandra calothyrsus*, and *Flemingia macrophylla* perform well.

1.8 LAND CAPABILITY CLASSIFICATION

The technique which allows determination of the most suitable use for any area of land is called land classification. A great number of systems of land classification are in use, varying mainly according to the purpose for which the land is classified. Land may be classified according to its present land use, its suitability for a specific crop under the existing forms of management, its capability for producing crops or combinations of crops under optimum management, or its suitability for non-agricultural types of land use. A good knowledge of the land capability and suitability combined with good understanding of the soil characteristics and management aspects are the keys to more productive and sustainable agriculture.

The purpose of land capability classification systems is to study and record all data relevant to finding the combination of agricultural and conservation measures which would permit the most intensive and appropriate agricultural use of the land without undue danger of soil degradation.

1.8.1 The USDA Land Capability Classification System

The best known of these systems is the United States Department of Agriculture system (Klingebiel and Montgomery, 1961). The USDA land classification system is interpretative, using the USDA soil survey map as a basis and classifying the individual soil map units in groups that have similar management requirements. At the highest of categorization, eight soil classes are distinguished, namely:

Class I soils have few limitations restricting their use. Erosion hazards on these soils are low; they are deep, productive and easily worked. For optimum production, these soils need ordinary management practices to maintain productivity, as regards both soil fertility and favorable physical soil properties.

Class II soils have some limitations that reduce the choice of plants or require moderate conservation practices. Limitations of soils in Class II include (singly or in combination) the effect of gentle slopes, moderate susceptibility to erosion, less than ideal soil depth, somewhat unfavorable soil structure, slight to moderate correctable salinity, occasional damaging overflow, wetness correctable by drainage, slight climatic limitation. Soils in this class require more than ordinary management practices for obtaining optimum production and for maintaining productivity.

Class III soils have severe limitations that reduce the choice of plants or require special conservation practices. The limitation of soils in this class are those of Class II, but in higher degree; including additional limitations such as shallow depth, low moisture-holding capacity, and low fertility that is not easily corrected. Class III soils require considerable management inputs, but even so, choice of crops or cropping systems remains restricted because of inherent limiting factors.

Class IV soils have very severe limitations that restrict the choice of plants and or require very careful management. Restrictions, both in terms of choice of plants and or management and conservation practices are greater than in Class III to such an extent that production is often marginal in relation to the inputs required. Limiting factors re of the same nature as in the previous classes but more severe and difficult to overcome. Several limitations such as steep slopes are a permanent feature of the land.

Some of the limitations due to sloppiness and erosion hazards in classes II to IV can be reduced by biological terracing as practiced in agroforestry and alley cropping.

In the USDA system, soils of classes V to VIII are generally not suited for cultivation, although certain of them may be made suitable for agricultural use with costly measures.

Class V soils have few or no erosion hazards but have other limitations, impracticable to remove, that restrict their use to pasture, range, woodland, or wildlife food and cover. Although they may be level or nearly level, many of these soils are subject to inundation or are stony or rocky.

Class VI soils have severe limitations that make them generally unsuited to cultivation and limit their use largely to pasture or range, woodland, or wildlife food cover. This class is a continuation of Class IV, with very severe limitations that cannot be corrected. They may serve for some kinds of crops, such as tree crops, provided unusually intensive management is practiced.

Class VII soils have very severe limitations that make them unsuited to cultivation and also, restrict their use largely to grazing, woodland, or wildlife. The limitations are such that these soils are not suited for any of the common crops.

Class VIII soils and land forms have limitations that preclude their use for commercial plant production.

In the second level of generalization of the USDA land capability classification system, sub classes specify the kind of limitations. Four kinds of limitations are recognized at this level, namely, risk of erosion; wetness, drainage or overflow; rooting zone limitations, and climatic limitation. The third level, that of the capability unit, provides more specific and detailed information for application to specific fields on a farm.

A new standard framework for land evaluation by means of land suitability classification has been developed by FAO (1983). As in other systems, the land suitability component of land evaluation is based on the survey of the physical attributes of the land (soils, climate, vegetation, topography, hydrology, etc.), and consequently requires interpretation of these attributes. The proposed FAO land suitability classification integrates relevant social and economic factors with the technical suitability classification. At the present stage, the system mainly concentrates on the classification of land based on technical suitability.

1.9 FEEDBACK EXERCISES

All answers can be found in Technical Paper 1.

1. Provide brief answers to the following questions:

   i) What is soil horizon? What is soil profile?

   ii) Name the factors that are often considered in the development of soil.

   iii) What is land capability classification?

   iv) In the USDA system for classifying land capability, what kinds of criteria are used to assign soils to a particular class?

2. a) Name the three soil orders that are most abundant in Africa's humid tropics, with approximate percentages, and FAO/UNESCO names.

Soil Order	Percentage of Land Area in African humid tropics	FAO/UNESCO Name(s)
1. ___________	_____%	_______
2. ___________	_____%	_______
3. ___________	_____%	_______

b) Draw lines to connect the names of soil order (left) to their characteristics (right). The names of soil order are from the USDA Soil Taxonomy.

ALFISOLS	Soils rich in organic matter such as peat and muck.
ULTISOLS	Young soils with limited profile development.
OXISOLS	Strongly weathered soils with very little variation in texture with depth.
VERTISOLS	Dark clay soils containing large amounts of clay minerals.
INCEPTISOLS	Soils with a clayey B horizon and exchangeable cation saturation greater than 50.
HISTOSOLS	Acidic, leached soils from humid areas of the tropics and subtropics.

3. Answer by circling T for true or F for false:

i) Shortening of the fallow period in traditional farming results in a decline in soil organic matter — T F

ii) Alley farming is a low chemical input technology and is not appropriate for low activity clays (LAC) soils — T F

iii) Acid Ultisols and Oxisols are better suited to tree crop production while Alfisols can be used for a wider variety of crops. — T F

iv) *In situ* mulches and hedgerow prunings are two options for sustaining productivity. Alley farming makes use of the second option. T F

v) On acid soils, *Leucaena* and *Gliricidia* perform better than other hedgerow tree species. T F

1.10 SUGGESTED READING

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TECHNICAL PAPER 2

Biological Nitrogen Fixation

2.0 Performance Objectives

2.1 Introduction

2.2 Mechanism of Biological Nitrogen Fixation

2.3 Specificity and Effectiveness

2.4 Factors Limiting Biological Nitrogen Fixation
- 2.4.1 Edaphic Factors
- 2.4.2 Climatic Factors
- 2.4.3 Biotic Factors

2.5 Estimation of Nitrogen Fixation
- 2.5.1 Short-term Estimation of BNF : Acetylene Reduction Assay
- 2.5.2 Medium-term Estimation of BNF: N-solute Analysis of Xylem Exudate

2.6 How to Increase BNF and N_2 Fixing Ability

2.7 Summary

2.8 Feedback Exercises

2.9 Suggested Reading

2.10 References

2.0 PERFORMANCE OBJECTIVES

Technical Paper 2 is intended to enable you to:

1. Describe briefly the mechanism of biological nitrogen fixation.

2. Discuss edaphic, climatic and biotic factors limiting biological nitrogen fixation.

3. Describe two simple methods of BNF estimation.

4. Discuss four major approaches to enhance biological nitrogen fixation.

Technical Paper 2: Biological Nitrogen Fixation

K. Mulongoy

2.1 INTRODUCTION

Biological nitrogen fixation (BNF) is the process whereby atmospheric nitrogen (N=N) is reduced to ammonia in the presence of nitrogenase. Nitrogenase is a biological catalyst found naturally only in certain microorganisms such as the symbiotic *Rhizobium* and *Frankia*, or the free-living *Azospirillum* and *Azotobacter*.

Biological nitrogen fixation is brought about both by free-living soil microorganisms and by symbiotic associations of microorganisms with higher plants. Our main interest in this paper centers on the legume-*Rhizobium* symbiosis. Leguminous plants fix atmospheric nitrogen by working symbiotically with special bacteria, rhizobia, which live in the root nodules. Rhizobia infect root hairs of the leguminous plants and produce the nodules. The nodules become the home for bacteria where they obtain energy from the host plant and take free nitrogen from the soil air and process it into combined nitrogen. In return, the plant receives the fixed N from nodules and produces food and forage protein.

2.2 MECHANISM OF BIOLOGICAL NITROGEN FIXATION

The biochemical mechanism of N_2 fixation can be written in simplified form as follows:

```
           nitrogenase
N2 (a)   ------------------> NH3 -->--->---> amino acids -------> proteins
         + ATP
         + H+
         low oxygen tension
```

The above mechanism indicates that N_2-fixing systems can thrive in soils poor in N, that they are a source of proteins, and that they provide N for soil fertility. Adenosine triphosphate (ATP) is the source of energy necessary for the cleavage and reduction of N_2 into ammonia. In rhizobia, for instance, ATP results from oxidative degradation of sugars and related molecules. These sugars are manufactured by the host-plant during photosynthesis and transferred to the nodules. In general, for each gram of N_2 fixed by *Rhizobium*, the plant fixes 1-20 grams carbon (C) through photosynthesis. This is an indication that symbiotic N_2 fixation requires additional energy which, in nitrate-fed plants, can be used to produce more photosynthates (products of photosynthesis). The extra energy cost of N_2 fixation can, however safely be carried by most field-grown legumes with little or no loss of production.

It is usually accepted that N_2-fixing systems require more Phosphorus (P) than non-N_2-fixing systems. Phosphorus is needed for plant growth, nodule formation and development, and ATP synthesis, each process being vital for nitrogen fixation.

Nitrogen fixation, which involves the chemical reduction of N_2 to NH_3 or NH_4, requires a source of electrons. Sources of electrons for the nitrogenase activity vary with the organism. They are all small proteins and highly reductive molecules such as flavodoxin, ferredoxin, nicotinamide, or ademine dinucleotide (phosphate).

Nitrogenase is an oxygen sensitive enzyme. The low oxygen tension condition is realized through compartmentation in cyanobacteria (heterokysts in *Anabaena azollae*), active respiration (in *Azotobacter*), synthesis of leghemoglobin (in *Rhizobium* legume). Leghemoglobin is a macromolecule synthesized by both symbiotic partners, the rhizobia and the host plant. *Rhizobium* synthesizes the heme portion, and the plant the globine. Like human hemoglobin, leghemoglobin fixes O_2. It is responsible for the red or brown color of active (i.e., N_2-fixing) nodules. Non-N_2-fixing nodules have a white nodule content, or a green content when the globine has degenerated.

2.3 SPECIFICITY AND EFFECTIVENESS

There are roughly 1,300 leguminous plant species in the world. Of these, nearly 10% have been examined for nodulation, 87% of which were nodulated. Thus not all legumes are infected by rhizobia. *Gliricidia sepium* and *Vigna unguiculata* (cowpea) nodulate freely but nodules have never been found on roots of *Cassia siamea*. A *Rhizobium* that nodulates cowpea may not nodulate *Leucaena* and vice versa. Leguminous species mutually susceptible to nodulation by a particular group of bacteria constitute a cross-inoculation group. Six cross-inoculation groups were defined in the early days of *Rhizobium* research in addition to the cowpea group. This classification scheme is undergoing modifications based on recent research. Table 1 gives a short list of rhizobia and their hosts to illustrate the grouping of rhizobia.

Mechanisms of recognition between the microsymbiont and the host-plant have been suggested to explain specificity. (This topic is beyond the scope of this paper).

Not all symbioses fix N_2 with equal effectiveness. This means that a given legume cultivar nodulated by different strains of the same species of *Rhizobium* would fix different amounts of nitrogen. Selection of elite strains of *Rhizobium* is based on this observation. Similarly, a given strain of *Rhizobium* will nodulate and fix different amount of N_2 in symbiosis with a range of cultivars of the same plant species. Thus, different provenances of a given legume (e.g., *Gliricidia sepium* in ILCA's

Table 1. A short list of *Rhizobium* species and their corresponding hosts

Rhizobium species	Host plants
Bradyrhizobium japanicum	*Glycine max* (soybean)
Rhizobium fredii	*Glycine max* (soybean)
R. phaseoli	*Phaseolus vulgaris* (common bean)
R. meliloti	*Medicago sativa* (alfalfa) *Melilotus* sp. (sweet clovers)
R. trifolii	*Trifolium* sp. (clovers)
R. leguminosarum	*Pisum sativum* (peas) *Vicia faba* (broad bean)
"Cowpea rhizobia" group or *Rhizobium* sp	*Vigna unguiculata* (cowpea), *Arachis hypogaea* (peanut), *Vigna subterranea* (Bambara groundnut) *Leucaena* sp, *Albizia* sp.,
Azarhizobium caulinodans →	*Sesbania* sp.*Sesbania rostrata* (stem nodulating)

international testing) can nodulate and fix nitrogen at different levels when they are established in the same field. Also, the free-nodulating *Gliricidia* or promiscuous varieties of soybean can nodulate profusely and fix a great deal of nitrogen depending on the effectiveness of the rhizobial populations present.

2.4 FACTORS LIMITING BIOLOGICAL NITROGEN FIXATION

Interactions between the microsymbiont and the plant are complicated by edaphic, climatic, and management factors. A legume- *Rhizobium* symbiosis might perform well in a loamy soil but not in a sandy soil, in the subhumid region but not in the Sahel, or under tillage but not in no-till plots. These factors affect either the microsymbiont, the host-plant, or both.

2.4.1 Edaphic Factors

Edaphic factors relate to the soil. The six main edaphic factors limiting biological nitrogen fixation are:

- excessive soil moisture,
- drought,
- soil acidity,
- P deficiency,
- excess mineral N, and

- deficiency of Ca, Mo, Co and B.

Excessive moisture and waterlogging prevent the development of root hair and sites of nodulation, and interfere with a normal diffusion of O_2 in the root system of plants. *Sesbania rostrata* and *Aeschynomene* sp. can actively fix N_2 under these conditions because they are located on the plant stems, rather than on the roots.

Drought reduces the number of rhizobia in soils, and inhibits nodulation and N_2 fixation. Prolonged drought will promote nodule decay. Deep-rooted legumes exploiting moisture in lower soil layers can continue fixing N_2 when the soil is drying. Mycorrhizal infection has also been found to improve tolerance of plants to drought (e.g., *Acacia auriculiformis* inoculated with the ectomycorrhizal *Baletus suillus*). Mycorrhiza are symbiotic associations between fungi and plant roots. Some mycorrhizal fungi develop exclusively outside the roots; these are called ectomycorrhiza (e.g., *Baletus suillus*). Others, called endomycorrhiza, grow inside the roots with their vesicles and arbuscules inside the roots and with their fungal filaments extended outside (e.g., *Glamus* sp.) . These are the vesicular-arbuscular mycorrhiza, usually referred to as VAM.

Soil acidity and related problems of Ca deficiency and aluminum and manganese toxicity adversely affect nodulation, N_2 fixation and plant growth Research work on the identification of symbioses adapted to acid soil should focus on the host plant, because effective rhizobia adapted to soil acidity can be found naturally and can be produced through genetic manipulations.

Phosphorus deficiency is commonplace in tropical Africa and reduces nodulation, N_2 fixation and plant growth. Identification of plant species adapted to low-P soils is a good strategy to overcome this soil constraint. The role of mycorrhizal fungi in increasing plant P uptake with beneficial effects on N_2 fixation has been reported. Dual inoculation with effective rhizobia and mycorrhizal fungi shows synergistic effects on nodulation and N_2 fixation in low P soils . The use of local rock phosphate has been recommended, particularly in acid soils, as an inexpensive source of P. The addition of P-solubilizing microorganisms, particularly of the general *Psemdamaias*, *Bacillus*, *Penicillium*, and *Aspergillus* can solubilize rock phosphate and organically bound soil P (which constitutes 95 - 99% of the total phosphate in soils). However, the use of these microorganisms is not widespread. Some reports show nodulation response to K under field conditions. However, other investigators consider the K effect to be indirect, acting through the physiology of the plant.

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* Trees are usually infected by mycorrhizal fungi in natural ecosystems in the tropics. The significance of this symbiosis in nature should be better recognised.

Mineral N inhibits the *Rhizobium* infection process and also inhibits N_2 fixation. The former problem probably results from impairment of the recognition mechanisms by nitrates, while the latter is probably due to diversion of photosynthates toward assimilation of nitrates. Some strains of *Rhizobium,* and particularly stem-nodulating *Azarhizobium caulinodans* , fix N_2 actively even when plants are growing in high-N soils (e.g., in the presence of 200 kg fertilizer N ha^{-1}) . Application of large quantities of fertilizer N inhibits N_2 fixation, but low doses (<30 kg N ha^{-1}) of fertilizer N can stimulate early growth of legumes and increase their overall N_2 fixation. The amount of this starter N must be defined in relation to available soil N.

Various microelements (Cu, Mo, Co, B) are necessary for N_2 fixation. Some of these are components of nitrogenase for example Mo.

2.4.2 Climatic Factors

The two important climatic determinants affecting BNF are temperature and light.

Extreme temperatures affect N_2 fixation adversely. This is easy to understand because N_2 fixation is an enzymatic process. However, there are differences between symbiotic systems in their ability to tolerate high (>35°C) and low (<25°C) temperatures.

The **availability of light** regulates photosynthesis, upon which biological nitrogen fixation depends. This is demonstrated by diurnal variations in nitrogenase activity. A very few plants can grow and fix N_2 under shade (e.g., *Flemingia congesta* under plantain canopy). In alley farming if hedgerows are not weeded, or if trees are planted with food crops like cassava, their nitrogen fixation and growth will be reduced due to shading. Early growth of legume trees is slow and they cannot compete successfully for light.

2.4.3 Biotic Factors

Among biotic factors, the absence of the required rhizobia species constitute the major constraint in the nitrogen fixation process. The other limiting biotic factors could be:

- excessive defoliation of host plant,
- crop competition, and
- insects and nematodes

Inoculation of Legumes

If specific and effective rhizobia are absent in a soil, or if they are present in low numbers, it is necessary to introduce the rhizobia in that soil to ensure proper nodulation and nitrogen fixation. This is called inoculation. If specific and effective rhizobia are present in a sufficient number, there will be no need to inoculate the legume. In agrisystems, whenever one is not sure of the presence and effectiveness of the native rhizobia, it could be necessary to inoculate the legume with an adequate strain of rhizobia.

How one can determine the need for inoculation? There are some simple tests: Are nodules absent or sparse on an uninoculated young plant growing in a low-N soil? (This is normally accompanied by plant N deficiencies). Or, are nodule sections white or green? (This is an indication of poor effectiveness).

A more accurate relative effectiveness trial will provide more precise information. The trial, in a simple term, consists of growing the legume with and without fertilizer N while controlling all other limiting factors. The relative effectiveness ratio (RE) is then calculated. RE is defined as: dry weight of unfertilized plants x 100/dry weight of fertilized plants. If the value of RE is more than 5, the inoculation is not required.

When the rhizobia in a soil are infective (i.e., capable of colonizing and nodulating a legume) but poorly effective, they constitute a barrier to the successful exploitation of *Rhizobium* inoculants. Introduced rhizobia must therefore be more aggressive and competitive as nodulators than the native strains. Inoculant rhizobia usually persist in the soil for long periods, particularly when the host is cultivated frequently or is permanent. Persistence of a strain is desirable because it obviates the need for inoculation in subsequent years, assuming inoculant strains maintain their original effectiveness.

Inoculation with rhizobia is usually recommended for newly introduced legumes. Most positive responses to inoculation are confined to crops which have specific requirements for *Rhizobium* (e.g., *Leucaena leucocephala*, American varieties of soybean). Indigenous legumes seldom respond to inoculation with introduced rhizobia because they nodulate with resident strains, even if these native rhizobia are not the most effective ones.

Inoculation with rhizobia should be considered as an exceptional farming practice rather than the rule. In Australia and the USA, inoculation has played a vital role in legume production. But in developing countries, the practice is not widespread. The major drawback to inoculation technology is the wide variability in yield responses in time and space for a given *Rhizobium* -legume symbiosis. Responses can vary from no response, and sometimes negative responses, to positive yield increases. Response to inoculation with a strain of *Rhizobium* vary with sites, legume cultivars, and the form of inoculant. Changes in climate, such as Africa's long droughts in recent years, and management factors including cropping systems and inoculant handling will also introduce variability in response to inoculation. Local rhizobia are not necessarily better inoculants than exotic strains.

All these considerations call for a substantial research support system capable of defining the most appropriate inoculants and procedures for each site and probably for each cropping season as well. The use of freely nodulating legumes will be much easier in this respect.

Inoculation procedures are detailed in Volume 1 of this training manual (see Appendices).

Defoliation, Crop Competition, and Pests

Defoliation (e.g., pruning and lopping) decreases the photosynthetic ability of legumes. It impairs N_2 fixation and can lead to nodule decay. For perennial legumes, nodule decay sheds a high number of rhizobia in the root zone. When new roots develop in subsequent vegetative cycles, nodulation of the legume is expected to improve. Scientists at IITA have observed that uninoculated *Leucaena leucocephala* nodulated very sparsely the first year and showed nitrogen deficiency symptoms. After a number of years nodulation improved and N deficiency symptoms disappeared.

Intercropping legumes with non-leguminous crops can result in competition for water and nutrients. This competition can affect N_2 fixation negatively. However, it has been shown that when mineral N is depleted in the root zone of the legume component by the non-leguminous intercrops, N_2 fixation of legumes may be promoted.

Insects and nematodes have also been reported to interfere with nodule formation, development, and functions.

2.5 ESTIMATION OF NITROGEN FIXATION

From the biochemical reactions of BNF presented in section 2.1, it is evident that N_2 fixing systems contribute to the quality and quantity of agricultural production. Measurement of BNF can provide information on whether actual N_2 fixation i. adequate. We discuss below two simple methods of BNF estimation. Measurement of BNF is a more reliable method than nodule counting, nodule weighing, or assessment of leghemoglobin.

2.5.1 Short-term Estimation of BNF: Acetylene Reduction Assay

Nitrogenase not only catalyzes the reduction of atmospheric N_2 to NH_3, but can also reduce acetylene (C_2H_4). The acetylene reduction assay (ARA) is carried out on detached nodules, detopped roots, or whole plants in a closed vessel containing 10% acetylene. A gas chromatograph is used to determine the amount of ethylene formed. Data are usually expressed as nanomoles or micromoles of ethylene produced per hour per plant or per weight unit of nodules. The acetylene reduction assay provides an instant measure of nitrogenase activity (but not necessarily of N_2 fixed) under the experimental conditions.

For long-term estimates, a series of measurements must be performed to include diurnal, daily, and seasonal changes. Variation in light intensity, temperature, and moisture in the field will increase the level of variation of nitrogenase activity and will reduce the significance of integration of short-term assays. A problem that is inherent in ARA is the need to calibrate the rates of ethylene production with the actual rates of N_2 fixation. The commonly used ratio of 3:1 for acetylene reduced per N_2 fixed is not always valid. Also, nitrogenase activity of some legumes declines considerably once nodules or roots are detached from the rest of the plant. For plants with long roots, it is difficult to collect all the nodules. To minimize this limitation, the plants are confined to open ended chambers and ARA is done *insitu*.

2.5.2 Medium-term Estimation of BNF: N-solute Analysis of Xylem Exudate

N-solute analysis of xylem exudate is a medium-term type of estimate because it involves the integration of more than one hour of events. The underlying principle is based on the fact that nitrogen from BNF can be transported to the leaves in the form of (1) ureides, allantoin and allantoic acid, or (2) asparagine and glutamine. In agricultural soils, where nitrate is the most readily available form of N for plant growth, the solutes derived from soil mineral N will contain principally free nitrate and organic products of nitrate reduction in the roots. Correlations can be established between the N_2 fixed nitrogen in forms (1), (2), and soil-derived N. Using these correlations, it should be possible to assess N_2 fixation, or at least to obtain an index of BNF by collecting and analyzing plant sap for the above-mentioned N compounds.

The methods are simple and have been used successfully in ureide legumes. Solute analysis can be used in farmers' fields because it is virtually non-destructive. It is also relatively inexpensive. Repeated measurements are also required to fully integrate measurements of total N fixed over a long period of time. Table 2 presents the occurrence of ureides in xylem sap of nodulated legumes.

Table 2. Occurence of ureides in xylem sap of nodulated legumes (Peoples et al. 1989)

Species in which ureides are major components of solute N (a)	Species in which ureides have been detected as a minor component (b)	Species in which ureides have not been detected
Albizia lophantha	Albizia falcataria	Acacia alata
Cajanus cajan	Bossaiae aquifolium	auriculiformia
Calopoganium caeruleum	Erythrina variegata	extensa
Centrosema spp.	Flemingia congesta	insauvis
Codariocalyx gyroides	Gliricidia sepium	pulchella
Cyamopsis tetragonoloba	Pisum arvense	Arachis hypogaea
Desmodium discolor	Sesbania rostrata	Baubinia spp.
renssonii	sesban	Caesalpinia
uncinatum	calothyrsus	Calliandra spp.
Stylosanthes bamata	Vicia ervilia	Cicer arietinum
Glycine max	sativa	Clitoria spp.
Hardenbergia spp.	Viminaria juncea	Derris elliptica
Lablab purpureus		Juncea spp.
Macroptilium atropurpureum		Lathyrus cicera
Macrotyloma uniforum		sativus
Pueraria javanica		Leucaena spp.
Phaseoloides		Lens culinaris
Phaseolus vulgaris		Lotus corniculatus
eunatus		Lupinus albus
Phophocarpus tetragonolubus		angustifolius
Tedbegi spp.		cosentinii
Vigna angularis		mutabilis
mungo		Medicago minima
radiata		sativa
triloba		Mimasa pigra
unguiculata		Pisum sativum
umbellata		Sesbania grandiflora
Voandzeia subterranea		Trifolium paratense
		subterraneum
		repens
		Vicia monantha
		faba
		Zornia spp.

(a) 40% or more of total N of xylem sap estimated to be in ureides.
(b) 10-25% of total N of xylem sap collected from glasshouse-grown or field plants estimated to be in ureides.

2.6 How to Increase BNF and N_2 Fixing Ability

Biological N_2 fixed represents N gain and determines inorganic N fertilizer savings in cropping systems. Legumes can fix more than 250 kg N ha^{-1}. However, the amounts of N_2 fixed can vary considerably in time and space. The nitrogen fixation process is influenced by factors such as:

- presence and effectiveness of rhizobia,
- pest damage,

- plant genotype and age,
- plant and rhizobia interactions,
- changes in soil physiochemical conditions, and
- various management practices such as tree pruning or pesticide application that can affect both symbiotic partners.

Four common approaches to enhance biological nitrogen fixation are:

- inoculation with proven strains (covered above),
- microbial screening for improved strains,
- host-plant screening and breeding, and
- adoption of cropping systems and cultural practices.

Microbial Screening

There are collections of effective rhizobia located at centers around in the world for most, if not all, legumes used in agriculture (Takishima et al, 1989). These strains may be screened to identify the most effective and competitive one(s) for a given agroecosystem. Once elite strains have been identified, the legume under consideration is inoculated. Instructions on inoculant use are usually given by the manufacturers. Seed inoculation using peat inoculant is the most commonly used method. However, studies are under way to assess the effectiveness of post planting inoculation as a corrective measure. Dual inoculation of rhizobia and mycorrhizal fungi has proven beneficial in some cases.

Host-plant Screening and Breeding

A screening of legume plants, with high N_2-fixing components can be carried out. Breeders have developed plant varieties with promiscuous nodulation to obviate the need for inoculation with rhizobia. In some laboratories in the USA, plants that do not nodulate with indigenous rhizobia but only with introduced "super" strains are being developed.

There are still many unexploited legume-*Rhizobium* symbioses in the world. The potential benefit of screening these symbioses is underscored by the fact that only about 0.5% of existing leguminous species are presently used for agricultural purposes.

Cropping Systems and Cultural Practices

It is evident that inclusion of N_2-fixing components in cropping systems will increase N inputs in agrisystems. Cultural practices can control some of the above-mentioned factors which limit BNF. Mulching, for instance, can control weeds and fluctuations of soil moisture and temperature. Liming can eliminate soil acidity, and Al and Mn toxicities.

2.7 SUMMARY

Since nitrogen is commonly the most limiting plant nutrient in arable farming in the tropics and also the most expensive element as a mineral fertilizer, biological nitrogen fixation (BNF) holds great promise for smallholder farmers in sub-Saharan Africa. Alley farming systems which use leguminous woody species in the hedgerows can reduce or eliminate farmers' needs for commercial N fertilizer.

Biological nitrogen fixation is the process of capturing atmospheric nitrogen by biological processes. It is accomplished by certain microorganisms and plant-microbe interactions. Legumes are N-fixing systems that have long been used for biological nitrogen fixation in agriculture.

Biologically fixed nitrogen can be estimated using the acetylene reduction assay method, xylem exudate analysis, or by other methods.

A number of edaphic, climatic, and biotic factors inhibit N_2 fixation. Among these, the absence of specific and effective rhizobia in the soil is the most important. The amount of biologically fixed nitrogen can be enhanced by different methods, including inoculation with proven strains, screening for improved microbial and host-plant materials, and introduction of improved cultural practices.

2.8 FEEDBACK EXCERCISES (Find out answers from the text)

1) Provide a brief answer to each of the following:
   a. What is nitrogenase?

      ____

   b. Name 4 microorganisms in which nitrogenase may be found.

      ____

      ____

      ____

      ____

c. What is the role of ATP in biological nitrogen fixation?

____

d. What specific functions do flavodoxin or ferredoxin perform in biological nitrogen fixation?

____

2) a. Complete the missing components of the mechanism of N2 fixation as shown below:

N_2 -------> ....?.... --------> amino acids -------> ...?....
+ ATP
+ ...?.....
+ ...?.....

b. Match the names of the Rhizobium species (on the left) with the appropriate host-plants (on the right).

. Cowpea rhizobia group	*Medicago sativa* (Alfalfa)
. *Rhizobium fredii*	*Leucaena* sp.
. *Rhizobium meliloti*	*Glycine max* (Soybean)

3) Circle T for true and F for false.

a. Excessive moisture in the soil inhibits biological nitrogen fixation primarily by creating iron toxicity.

T F

b. Under dry conditions, deep-rooted legumes behave exactly the same way as shallow-rooted legumes in terms of the amount of nitrogen fixed T F

c. Phosphorus deficiency reduces plant growth and nodulation, thereby adversely affecting nitrogen fixation.

T F

d Excess mineral nitrogen in the soil will enhance nitrogen fixation by legumes because it increases plant vigor.

T F

e. Because biological nitrogen fixation normally occurs in the roots, light availability will have no impact on N_2 fixation.

T F

f. Different symbiotic systems have different tolerances to temperatures.

T F

g. *Inoculation is the process of introducing specific and effective rhizobia in the soil to ensure nodulation and nitrogen fixation.* T F

h. Defoliation of pruning increases nitrogen fixation by creating a greater demand for nitrogen by the plants. T F

4) What are the two major benefits of growing leguminous species in the hedgerows of an alley farm, as compared with non-leguminous hedgerows? (select 2 from the list)

a. Leguminous hedgerows protect the food crops from wild animals.

b. Prunings from leguminous hedgerows are source of nutritious protein-rich feed for livestock.

c. Leguminous hedgerows prunings have insecticidal value and their incorporation in soils protects plants from soil-borne pests.

d. Prunings from leguminous hedgerows provide cheap nitrogen for food crops.

e. Leguminous hedgerows create a cool microclimate which indirectly benefits the associated crops.

2.9 SUGGESTED READING

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TECHNICAL PAPER 3

Agroforestry Systems-Concepts and Classification

3.0 Performance Objectives

3.1 Introduction

3.2 Basic Elements of a System

3.3 Application to Agriculture and Agroforestry
3.3.1 Farming Systems
3.3.2 Other Systems

3.4 Systems Analysis
3.4.1 System Assessment Criteria
3.4.2 Analytical Steps

3.5 Systems and Interdisciplinary Research

3.6 Classification of Agroforestry Systems

3.7 Summary

3.8 Feedback Exercises

3.9 Suggested Reading

3.10 References

3.0 PERFORMANCE OBJECTIVES

Technical paper 3 is intended to enable you to:

1. Explain the systems concept.
2. Describe 6 basic elements of a system.
3. Discuss the use of systems terminology in agriculture and agroforestry.
4. Describe analytical steps in systems analysis.
5. Explain interdisciplinary nature of systems research approach.
6. Identify criteria to classify agroforestry systems.
7. Classify agroforestry systems.

Technical Paper 3:

Agroforestry Systems — Concepts and Classification

M. Avila

3.1 INTRODUCTION

The word system is used very often in the agricultural research and development literature. Yet use of the system concept is rather a recent development and consequently lacks uniformity in its conceptual definition and methods of approach. In a broad sense, a system is defined as a group of associated elements forming a unified whole and working together for a common goal. For example, the sociological household is a system composed of elements of persons, resources, customs, etc. A farm is an agricultural system composed of crops, livestock, trees, etc.

An important characteristic of a system is that since different elements of the system are interrelated, a change in one element causes change in one or more of the other elements. Further, an element of a system can itself be considered as a system. The crop production activities of a farm constitute its cropping systems. An animal is also an example of a living system, an element of the animal production system. Every system can be thought of as one component of another larger system.

Many different systems approaches are used by scientists to unravel complexities. Humankind is ever busy trying to understand the real world. To make sense of reality, scientists use their imagination to define systems that simplify real phenomena. Systems can be of any size or complexity varying from a molecule to a solar system. Where systems are highly complex, they are studied in terms of sub-systems. Models, which are extensions of the known to understand the unknown, are often used to visualize systems. A model is appropriate if it incorporates all relevant elements and their relationships. Reality, however, is too complex to be represented completely by a model.

Although scientists are always keen on the descriptive and/or analytical value of their systems, other professionals and practitioners are also interested in systems, perhaps for different reasons. For example, the systems approach can be effective for management (e.g., for monitoring key factors that can improve operations and performance), predictions (knowing what will happen if key factors change in the future), or for training (e.g., for auto mechanics, electronics, agricultural production).

A systems approach helps to focus attention on what is important, effective, and practical.

3.2 BASIC ELEMENTS OF A SYSTEM

A system may have many elements. The six basic elements of any system are:

- boundary
- structure
- function
- state
- hierarchy
- type

A system has a boundary, This clearly defines what remains inside (endogenous) and what remains outside (exogenous). Understanding a system means knowing how the endogenous parts relate to each other and how they independently and holistically relate to the exogenous environment. Boundaries can be real or imaginary.

A system has structure. This refers to how the parts relate to each other in terms of space and time. In other words, structure signifies spatial and temporal arrangements.

A system has function. This refers to input-output relationships. A function is a process in which inputs are introduced, managed, and converted into outputs within a time spectrum, in order to achieve desired objectives or goals.

A system also has state. For example, a steady state system is one that does not experience any change in structure or function within a given period. This would not be the case in a system that is just being developed, or a system experiencing a declining state of resources or productivity. Both endogenous and exogenous factors can cause changes in the state of the system.

There is a hierarchy of interrelated and interdependent systems. For example, a human being system is part of a household system, which is part of community system, which is part of a regional system, which is part of a nation, which in turn is part of a community of nations. This means that the analysis of any system in this hierarchy must take cognizance of the influence of higher and lower-order systems. For example, one cannot fully understand an individual person's behavior without understanding the household and community of which he or she is part.

Furthermore, there is the question of how generally or specifically a system is defined. One could describe and analyze a human being system, for example, at a general level such that it applies to all human beings on earth, or at a very detailed level such that each person is, in fact, a different system. Thus the choice of the precise level in this hierarchy is critical for systems definition and analysis.

Basically, there are two types of systems: mechanistic and purposeful. In the former, behavior is predictable as the system does not determine its own goals, rather it reacts to predetermined stimuli (e.g., a computer or an airplane). A puposeful system determines its own goals and the ways to achieve them (e.g., an animal, household or nation).

3.3 APPLICATION TO AGRICULTURE AND AGROFORESTRY

There are many uses of systems terminology in agriculture, such as ecozone system, land use system, farming system, cropping system, livestock system, agroforestry system. Let us develop one of which is in common use today, the farming system, and refer to it to explain others.

3.3.1 Farming Systems

Most experts agree to a definition of a farming system as a combination of crops, livestock, and trees, managed in diverse spatial and temporal arrangements, subject to biophysical and socioeconomic conditions, to satisfy the household's objectives and priorities. Such a system can be described, first, in terms of structure (Figure 1). Literally, structure is what one sees on a farm and where each component is located in relation to the others: boundary, buildings, crops, animals, etc. Often the structure of a farming system is subject to seasonal variations within or across years particularly with respect to the temporal arrangement of annual crops.

A farming system can also be described functionally, as in Figure 2. This is a qualitative representation, indicating the endogenous interactions among production systems and the household, and also the exogenous interactions with the environment. It is imperative to quantify these interactions in order to understand how well this system is managed and how well it is meeting the household's objectives as well as to identify its constraints.

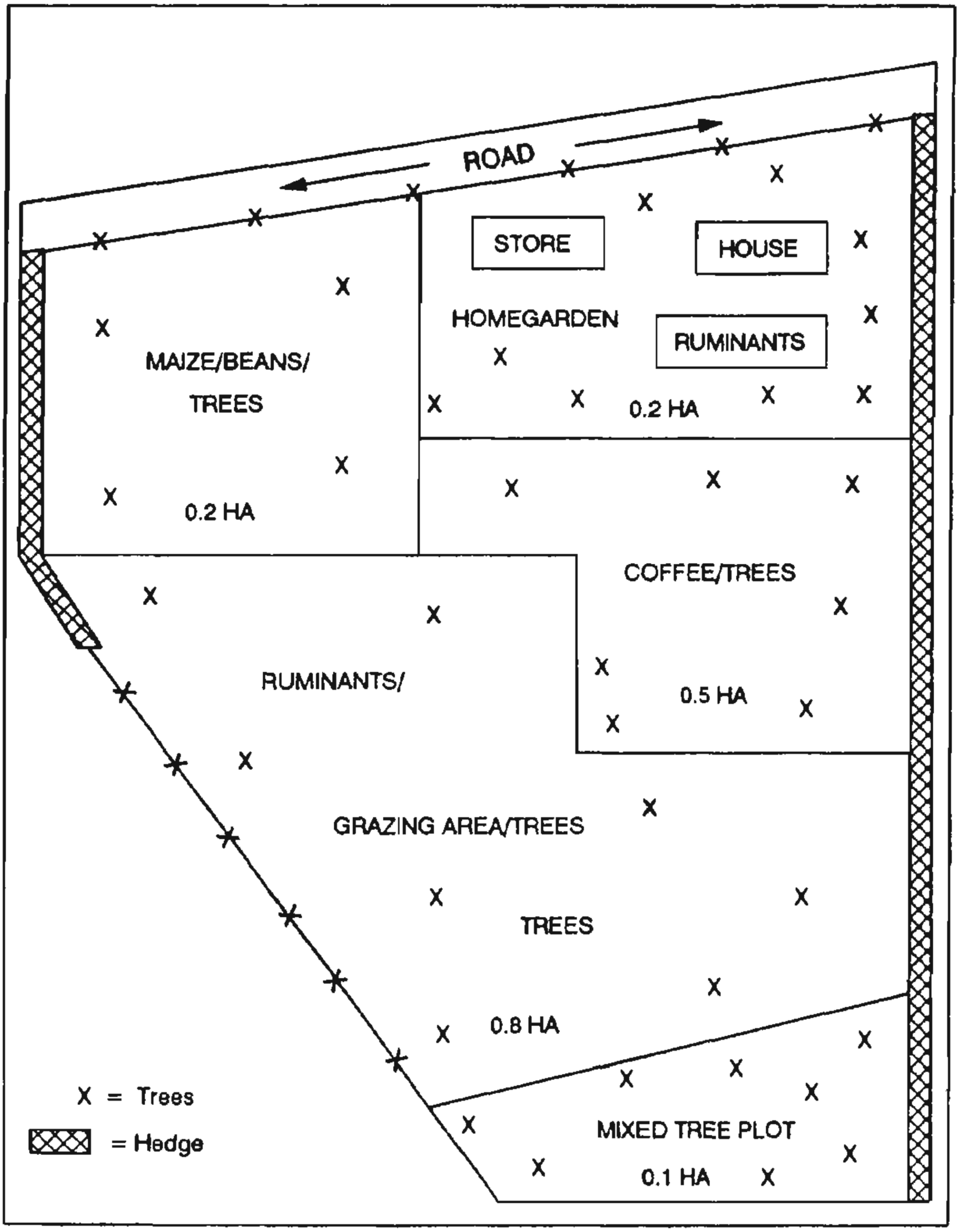

Figure 1. The structure of a sample small-farming system. This is an example of *structural* description in system analysis.

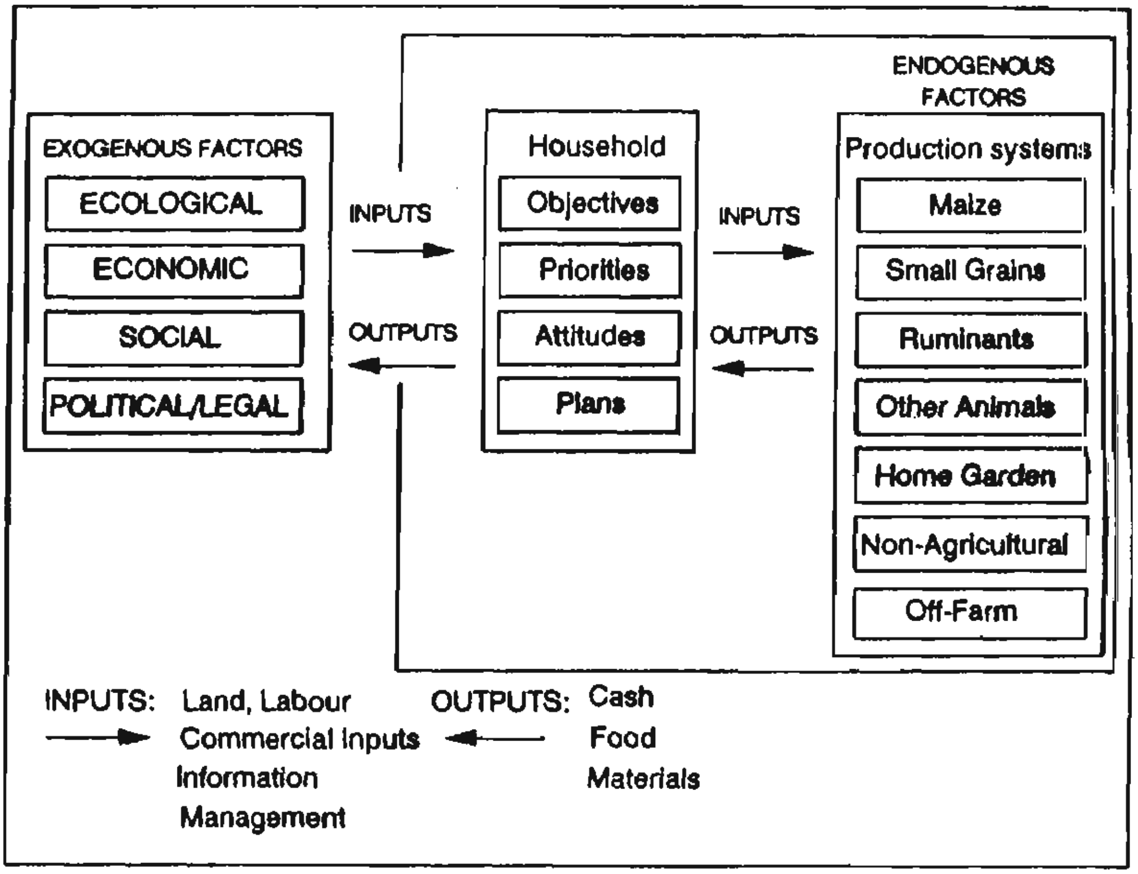

Figure 2. **Production systems in relation to household goals and exogenous factors. This is an example of *functional* description in system analysis.**

3.3.2 Other Systems

Cropping and Livestock Systems: A structural description of the crop component alone, that is to say the cropping system of a farming system, is presented in Figure 3. The figure shows how different cropping patterns are managed with respect to spatial and temporal arrangements. A functional description of the livestock component is presented in Table 1. It identifies the specific contributions of various livestock species to the household and to other components of a farming system.

Agroforestry systems: The presence of trees on external and internal boundaries, cropland, homestead plots or on any other available niche of farmland, defines the agroforestry systems structurally (see Figure 1). There are several agroforestry systems on this farming system, and each can be described functional, i.e., in terms of inputs used and outputs generated. Table 3 contains a full list of structural and functional considerations which can be used to define and analyze agroforestry systems. However, it is essential to remember that any agroforestry system can be subdivided into other systems and is a part of larger systems.

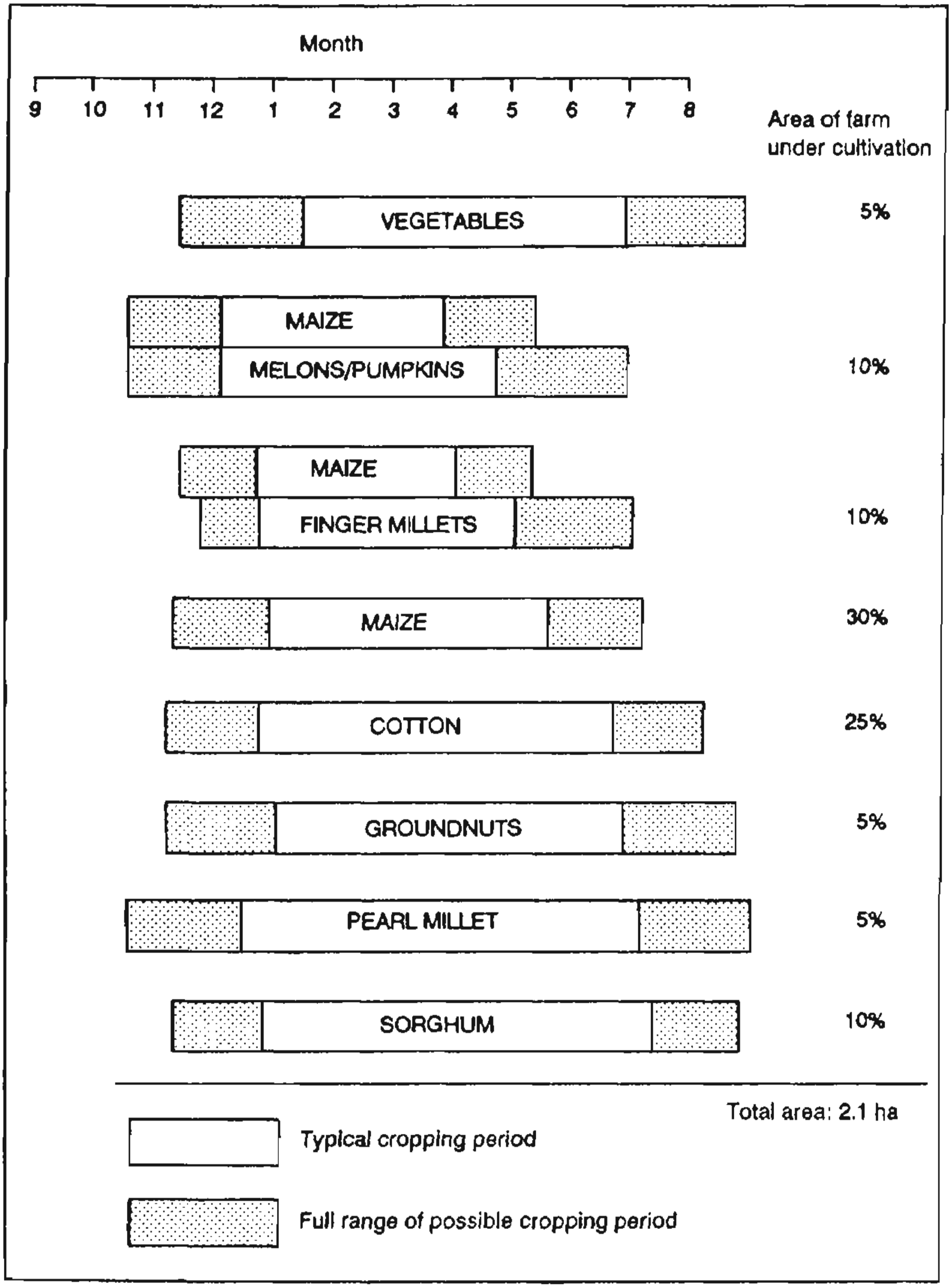

Figure 3. Structure of cropping sub-system of a small-scale farming system.

Land-use systems: What is a land-use system? Each system identified thus far can be described and analyzed with emphasis on how land as an essential resource is being used and managed by the household in the farming system or in any production system.

The land-use systems analysis could comprise:

- household priorities and objectives,
- land-use intensity, namely, units of inputs or labor per hectare,
- levels of management,
- productivity levels and potentials, and
- disposal and use of outputs.

Similarly, one could analyze systems defined on the basis of other crucial factors such as labor, household information, or market participation. It is all a question of the desired focus or emphasis for understanding a given farming system or its parts.

Ecozone System: One usually wants to study farming systems within a larger system, e.g., an ecozone system. The latter could be defined on the basis of homogeneous characteristics such as altitude, climate, topography, soil type, or vegetation; or, alternatively, on the basis of specific farming and/or production systems which reflect to a large extent what is feasible in terms of the above agroecological determinants. The analysis at this level can be conducted as follows: If one studies many farming systems in a particular ecozone, one notices common patterns with respect to strucutural and/or fuctional characteristics which provide a logical basis for classifying farming systems. A general definition criteria (e.g., systems with maize and cattle), will encompass a greater number of farms, while a more specific definition criteria (e.g., systems with specific management and yield levels of maize), will contain a lesser number of farms.

3.4 SYSTEMS ANALYSIS

Systems analysis aims at comparing one system with others or assessing the comparative performance of the same system over different periods of time. The performance of a system depends to a large extent how its components interact, both structurally and functionally. To analyze a system one should use assessment criteria based on the relationship between structural and functional components of the system. Farming systems in tropical environments are typically characterized by multiple combinations of structural and functional interactions and therefore it is important to identify such interactions and to quantify their positive and negative effects.

Table 1. Qualitative assessment of livestock roles in a farming system

Role	Cattle	Goats	Sheep	Donkeys	Pigs	Poultry	Wildlife
Food							
Meat	X	XXX	X			XXX	XX
Milk	XX	X					
Egg						XXX	
Traction							
Land prep	XXX			XXX			
Cultivation	X						
Transport	XX			XXX			
Manure/Fert.	XXX	X	X			X	
Storage							
Food Supply		XXX	X		X	XXX	
Capitalization	XXX	XX	X				
Seasonal feed excesses	XXX	XXX	X		X	XX	
Weed and Bush Control	X	X					XX
Cultural Needs							
Contract agreement	XXX	XX					
Rituals	XXX	XXX				X	
Ornamentation	X	X					XX
Sports/Recreation	X	X					X

X = Weak XX = Moderate XXX = Strong

3.4.1 System Assessment Criteria

Three useful indicators of performance for a system are:

- Management intensity, which is measured as an input/input ratio. For example, amount of fertilizer/ha, or labor input/ha.

- Productivity, which is measured as an output/input ratio, For example, yield/ha, or yield/livestock unit.

- Profitability, which is measured as output value/input. For example, net benefit invested or net benefit/ha.

Other indicators include those related to the physical resource status, such as soil fertility and structure, or vegetation cover.

The criteria are calculated for a given time period, usually a season or year. If one studies how and why these indicators vary over the medium term (2 - 5 years) or the long term (5 - 15 years), then one can assess whether the system in question is stable and sustainable. Thus, sustainability of a system can be ascertained by studying long-term trends in the indicators of physical resource status, management intensity, productivity, and profitability.

3.4.2 Analytical Steps

In a general sense, systems analysis means an explicit consideration of system objectives, interplay of endogenous components and factors, and interaction/linkages with exogenous systems; the analysis uses the time factor as an important variable. On the basis of the preceding sections, the systems analysis process can be broken into a series of steps, each answering one of the following key questions:

<u>Present Performance of the System</u>

- **What is the structure of the system(s)?** The structural components refer to basic resources such as edaphic, biotic, abiotic, or economic resources.. Structural assessment involves a specification of boundary and spatial, as well as temporal arrangements of physical components; this is usually done on a qualitative and/or quantitative basis.

- **What is the function of the system(s)?** The functional components refer to management resources, viz. input levels used, technological and economic input, and output levels achieved, both in physical and/or economic terms.

Functional assessment involves a description of inputs (use of labor, cash inputs, information), outputs (food, feed, materials) and their disposal (home consumption, sale), and the timing of when these events occur. Management and performance analysis is needed here, including quantitative analysis. Bio-physical as well as socioeconomic criteria should be used for functional assessment over a given period such as 1, 2, or 5 years.

- **What is the state of the system?** Answering this requires analysis of trends with respect to changes in the basic structure and/or functions of the system. Stability and sustainability are important considerations in this step.

In all these investigations, the influence of risk and uncertainty factors (e.g., climate price structure, human emergencies) should not be underestimated, especially in agriculture-based systems.

Future Improvements

The above questions seek information on the present performance of the systems. If the task is to improve the system, then one must ask a set of additional questions:

- **What are the objectives of the system manager(s)** (e.g., farmer and household). And how do those objectives match up with present system performance? It should be noted that, although the manager's objectives and priorities for the system may not acceptable to all, they can be ascertained and recorded accurately.

- **What are the positive and negative effects on the system of the present component structures and/or functions?** How could they be modified or replaced to achieve higher levels of performance? Any proposed interventions must to be appropriate and acceptable to the manager(s).

- **What are the positive and negative effects on the system of exogenous factors**, and what should be done about these factors to move the system in the desired direction?

- If endogenous and/or exogenous changes should be carried out, **what adjustments of structure and/or function are required** by the system manager to successfully implement the proposed changes? Are they feasible technically, managerially, and economically?

The primary focus analysis of system performance is the identification of *constraints and key opportunites for improvement. This leads to a better understanding* of the type of changes to structure and function that would be required to make the system perform as expected by its manger(s) — whether fine-tuning, incremental changes, or major changes.

3.5 SYSTEMS AND INTERDISCIPLINARY RESEARCH

Research with a systems approach is used in almost all biophysical disciplines, such as ecology, genetics, soil science, husbandry, pathology, and engineering, as well as in social science disciplines including economics, sociology, anthropology, and political science. However, there is a major difference in the conceptual framework and analytical methods used by natural scientists, as compared to social scientists. For the former, research typically deals with plants, organisms, and animals under "controlled" conditions, while for the latter, research deals with people in their "natural" habitat where "controls" can be exercised only through analytical methods. In this respect, each discipline in the natural and social sciences has different tools for studying and improving land-use production systems.

An interdisciplinary, systems approach is often used in research on land-use systems, whether homogenous or mixed systems (Table 2). Research to improve any of the land-use systems shown in Table 2 would require interaction among scientists from the different disciplines. Particularly in the case of mixed systems, interdisciplinary research can be quite complex and challenging. To be effective, team interaction should be based on a consensus on the systems analysis process and on the specific contribution to be made by each discipline to the overall research strategy. Productive interdisciplinary research requires a leader or leaders possessing expertise in systems analysis, orientation to client farmer needs, technical know-how, and team management skills.

3.6 CLASSIFICATION OF AGROFORESTRY SYSTEMS

Agroforestry systems can be classified in different ways using structural and functional considerations (Table 3). One common classification of agroforestry includes agrosilvopastoral, silvopastoral or agrosilviculture systems, which can be further sub-divided depending on specific arrangements and/or functions.

Table 2. Types of land-use systems.

Type of System	Examples of Components
Homogenous Systems	
Monocropping systems,	Maize, wheat, rice.
Mono-animal systems	Cattle, sheep, poultry.
Mono-tree systems	Timber plantations, woodlots.
Mixed Systems	
Crop-crop	Maize/cassava, maize/beans.
Animal-animal	Cattle/goat, cattle/poultry.
Crop-animal	Maize/cattle, cereals/poultry/household waste.
Crop-tree	Alley farming, mixed intercropping, boundary tree planting.
Animal-tree	Alley grazing, fodder tree banks.
Crop-animal-tree	Homegardens, alley farming with Livestock.

Another classification divides agroforestry systems into "mainly agrosilvicultural" (i.e., trees with crops), "mainly or partly silvopastoral" (i.e., trees with pasture and livestock) "tree-component predominant", and "other components present". This scheme recognizes further subdivision according to structural or functional considerations (Table 4). This particular classification is probably best suited for analysis of the potentials of agroforestry.

More recently, with a view to reviewing and synthesizing the state-of-the-art in agroforestry research and development for an annual ICRAF three-week course, the author and a lecturing team adopted the classification shown in Table 5.

Table 3. ***Structural and functional criteria for defining and classifying agroforestry systems.***

Criteria for Definition and Classification Plot	Homestead/ Garden	External Boundary	Internal Boundary	Annuals	Pere-nnials	Grass land	Tree plot	Other
1. Spatial Arrangement								
. Line	X	X	X	X	X			
. Strip			X					X
. Block							X	
. Mixed	X			X	X	X		
2. Time Arrangement								
. Concurrent	X	X	X	X	X	X		
. Relay					X	X		
. Rotational					X	X		
3. Management								
. Crown lopping (e.g., Selective lopping, Pollarding)		X	X		X	X		
. Hedging				X				
. Coppicing				X				
. Graze/browse				X				
. Free growing		X	X					
Outputs *								
. Human food	X							
. Livestock feed	X	X	X	X	X	X	X	
. Soil conservation				X				
. Wood (Poles, etc.)	X			X	X			
. Fence								
. Shelter (wind, shade)		X				X		
. Miscellaneous (latex, oil, etc).								

* Each can derive from: leaves, flowers, fruits, wood, bark and root effects.

Table 4. An example of the classification of agroforestry systems. (After Young, 1987).

1. Mainly Agrosilvicultural (trees with crops)

<u>Rotational:</u>
- Planted tree fallow
- Taungya

<u>Spatial mixed</u>
- Trees on cropland
- Plantation crop combination
  - with upper-storey trees
  - with lower-storey
  - tree/shrubs crops
  - with herbaceous crops
- Tree gardens:
  - multistorey tree gardens
  - home gardens

<u>Spatial zoned:</u>
- Alley farming
- Boundary planting
- Trees for soil conservation:
  - barrier hedges
  - on grass barrier strips
  - on bunds, etc.
  - on terraces
- Windbreaks and shelterbelts
- Biomass transfer

2. Mainly or partly Silvopastoral (trees with pastures and livestock)

<u>Spatial mixed:</u>
- Trees on rangeland or pastures
- Plantation crops with pastures

<u>Spatial zoned:</u>
- Live fences
  - mainly barrier function
  - multipurpose
- Fodder banks

3. Trees Component Predominant

- Woodlots with multipurpose management
- Reclamation forestry leading to production:
  - on eroded land
  - on salinized land
  - on moving sands

4. Other Components Present and Special Aspects
- Apiculture with forestry
- Aquaforestry (trees with fisheries)
- Trees in water management
- Irrigated agroforestry

Table 5. A second example of the classification of agroforestry systems (Torquebiau, 1989).

1.	Alley Farming (hedgerow intercropping)
2.	Crops under tree cover
3.	Pastures and animals under tree cover
4.	Agroforests (live fencing, boundary planting, windbreaks, shelterbelts)
5.	Sequential technologies (shifting cultivation, taungya, improved fallow)
6.	Other technologies (aquaculture and apiculture with trees)

Structural criteria are readily applicable in classifying agroforestry systems. In contrast, the use of functional criteria to classify agroforestry systems is uncommon. The science of agroforestry is not yet sufficiently advanced in the analysis of technology management and performance to define useful functional criteria for system classification. The occasional exceptions include, for example, speaking of alley farming for soil fertility improvement or for fodder production, or indicating how a farming system's output is to be disposed of (e.g., for home consumption, cash generation, or both).

The key task at present is to determine the most appropriate criteria to apply in classifying agroforestry systems. The choice of classification depends on its intended use of the classification. For purposes of technology development, the chosen classification should provide a useful framework for guiding research and assessing research progress.

3.7 SUMMARY

This paper presented six basic elements of a system namely, boundary, structure, function, state, hierarchy, and type. These were applied to define and describe farming systems, agroforestry systems, and land use systems. Subsequently, systems analysis was explained in terms of the types of interactions, assessment criteria, and analytical steps researchers should follow as they seek to answer specific questions related to understanding and improving sytems. The implications of the systems approach for interdisciplinary research and for classification of agroforestry systems were reviewed.

3.8 FEEDBACK EXERCISES (Find out the answers from the text)

1. Fill in blank spaces in the following sentences.

   a.) A system may be defined as a group of ____________ forming a ___________ and sharing a common _____________.

   b.) Where systems are highly complex, they are studied in terms of ______________.

   c.) Models are often used to visualize a system. However a model is appropriate only when all______________ and their ___________ are incorporated in the model.

2. Identify the correct statements.

   a.) A system has a state, which refers to input-output relationship.

   b.) All systems can be grouped into two categories, namely, mechanistic and purposeful.

   c.) A system's structure refers to spatial and temporal arrangement of its parts.

   d.) Systems are governed by the theory of hierarchy. This means every system is composed of sub-systems, which in turn are composed of further sub-systems.

3 a) Give four examples of the use of system's terminology in agriculture.

   1) _______________
   2) _______________
   3) _______________
   4) _______________

   b) Prepare a rough sketch of a farming system in terms of its functions.

c) When describing an agroforestry system as a part of a farming system, what two functional criteria can be used?

1) ____________________

2) ____________________

d) Name four indicators of system performance

1) Management intensity

2) ____________________

3) ____________________

4) ____________________

4 a) Write 3 questions that should be asked to learn about the present performance of a system.

1. ____

2. ____

3. ____

b) What additional 4 questions should be asked to address improvement of the system?

1. ____

2. ____

3. ____

4. ____

5. An interdisciplinary team is to work on constraints' analysis of some mixed production systems. Can you name 6 possible types of mixed systems for such a study?

1) Crop-crop system

2) ____________________

3) ______________________________

4) ______________________________

5) ______________________________

6) ______________________________

6 a) What are the two main types of criteria used to classify agroforestry sytems?

1) ______________________________

2) ______________________________

b) List 6 classes of agroforestry systems as per a recent ICRAF classification scheme (Torquebiau, 1989).

1) Alley Farming ______________________________

2) ________________________

3) ________________________

4) ________________________

5) ________________________

6) ________________________

c) Would this classification be useful for your research work? Why or why not?

____

____

____

____

____

3.9 SUGGESTED READING

Bertalanffy, L. von. 1973. General Systems Theory. Fourth Edition. Brazillier. New York, U.S.A.

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3.10 REFERENCES

Torquebiau, E. 1990. Introduction to the Concepts of Agroforestry. ICRAF working paper 59, 122 pp.

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TECHNICAL PAPER 4

Diagnosis and Design Methodology

4.0 Performance Objectives

4.1 Introduction

4.2 The Agroforestry Systems Research Process

4.3 Macro D & D
- 4.3.1 Identification of Study Ecozones
- 4.3.2 Delineation of Land Use Systems
- 4.3.3 Description of Land Use Systems
- 4.3.4 Analysis of Land Use Systems Constraints and Potentials
- 4.3.5 Analysis of Potential Agroforestry Technologies
- 4.3.6 Definition of Agroforestry Research Needs
- 4.3.7 Inter-Institutional Coordination

4.4 Micro D & D
- 4.4.1 Analysis of Land Use System and Constraints
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4.5 Methodological Considerations in D & D
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- 4.5.2 Research Domains and Recommendation Domains
- 4.5.3 Data Collection Methods
- 4.5.4 Analytical Methods and the Role of Farmers
- 4.5.5 Logistical and Operational Aspect

4.6 Summary

4.7 Feedback Exercises

4.8 Suggested Reading and References

4.0 PERFORMANCE OBJECTIVES

Technical Paper 4 is intended to enable you to:

1. Explain three major purposes of the Diagnosis and Design methodology developed by ICRAF and relate its role in alley farming research.

2. Discuss two main features of Agroforestry Systems Research Process and list the various steps involved in carrying out the process.

3. List four main objectives of Macro D & D and describe seven steps in conducting Macro D & D exercise.

4. Specify three main objectives of Micro D & D along with the major steps involved in performing Micro D & D exercise.

5. Recall and describe some important methodological considerations in D & D.

Technical Paper 4: Diagnosis and Design Methodology

M. Avila and S. Minae

4.1 INTRODUCTION

Diagnosis and Design (D&D) is a systematic and objective methodology developed by ICRAF to initiate, monitor, and evaluate agroforestry programs. D&D is based on the philosophy that knowledge of the existing situation (diagnosis) is essential to plan and evaluate (design) meaningful and effective programs in agroforestry research for development. The methodology plays a strategic role in all the phases of the agroforestry research process (Huxley and Wood, undated). It borrows from other methodologies used by research or development agencies, such as baseline surveys and feasibility studies. However, D&D is unique in that it has been specially developed for the following purposes (Raintree, 1987):

- to describe and analyze existing land use systems;
- to design appropriate agroforestry technologies to alleviate those constraints;
- to design appropriate research work, such as trials and further surveying.

The basic unit of D&D analysis is the land use system (LUS). The LUS can be defined and analyzed at the level of a country, ecozone, farming system, crop system, or any other unit. The structure and function of any LUS are determined by climatic, physical, biological, technological, economic, social, and political factors. D&D focuses on the interactive effects these factors have on the LUS, and searches for opportunities for improved system development in the LUS.

Within the context of alley farming research, ICRAF's D&D methodology can serve a variety of useful roles. It can, in the first place, provide a justification for alley farming research by demonstrating land use constraints which the system can address (e.g., soil degradation, land scarcity, need for low-input technologies). At the same time, it reminds researchers that alley farming is just one land use system among many, and that other agroforestry or non-agroforestry interventions may be more appropriate in specific cases. Finally, D&D methods can guide researchers as they find ways to adapt alley farming prototypes to local conditions.

D&D can be done at two level's: **Macro D&D** is a large-scale analysis of an ecozone within a country or a group of countries. For example, ICRAF has conducted collaborative macro D&D exercises with Kenya, Uganda, Rwanda, and Burundi for the bimodal highland ecozone. Macro D&D is important for deciding on national agroforestry research and extension agenda at the national level. **Micro D&D,** in contrast, focuses on one land use system (LUS) within the larger ecozone that has special priority for agroforestry intervention. Micro D&D involves a detailed analysis of households and production systems in the LUS. It leads to guidelines for research that will address the constraints of the prioritized LUS.

4.2 THE AGROFORESTRY SYSTEMS RESEARCH PROCESS

The basic objective of ICRAF's agroforestry research is to develop technologies to solve farmers' problems in priority land use systems in specific ecozones. An agroforestry technology should be specified with reference to at least its principal components: MPT species, spatial arrangement, management regimes (i.e., management of the trees and associated components), and performance levels (i.e., technical and socioeconomic criteria). To this end, ICRAF has developed a research process that uses a systems perspective and an interdisciplinary approach. D&D exercises initiate the process, and the design of agroforestry technologies is the pivotal step.

The process is called Agroforestry Systems Research. It is recommended for any D&D program in alley farming or other areas of agroforestry. There are six main steps in the process:

- Macro D&D (national and ecozone level),
- Micro D&D (land use analysis at the production systems level),
- Technology design,
- Component experimentation,
- Technology testing, and
- Technology dissemination and adoption.

The AFNETA/NARS collaborative research program as a whole encompasses all six steps. Individual AFNETA projects, however, would normally be too limited in scope to include a macro D&D exercise. On the other hand, micro D&D methods are useful in a project's pre-experimental stage, and during on-farm experimentation. (The final four steps, which are integral components of the different phases in AFNETA projects, are covered in Volume 1.)

4.3 MACRO D&D

The Objectives of Macro D&D

Macro D&D is an analysis of an ecozone within a country or group of countries. The four main objectives of the Macro D&D are:

- to identify broad issues and problems constraining all the land use systems in a given ecozone;
- to identify and prioritize areas for potential agroforestry interventions;
- to identify research priorities and formulate research programs; and
- to identify needs, opportunities, and mechanisms for inter-institutional collaboration for technology development.

To meet these objectives, macro D&D uses rapid appraisal techniques. It relies heavily on secondary data which are verified and complemented by quick field surveys.

Steps in a Macro D&D Excercise

There are seven steps in macro D&D excercise:

1. Identification of study ecozone,
2. Delineation of land use systems within the ecozone,
3. Description of land use systems,
4. Analysis of land use system constraints and potentials,

5. Analysis of potential agroforestry technologies,

6. Definition of agroforestry research needs, and

7. Inter-institutional coordination.

We will discuss these one at a time.

4.3.1 Identification of Study Ecozones

The first step in macro D&D is the selection of an ecozone for study. The zone covered in a macro D&D exercise is large, containing significant variations in land characteristics with respect to current uses and constraints. The choice of the study zone should reflect its biological and socioeconomic importance at the national level based on:

- the zone's contribution to food production and/or income;
- the total population it supports and/or the area it covers;
- the urgency of its constraints;
- the extent of its unexploited potential for production; and
- the level of its development with respect to other areas.

For example, in the case of Eastern and Central Africa, the bimodal highland ecozone seems to be an important study zone. According to Hoekstra (1988), it contains a significant proportion of the area and human population:in Kenya (15% of area and 50% of population), Uganda (40% and 62%), Rwanda (62% and 73%), and Burundi (85% and 90%).

Each ecozone contains within it a variety of land use systems (LUSs). Delineation (definition) of the LUSs is the next step in macro D&D

4.3.2 Delineation of Land Use Systems

A land use system (*LUS*)within an ecozone level can defined as follows: *It is a* population subgroup in which the features and constraints of the farming systems are sufficiently homogeneous to yield similar results if a given agroforestry technology is introduced into those farming systems. The main guideline for distinguishing land use systems is that each system should display unique constraints and potentials differentiating it from other systems in the ecozone of interest.

Accordingly, an LUS consists of a distinctive combination of soils, crops, livestock, trees and/or other production systems; it occupies a given unit of land where specific outputs are desired and obtained by a given management unit. Normally the smallest unit of decision-making is the household, but any unit (i.e., clan, communal group, cooperatives or company) that makes management decisions collectively and/or shares intimately in the input/output flows of a system is also considered to be an LUS unit. Some examples of delineated land use systems are given in Table 1 to clarify the above points.

4.3.3 Description of Land Use Systems

All delineated LUSs are described by specifying the characteristics that are known to affect their current management and performance, and would be expected to affect the introduction of potential agroforestry technologies. These characteristics are outlined below:

I. Title of system

II. Location: administrative and political divisions, with map if available.

III. Ecological characteristics

- Agroecological zone,
- Altitude range (m),
- Topography: slope (gradient),
- Rainfall: total annual, monthly levels, range,
- Number of growing seasons: with months and growing days,
- Soil: type, texture, pH, fertility, etc.,
- Hydrology: river network, water table level, etc., and
- Vegetation: natural and secondary.

Table 1. Examples of land use systems (LUSs) which have been delineated during macro D&D.

COUNTRY	ECOZONE	LAND USE SYSTEMS IN ECOZONE
1. Zambia	Unimodal upland plateau (Kwesiga and Kamau 1988)	• Shifting cultivation • Grass mound system (cereal/livestock semi-commercial,system practiced in open savannah areas where grass is abundant) • 'Barotse' agropastoral system in flood plains (an intensive cropping system during the wet season and grazing/crop cultivation in the dry season) • Maize/cattle mixed system of southern/eastern and central plateau regions • Maize/small stock system
2. Cameroon	Humid lowland (Djimbe and Raintree, 1988)	• Coffee/household farming systems of plantationworkers, found throughout the southern plateau. • Cocoa/food crop/coffee system found throughout the southern plateau on low fertility Orthic ferralsols
3. Kenya	Bimodal high-lands (Minae and Akyeampong, 1988)	• Tea-based • Coffee-based • Maize-based • Potato-based • Sugar-based • Food crop systems

IV. Socioeconomic characteristics

- Total land area in the LUS (km^2 or ha)
- Total population in the LUS,
- Population density: persons/km^2,
- Ethnic groups: religion, culture, etc.,
- Tenure system: ownership or user rights for crops pastures, land,trees,
- Farm income: levels and sources, and
- Infrastructure: roads, electricity, commercial centers, etc.

V. Land use characteristics

- Farm size: average, range, distribution,
- Spatial arrangement: location of homestead, crop, livestock, trees,
- Major and minor agricultural production activities: food and cash crops, large and small livestock, trees, etc.,
- Area covered by various components: ha or % of total farm; activities,
- Crop production: main crops - land preparation, planting methods/timing, use of manure/ fertilizer/pesticides, weeding, soil conservation, harvesting, level of production, storage,etc.,
- Livestock production: type, herd size, breeds, feed sources and management (tree/zero grazing, etc), type/use of output.,
- Tree production: species, main uses, land use niche, management, and arrangement, etc; traditional and new agroforestry systems (Note arrangement, management, or any data on performance., and
- Production systems interactions: relationship between crops, livestock, trees.

VI. Resources/supporting services

- Labor availability and utilization: family owned, hired, communal, etc.,
- Farm power and equipment used,
- Marketing: markets, marketing channels, prices, etc.,
- Credit facilities: type available and for what farm activities,
- Extension services: nature and organization of extension services, and
- Local organization: cooperatives, farm organizations, churches.

VII. Development activities and policies

- Review of relevant government policies and strategies, and
- Review of research and development projects, e.g., in agroforestry.

4.3.4 Analysis of Land Use Systems Constraints and Potentials

Each system has to be evaluated for factors that prevent its households from obtaining optimal outputs from the available resources. This step requires analysis of farmers' needs and priorities to see how well these are being met by current performance of the LUSs. The performance gap is evaluated by comparing the present levels of outputs with the biophysical and socioeconomic potential of the resources. For instance, one can compare the range of yields obtained in different LUSs with yields obtained in on-station or on-farm research.

Constraints analysis is based on problems facing households — both present problems and envisaged future problems. Emphasis is put on constraints which agroforestry can address.

To diagnose constraints properly, the research team must understand the relationships between manifested symptoms and causal factors. An example of constraints analysis is given in Table 2.

Because almost every constraint identified has several causal factors and symptoms (effects), the D&D team must have a multi-disciplinary capability. It must be able to interpret the relationships between these factors and the objectives of the household. Furthermore, it must be able to determine what opportunities exist to address the constraints. For this reason, constraint analysis is done concurrently with LUS characterization. For example, if one observes steep slopes in cropland, one can conclude that soil erosion is a likely hazard if nothing is being done to prevent it.

4.3.5 Analysis of Potential Agroforestry Technologies

In this step, potential interventions are identified and assessed for their relevance to the constraints and their likelihood of increasing or sustaining productivity of the LUSs. First, all possible interventions are identified, whether they are from the areas of agronomy, forestry, or agroforestry. For example, low soil fertility could be addressed by various technologies such as fertilizer, livestock manure, green manure from trees or shrubs, crop rotations. Next, each alternative is evaluated for its technical potential and suitability to farmers' resources and capabilities, infrastructure, and support services. A judgement is then made on what interventions seem to have the highest potential. Agroforestry interventions are proposed only when they have a comparative advantage.

If agroforestry seems viable, the list of high-priority constraints will suggest specific options for consideration. For example, a fodder shortage problem could be addressed through these seven agroforesty options:

a. establishment of fodder banks for a cut-and-carry system;

b. improvement of grazing management through live fencing;

c. introduction of fodder trees for browse in grazing lands (e.g., alley grazing);

Table 2. An example of constraint analysis analysis in macro D&D: the case of the coffee-based LUS in Kenya (Minae and Akyeampong, 1988).

Symptom 1:	Inadequate food production and income generation to support the household.
Cause:	Small farm size, dense human population, and long-term settlement.
Symptom 2:	Low crop productivity.
Cause:	Continuous cultivation on steep slopes, soil erosion, insufficient use of manure and inorganic fertilizers, lack of cash to purchase needed inputs.
Symptom 3:	Low livestock productivity.
Cause:	Insufficient availability of feed in dry season, poor organisation of milk marketing in some areas of LUS.
Symptom 4:	Fuelwood and building material shortage.
Cause:	Total clearing of indigenous trees except for those of high quality timber.
Note:	Significant interest in this problem has led farmers in one area of LUS to plant Grevillea and Eucalyptus species on their farms. There is a high demand for propagating material for fruit trees, fencing and fuelwood.
Symptom 5:	Labor scarcity for agricultural activities, especially during the coffee harvest season.
Cause:	Higher wage for coffee harvest.
Symptom 6:	Problem of weeds and moisture conservation during the dry season in coffee plots.
Cause:	Lack of labor, scarcity of mulch material.

d. planting of fodder trees with grass in intensive feed gardens;

e. planting of MPT/grass strips along contours in crop land; and

f. establishment of MPT/grass/legume rotations.

g. establisment of alley farming mainly for fodder production

Each technology must be assessed to determine how it would fit into the existing system. For example, d, e, and g are likely to be suitable for intensive systems where farmers are already practicing zero grazing; f is for semi-intensive systems, while c is probably preferable for farmers who have grazing land.

"Ex-ante" evaluation of a technology is part of technology assessment. It is carried out to determine a technology's potential for adoption. Ex-ante evaluation means the evaluation of the likely impact of a proposed technology *before* the technology has been introduced. It is based on appropriate assumptions using relevant data from other sources. This requires knowledge of technology management and performance under the specific conditions of the LUS.

4.3.6 Definition of Agroforestry Research Needs

If a proposed technology is well known and some farmers are familiar with its management and requirements, then a recommendation for extension programs can be formulated. On the other hand, if very little is known about the technology, then the D&D team will need to propose research activities. The team should propose a program of research to develop specific components, understand technical relationships, and/or to test/adapt the technology or components. The research will address critical information gaps for designing viable and adoptable technologies.

The proposed research activities will be conducted either on-station or on-farm, depending upon the specific objectives of the research activity (more detailed information is given under micro D&D). Possible activities include:

- literature searches and reviews;

- MPT surveys and local collection of seeds;

- nursery propagation and development of improved nursery techniques;
- MPT screening trials; and
- MPT management trials and/or other technology testing trials.

The team should next carry out a comparative analysis of the research needs for each agroforestry technology for each LUS within an ecozone. This analysis will be the basis for the design of appropriate research programs. Thus the main output of the macro D&D exercise is the definition of a research agenda to develop relevant technologies for the ecozone of interest.

4.3.7 Inter-Institutional Coordination

A macro D&D exercise should initiate an inventory and review of past and present agroforestry research or development programs. For example, the research team in the Kenyan study identified all the national or international institutions with existing research on the prioritized agroforestry technologies. The team classified the existing research according to MPT species being evaluated (Table 3). The results of macro D&D will suggest specific problem areas for complementary research in different institutions and better use of their scientific and physical resources. If several countries are involved, as in the case of a network, macro D&D provides a sound basis for planning inter-institutional collaboration across countries.

In practice, inter-institutional coordination is established even before macro D&D begins, based on institutional interests, programs, and potential contributions from the disciplinary areas essential to agroforestry. In some countries, agroforestry coordinating institutions may already exist, e.g., Ghana, Malawi, and India, where ICRAF has facilitated the creation of coordinating mechanisms.

Basically three types of institutional coordination can be established, namely:

- A steering committee to set policy, review and approve research;
- A technical committee, possibly a subgroup of the steering committee, to coordinate implementation, monitoring and evaluation research programs. For example, the steering committee in Kenya has 15 institutional members while the technical committee has just two members;

Table 3. Existing Research on Mixed Intercropping/Enriched Fallow for Soil Fertility in Cropland (Minae and Akeampong, 1988)

SPECIES	INSTITUTION	SITE	EVALUATION OF SPECIES	MIXED INTER - CROPPING	ENRICHED FALLOW TRIALS
Acacia albida	KREDP	Ngong	x		
		Wambugu	x		
Cajanus cajan	CRSP	Maseno, (Kisumu)		x	
		Hamisi (Kakamega)		x	
		Musimbi (Siaya)		x	
	U. Nairobi Crop Science	Kabete	x		
Calliandra calothyrsus	KREDP	Kisii	x		x
Cordia abyssinica	KREDP	Kisii	x		
Gliricidia sepium	KREDP	Kisii	x		
	CRSP	Maseno (Kisumu)			
Leucaena leucocephala	KREDP	Kisii	x		x
		Kiambu-nyoro	x x		x x
	CRSP	Maseno (Kisumu)			x
		Hamisi Kakamega		x	
		Musimbi (Siaya)			x
Sesbania sesban	CRSP	Maseno		x	x
		Hamisi			?
		Musimbi			x

CRSP: Collaborative Research Support Project, USAID.
KREDP: Kenya Renewable Energy Development Project, Kenya
X: Means doing research on the topic

- Task forces, i.e., multi-disciplinary teams, to carry out specific assignments such as macro D&D, micro D&D, MPT surveys. Often the same scientists are members of different task forces.

Multi-institutional participation in strategic phases of the research, such as D&D exercises, definitely facilitates the integration of individual efforts and the development of coordinated programs.

Promotion of inter-institutional collaboration on alley farming research is a key objective of AFNETA. In 1991, the directors of NARS institutions collaborating in AFNETA projects met to discuss and improve such inter-institutional coordination within their countries. Where National Agroforestry committees already exist, coordination of alley farming research takes place within that framework (AFNETA, 1991).

4.4 MICRO D & D

Objectives of Micro D&D

The objectives of micro D&D are similar to those of macro D&D. The major difference is that whereas macro D&D has a broad scope (i.e., an ecozone), micro D&D focuses on detailed analysis of one prioritized LUS. The three main objectives of micro D&D are:

- to describe and analyze an LUS in order to identify its constraints; and

- to design and evaluate agroforestry technologies to address the constraints

- to design and evaluate appropriate research programs aiming to develop these technologies.

The basic principles for achieving these objectives were presented under macro D&D (section 4.3) and are also relevant for micro D&D.

Since resources are inevitably limited, a country, institution or project will have to be selective in deciding which LUSs should be subjected to micro D&D. The choice of the LUS for micro D&D depends on criteria such as:

- political and economic importance of the system,
- technical potentials for improvement of the LUS, and
- scientific expertise and other resources in the national collaborating institutions for carrying out research in the LUS.

Although it is not essental for a macro D&D exercise to precede a micro D&D exercise, the task of prioritizing LUSs, defining the research focus, and defining areas for institutional collaboration will be much easier after macro D&D has been completed.

4.4.1 Analysis of Land Use System and Constraints

This phase of micro D&D aims at:

- prioritizing the needs of the household;
- identifying production constraints (both those that can and cannot be manipulated); and
- assessing potentials for system development.

The basic framework used for this analysis is a farming system, where the decision-making unit is the household. The household usually manages a combination of crop, livestock, and tree production systems, along with other non-agricultural and off-farm activities, to satisfy its basic felt needs of food, cash, fuelwood, building materials, and security. Besides endogenous factors, the farming system is influenced by exogenous factors of a political, social, economic, or technological nature. Understanding the interactions within the farming system and the effects of environment is essential for prioritizing the needs of the household, identifying production constraints, and assessing potentials for system development.

The micro D&D research team, therefore, will want to quantify resources, management, and yield of each component of the farming systems, including characteristics and priorities of the household. (More information on farming systems analysis is presented in Volume 1 and in Technical Paper 5.)

One component of the farming system analyzed by the team is agroforestry technology and MPTs used by farmers. A brief example of the use of MPTs is presented in Table 4, taken from the Zambian D&D exercise. This initial description is

Table 4: **Indigenous trees and their uses as identified by farmers** (Ngugi, 1988)

TREE SPECIES	CHARACTERISTICS			USES			
	Crown	Stem	Flowering/Seeds	Fodder	Timber	Fuelwood	Medicinal
PSEUDOLACHYNOSTYLIS MAPROUNEIFOLIA local (Nyanja) name : Msolo Family:Euphoribiacea	Light conical or rounded	Short boled or shrub	Flowers: July - Dec. Fruits ripen June - October Seeds collected from ground	Leaves	Joinery	x	x
DIPLORHYNCHUS CONDYLOCARPON Local (Nyanja) name : Mtowa Family: Apocynaceae	Light, narrow semi-deciduous	Multistemmed: shrub or tree	Flowers: August-Nov. Fruits ripen June - August up to 11 m tall	Leaves	Live fence poles, curving	x	x
DIOSPYROS KIRKII Local (Nyanja) names: Mkulo, mchenjakulo Family: Ebenaceae	Evergreen or semi-ever shrub or tree	More or less cylindrical may be crooked	Flowers: Sept.-Dec. Fruiting:July-Oct. Edible fruit	Leaves pods	-	-	-
AZELIA QUANZESIS Local (Nyanja) name: Mpapa, Mupapa or Mkolando Family: Caesalpiaioideae	Heavy branches forming a crown leafless from 3 days to 3 weeks	Cylindrical	Flowering: July-Nov. Fruits : maturing a year later, pods, contain 6 - 10 seeds Seeds eaten by birds animals, insects hence hard to find on the ground	x	very valuable timber	x	x
ALBIZIA ADIANTHIFOLIA Local (Nyanja) name: Mtanga Family: Mimosoideae	Light crown semi-deciduous		Flowers Sept.-Oct. Pods mature a year later contain 8-12 seeds	x	-	-	x
FICUS SPP Family : Moraceae	Varies from large spreading to small crowns	Variable	Fruits edible	x	-	x	x

usually followed up by special studies to fine-tune the researchers' understanding of the existing systems.

The Zambian case also provides an example of constraint analysis. The micro D&D analysis of a low-input maize/livestock farming system in the unimodal upland plateau of Zambia looked at the causes of insufficient cash and food supply. A large number of factors combined to produce these problems, including factors related to physical resources (animals, oxen, labor), management practices (poor technology, land preparation, and planning, low or no use of input use, burning of crop residues, animal diseases). low yields (fallow land, cropland and livestock), and exogenous factors (health, markets, village structure).

Another micro D&D exercise analyzed the coffee-based farming system in the bimodal highland ecozone of Kenya. The team identified the critical constraints of each production system (livestock, crop, and wood production), defined the causes of each constraint, and proposed a corresponding role for agroforestry to address each constraint (Table 5). The research team subsequently identified suitable agroforestry technologies for every potentially exploitable niche in the farming system (Table 6).

The constraints analysis aspect of micro D&D is well suited for planning the initial stages of research. However, later stages of research may require a re-assessment or a more precise measurement of some of these constraints.

4.4.2 Design and Evaluation of Agroforestry Technologies

The word design here refers to the act of combining various innovations into a technology and specifying the techniques to test the technology. Accordingly, the design and evaluation objective of micro D&D focuses mainly on:

- technology specification, and
- ex-ante evaluation of technology.

Technology specification

For any type of production system, whether crop, livestock or agroforestry, a technology can be defined as a "package" of husbandry practices and inputs which is specified in terms of:

- the farming systems/households it is targeted to;

Table 5. Summary of LUS constraints with identified agroforestry potential, Kenya (Minae, 1988).

Constraint		Cause		Proposed AF Role	
1.	Livestock Production				
1.1.	Low quality fodder (low protein)	1.1.1	Lack of leguminous component in fodder production	1.1.1.1	Introduce fodder MPTS
1.2	Low quantity fodder during the dry season	1.2.1	Inadequate land allocated to fodder production	1.2.1.1	Introduce fodder MPTS to be harvested for leaves and pods during dry season
2.	Crop production				
2.1	Inadequate application of fertilizer/manure	2.1.1	Lack of cash to purchase farm inputs		
		2.1.2	Insufficient production of manure due to limited livestock and or biomass	2.1.2.1	Increase biomass converted to brown manure through animal fodder from MPTS
2.2	Under exploitation of agricultural potential	2.2.1	Lack of technologies to optimise available resources	2.2.1.1	Increase the tree (fruits) production on the farm
				2.2.1.2	Improve present MPTS/crop combination
2.3	Poor management of soil/ water resources	2.3.1	Lack of appropriate management options	2.3.1.1	Incorporate MPTS component in soil conservation practices
		2.3.2	Insufficient labour		
3.	Wood production				
3.1	Insufficient land area to plant MPTS	3.1.1	Low competitiveness of trees with other enterprises	3.1.1.1	Introduce/Increase more productive, better quality timber/fuelwood MPT production activities
3.2	Poor management of existing MPTS	3.2.1	Lack of knowledge/ skills in tree production/management	3.2.1.1	Improve knowhow/management of present MPTS

Table 6: Potential agroforestry technologies based on niches (Minae, 1988).

NICHES	POTENTIAL OF INTERVENTIONS	ROLE OF TREES
1. Homegarden	1.1 Multistrata homegarden	1.1.1 fruits 1.1.2 timber/fuelwood
	1.2 Mixed cropping	1.2.1 fruits 1.2.2 industrial tree products
2. Food crops	2.1 Mixed cropping	2.1.1 fruits 2.1.2 timber/fuelwood 2.1.3 honey
	2.2 Hedgerow intercropping	2.2.1 soil conservation/fodder 2.2.2 soil conservation/fertility 2.2.3 soil conservation/fuelwood
	2.3 Contour hedgerow on grass strips	2.3.1 soil conservation/fodder 2.3.2 soil conservation/fertility 2.3.3 soil conservation/fuelwood
3. Coffee plot	3.1 Mixed cropping	3.1.1 fruits 3.1.2 shade?
4. Napier plot	4.1 Hedgerow intercropping	4.1.1 fodder 4.1.2 fuelwood/poles
	4.2 Mixed cropping	4.2.1 poles/fuelwood/timber
5. Internal boundaries	5.1 Row of MPTs	5.1.1 fruits 5.1.2 timber/fuelwood
	5.2 Multistorey hedgerow of MPTs	5.2.1 fodder 5.2.2 poles/fuelwood 5.2.3 soil fertility
6. External boundaries	6.1 Multistorey/ Hedgerow of MPTs	6.1.1 timber/fuelwood-top storey 6.1.2 poles - Midstorey 6.1.3 fodder-lower storey 6.1.4 fuelwood - lower storey 6.1.5 fertility - lower storey
	6.2 Row of MPTs	6.2.1 timber/fuelwood 6.2.2 fruits
	6.3 Double hedge/ row	6.3.1 timber/firewood-outer row 6.3.2 fodder - inner hedge
7. Valley bottoa?	7.1 Mixed cropping	7.1.1 fruits
8. River banks	8.1 Row of trees	8.1.1 fodder 8.1.2 poles

- its components and resource requirements;
- the management and implementation regimes to be followed by the farmers;and
- the estimation of real benefits and costs to the farmers under favorable and unfavorable conditions.

In other words, technology specification should provide sufficient detail to permit technical feasibility analysis, socioeconomic analysis, and assessment by farmers. An example of technology specification in the process of designing MPT hedgerows for napier plots in the coffee-based system in Kenya is given in Table 7.

In the course of technology design, several outcomes can be derived depending on the particular decisions and assumptions made by the team at each juncture, especially with respect to target levels of performance desired, management possibilities of the farmers, and endogenous and exogenous conditions of the farming systems. Developing realistic future scenarios in the above areas is an essential part of the technology design exercise.

Technology specification demands a lot from the D&D team. It raises a large number of specific questions requiring knowledge of the farming systems and scientific expertise. It demands the intuition to integrate fragmented pieces of information. If the questions raised cannot be resolved to the satisfaction of the team, then specific priorities for research (farm or community studies, experiments) have to be established. For example, the team in a Ugandan D&D study prioritized research areas for each technology that was being designed (Table 8).

Because agroforestry is a new science, there is a dearth of technical information on most components. For examples, information on the biophysical productivity of MPTs under different arrangements and management regimes is known only for a few species in selected environments. Similarly, not much is known about utilization and timing of MPT outputs for crop and livestock productivity in alley farming. Successful technology design requires adequate research experience.

The D&D team may design several technologies to address constraints of the farming system, in terms of the number of innovations, management requirements, and performance levels. For example, one technology may comprise small incremental changes, another quite radical changes relative to the practices of the farmers, and still another could be an "optimal" design of a technology that is absolutely new to the farmers.

Table 7. An example of technology specification from a micro D&D exercise in Kenya.

Objective:	To increase biomass productivity/quality of fodder for milk production (3 livestock units) by introducing high protein fodder MPTs in existing napier plots of the coffee-based LUS.
Land niche:	In napier plot with average size of 0.5 ha per farm.
Arrangement:	Napier is currently established under 1 x 0.5 m spacing; MPT hedgerow will be introduced at 0.5 x 4 m, replacing one row of napier.
Components:	Non-woody species is napier grass (Pennisetum purpureum, common varieties are Bana and F. camerona); proposed MPT species is Leucaena leucocephala (K8); other species may be better but management and yield unknown.
Management of napier:	Similar to the management of farmers: Establishment: cuttings at onset of rains; Manure: 1bucket at planting, small amounts of fertilizer after that; Age at 1st cutting: 6 months; Frequency of cutting: every 6-8 weeks (1 m height).
Management of MPT:	Propagation by seedling (6 mos before napier during long rains); Age at 1st cutting: 1 year; Height of cutting: 0.5 m; Frequency of cutting: 3 times/year Manure: proposed 0.5 bucket at planting; Weeding: 2 times/year or as often as necessary.
Required Inputs:	Similar to the existing fodder plots; Manure at establishment; Labor at establishment, for weeding and for regular harvesting.
Anticipated output:	Yield of napier not known exactly but farmers require about 0.5 ha/LUS depending upon management and age of napier; research results in the area suggest that 0.2 ha well managed can support 1 cow producing an average of 2500 litres milk per lactation (Karanja, 1986). Yield of *Leucaena* in napier could be from 1.5-2.5 tons DM/ha; a cow would require about 6.25 kg DM/day (2.5% of live weight); MPT N-fixing capacity should directly benefit napier.

Table 8: <u>SUMMARY OF PROPOSED RESEARCH</u> (Source: Okorio and Hoekstra, 1988).

Type of research	TECHNOLOGY			
	Hedgerow intercropping	Grass/shrub strips	Upperstorey trees	Fruit trees
1. Literature search & international seed acquisition	x	x	x	x
2. MPT identification survey	x	x	x	x
3. Local collection of seeds	x	x	x	x
4. Nursery propagation	x	x	x	x
5. MPT selection trials	-	-	x	x
6. Technology development trials	-	-	x	x
7. Prototype trials	x	x		
8. Extension research	x	x		

<u>Note</u>

X = Areas for immediate research
- = Areas not requiring a lot of research
= Areas where research will follow after the immediate research areas

Ex-ante evaluation of technology

Once a technology has been specified in its main components, it becomes possible to carry out an ex-ante evaluation based on data from relevant situations. Ex-ante evaluation is simply the analysis of its probable impacts and implications. This analysis looks at benefits and conflicts or problems likely to arise at the levels of:

- **farming system**, with respect to household division of tasks and benefits, on-and off-farm activities, and resource use schedules;
- **community or village**, with respect to obligations, organizations, management, and regional or catchment-level systems; and
- **region or catchment area**, with respect to land tenure, market incentives, credit and extension agencies.

The ex-ante analysis should use indicators that are relevant to farmers, in addition to those which researchers and extensionists may consider relevant to their technical domains. It should assess the production potential and technical feasibility of the technology. There are four essential types of analysis involved in ex-ante evaluation, namely:

- **Economic viability**: benefit/cost ratio; net returns to land/labor/cash; risk and sensitivity analysis.
- **Sustainability**: analysis of the technology 's capacity to meet objectives in short -and long-terms; also, analysis of expected changes and requirements related to soils, water, vegetation, management, and commercial input/output streams.
- **Farmer acceptability**: compatability analysis with respect to resources and management; also, social analysis with respect to defined rules and responsibilities within household obligations, tenurial conditions, etc. It is essential to analyze who in the household makes decisions on the resources required, who has to do the work, and who will receive the benefit accruing from proposed changes.
- **Adoption potential**: analysis of technology impacts in terms of number of farmers, regional development priorities, tenure rights, institutional and infrastructural support systems, etc. (Macro D&D also plays a key role here.)

It is logical to expect that the larger and more complex the technology, the more demanding is the ex-ante analysis. During the design process, the team should interact with typical households of the target system and with extension and development agents, particularly in relation to the following topics:

- priority problems being addressed and expected performance levels of the technology;
- endogenous factors and constraints to successful adoption;
- resource and management requirements for effective establishment (transitional analysis); and
- expected benefits, and impacts on farmers' objectives.

The ex-ante analysis is not confined only to micro D&D but extends into the later technology testing phases as well.

4.4.3 Design and Evaluation of Research Programs

There are four types of scietific research, namely:

- basic research which is designed to generate new knowledge or understanding;
- strategic research to solve specific research problems;
- applied research to create new technology; and
- adaptive research to adjust technology to the specific needs of a particular set of biophysical or socioeconomic conditions.

It is generally recognized that these are part of a continuum in the technology development process, and that productive research requires an integrated and complementary research strategy consisting of on-station research (OSR) and on-farm research (OFR). OSR consists mainly of basic and applied research; it must be able to offer technical components, information and support to the OFR activities. OFR complements but does not substitute for OSR. OFR provides feedback for setting OSR priorities, and adapting technologies or components coming out of OSR. In the case of agroforestry, where basic and applied research is not well developed and where farmers have more experience than scientists with management of technologies, OFR may have a stronger role to play in the research strategy, including applied research.

Research Design Criteria

A technology comprises a number of components. Experiments are designed to develop the technical components and to understand relationships among them. As discussed previously, agroforestry technology must be specified at least in its principal components, namely, MPT species, spatial arrangement, management regimes, and performance levels. Different types of trials are conducted to achieve these specifications. Within the ICRAF D&D scheme, the three general categories of agroforestry trials are:

- General MPTs screening trials,
- MPTs technology screening trials, and
- MPTs management trials.

This general scheme is similar to AFNETA's classification of alley farming research projects into four broad types, namely:

- MPT screening and evaluation,
- Alley farming management trials,
- Livestock integration trials, and
- On-farm research and socioeconomic assessment.

While all D&D teams have a mandate to design a program of research,the scope of their proposals may vary. For example, the Ugandan team proposed four relevant agroforestry technologies (e.g., alley farming, fruit trees), and then specified a set of up to eight different research needs for each technology (e.g. literature review, MPT screening) (Table 8). Another proposal emphasized the chronological sequencing of research activities during a five-year program (Table 9). A more detailed research program attempted to identify specific objectives, factors/treatments, and assessments for several types of proposed research (Table 10). Table 11 presents an example of a summary of an experimental station protocol. It is expected that any D&D exercise will provide sufficient understanding of the farmers' environment and production systems for design the types research programs exemplified in these tables. To achevie this, it

Table 9: CHRONOLOGICAL SEQUENCE OF RESEARCH STEPS (After Ngugi, 1988).

		1987 - 88	1988 - 89	1989 - 90	1990 - 91	1991 - 92
Literature review and international germplasm acquisition		—	—	—	—	—
Ethnobotanical survey Cattle feeding practices survey		—				
PROPAGATION STUDIES		—	—	—	—	—
MPT SELECTION TRIALS		—	—	—	—	—
ALLEY CROPPING	Establishment/Trials and Management					
	Prototype Trials/ Extension Research					—
LIVING FENCES	Establishment/ Management Trials		—	—	—	—
	Prototype Trials/ Extension Research			—	—	—
FODDER BANKS	Establishment Trials	—	—	—	—	—
	Phenology/Field Screening Trials		—	—	—	—
	Management Trials				—	—
	Prototype Trials/ Extension Research					
BOUNDARY PLANTINGS	Establishment/ Management Trials		—	—	—	—
	Prototype Trials/ Extension Research				—	—
FRUIT TREES	Phenology/Establishment Trials	—	—	—	—	—
	Prototype Trails/ Extension Research	—	—	—	—	—

Table 10. Multistorey MPT hedgerow on boundary planting (fuelwood/timber/poles), Kenya (Minae, 1988).

Type of Research	Objectives	Factors (Treatments)	Assessments
A. Species selection Design RCB Duration > 5 years	To determine suitable MPT for boundary planting for production of fuelwood/ timber/poles to identify ecological adoptation/ provenances	MPT species Upper storey - *Grevillea robusta* - *Grevillea glaucar* - *Casuarina equisitifolia* - *Croton megalocapus* - *Markhamia lutea* - *Cassia siamea* - *Pinus panla* - *Alnus Petala* - *Eucalyptus ssp.* Understorey - *Calliandra calothyrsus* - *Leucaena diversifolia* - *Leucaena leucocephala* - *Sesbania grandiflora*	For upper storey: Survival rates Growth rates Woody biomass production Morphology - canopy (size and density) For understorey: Fodder biomass Tolerance to shading Nutritive value Woody biomass survival Growth rates
B. Management trials Design - Randomized complete block for on-station trials - Either randomized complete block or incomplete block for on-farm trials	- To determine suitable MPTs for boundary planting - To determine the best establishment and management methods - To evaluate the effect of time of harvesting	Spacing arrangements within the hedge - Time of first harvesting - Distance of crop from boundary - Frequency of pruning/pollarding	- Tree growth (height and diameter) - Tree canopy cover (diameter) - Crop yield - Interval from boundary - Tree percent survival/ initial after 2 years old - Coppicing and pollarding/pruning characteristics - Observation on morphology
C. Technology testing trials Design - Randomized complete block for on-station trials - Either randomized complete or incomplete block for on-farm trials Duration 3 years	- Researcher and farmer evaluation of boundary planting under farm conditions	- Application of various management techniques - Species combination	- Labour input for establishment and management - Interactive effects on adjacent crops and soil - Farmer evaluation of yield and value of harvesting products
D. Extension research Design to be determined Duration done concurrently with prototype trials	- To evaluate the impact of the technology on farm overall performance		- Farmers acceptability

Table 11. On-Station Experiment No. 2 KEN/88 (Personal communication, G.B. Singh, 1988)

<u>Title</u> - Fooder production potential of different MPTs and grass combinations on the field bunds

<u>Location</u> - Maseno (Kenya)
<u>Date of start and duration</u> - April, 1988, for 4 years

<u>Objectives</u> - i) to determine the fodder yield of Napier grass and <u>Sesbania sesban, Calliandra calothyrsus</u> MPT species and their combinations,

ii) to determine the effect of trees and grass raised on field bunds on the yield of associated crops.

<u>Treatments</u> T1: Leucaena leucocephala - Melinda Forest Station, Blize
T2: Sesbania sesban - Kakamega, Kenya
T3: Calliandra calothyrsus - KFSC:Guatemala
T4: Napier grass - vet. farm, Maseno, Kenya
T5: T1 + T4
T6: T2 + T4
T7: T2 + T4

<u>Experimental design</u> - RDB with 4 replications

<u>Experimental details</u>

i) Field bund is constructed across the slope for planting trees and grass;
ii) Each bund plot is of 4 x 1 m dimension. Grass is to be planted on the upper side and trees on the lower side of the bund
iii) Where tree and grass are to be planted together, the grass will be planted only after the establishment of the trees;
iv) In between two bunds bean crop GLP-2 (Rose-coco) will be planted in the first year and in the second year maize will be cropped. The bean and maize crops are fertilised as per local recommendations. The plot, including cropped area, will be on both sides of the bund;
v) Distance between two rows on the bund will be 50 cm and within the row, plants will be at 25 cm.

<u>Observations to be recorded</u>

i) Survival of trees and grass after establishment;
ii) Monthly height and diameter observations till the cutting for fodder starts;
ii) Fodder yield from grass and trees;
iv) Estimation for fodder quality (crude protein, crude fibres, etc)·

may be necessary for the D&D teams to carry out multi-visit surveys and interactions with land users and to review scientific secondary information.

4.5 METHODOLOGICAL CONSIDERATIONS IN D&D

4.5.1 Research Team

The nature of agroforestry systems suggests the need to set up multi-disciplinary and multi-institutional teams to achieve the objectives of D&D. For macro D&D, efforts should made to form teams comprising:

1) biophysical scientists from the fields of soils, crops, climate, livestock, and forestry, and

2) social scientists from the fields of agricultural economics, rural sociology, or anthropology.

These scientists should have experience in research and extension. For micro D&D and follow-up studies, the expertise and composition of the team are based on the prioritized LUS, its identified constraints, and the specific objectives of the study. Normally teams implementing macro and micro D&Ds should consist of 5-10 members. The minimum of 5 members allows for a multi-disciplinary range and inter-institutional representation, while the maximum of 10 avoids management problems.

Team leadership is critical for successful D&D implementation. In the first instance, the leader should have experience with, and an appreciation for, the conceptual framework and "tools" used by both biological scientists and social scientists. Interaction should be focused on the objectives of the D&D exercise, and on the specific contributions which can be made by each discipline to the overall research strategy. An objective D&D strategy is the key to bringing disciplines to work together to address the problems of the farmer in an integrated manner.

Care should be taken to provide an effective interface between the D&D exercise and the planning and implementation of technology development research. It is essential that the scientists who will implement the experimental program participate in the D&D teams, or at least that those who carry out the D&Ds participate in the design of the experimental programs.

4.5.2 Research Domains and Recommendation Domains

Defining the target land use system or farming system is probably the most crucial step in the Agroforestry Systems Research process. The problem is that unless researchers have developed the technology and know how to manage it, what requirements it has and exactly what it can do, they do not have a solid basis to define an appropriate recommendation domain. For this reason, it is better in the preliminary stages of technology design to speak of a "research domain" until there is sufficient understanding of the technology to determine precisely where it can fit. Accordingly, the research team should always be concerned about whether and how technology development is modifying the original research domain.

Precise definition of the target system is also important for the reason that every farming system or household is somewhat different. Some customizing or fine-tuning of technology is required for each case; this is what occurs in the adoption process. However, in research the objective should be to develop and give priority to the technology or technologies with the widest possible application and greatest impact, so that research resources can yield good returns. Thus the definition of research domains should strike a wise balance: not too general so as to be useless as a guide to research, nor too specific so as to apply only to a small number of farms or households.

The research team can assess the effect of its work on the research domain by answering the following questions:

- Which LUSs are most affected by the problem under investigation?
- Which systems can benefit (one hopes the majority) and to what extent can they benefit from the technologies being developed?
- What are the major conditioning and determinant factors, endogenous or exogenous to the farming system, for technology management and performance?
- What are the expected benefits and impacts of technology adoption?

The concept of research domain is a tool to facilitate and expedite the task of focusing on these key questions. If the team can answer them adequately, the concept has served its purpose.

4.5.3 Data Collection Methods

The D&D methodology employs several data collection methods appropriate to its specific objectives. Each method has its own strengths, weaknesses, degree of reliability of collected data, and resource requirements (Table 12). For example, the informal survey is fairly effective for identifying constraints, designing technology, promoting interdisciplinary interactions, and contributing to research planning, but the reliability of the data is not up to the standard of other methods. An informal survey also requires the most input from senior scientists, but its implementation is the quickest with minimum logistical and computer requirements. This offers a definite advantage if the research team does not have access to computer facilities.

D&D exercises should generate a minimum of raw data, a maximum of useful information, and in a timely matter. For this reason, the preliminary D&D work will take a rapid appraisal approach using secondary information surveys. D&D work at later stages in the research and development process will use methods that make a maximum contribution within the limits of available human and physical resources.

4.5.4 Analytical Methods and the Role of Farmers

The major decisions in the D&D analysis are derived using interactive and heuristic methods, with the principal actors being the D&D team and the farmers/households. This interaction should be based on solid information, consultation with development agents and policy-makers, and a commitment to arrive at logical conclusions in the process.

To ensure effective participation in discussions, all participants must show mutual respect and accept that each can make a valuable contribution. This should be reflected in observance of the following guidelines of behavior:

- understand a point from the other's perspective,
- criticize constructively, admit if wrong, stress the positive,
- reason - don't argue,
- explain thoroughly,
- offer helpful suggestions, and

Table 12: CRITERIA TO SELECT D & D METHODS.

CRITERIA	METHODS: Secondary information	Key informants	Informal survey	Formal survey	Multi-visit survey	Technical monitoring	Case studies
OBJECTIVES							
LUS description	1	3	3	1			
Recommendation domain	1	3		2			
Constraints identification		3	2		1	3	
Technology design and evaluation			2		1	3	
Research design and evaluation			3		1	2	
Scientists' interaction			1			2	3
Farmers' participation			2		1		3
Extensionists' participation		1	2		3	3	
RELIABILITY (TYPE OF DATA)							
Sectoral/Village	1	3		2			
Household priorities, needs, etc.			1		1		3
Biophys. & S-Econ resources	2			1	3		
Management: Crops			3	1	1		
Livestock			3	1	1		
Trees				1	1	3	
Performance: Crops			3		2	1	
Livestock			3		2	1	
Trees			3		2	1	
RESOURCES (COST)							
Time/speed	1	2	3				
Human resources	1		1	3			
Logistic (ven., comp. etc.)	1	1	3				

- avoid snap judgements.

However, this does not mean that participants should accept everything said; there is a need to challenge, seek clarification, and discover the root causes of disagreements or conflicts. In this respect, the farmers should be treated as equal participants.

4.5.5 Logistical and Operational Aspect

For macro D&D, the total staff time required from planning to conclusion is estimated to be roughly 3 months. An approximate breakdown of the work schedule could be as follows:

- planning the study and orientation of the entire team — from 2 to 3 days;
- review and synthesis of secondary information — from 2 to 3 weeks;
- field work — from 2 to 3 weeks depending on the geographical size of the ecozone;
- final analysis and reporting — from 1 to 1.5 months.

The review work and report preparation do not require participation of the whole team; two members could do these with occasional assistance from the others. Computer support is not essential except, perhaps, for word processing.

For micro D&D, the total input of staff time and logistic support is approximately similar. However, a formal survey (i.e., a survey of 5-100 farmers with a semi-structured questionnaire) will normally consitute an important part of the study. Formal surveys require computer capability. In addition, the team may need to allocate relatively more time to the review of relevant agroforestry researcher and extension work to strengthen its analysis.

ICRAF, in collaboration with national institutions, can implement the entire sequence of a macro and micro D&D exercise in about eight months, including a short workshop after each phase to discuss and digest its results. Normally the process takes longer because the research team does not work on a full-time basis. In addition, ICRAF typically does not rush through, since the training objective is a high priority in such exercises — particularly for national scientists who have not been exposed to farming systems or on-farm research.

4.6 SUMMARY

This technical paper has presented Diagnosis and Design (D&D) as a systematic and objective methodology used to initiate, monitor, and evaluate agroforestry research for development. It can be applied at the level of an agroecological zone (macro D&D) or at the level of a specific land use system (micro D&D). Methodological guidelines have been presented to explain how the D&D achieves its basic objectives, which are:

1. Describing and analyzing existing land use systems;
2. Diagnosing their constraints and causal factors;
3. Designing appropriate agroforestry technologies;
4. Designing appropriate research work; and
5. Identifying needs and opportunities for inter-institutional collaboration.

The key methodological considerations for D&D implementation are: the composition of the research team; the definition of research domains and recommendation domains; data collection methods; and logistical and operational aspects.

4.7 FEEDBACK EXERCISES (Find out answers from the text)

1. Match these terms to fill up the blank spaces in sentences given below:

   Terms: Technology, diagnosis, production systems, household, spatial arrangement, land use system, design, systems perspective, performance levels.

   i) D and D stands for ________ and __________.

   ii) The basic unit of D & D analysis is ____________ which can be defined at the level of country, ecozone, or household.

   iii) The four main components of agroforestry technology are: 1) MPT species 2) ______ 3) management regimes and 4) _____________

iv) ICRAF has developed a research process for developing technologies to solve farmer's problems. This research process uses a _______________ with an interdisciplinary approach.

v) Macro D & D is an analysis of an ecozone within a country while micro D & D is a detailed analysis of the ____________ and ____________.

vi) The three main types of screening to judge the potential of MPTs are: 1) general screening 2) _______________ trials 3) management trials.

2. Place the following terms associated with the Agroforestry Research Process in their correct order of implementation.

- technology design
- technology testing
- Micro D&D
- Component experimentation
- Macro D&D
- Technology dissemination and adoption.

3. Circle A for agree and DA for disagree.

i) In selecting a study ecozone under macro D&D, the single criterion used used is the level of development of the ecozone with respect to other areas
A DA

ii) The criteria for distinguishing one land use system from others vary depending on the factors that influence LUS managements and performance.
A DA

iii) The delineation of an LUS is a one-time process based on the understanding of biophysical and socioeconomic potentials of the system. A DA

iv) Constraint analysis identifies two types of constraints, namely modifiable and fixed, but does not explore causative factors. A DA

v) Constraint analysis is done concurrently with LUS characterization.
A DA

4. In what way do macro D&D and micro D&D differ? Tick the correct answer.

   i) In their three objectives.
   ii) In their scope - macro D&D focuses on the ecozone while micro D&D on the farming system.
   iii) In the composition of the multi-disciplinary team.
   iv) In basic principles to achieve the three objectives.

5. a) Fill in the blanks. The three components of a research continuum to generate technologies are:
   i) ______________________________
   ii) strategic research
   iii) ______________________________
   iv) ______________________________

   b) Expand the following abbreviations.
   i) LUS ________________________
   ii) OSR ________________________
   iii) OFR ________________________
   iv) MPT ________________________

6. a) What are the two categories of scientists that form the macro D&D team. Which disciplines and subjects are represented in each category?
   1) ______________________________

   2) ______________________________

   b) Differentiate between research domain and recommendation domain.

   ____

   ____

7. To complete a macro D&D analysis what is the suggested length of time for following stages:

   i) ________________________ planning and team orientation
   ii) ________________________ review and synthesis of secondary information
   iii) ________________________ field work
   iv) ________________________ final analysis and reporting

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TECHNICAL PAPER 5

Concepts and Methods for Economic Evaluation of Alley Farming

5.0 Performance Objectives

5.1 Introduction

5.2 Key Economic Principles and Concepts

5.3 Economic Evaluation Criteria

5.4 Application of Economic Concepts in Economic Evaluation of Alley Farming Technology
- 5.4.1 Profitability Analysis
- 5.4.2 Calculation of Values of Economic Evaluation Criteria
- 5.4.3 Calculation of Values of Profitability Indicators
- 5.4.4 Management Feasibility
- 5.4.5 Risk Analysis
- 5.4.6 Long-term Economic Evaluation

5.5 Summary

5.6 Feedback Exercises

5.7 Suggested Reading

5.8 References

5.0 PERFORMANCE OBJECTIVES

Technical Paper 5 is intended to enable you to:

1. Explain key principles and concepts of economic analysis for allocating scarce resources to competing options.

2. Describe important economic evaluation criteria for technology evaluation.

3. Perform short-term profitability analysis of alternative technologies by applying relevant economic concepts and measurement criteria.

4. Describe principles involved in management feasibility analysis and risk analysis.

5. Define "total present value", "net present value", "benefit cost ratio" and "internal rate of return".

6. Describe the procedure to perform a long-term economic evaluation of alternative technologies by citing a practical example.

Technical Paper 5 :

Concepts and Methods for Economic Evaluation of Alley Farming

M. Avila

5.1. INTRODUCTION

The objective of any agroforestry research and development effort is to improve the efficiency and productivity of the use of basic resources in the production process, either at the level of the farm or for the entire agricultural sector. In order to determine the expected benefits, losses and other implications of a proposed change, it is necessary to evaluate the management and performance of both the existing production systems and the recommended improvements. The consideration of economic factors together with biophysical factors provides a logical framework for comparing traditional and alternative systems.

Research suggests that alley farming technology may be economically feasible and ecologically sound under appropriate conditions. However, there is a continuous need to monitor the economic viability of alley farming systems vis-à-vis other alternative systems under various biophysical and socioeconomic conditions. A basic framework for socio-economic assessment of alley farming was presented in Volume 1 (Unit 6). The paper explores the topic in more depth. It begins by reviewing key economic concepts and criteria, and then applies these concepts to the economic evaluation of alley farming in a hypothetical maize-bean system.

5.2 KEY ECONOMIC PRINCIPLES AND CONCEPTS

Economics provides a rational basis for making decisions in allocating scare resources among various options to achieve competing goals. Every person is faced with such situations, where many decisions are possible. One applies economic principles to make rational choices. If resources were not limiting, there would be no need for economic consideration. Some important basic principles of economic analysis are outlined below (Osborn and Schneeberger, 1978).

Optimization criteria: To optimize net income from several possible production options, one considers the additional return (i.e., marginal value product) obtained from using one additional unit of an input. If option X gives a higher return than other options (e.g., return to land), then additional units of land should be allocated to option X.

Comparative advantage: Specific production enterprises or combinations have different requirements and should be located in those areas or parts of the farm which are best suited to them. For example, vegetable and dairy production area should usually be located closer to the homestead because they require more attention and management by the household. Tree plots and perennial crops are usually the most distant from the homestead, established on sloping areas, etc. Cut-and-carry fodder plots should as close as possible to the livestock pen to minimize transport costs.

Diminishing returns: Increasing use of a resource will yield increasing returns up to certain level beyond which the marginal returns begin to decrease. How much resource one should use depends on the marginal return and cost of the resource. One should not go above the level where the marginal benefit equals the marginal cost. One loses net income with each additional unit of resource beyond that point.

Substitution of resources: A given technology is simply a particular combination of resources applied in the production process. An appropriate technology in developed agricultural systems is one that uses labor efficiently, as labor is a scarce and expensive resource. Ratios of land/labor and capital/labor are high, technology should hence offer a high income/unit of labor ratio. If land is abundant and cheap relative to capital, i.e., a low capital/land ratio, then a rational farmer would use land abundantly and capital sparingly, thereby seeking high returns to the scarce resource.

Cost analysis: For a given production period, for example one year, some costs of production will vary with the level of production. These are variable costs. Other costs of production will be incurred by the farmer, irrespective of the level of production. These are the fixed costs. In the short run, the farmer has to manage the variable costs efficiently. In the long run, say five years, the fixed costs may drop out completely.

Opportunity cost: Any resource has a real value to a farmer equivalent to the return he or she could obtain in the best alternative use of that resource. If a farmer has three options to use capital, the highest return of the three is the opportunity cost of that resource irrespective of where the capital is allocated. Products also have an opportunity cost, which is equal to the price the farmer would have to pay to obtain them.

Although the manager of a farming system may understand and want to apply these economic principles, he or she may find it difficult to apply them in a real life situation. There may be various reasons for the difficulty of applying the above principles:

- First, the farming system and its environment are dynamic, hence what is optional today may not be tomorrow. The main factors determining profits may change often and it may not be possible to make adjustments immediately.
- Secondly, the manager may face emergency situations (e.g., when members of the household or village pass away) when these principles do not apply.
- Thirdly, a lack of incentive or great instability in market conditions may work against implementation of seemingly rational changes.
- Fourthly, the manager may not have adequate information on critical indicators for appropriate decision making.

A combination of these management constraints contributes to decreasing economic efficiency in agricultural production. Normally farmers make decisions on a continuous basis, using well established rules of thumb in relation to the behavior of key variables and indicators, some of them economic in nature.

5.3 ECONOMIC EVALUATION CRITERIA

Economic evaluation of the technology can be carried out using various criteria: money, energy, labor value, etc. The only requirement is that the criteria be quantifiable and possess a common denominator such that any input or output can be measured on the same basis. Non-quantifiable criteria can also be included to weigh different options, for example to maximize net income subject to minimum soil degradation. Specifically, for evaluation at the farmer's level, outputs and inputs of a production system are valued as follows (adapted from Perrin et al. 1976):

Net yield: This is the measured physical yield/ha in the field for each output, minus harvest and storage losses when they apply.

Field price of output: This is the market price of the output minus costs for storage, transportation, and marketing, and quality discount. If no market exists, the field price can be estimated by determining the cost to the farmer of obtaining equivalent substitutes.

Field price of input: This is the total cost/unit of bringing an input into the field. It equals the purchase price plus other costs of transport, losses, etc. The field price of capital to purchase commercial inputs, for example, includes interest, service charges, and a risk premium of at least 20% per year above the direct costs.

Time Factor: Another key component of economic evaluation is the time factor. Depending on the type of production system, an appropriate time period has to be determined, (e.g. 6 or 18 months, or 10 years). During that period, particular activities, resources and other factors will change, and require monitoring and analysis. For analytical periods of less than 1 year, the valuation of inputs does not cause any problem. However, if the farmer must invest inputs in a production system today, and receive the outputs after 3 years, one cannot simply add or subtract their monetary values. The concept of discount factor must be applied. The reason is that if the farmer was to make that investment, let's say in the bank (which is the lowest return option), interest earned for the next 3 years would increase the value of this investment.

Discount factor: For long term evaluation of benefits and cost, the discount factor concept is necessary (Gittinger, 1972). It is defined as the present value, at the beginning of year 1, of one dollar ($1) at the end of n years. An interest rate of r is used as the cost of capital. The discount factor (DF) is calculated as:

$$DF = \frac{1}{(1 + r)^n}$$

For example, if n = 5 and r = 10%, the value of discount factor will be:

$$DF = \frac{1}{(1 + 0.1)^5} = \frac{1}{(1.1)^5} = 0.62$$

Thus if interest rate is 10% and $100 will be received or expended at the end of 5 years, the present value of the capital is $62 and the value of the discount is 0.62.

The critical variable of the DF is the "r". An r should be used which reflects the real opportunity cost of capital to the farmer. A high "r" (20-30% per year) means that the farmer puts a premium on short-term rewards whereas a low "r" (less than 10%) means that the farmer would rather defer short-term rewards for investment into the distant future.

Present value of a constant annuity: The discount factor is used to calculate the present value of a constant annuity (PVCA). The PVCA is defined as the present value of $1, to be received annually during X years, at an interest rate of r as the cost of capital. It is calculated for a 3-year project at an r of 10%, as follows:

$$PVCA = \sum_{n=1}^{x} \frac{1}{(1+r)^n} = \frac{1}{(1.10)^1} + \frac{1}{(1.10)^2} + \frac{1}{(1.10)^3} = 2.49$$

If the constant annuity is $500, its total present value is $1245 (= 500 x 2.49). Thus a constant stream of benefits or costs for any length of time in the future can be reduced to its present value by using the PVCA.

High inflation is a serious problem for long-term economic analysis. Accordingly, the effect of inflation on the timing of costs and benefits of the production system has to be considered in economic evaluation. If the streams of costs and benefits were proportionately distributed in time, there would be no need for concern as inflation would affect both streams similarly. However, since this is not the case, high inflation would tend to discourage farmers from making long-term investments because of the uncertainty associated with such market factors.

Using these basic principles and concepts, one can proceed to carry out and interpret economic evaluation of production systems such as alley farming.

5.4 APPLICATION OF ECONOMIC CONCEPTS IN ECONOMIC EVALUATION OF ALLEY FARMING TECHNOLOGY

Economic evaluation of a technology involves comparing technology options that are available to the farmer. One of the options that constitutes the basis of comparison is the present practice of the farmer. The other options include improved alternative practices. For evaluating the economic and technical feasibility of alley farming technology, we shall compare the following three options from a hypothetical case study:

- Farmers' traditional maize-beans cropping system,
- Improved maize-beans cropping system, and
- Alley farming system with *Leucaena* hedgerows and intercropped maize-beans.

The data from the hypothetical case study is given in Tables 1 to 8. Data are based on available estimates from studies in the sub-humid zone (Avila, 1978). Economic feasibility is assessed by profitability analysis. Management feasibility, which is one aspect of technical feasibility, will be assessed briefly in terms of labor availability. Risk analysis will also be discussed briefly.

5.4.1 Profitability analysis

To illustrate the procedure for profitability analysis, we will use hypothetical data on labor, inputs, and outputs to determine the values of various economic criteria and profitability indicators.

As mentioned before, we shall be comparing three farm management options, namely, traditional maize-beans, improved maize-beans, and alley farming technologies. Tables 1, 2 and 3 present measurements of labor use and commercial inputs for the three options.

Table 1. *Traditional maize-beans cropping system: Monthly activities, use of labor and commercial inputs per hectare.*

Month	Activity	Labor Days (6 hrs/day)	Commercial Inputs Type	Units	Cost($)
March	Land preparation	10			
April	**Maize**				
	planting	4	Seed	1 kg	2.00
	fertilization	3	Various	6 kg	12.00
	weeding	10			
May	weeding	8			
June	weeding	4			
August	doubling	3			
September	harvesting	8			
	shelling	10			
	Beans				
	land preparation	2			
	planting	2	Seed	50 kg	30.00
October	weeding	4			
December	harvesting	6			
	threshing	7			
Total		81 days			$ 44.00

Table 2. Improved maize-beans cropping system: Monthly activities, use of labor and commercial inputs per hectare. Source: CATIE's Small Farmer Cropping Systems Project.

Month	Activity	Labor Days (6 hrs/day)	Commercial Inputs Type	Units	Cost($)
March	Land prep.	12			
April	**Maize**				
	planting	4	Seed	20 kg	5.00
	soil insect treatment	2	Aldrin 2.5%	40 kg	15.00
	fertilization 1	3	15-30-8	204 kg	40.00
			Me. sulph.	200 kg	41.00
	herbicide appl.	2	Gramaxone	1.2 lt	7.30
May	insect control	2	Volaton 50%	3 lt	21.78
	weeding	5			
	fertilization II	3	ammonium Sulphate	143 kg	23.40
	earthing up	8			
June	weeding	3			
August	doubling	4			
September	harvesting	9			
	shelling	13			
	Beans				
	land preparation	3	Gramaxone	1.2 lt	7.30
	planting	6	Seeds	65 kg	40.00
			Caplan	16 kg	3.00
	fertilization I	3	Ammonium-sulphate	143 kg	23.40
	pesticide application	2	Sevin 80%	1 kg	7.00
October	leaf disease treatment	3	Dithane M45	1 kg	3.75
	weeding	5			
November	fertilization II	3	Ammonium-sulphate	143 kg	23.40
December	harvesting	7			
	threshing	7			
	Total	109 days			$261.33

Table 3. Alley farming system with *Leucaena* L: Monthly activities, use of labor and commercial inputs per hectare.

Month	Activity	Labor Days (6 hrs/day)	Commercial Inputs		
			Type	Units	Cost($)
March	Land preparation	6			
	1st pruning	18			
April	**Maize**				
	- planting	4	Seed	15 kg	2.00
	- weeding	6			
May	- weeding	4			
June	- 2nd pruning*	14			
August	- doubling	3			
September	- harvesting	9			
	- shelling	11			
	Beans				
	- land preparation	2			
	- 3rd pruning*	14			
	- planting	2	Seed	50 kg	30.00
October	- weeding	3			
December	- harvesting	6			
	- threshing	7			
	- 4th pruning	14			
	Total	123 days			$32.00

* The fodder was harvested from September and December prunings, while fuelwood was harvested from all three prunings.

In all three technology options, the values for labor are derived when each system is fully established and operating at a normal expected level. Variation in these labor coefficients with respect to levels of inputs used and yield obtained is expected, due to differences in climate and site. Accordingly, averages and estimates are used to calculate these coefficients.

Tables 1, 2 and 3 list prices for inputs. The prices for outputs are as follows:

Maize:	\$0.18 + 0.02/kg during last 2 years
Beans:	\$0.42 + 0.05/kg during last 2 years
Tree fodder:	\$0.06/kg DM
Fuelwood:	\$0.05/kg

These are "field prices" as defined before. For labor, the going cost is \$4 per 6-hour day. If there is seasonal variation during the year, the specification of monthly use permits calculation of total labor costs.

5.4.2 Calculation of Values of Economic Evaluation Criteria

Table 4 provides an economic comparison of the three technology options. The performance criteria for economic evaluation of outputs are calculated as follows:

Output

- **Gross yield**: This is the actual yield obtained in the field.
- **Net yield**: Gross yields are adjusted by reducing them by 10% to account for the usual losses.This reduction is not applied to the traditional system or the fuelwood component.
- **Gross income**: Gross income is derived by multiplying net yield of each component with their respective field prices.

Input

- **Variable costs** (labor and commercial inputs): These are calculated from the quantity used and the respective field prices.
- **Fixed costs**: Land is included because it has an opportunity cost.

- **Cost of hedge establishment** (*$608/ha in present case*): The cost factors are given in Table 5.

- **Depreciation** reflects a cost due to the use of structures or equipment which have to be replaced after their productive cycle, in this case the hedgerows and tools. The linear model is used to calculate annual depreciation.

Hedgerows are assumed to lose productivity after 8 years and require uprooting. (This assumption does not apply to many alley farming systems.) As above, the total cost of establishing the hedge is $608/ha. The annual depreciation for the hedge per ha. will be:

$$\frac{\text{Total Investment - Salvage Value}}{\text{Number of Productive Years}} = \frac{608 - 0}{8} = 76$$

There is no salvage value in this case. Although some products will be derived when the hedges are replaced, it is expected that their value will merely compensate for the labor to uproot the old hedges. If hedges are established gradually using low opportunity cost labor of the household, establishment costs could be much lower. Moreover, hedgerows under many circumstances will remain productive longer than 8 years.

For small tools used in these options, which are replaced every other year, a small sum is included for annual depreciation.

5.4.3 Calculation of Values of Profitability Indicators

Profitability indicators for this short term analysis are calculated as net or gross returns per unit of the scarce resource. These indicators are calculated as below:

$$\text{Net Income (NI)/ha} = \text{Total Gross Income - Total Costs}$$

$$\text{Net Return/Labor Day} = \frac{\text{NI/ha + Variable Labor Cost}}{\text{Total Labor Days}}$$

$$\text{Net Returns/\$ Cash Input} = \frac{\text{NI/ha}}{\text{Variable Commercial Input Cost}}$$

$$\text{Gross Returns/\$ Cash Input} = \frac{\text{Gross Income}}{\text{Variable Commercial Input Cost}}$$

Table 4. Comparative economic analysis of Traditional maize-beans, Improved maize-beans, and Alley Farming System.

Criteria		Traditional Maize-beans	Improved Maize-beans	Alley Farming
Gross yield:	maize	1350	3150	1900
(kg/ha)	beans	500	700	600
	fodder	-	-	1200
	fuelwood	-	-	1000
Net yield:	maize	1350	2835	1710
(kg/ha)	beans	500	630	540
	fodder	-	-	1080
	fuelwood	-	-	1500
Gross income:	maize	243.00	510.30	307.80
($)	beans	210.00	264.70	226.80
	fodder	-	-	64.80
	fuelwood	-	-	75.00
	Total	453.00	775.00	674.40
Variable costs: ($)				
	labor	324.00	436.00	492.00
	commercial inputs	44.00	261.33	32.00
Fixed costs: ($)				
	land	30.00	30.00	30.00
	depreciation of hedges*	-	-	76.00
	depreciation of tools	10.00	25.00	15.00
Total costs: ($)		408.00	752.33	645.00
PROFITABILITY INDICATORS ($)				
Net income/ha		45.00	22.67	29.40
Net returns/labor day		4.56	4.21	4.24
Net returns/$ cash input		1.02	0.09	0.92
Gross returns/$ cash input		10.30	2.97	21.07

* Depreciation of hedges assumes that hedges will become unproductive after 8 years and require uprooting. In many alley farming systems, hedgrows can be maintained for longer than 8 years and may never require uprooting.

Table 5. Investment in establishment of hedges in year one of introduction of Alley Farming.

Criteria	Units	Costs $
MPT seedlings: 1st planting*	5000 plants	250
Replanting	1000 plants	50
Land prep: Digging	30 days	120
Refilling	20 days	80
Protection	10 days	40
Reduction of maize-beans yield**	279 kg/ha	68
Total		$608

* Planting and replanting costs include labor materials, inoculum. In the first year, crop yields may be reduced. The figure here represents 15% reduction from traditional system. After 2-3 years, net increases in yield may result from improved soil.

The Net Income/ha represents the return to the management resource because this is the only resource which has not been costed yet. Net Returns/Labor Day shows how much labor earns in each alternative. This can be compared with its opportunity cost of $4.

The values of the profitability indicators for these options are given in Table 4. From this analysis one observes that the traditional system is more profitable in terms of all the indicators except Gross Returns/$ Cash Input, where it is surpassed by alley farming.

5.4.4 Management Feasibility

A management feasibility analysis uses dynamic criteria such as labor availability and cash flow to determine whether a farmer can manage a new technology or system.

Table 6. Monthly availability and use of labor in a typical small farming system (1 Labor Day = 6 hours).

Criteria	J	F	M	A	M	J	J	A	S	O	N	D	Total
Labor Availability (hr)													
Household Labor	90	80	80	80	80	90	90	80	80	80	90	90	1010
Hired labor	0	20	6	3	11	6	6	0	4	9	12	0	77
Total available	90	100	86	83	91	96	96	80	84	89	102	90	1087
Labor use (hr)													
On-farm*	72	69	66	65	74	76	76	67	72	72	72	74	855
Off-farm	16	31	20	18	17	20	20	8	12	17	20	12	211
Total used	88	100	86	83	91	96	96	75	84	89	92	86	1066
Surplus labor (hr)	2	0	0	0	0	0	0	5	0	0	10	4	21
Options (for 1.5ha farm, in hr)													
Traditional-Maize-Beans*	0	0	15	25.5	12	6	0	12	33	6	0	19.5	129
Improved Maize-Beans*	0	0	18	16.5	27	4.5	0	6	54	12	4.5	21	163.5
Alley Farming	0	0	36	15	6	21	0	4.5	57	4.5	0	40.5	184.5

*These values included in On-Farm labor use above.

In the management of all on-farm and off-farm operations in a farming system, the labor resource is probably the most critical due to the seasonally based patterns of labor use. In Table 6, a monthly profile of labor availability and use is presented, including the periods when the farmer has to hire labor or has some surplus labor. In the same table, the monthly labor requirements of the three technology options are also given. The data indicate that for the improved maize-beans system, the May and September periods do not appear favorable. For the alley farming system, labor requirements in March, June, September and December are exorbitant. The traditional system has a more moderate labor demand. To adopt either of the two new systems, the farmer would have to hire more labor. Alternately, researchers could explore ways to spread or shift some of these operations to the few slack months.

Table 7 Analysis of climatic risk for Traditional Maize-Beans, Improved Maize-Beans and Alley Farming Systems.

	Traditional		Improved		Alley Farming			
Indicator per season quality	Maize	Beans	Maize	Beans	Maize	Beans	Fodder	Fuel
Gross Yield (kg/ha)								
• Dry (30%)*	1200	400	2650	550	1700	500	1100	1400
• Average (50%)	1350	500	3150	700	1900	600	1200	1500
• Wet (20%)	1500	600	3650	850	2100	700	1300	1600
Yield adjustment	-	-	-	10%	10%	10%	10%	-
Gross Income (S)								
• Dry	384		637		594			
• Average	453		775		674			
• Wet	522		913		765			
Net Income ($)								
• Dry	-24		-115		-51			
• Average	45		23		29			
• Wet	114		161		12			
Expected Net Income (S)	39		9		23			

*In parentheses, percent probability of occurence.

Cash flow is a similar dynamic type of indicator used to determine whether the farmer can manage a new system. It is evident that the improved maize-beans system may encounter problems because of its high cash input requirement in selected months of the year (Table 2), whereas the alley farming system does not require much cash input (Table 3).

5.4.5 Risk Analysis

In an ideal world, external conditions such as the weather would always be optimal for the farmers. In a nearly ideal world, conditions might not be perfect but at least they would be predictable. Of course, in the real world of farmers, fine weather is never guaranteed, markets are unreliable, outbreaks of crop pests can occur at any time.

Newly introduced systems may alter a farmers' capacity for coping with such risk factors. Thus, risk analysis is an important part of both technical and economic evaluation of a system.

In this discussion of risk analysis, we will use the example of uncertain seasonal quality in which the hypothetical conditions range from best (wet) to worst (dry). The probability of the occurrence of dry, average, and wet seasons influences the management and performance of the three alternative systems.

For each quality of season (dry, wet, average), the gross income, net income, and expected net income are derived. These measurements can be used to determine the best technology choice (Table 7). The average yield figures here are taken from Table 4.

Net income under the various possible conditions can be used as criteria for selecting a system. From Table 7, one observes that the option with the maximum returns under the conditions of minimum rainfall is the traditional system. In shorthand rotation, this may be called the *maximin* criteria. The *maximax* criteria would select the option that provides the maximum returns under maximum rainfall, which in this case is the improved maize-bean system. The *most probable* criteria chooses the system which provides the best returns under average conditions, which is the traditional system in this case.

The Expected Net Income (ENI) is another criteria used in risk analysis. It is calculated as the sum of Net Income per season quality multiplied by the respective probability of that season quality. Thus ENI for improved maize-bean works out as:

Season Quality	Net Income	x	Percent Probability of Season Quality		Expected Net Income
Dry	\$-115	x	$\frac{30}{100}$	=	-34.50
Average	\$23	x	$\frac{50}{100}$	=	11.50
Wet	\$161	x	$\frac{20}{100}$	=	32.20
			TOTAL	=	\$9.20

The ENI can be interpreted as average profit per hectare that the farmer would receive in the long term, taking into account the variability of season quality. Again the traditional system has a higher ENI. The alley farming system is also very attractive in terms of ENI.

The choice of any which decision criteria to apply depends on the disposition of the farmer. If he or she is risk averse, *maximin* criteria would be appropriate. If he or she prefers to take risks in hope of a higher pay-off, the *maximax* could be more appropriate. If he or she can absorb short-term risks and is concerned with optimizing returns in the long-term, the *most probable* and ENI criteria would be appropriate.

5.4.6 Long-Term Economic Evaluation

The yearly distribution of benefits and costs for a 9-year period for the traditional maize-beans and alley farming system is presented in Table 8. In the traditional maize-beans system, there is a 10% yearly decline in yields of both crops due to the fact that the farmer is not replenishing soil nutrients at a rate that would sustain yields indefinitely. Costs remain constant for the duration of the study period. Some of the tools are replaced every two years. Costs exceed benefits after year 4, which means that in theory the farmer should cease cropping and leave the land fallow. However, the farmer continues operating because he or she needs food and does not worry about compensation for the in-kind resources used (i.e., labor). Land cost is not included in costs because land usually maintains its present value over time.

In the alley farming system, benefits remain constant on the assumption that enough multipurpose tree (MPT) biomass will be retained to maintain soil fertility, hence a constant crop yield. Except for the initial hedgerow investment, all other costs also remain constant.

At the bottom of Table 8, discount factors for r = 10% and r = 15% are computed for each year of the study period, using the formula presented in section 5.3.

The three performance indicators used for long term economic evaluations are:

- Net Present Value (NPV);
- Benefit/Cost Ratio (B/C); and
- Internal Rate of Return (IRR).

In order to determine these indicators one has first to determine the Total Present Value (TPV) of benefits and costs using the discount factor.

Table 8 Yearly distribution of benefits and costs and their Total present Values for the Traditional Maize-Beans System and the Alley Farming System.

Criteria	0	1	2	3	4	5	6	7	8	9
Traditional Maize-Beans										
Benefits										
• Maize		243	243	218	196	177	159	143	129	116
• Beans		210	210	189	170	153	137	124	111	100
• Total		453	453	407	366	330	296	267	240	216
Costs										
• Labor		324	324	324	324	324	324	324	324	324
• Inputs		44	44	44	44	44	44	44	44	44
• Tools	40			20		20		20		20
• Total	40	368	368	388	368	388	368	388	368	388
Alley Farming										
Benefits										
• Maize		211	307.8	307.8	307.8	307.8	307.8	307.8	307.8	307.8
• Beans		174	226.8	226.8	226.8	226.8	226.8	226.8	226.8	226.8
• Fodder		32.4	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8
• Fuelwood		37.5	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
• Total		454.9	674.4	674.4	674.4	674.4	674.4	674.4	674.4	674.4
Costs										
• Labor		324	492	492	492	492	492	492	492	492
• Inputs		32	32	32	32	32	32	32	32	32
• Tools	45		-	23	-	23	-	23	-	23
• Hedges	608	-								
• Total	653	356	524	547	524	547	524	547	524	547
Discount Factors										
10%	1.0	0.91	0.83	0.75	0.68	0.62	0.56	0.51	0.47	0.42
15%	1.0	0.87	0.76	0.67	0.57	0.49	0.43	0.38	0.33	0.28

Calculation of TPV

Using the data given in Table 8, the Total Present Value (TPV) of the Benefit at r = 10% for traditional maize-bean system for a 9-year period is calculated by summing the discounted total benefits for years 1-9.

TPV = (453 x 0.91) + (453 x 0.83) + (407 x 0.75) + (366 x 0.68) +

(330 x 0.62) + (296 x 0.56) + (267 x 0.51) + (240 x 0.47) +

(216 x 0.42) = $2052

The TPV for the cost could be calculated in the same way. Similar calculations can be made for alley farming system as well. Thus the TPV for benefits and costs for the two systems are as follows:

		Traditional System		Alley Farming System	
	r :	10%	15%	10%	15%
Benefits	:	$2052	$1750	$3677	$3032
Costs	:	$2202	$1835	$2766	$3053

Calculation of NPV and B/C

a) For a discount rate of 10%

Traditional System

Net Present Value (NPV) = $2052 - 2202 = $-150

Benefit/Cost Ratio (B/C) = $2052 ÷ 2202 = $0.93

Alley Farming System

NPV : $3677 - 2766 = $911

B/C Ratio : $3677 - 2766 = $1.33

b) For a discount rate of 15%

Traditional System

NPV : $1750 ÷ 1835 = $0.95

B/C Ratio : $3032 ÷ 3052 = $0.99

Alley Farming System

NPV	:	\$3032 - 3052	=	-\$20
B/C Ratio	:	\$3032 - 3052	=	\$0.99

The NPV is interpreted as the net profit of the technology, whereas the B/C is the ratio of total benefits to total costs. For a technology to be acceptable, NPV must exceed 0, which means that the B/C ratio exceeds 1.0. In the case of the traditional maize-beans system, there is an abnormal result in the sense that as the discount rate increases, the NPV decreases. Normally there would be a direct relationship between the two. This happens because after the fourth year the total costs increasingly exceed the total benefits in this system.

These calculations indicate that alley farming offers greater net profits and equal or improved benefit/cost ratios than the traditional system. The indicators are particularly favorable for alley farming at a discount rate of 10%.

Calculation of IRR:

As stated earlier, another key long-term indicator for economic evaluation of technologies is the Internal Rate Return (IRR). The IRR is the exact discount rate at which benefits are equal to costs. At a discount rate equal to IRR, the NPV = 0 and the B/C Ratio = 1.0. The IRR can be estimated with the following formula:

$$IRR = r_1 + \frac{(NPV_1) \times (r_2 - r_1)}{(NPV_1 - NPV_2)}$$

where NPV_1 corresponds to interest rate of r_1 and NPV_2 to interest rate of r_2. Taking the value of r_1 as 10% and r_2 as 15%, the IRR for the alley farming may be computed as:

$$IRR = 10 + \frac{911 \times (15 - 10)}{911 - (-20)} = 14.9\%$$

It means that at IRR of 14.9%, benefits are equal to costs. Though an IRR of 14.9% appears to be attractive, the opportunity cost of capital for the farmer determines whether this technology can offer better returns. In most cases, the real cost of capital to resource-limited farmers is in the range of 30-35%. However, there are other attributes of alley farming that should be assessed to decide whether to adopt the alley farming system (Avila, 1989).

Risk analysis can also be conducted in the long-term by modifying the calculations of yearly benefits, discount rates, or their determinants and observing the effect on the NPV, B/C Ratio, or IRR.

Finally, there is a computerized model (MULBUD) to carry out long-term evaluation of agroforestry sysems, such as alley farming, which was developed at ICRAF (Etherington and Mathews, 1984). The mathematical calculations performed here would take just a few minutes with MULBUD.

5.5 SUMMARY

The key economic concepts for short and long-term evaluation have been presented. These concepts were applied to compare the profitability, management feasibility, and risk considerations of three alternative technologies : a traditional maize-beans system, an improved maize-beans system, and an alley farming system.

Since not all the biophysical and other coefficients in the hypothetical data are based on validated evidence, these results should not be used to make conclusive statements on the economic worthiness of the alley farming system. However, these coefficients can be assessed and their precision improved using new or site-specific research results. The basic procedures used in this exercise provide a useful guideline as to the type of data required, basic questions and issues to be addressed, and appropriate interpretations for the economic assessment of alley farming.

5.6 FEEDBACK EXERCISES (Find out answers from the text).

1. Circle T for true and F for false in the statements given below:

   i) The principle of cost analysis deals with criteria for optimizing income from several possible options. **T F**

   ii) Opportunity cost denotes value of inputs in their best alternative uses. **T F**

   iii) The law of diminishing returns states that increasing use of resources results in dminishing returns up to a certain level of resources used and increases thereafter. **T F**

iv) Variable costs of production vary with the levels of production. T F

v) If land is cheap and fertilizer is costly, land can be substituted for fertilizer.

T F

2 Given below are the incomplete definitions of 4 performance criteria used in economic analysis. Fill in the missing components.

i) Net yield = Physical yield/ha minus..
....

ii) Field price of output = ...
minus storage, transportation, marketing and ....

iii) Field price of input = Purchase price plus
....
....

iv) Discount factor = Present value, at the beginning of year 1, of
....
....

3. i) Prepare a tabular format to record labor use and commercial inputs for different activities associated with alley farming.

ii) What are 3 steps involved in calculating gross income of a maize-bean cropping system?

____

____

____

iii) What general items you will include for variable costs and fixed costs in profitability analysis of alley farming system?

____

____

____

4. Write the formula to calculate the profitability indicators given below:

   i) Net income/ha = Total gross income - Total cost

   ii) Net-return/labor day =

   iii) Net returns/$ cash input =

   iv) Gross returns/$ cash input =

5. Fill in the blank spaces in the following sentences

   i) The main objective of the management feasibility analysis is ____________

   Management indicators in this analysis could be _______ and/or ________

   ii) In risk analysis, maximax criteria is the best return under the best condition while the most probable criteria is the best return under ________________ conditions.

6. i) Some of the economic indicators used for long term economic analysis of technology are abbreviated as TPV, NPV, B/C. What are the full forms for these abbreviations? How are they defined?

   TPV____

   ____

   NPV____

   ____

   B/C____

   ____

   iii) Explain the term Internal Rate of Return:

   ____

7. In the example provided in this paper, which evaluation criteria or indicators suggest that alley farming is preferable to the traditional system. Which indicators showed traditional farming to be preferable?

5.7 SUGGESTED READING

Arnold, J.M. 1987. Economic considerations in Agroforestry. In Steppler, H.A. and P.K. Nair, eds. Agroforestry: A Decade of Development ICRAF, Nairobi, Kenya.

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5.8 REFERENCES

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TECHNICAL PAPER 6

Socio Economic Data Collection Methods

6.0 Performance Objectives

6.1 Introduction

6.2 Exploratory Surveys
6.2.1 Key Informant Interviews
6.2.2 Village-level Group Interviews

6.3 Topical Surveys

6.4 Cost-route Studies

6.5 Summary

6.6 Feedback Exercises

6.7 Suggested Reading and References
Addendum A : Exploratory Survey
Sample Group Interview Form

Addendum B : Topical Survey
Sample Questionnaire

Addendum C : Field Measurements

6.0 PERFORMANCE OBJECTIVES

Technical Paper 6 is intended to enable you to:

1. Recall three parts of an IITA project used as a case study for collecting economic data.
2. Describe the procedure followed by IITA to conduct an exploratory survey.
3. Discuss how a topical survey differs from an exploratory survey and explain what type of data is collected in a topical survey.
4. Discuss limitations of the cost-route study and recall various steps in its conduct.

Technical Paper 6: SocioEconomic Data Collection Methods

Karen Ann Dvorak

6.1 INTRODUCTION

Assessment of socioeconomic issues related to alley farming is in its beginning stages. Some useful examples include Sumberg et al. (1987) and Ngambeki (1985). Because of a general lack of on-farm economic data for agroforestry systems, many studies to date have used secondary and simulated data. Researchers can make important contributions to this field by conducting well planned, well executed, socioeconomic data collection exercises.

In this chapter, we will review certain principles of economic data collection for the socio-economic analysis of alley farming, using an on-going IITA project as a case study.

The IITA study was started in 1988 and consists of three parts:

- an exploratory survey,
- a topical survey, and
- an intensive data collection (cost-route or panel study).

6.2 EXPLORATORY SURVEYS

Exploratory surveys are useful tools for conducting socioeconomic inventories of resource management and resource availability in farming systems. Two types of surveys may be used:

- key informant interviews, and
- village-level group interviews.

Individual or household-level interviews are also useful tools for social science research. However, they are more time consuming than key informant or village-level surveys, and generally are not used as exploratory surveys.

6.2.1 Key Informant Interviews

Key informant interviews are useful tools for exploratory surveys. A "key informant" is generally a person with a special expertise selected to provide information.

Experienced district officers, extension agents, or senior members of the farming community may be purposely selected to provide information on local cropping systems, soil management practices, or production constraints.

Similarly, key informant interviews with women traders could be used to provide information on marketing practices, marketing margins, or costs of transporting agricultural produce. Key informants need not be randomly selected. The researchers may use his or her judgement in selecting participants most likely to be knowledgeable about the subject under investigation.

Key informant interviews may be informal or formal. They may use an "open-ended" or "closed" questionnaire format, or a "check-list" approach. With a check-list approach, the researcher lists the topics to be covered in the interview, which takes the form of a discussion. The check-list is essentially a reminder to the researcher of the topics that need to be covered in the conversation.

For more formal surveys, a set of specific questions are printed. The researcher moves through the questionnaire asking each question in turn. "Closed" questions require that specific responses be recorded, for example:

In this region, what is the most common length of fallow following cassava production?

___ No fallow ___1 year ___2-3 years ___ more than 4 years

An "open-ended" question does not require a fixed response. The researcher simply records the response of key informant, for example:

Please describe the most common cropping pattern in this area

____

____

____

____

Open-ended questions are more suitable for qualitative data. Closed questions are more suitable for quantitative data.

Many socioeconomic topics can be usefully investigated using key informant interviews, including the following: types of land tenure, price trends, prevalence and sources of hired labor, availability of land, use of communal labor, methods of paying labor, household structure, cropping practices generally, transportation costs, market access, information on food storage and processing techniques. Key informant interviews have the advantages of being relatively rapid and inexpensive.

6.2.2 Village-Level Group Interviews

Interviews in the IITA Project

In the IITA project, village-level group interviews were used as the exploratory survey method. Villages were randomly selected from a list of villages procured from the local government for the area under study. Village contacts were made through the assistance of extension agents. Meetings were fixed one day in advance. Fifteen to twenty people representing small and large farmers and men and women were invited to attend the meeting. Generally two meetings were held per day.

Apart from a few general questions to let the meeting get going, the following topics were addressed:

- fallow periods and use of fallow vegetation,
- land tenure,
- management of trees, and
- price and markets.

Some questions were also asked on labor availability but since this is frequently a sensitive topic it cannot be explored in a great detail in the format of a village interview. Nevertheless, labor availability remains a crucial factor in alley cropping economics.

An example of a form used for the IITA exploratory survey is presented at the end of this paper (Addendum A).

How to Conduct Interviews

Always introduce yourself and your colleagues and explain the purpose of your study. It may be necessary to establish at the outset that you will not pay the villagers or hand out gifts for participation. A thorough explanation of the purpose of your research and the role of information collected from the farmers can help prevent later difficulties.

Include information on how many villages you will visit and how they were selected. If villagers do not wish to participate, move on to another village.

In conducting group interviews, it is important to allow the villagers enough time to discuss matters among themselves before recording an answer. Such discussion should be encouraged, not discouraged. Avoid accepting answers from a single spokesman for all the villagers. Stress that there is no "right" answer — that your interest is the farmers' opinions, problems and concerns. Pay attention to differences in answers. For example, men and women may feel that different crops are the most important. Or, women may have different ideas than men about access to bush off-takes such as firewood.

Data from group interviews of this nature is most reliable when dealing with general practices village-wide. Crop and fallow management questions are appropriate for this method. General information on prices and markets may be asked. Group interviews are not suitable for investigating distribution of wealth, land ownership, labor hiring.

Questions should be neutral; that is, avoid "leading questions". Leading questions have a particular answer embedded in the question itself, for example:

Is oil bean your most important fuel wood material?

— Yes — No

In this leading question, you are suggesting to the farmer that the oil bean tree is the most important fuel wood. This question would be better phrased:

What three materials are most often used for firewood?

(1) ______________________________

(2) ______________________________

(3) ______________________________

Any list of interview questions (called an interview schedule) should be pretested with a small number of villages (or individuals if appropriate). Modify any questions the farmers have difficulty understanding. Eliminate questions which result in ambiguous answers. Pre-tests should not include part of your final sample. Allow time in research planning for pre-testing and revising the questionnaire.

Always record the date of interview and interviewers' names on each form, as well as an indication of the location of the interview. Your interview schedule should also be dated in case you make later revisions, resulting in more than one version of the interview schedule.

In closing the interview, always thank the participants sincerely for their time and information. Ask if there is any information that they would like to add on the topics that have been discussed. It may be helpful to ask if they have any questions. Many of their questions will be technical, so an extension agent or familiarity with extension recommendations is often helpful.

Review the material at the end of each day with other team members. Note any problems or ambiguities in responses. These may be cleared up by follow-up visits, or at least corrected in future interviews.

6.3 TOPICAL SURVEYS

The exploratory survey, described above, deals with rather general crop and resource management issues at the village level. It is a useful tool for describing agricultural practices across a region, and for identifying areas for research. A topical survey, on the other hand, is typically very specific and designed to answer particular questions on a focused topic. It is often more appropriate to administer a topical survey to individual farmers. When properly designed, a topical survey can provide quantitative data which can be subjected to statistical analysis.

For example, data could be collected on land tenure and a table drawn up of the number of plots borrowed, rented, and owned. Such data could then be compared with regard to successful and unsuccessful alley farms (Table 1). To cut and carry the fodder for livestock may require farmers to make daily visits to their alley farm; data on distance from the compound to the alley farm could be collected and analyzed for its effect on the practice of using hedgerow species as fodder (Table 2). Farmers' characteristics such as gender, place of origin, degree of contact with extension personnel, major occupation, are suitable for a topical survey.

A topical survey may also be useful for obtaining farmers evaluations of alley farming. Farmers may be asked to list their uses of the hedgerow species. They may be asked to suggest other species which they think would be suitable for alley farming systems. Any "criticisms" should be carefully noted and evaluated for possible improvements in the system and its management.

A sample form used for a topical survey in the IITA project is presented at the end of this paper (Addendum B).

Table 1. **Tenure and current status of alley farms established in 1985 in XXX village, VVV province**

Status in 1987	Own	Borrowed	Rented	Total
Successful	12 (60)*	3 (5)	5 (25)	20
Unsuccessful	4 (50)	2 (25)	2 (25)	8
Total	16 (57)	5 (18)	7 (25)	28

*Numbers in parentheses are row percentages.

Table 2. **Distance from compound to the alley farm and the use of hedgerow biomass from alley farms established in 1985 in XXX village, VVV province.**

Distance to compound (minutes)	Fodder	Mulch	Poles	Total
<3	12 (60)*	8 (40)	0 (0)	20
>3 and <10	4(40)	5 (50)	2 (10)	11
>10	1 (10)	7 (50)	2 (10)	10

*Number in parentheses are row percentages

6.4 COST-ROUTE STUDIES

Cost-route studies are highly detailed field study analyses of inputs and outputs related to farmers' use of a particular technology. They demand close participation in and observation of the adoption of a technology in the farmer's environment over an extended period of time. Generally speaking, cost-route studies (also called panel studies) are expensive and time-consuming. There is a tendency to generate data which is difficult to manage and may never be used. Cost-route studies are a last resort and must be justified by the absence of any other means to answer important research questions. Often, exploratory and special topical surveys can be used in place of cost-route studies.

Study Site

IITA conducted a cost-route study of alley farming in Ayepe village of Irewole Local Government Area (ILGA), Osun State, Nigeria. The village is an established site for IITA on-farm research and is situated in the "cocoa belt" of the lowland, semi-deciduous, humid forest, about 60 km southeast of IITA headquarters in Ibadan. Average annual rainfall is between 1250 and 1500 mm. The main rainy season is from late March to late July, followed by a break and a short rainy season from late August to early November. Soils generally belong to the Egbeda association.

Cassava (*Manihot esculenta)* is the primary staple and food crop produced, frequently in association with maize. Cocoyam (*Zanthosoma sagittifolium)* and yam (*Dioscorea spp.*), and small quantities of vegetables, including egusi melon (*Citrullus lanatus),* tomatoes (*Lycopersicon esculentum),* peppers (*Capsicum spp.),* leafy green vegetables (*Amaranthus spp., Corchorus olitorius* and *Celosia spp.*) and okra (*Hibiscus esculentus*) are also produced. Plantains (*Musa paradisiaca*) and bananas (*Musa musaaceae*) appear in dense stands in small "backyard" areas, scattered in food crop fields, and in plots of cocoa (*Theobroma cacao.*) Cocoa plots are not well maintained, yet earnings from cocoa remain an important source of cash and some farmers continue planting new cocoa. "Wild" oil palm are protected, and processing of palm oil is another important source of cash income, particularly for women.

Methods

Eleven farmers in the Ayepe area were assisted in planting hedgerows of *Leucaena leucocephala* in the 1987 rainy season. Scarified, but not inoculated, *Leucaena* seeds were planted to create six hedgerows 4m apart, each at least 25m long. Three seeds per hole were dibbled at an intra-row spacing of 25cm. The alley crops were cassava + maize. The principles of hedgerow management to maintain soil fertility were explained. After planting, management was under farmers' control.

Detailed data collection started during the rainy season of 1988, just prior to the main cropping season. In April-May, each field with hedgerows was visited and height and spacing of all *Leucaena* plants was measured. This management was repeated in January-February 1989. All field crop plots managed by farmers were visited and measured. Trees present in each plot were counted and mapped. The distance from compound to each plot, in kilometers and walking time, was also measured.

Panel surveys on agricultural inputs and outputs began in October 1988. Data were obtained on all activities, inputs and outputs for each plot under the farmers' management. Each farmer was visited every three days, and interview data was recorded on a field worksheet. Coding and data entry were done at office headquarters. Data analyses were carried out using SAS computer software.

The type of data recorded in the IITA panel surveys in Ayepe consisted of:

- date of an operation,
- type of operation (clearing, weeding, pruning, harvesting, etc), and
- the hours spent by each family member in each operation.

The farmers selected in this study met 95% of the labor requirement from their family members. Work by young people and children was also included. Although they did not work as efficiently as adults, these groups nevertheless contributed to the work on the farm. Some operations, such as distributing cassava cuttings or gathering maize cobs, may be done entirely by children.

A list of field measurements taken, with a description of each measurement, is presented at the end of this paper (Addendum C). An example of a field worksheet used in a panel survey is also provided (Addendum D).

Special Topical Surveys as an Alternative to Cost-Route studies

Because so much data is generated by full cost-route studies, they require large computers and skilled programming for data management and analysis. This is one reason why cost-route studies should be avoided, whenever possible. Instead, it will in most cases be preferable to design a topical study which focuses on specific subsets of activities.

For example, in a study focused on labor requirements, data on major labor operations may be recorded for an alley farm and one additional field (similar to a control). Such a study could be conducted in conjunction with an agronomic on-farm trial that assesses the potential of alley farming for mulch and fodder production under farmer management. The researcher may wish to record labor requirements for clearing, weeding, pruning, and mulching, and for cutting and carrying fodder.

Dates of operations, and the age and gender of workers should be recorded. Dates of operations will be important because some periods in the season are especially busy, e.g., clearing and planting time(s), and time of first weeding. When farmers find it necessary to postpone pruning, the shading of alley crops by hedgerows may cause yield losses. It is important to note, if alley farming increases, than labor requirements are peak labor demand periods. Likewise, the researcher should note when tasks are done primarily or exclusively by either men or women.

6.5 SUMMARY

This paper described the procedures followed in an IITA project to collect data for the socioeconomic study of alley farming. Exploratory surveys focus on issues at the village level while topical surveys are more specific in nature and are aimed at collecting quantitative data on land tenure, farm practices, farmer's characteristics, etc. related to individual farmers. Cost-route or panel studies are more expensive and time consuming. The amount of data procured in cost-route studies is quite large and can be analysed by using the SAS computer program. Sample forms for data collection using each of the methods are given at the end of the chapter.

6.6 FEEDBACK EXERCISES (Find out answers from the text)

1. Name two types of surveys that may be used as exploratory surveys.

2. Name four or more topics on which information can be sought in an exploratory survey for economic data collection on alley farming.

3. Circle A for agree and DA for disagree.

   a. A topical survey deals with village-level problems while an exploratory survey focuses on individual farmers.
   A DA

   b. The study of farmers' characteristics falls in the domain of topical surveys.
   A DA

   c. The topical survey offers an opportunity to collect quantitative data which may be subjected to statistical analysis.
   A DA

   d. "Cost-route study" and "panel study" refer to the same thing.
   A DA

   e. The cost-route study is preferred over exploratory and topical surveys due to its simplified and rapid approach.
   A DA

4. The five major steps in the conduct of a cost-route study in Ayepe Village by IITA scientists were:
   . Selection of 11 farmers
   . ________________
   . Data collection on various activities, outputs and inputs
   . ________________

6.7 SUGGESTED READING AND REFERENCES

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Addendum A: Exploratory survey
Sample Group Interview Form

Source : Adapted from Karen Dvorak, Joost Foppes and Abe Goldman "Survey on Resource Management Needs and Strategies Group Interview Form", (International Institute of Tropical Agriculture, March 1988)

Village:______________________________ LGA:_________________________

Community:__________________________ Country:______________________

Interviewer:___________________________ Form # 2A(3.88)

I. CROPS

1. In your village, what crop is the most important for:

   a. food_____________________________
   b. cash_____________________________
   c. area_____________________________

2. What other crops are important in your village (rank in order of importance)?

__________ Yams ( ) __________ Cocoyams ( ) _______ Cassava ( )
__________ Platain ( ) __________ Maize ( ) _______ Rice ( )
__________ OilPalm ( ) __________ Kola ( )
__________ Vegetable & fruits ( ) [Specify] __________ Others [specify]

II. FALLOW SYSTEM AND FIELD TYPES

3a. Do people in this village move their cultivated fields every year all together?
__________ Yes __________ No

3b. [If Yes] How many areas does the village have in this rotation cycle?
__________ Years

3c. Was the number of areas the same (same length of cycle) 20 years ago?

------------ Yes ____________ No, if no, how many years rotation? ______

4a. What is the best length of time to rest a field after cropping?
(Distinguish between actual fallow periods and cycles that include fallow+cropping)

Cropping:_________ years Fallow:________years Full cycle:______ years

4b. Are some fields in the village rested for more than (the required number of years)?

________ No ____________ Yes, if yes, what is the longest period that fields are rested? __________ years

4c. How many years are most fields in this village rested before replanting?

_______ years

4d. What is the fewest number of years that fields in this village are rested? _____ years

5a. Do you have compound farms? _________ Yes ___________ No

5b. Are these fields ever rested? _________ No ___________ Yes. If yes, for how long? ____________ years

6a. Other than compound gardens, are all fields fallowed for the same length of time?

_____________ Yes ______________ No

6b. (If No) What are the differences?

Group 1:

Group 2:

III FALLOW VEGETATION

7a. What are the most important plants in the bush/fallow? (Enter names in 7b below)

7b. What are their uses?

	Plant (local)	(Scientific)	Use
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			

8. When you clear a field, are all trees cut? ______Yes ________ No. If no, which ones are not cut?

9a. Do you plant any trees in fallow fields? ________ No ________Yes. If yes, what are they?

9b. (If yes) please describe how you do the planting

9c. Why are these trees planted?

10a. What is the best plant for staking? __________________ Why?

10b. Is this the one most often used? __________ Yes _________ No. If no, which is most often used? ______________________

11a. Do many people here buy staking? _______ No ________ Yes. If yes,

(i) What is the main type of wood that is bought? ___________

(ii) What is the usual price for these stakes? _____________

11b. Can anybody take stakes from the bush? _________ No __________ Yes

12a. What is the best wood used here for firewood? _______________

12b. Which types of wood are most often used for firewood? ________________

______________________ ________________________

12c. Is much wood from here sold to other areas? ____________ No _________Yes

12d. Do you buy firewood? __________ No ______________ Yes

12e. Can anyone take firewood from the bush?__________ Yes ____________ No

IV LAND ECONOMY AND AVAILABILITY

13a. Do people from outside the village use land in this village? _______ No______ Yes

If yes, how do they pay for it?

________Gift ________Loan ________Rent ________Pledge ________Buy

13b. Where do they come from?

13c. Is land in this village owned ____________ communally only _______ individually only ________________ both

14. If a family in the village does not have enough land, can they get more? ______ No _______ Yes. If yes, how would they obtain it and how would they pay of it?

(Note length of time)

__________ Gift ___________ Loan ____________ Rent _________ Pledge

15. Do some people from the village farm land on other areas?

________ No ________ Yes. If yes, where do they go? ____________________

V. LABOR AND AVAILABILITY

16a. Is it very difficult to hire labor? _______No _______ Yes. If yes, when is it most difficult? _________________________

16b. What is the daily rate for hired labor?

Operation	Enough labor	Not enough	Men		Women	
			Wage	Food or Wine	Wage	Food or Wine

16c. Are many people from this village working outside the village? ________ No

__________ Yes. If yes, where are they working? ____________

17. Where is most of the food sold that is produced in the village? _____________

Market	Distance	Travel Time

Addendum B:Topical Survey
Sample Questionnaire

FARM/FARMER DATA 22.8.89 kd Project Reference: __________ Farm number: __ __

Locality: ____________ Village: _____________ Farmer name: ___________ Date: _____

Planter's name if not original farmer: _________Year planted: _______ Interviewer: _____

Species 1:_________ Species 2: __________ Local staff member/contact: _____________

===

A1. Visit to field? ____ Yes ____ No

YEAR	CROPS
Before alley Est. year	

A3. Is hedgerow ongoing? ___ Yes ___ No

If NO - Reason for failure

____ Establishment failure
____ Maintenance failure
____ Overtaken by weeds
____ Moisture stress
____ Returned to owner*
____ Abandoned field*
____ Poor stand
____ Shading
____ Lost in burn
____Slashed
____ Waterlogged
____ Infertile soil
____ Cannot locate ___farmer field

Farmer evaluation of failure:

A4. Current use
____ Temporary fallow
____ Cassava fallow
____ Cropping:
Pattern: ______________
Date planted: _________
____

IF YES

A5. Most recent pruning: _________
A6. Most recent weeding: _________
A7. Hedgerow biomass uses:
____ Mulch ____ Feed ____ Timber
____ Stakes _____ Fuel
____ Combination (specify):

____ Other (specify): ____________

A8. Farmer evaluations:
1. Hedgerow uses
2. Crop yields (and/or soil improvement)
3. Weed suppression
4. Labor requirements

5. Management requirements

===

FARMER CHARACTERISTICS

B1.____ Indigene or ____ stranger (if stranger: B1a. Years in village: ___B1b. Home:___)
B2. Number of ____ goats ____ sheep ____ cattle B3. Cocoa fields? ___ Yes ____ No
B4. Tenure of alley farm: ________________ B5. Oil palm? _____ Yes _____ No
B6. Main occupation (by income source): _______________ Seconday: ______________
B.7 Number of adults in compound doing farm work: ________

B.8 Hires annual labor? ______ Yes _____ No   B9. Hires task labor? ___ Yes ___ No

==

DIFFUSION

C1. Have you undertaken gap filling? ________ Yes ___________ No
C2. Have you extended the size of your first alley? _________ Yes _______ No
C3. Have you planted a new alley? _________ Yes _________ No
C3a. If yes, is it also experimental? _______ Yes ______ No. C3b. If yes, give ID:
C4. Has any other family member planted hedgerows? ______ Spouse ____Other ___ No
C5. Have you given seed to any other farmer? ________ Yes ________ No
C6a. If yes, may we know to whom (name and location)
C6b. When were the seeds given? _______________
C6c. Do you know if they were planted? ____ Planted ___Not planted ___Don't know
C7. Have other farmers asked you about alley cropping/alley farming? ___Many __ Some ___None
C8. What changes would you recommed in the alley cropping/farming system?
C9a. What do you think is most important for obtaining good stand?

C9b. For obtaining good biomass production?

Addendum C: Field Measurements

Source: IITA Ayepe Studies, 1989

(1) Field size

Field measurements were initially done using flexible tapes laid along two boundaries. Areas were approximated as rectangles. This was not a very accurate measurement, but served the purposes for the first stages of data collection. From April 1989, all field measurements were done using compass and tapes or pacing.

(2) Tree counts

All established trees within a plot's boundaries were identified and coordinates marked on 2 plot map. Coordinates were determined by laying two flexible tapes along two boundaries of the field, and estimating location of the tree relative to the baseline tape. Coordinates obtained in this manner were approximate.

(3) Stand counts of *Leucaena leucocephala*

A flexible tape was laid on the ground along the base of the trees in a hedgerow. The reading for each tree was recorded. Plant height was measured for the tallest stem, using a metal metal tape or, for trees in excess of a height for easy reading, a marked rod.

(4) Biomass measurements

For each of the six hedgerows, every fifth stand of *L. leucocephala* was cut to a height of 50 cm from the ground. Small branches (<3mm thick) and leaves were stripped from the stems. Fresh (leaves + small branches) weights of stems and leaves small branches were taken separately using a spring balance in the field. Foliage and stems were spread on the alleys, stacked at the field, or returned to the farmer according to the farmer's preference.

Addendum D: Cost-Route Study

Sample Data Sheet

Source: IITA Ayepe Study, 1989

RME004 ALLEY CROPPING TRIALS KAD 4.9.89 700 FARM ______PAGE ____
Coding: _____ Data entry: ______Interviewer: _______ Circle farmer estimates 24 bowls
Proofreading 1:_____Proofreading 2:____Asterick by enumerator observations 42* bowls
Country:_______ State:______ Village:_____Underline enumerator estimates 16 years
Locality:_______ Currency: __________ Stratum:__________

Farm	Page	Entry	Updates Farm-Page-Entry	Respondent	Code	Interview date	
Operation date dd-mm-yy		Operation/ Method	Operation code	Plot code	Plot code	Season	Activity or Pattern
Select one L. Labor	Code	Time or quantity	Code	Crop	Code	Whole or Part Area Code	
I Input				Aggregated or Unaggregated a u		Main or Secondary m s If S give	
O Output				(1) aggregated over (2)		main Farm-Page-Entry	
Labor/Input source or output destination			Code Code	Conversion Reference		Tools and Equipment Code	
No. prices	Price or Value p	v Cash or Kind	c k				

TECHNICAL PAPER 7

Statistical and Experimental Design Considerations in Alley Farming

7.0 Performance Objective

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7.8 Summary

7.9 Feedback Exercises

7.10 Suggested Reading

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7.0 PERFORMANCE OBJECTIVES

Technical paper 7 is intended to enable you to:

1. List nine important factors to consider in designing alley farming trials.
2. Differentiate among data collection, data screening, data transformation and data coding.
3. Recall six variables commonly used to compare treatment effects in alley farming trials.
4. Describe briefly various procedures to analyse data obtained from alley farming trials.
5. Define experimental design.
6. Explain terms: plot, treatment, experimental error, replication, randomisation and blocking.
7. Identify twelve determinants in selecting appropriate experimental designs.
8. Differentiate between single factor and multi factor experiments.
9. Discuss distinguishing features and layouts of Completely Randomised Design (CRD), Randomised Complete Block Design (CRBD) and Latin Square (LS) design.
10. Describe objectives of incomplete block designs.
11. Recall major advantages of factorial experiments over a single factor experiment.
12. Explain main characteristics and uses of nested treatments and split-plot treatments in factorial experiments.
13. Differentiate between a fractional factorial design and a confounded design.
14. Recall and discuss six major factors to consider in laying out field plots for alley farming trials.
15. Discuss designs and experimental layouts for on-farm trials keeping in view different possibilities about farmers' plot sizes.

Technical Paper 7:

Statistical and Experimental Design Considerations in Alley Farming

Sagary Nokoe

7.1 INTRODUCTION

Scientific planning of each of the various operations in alley farming is based on proper experimentation that yields results which are statistically valid and easily verifiable. This paper has been written to assist researchers concerned with alley farming in designing appropriate experiments. Illustrations of designs and layouts are provided in Technical Paper 8, while the standard AFNETA experimental guidelines and trial designs are given in Volume 1 (Annex).

This paper's discussion of design and layout pertains to all major types of alley farming trials namely:

- multipurpose tree screening and evaluation
- alley farming management (e.g., mulching effects, crop productivity)
- livestock integration (e.g., feed supplementation, animal productivity)
- socio-economic assessment (e.g., economic returns)

The long-term nature of trials involving woody species and the varying objectives and expectations of alley farming trials demand that adequate caution be exercised in their design. Nine important issues worth noting include:

- restrictions on land availability and topography;
- general increase in soil heterogeneity with increasing land area, and modification of soil characteristics by imposed hedgerow trees or shrubs;
- effect of types of land preparation on changes in soil fertility gradients;
- conferment of varying efficiencies on factors in layered or split-plot arrangements;

- consistency of design, to ensure the possibility of combined analysis;
- the need to reduce the number of factors and their levels to the basic minimum;
- the possibility of using farmers' plots (in on-farm trials) as replicates rather than as a complete experiments;
- required plot sizes and number of plots for efficient estimation of errors;
- edge effects and the rows of discards

7.2 STATISTICAL METHODS

7.2.1 Steps in Experimentation

In scientific research, the seven major steps in experimentation to find solutions to a problem are:

(1) define and state the problem;
(2) identify objectives and develop a hypothesis;
(3) design and conduct experiments to test the hypothesis;
(4) collect data;
(5) analyse the data;
(6) interpret the data;
(7) draw conclusions about the hypothesis.

Statistical methods are useful in the proper execution of each of the seven steps. We shall be briefly touching here the common methodologies used in alley farming trials for data collection, data screening, data transformation and coding, selection of variables or observational parameters, and data analysis. Experimental design and procedures for establishing trials are discussed in a greater detail in the section to follow (7.3).

7.2.2 Data Collection

Specification of the objectives, definition of the problem, and formulation of a hypothesis are initial requirements for data collection strategies. The merit of any data will depend on their representativeness of the underlying population and their capacity for assessment and minimization of the various errors. For example, while studying the changes in soil properties as affected by alley farming it is always advisable to collect soil samples separately from alleys and hedgerows in order to assess the effects of mulching and nitrogen fixation. B. T. Kang (Pers. comm.) has observed great vertical and horizontal variation in soil properties between and across alleys and tree hedgerows.

There are three data collection strategies: experimentation, sampling, and routine observational data collection. Experimentation is discussed in much detail in a later section. Sampling procedures are used in on-farm surveys of farming practices and adoption rates, and in the collection of data from trial plots.

A sample from a real (not imaginary) population is defined as a sub-collection of that population. For statistical inference and for purposes of error minimization and reduction of observer-bias, these collections should be randomly obtained. The number and larger size of sampling units can be determined optimally by considering a cost/variance function. Generally, a highly variable population will require greater number of sampling units than for a fairly homogenous population.

A useful guiding principle for sampling is that the plot size and/or frequency should be large enough to include a good representation of the population, but small (or few) enough to ensure that sampling is achieved within a reasonable period of time. Further discussion on plot sizes and layouts is provided in the section "Notes on laying out Field Plots" (section 7.6).

7.2.3 Data Screening

In many cases, not all data collected will adequately represent the population under study. Two obvious reasons could be: faulty experimental or sampling technique, or wrongly derived data due to incorrect calculations or measuring scales. In data screening, unrepresentative or otherwise faulty data is rejected.

A good practice is to assume the possibility of errors in data, and then perform screening procedures to test the assumption. The procedures include:

- re-checking of data, which could imply revisiting the study site or re-examining the collected sample in cases of suspect observations;
- re-computing derived values and checking for consistency in measuring units (inches or meters, kilograms or pounds, acres or hectares, etc).

When the suspect values are not due to measurement errors, one can further subject the data to statistically acceptable data screening procedures. These tests are usually referred to as "tests of outliers or spurious observations." They depend largely on the statistical distributions principle. A common procedure for data assumed to follow the normal distribution is to compute the 95% confidence limits on the mean of the observations. If the suspected outlier falls outside the limits, it is rejected from further statistical analysis.

7.2.4 Data Transformation and Coding

Transformation of data may be carried out to achieve one or all of the following objectives:

- equalization of variances
- normalization of observations
- selection of appropriate regression variables

The overall aim, however, is to ensure the use of correct statistical procedures. Common transformations include the square root and logarithm for counts and the angular for percentages.

Data coding is different from data transformation. Ranking of data from original observations,reducing or increasing all data by a common factor are common forms of data coding. Sometimes this is done to simplify the arithmetic computations or in the case of species coding, to facilitate the use of conventional statistical procedures.

7.2.5 Variables

Variables are the characteristics a researcher intends to observe and compare among the various treatments. They are usually explicitly stated along with the statement of the problem. The six important types of variables related to alley farming trials are:

- **Agronomic variables** — germination and survival percentages, tree height and growth, stem form, biomass weight, crop yield, etc.;
- **Soil chemical variables** — soil fertility (nutrients type and level) with regard to hedgerows or alleys;

- **Plant chemical variables** — levels of essential elements (N, P, K) etc.;

- **Socio-economic variables** perceived to be of importance to the farmers. Examples include farmer views of the importance of a particular treatment, or the social costs and benefits of alley farming;

- **Economic variables;**

- **Derived variables,** e.g., differences in response of control and introduced treatments.

7.2.6 Data Analysis

Analyses of alley farming trials are usually straight-forward and involve one or more of the procedures listed below. (The reader is referred to the suggested readings for detailed descriptions of data analysis procedures.)

- **Treatment means comparisons** procedures, using the **t-test** (for two means at a time) and the **analysis of variance** (for more than two comparisons at a time);

- The use of **regression procedures** to establish or identify relationships between the independent and dependent variables;

- The use of **covariance procedures**;

- **Non-parametric** or **distribution free procedures** for assessing variables;

- The method or **repeated measures analysis** is particularly relevant in alley farming trials and long term studies. This procedure enables one to study differences between treatments at any particular period, differences between periods for specified treatments, interactions between period and treatments, and the identification of trends in response variables;

- Jolayemi (1989) has also suggested the method of **differencing** for removing the effects of auto-correlation which are inherent in repeated measures (time-dependent data) or adjacent plots. Routine analysis of variance may then be performed on such differenced data;

- The use of the **land equivalent ratio** could be considered when more than one crop are planted in the alley. This ratio is simply the sum of the ratios of the yields when planted on an area of the same size used for all the intercrops. This data conversion procedure is used to ensure the use of a single yield component for assessing different intercropping combinations.

- **Additional Treatment means comparison** procedures, such as the *Duncans multiple range, the Student-Neuman-Keuls procedure, etc.* The least significant difference and single degree of freedom contrasts could also be useful for pre-experimentation comparisons.

7.3 EXPERIMENTAL DESIGN: BASIC CONCEPTS

7.3.1 What is Experimental Design?

In experimentation we attempt to monitor the effects of certain inputs or material on the subject matter, of interest. The inputs could be different hedgerow leguminous plants planted under identical conditions, while the effects to be monitored could be the changes in soil fertility status, the yield of agricultural crops planted between the rows, the productivity of the animal being fed with the foliage from the tree crops, or the tree crop performance. The allocation of treatments (inputs) to the experimental units (plots) may be loosely referred to as the design.

The experimenter decides which individual unit is to receive which particular treatment according to a laid down procedure. The choice of procedure will often determine the basic design. What is important, however, is that during an experiment, the researcher has a choice as to how and when to apply the treatments. (In a survey situation, in contrast, there is no such choice). The choice of design is influenced by several considerations, notably the objectives, the amount of resources, and the time available. In all cases, however, the emphasis is on the reduction of unknown error and the elimination of systematic bias.

7.3.2 Basic Terminology and Concepts

- **The plot** or **experimental unit** is the smallest unit receiving a certain treatment. The information or data for comparison are from such single units. Examples include a single animal or group of animals receiving the same feed from the same source, a small plot having the same type of trees or agricultural crops, and so on.

- The **treatment** is the **material** being forced on the subject (unit) and whose effect is to be monitored. The treatment can be either qualitative (e.g., species, fertilizer types) or quantitative (e.g., time periods, quantified levels of a fertilizer type).

- The **experimental error** is a measure of the sum of variation between plots or units receiving same treatments. Suppose there are five different treatments with each treatment repeated or replicated four times. We could obtain the square of the deviation of each observation from its treatment mean, sum these up, and then obtain the average to give an idea of that treatment variance. There will be five such treatment variances. The "average" of these variances is roughly a measure of the experimental error. Inherent variability in the subject, uncontrolled external influences, and lack of uniformity in the application of treatments are possible causes of experimental error. Experimental error should be controlled so that we can estimate the treatment effects properly and compare effects of various treatments effectively.

- **Types of Field Experiments**: The several types of experimental trials include:
    - variety trials;
    - provenance trials;
    - field germplasm or screening trials;
    - fertilizer trials;
    - cultural/agronomic trials;

- chemical (other than fertilizer) trials.

It is quite common to have more than one type of trial in the same experiment. For instance we can compare different hedgerow species under weeding and no-weeding, that is, a situation involving both variety and cultural trials. However, species screening trials are best done on their own, rather than mixed up with other trials. Having selected the most suitable species for a particular area, aspects of intra-row spacing and other agronomic/management inputs can then be investigated.

- **Replication**: Experiments of the same nature, when presented under similar conditions, should yield similar results. In other words, researchers would want to ensure consistency in their results. The simplest way to achieve this is through the "repetition," i.e. "replication," of the same treatment on several plots or experimental units. Repetition on the same plot is not recommended as observations are unlikely to be independent. Moreover, the use of several small plots instead of one large plot ensures minimization of the effect of uncontrolled variability in the field.
- **Randomization**: This refers to the allocation of treatments to plots in such a way that, within a specific experimental design, units are not discriminated for or against. Each unit is supposed to have the same chance of receiving a particular treatment. Randomization is a necessity as no two units or plots are exactly the same. Statistically, the randomization procedure allows elimination of bias and ensures the computation of valid sampling errors.
- **Coverage or Blocking**: A block is a relatively large area or several identical units receiving all or most of the treatments. One is encouraged to "block" if one can vouch for the homogeneity within blocks and the heterogeneity between blocks. Because of the limitation of homogenous plots and the relatively large area required for alley-farming and agroforestry trials, one could also consider a location as a "block." The distinction between "replication" and "blocking" should be evident. Blocking is another way of improving the estimation of the error term, but only if the blocking is justified.

7.3.3 Determinants in Selecting Experimental Designs

To ensure the selection of appropriate experimental designs, the experimenter will need to respond to the following twelve issues:

- What are the specific study objectives?
- What are the variables to be observed (i.e. the dependent variables)?
- Are these dependent variables quantifiable and/or measurable? If these are not measurable, what criteria will you use for later comparisons among treatments?
- What are the independent variables that is to say, the treatments to be applied)?
- Are these treatments fixed or random? In other words, do you have several treatments to choose from or do you have a fixed number of treatments among which specific comparisons are desired?
- Are the levels of treatments qualitative (e.g. Species - *Acacia, Gliricidia, Eucalyptus* or quantitative (e.g.,solutions - 10 mg/l, 20 mg/l, 30 mg/l etc.)?
- How many replicates of each treatment can be available?
- Will all the replicates be available at the same time?
- How much land or material (to which the treatments are to be applied) are available?
- Are the subject materials or available land uniform enough to receive all treatments at a time?
- What will be the sampling unit? That is, indicate how small or large is the area or material to be observed. (In response, one may simply define the area.)
- How often will data (from dependent variables) be collected?

7.4 EXPERIMENTAL DESIGNS FOR ALLEY FARMING TRIALS: Single-Factor Experiments

7.4.1 *Introduction to Single-Factor Experiments*

Knowledge of experimental design is necessary for selection of simple designs that give control of variability and enable the researcher to attain the required precision. We have already discussed certain factors which are important in selecting an experimental design. The three most important among these are:

- type and number of treatments,
- degree of precision desired,
- size of uncontrollable variations.

We generally classify scientific experiments into two broad categories, namely, single-factor experiments and multifactor experiment. In a single-factor experiment, only one factor varies while others are kept constant. In these experiments, the treatments consist solely of different levels of the single variable factor. Our focus in this section is on single-factor experiments.

In multi-factor experiments (also referred to as factorial experiments), two or more factors vary simultaneously. The experimental designs commonly used for both types of experiments are classified as:

- Complete Block Designs
  - completely randomised (CRD)
  - randomised complete block (RCB)
  - latin square (LS)
- Incomplete Block Designs
  - lattice
  - group balanced block

In a complete block design, each block contains all the treatments while in an incomplete block design not all treatments may be present. The complete block designs are suited for small number of treatments while incomplete block designs are used when the number of treatments is large.

7.4.2. Complete Block Designs

We will discuss here three basic designs which come under the category of complete block designs, namely CRD, RCB, and LS.

The layout of the designs will be illustrated with the example of a modified research protocol on the "Evaluation of four *Gliricidia* accessions in intensive food production" (Atta-Krah, pers. comm.). The objective of the protocol is to evaluate top potential *Gliricidia* accessions under intensive feed garden conditions. The plot size is 8 x 5 m with 3 rows or columns of an accession in each plot. The available area is capable of containing a maximum of 16 plots.

Completely Randomised Design (CRD)

This is the simplest design. In CRD, each experimental unit has an equal chance of receiving a certain treatment. The completely randomised design for p treatments with r replications will have rp plots. Each of the p treatment is assigned at random to a fraction of the plots (r/rp), without any restriction. As stated above, if we have four *Gliricidia* accessions designated as A, B, C and D and we evaluate them using four replications in CRD, it is quite likely that any one of the accessions, say A, may occupy the first four plots of the 16 plots as illustrated in the following hypothetical layout.

A	A	A	A
B	C	C	D
D	B	C	B
D	C	B	D

A useful assumption for the application of this design is homogeneity of the land or among the experimental materials. This design is rarely used in most trials involving woody vegetation, but could be used under laboratory and possibly green house conditions.

The total source of variation (error) is made up of differences between treatments and within treatments.

Randomised Complete Block Design (RCBD)

One possibility that could arise in design or layout of alley farming trials is differences in the cultural practices or crop-rotation history of the portions of land available for the study. Alternatively, there could be a natural fertility gradient or, in the case of pest studies, differences in prevailing wind direction. If any of these heterogenities are known to exist, one can classify or group the area into large homogenous units, called blocks, to which the treatments can then be applied by randomization.

Randomized Complete Block Design (RCBD) is characterized by the presence of equally sized blocks, each containing all of the treatments. The randomised block design for P treatments with r replications has rp plots arranged into r blocks with p plots in each block. Each of the p treatments is assigned at random to one plot in each block. The allocation of a treatment in a block is done independently of other blocks.

A layout for 16 accession plots, grouped in 4 blocks, may be as follows:

PREVIOUS CROPPING HISTORY	BLOCK	ACCESSION			
Fallow	1	A	C	B	D
Maize	2	A	B	D	C
Gmelina	3	B	D	C	A
Maize/Gmelina	4	B	C	A	D

The arrangement of blocks does not have to be in a square. The above arrangement can also be placed as follows:

```
A  C  B  D     A  B  D  C     B  D  C  A
||  ||  ||  ||    ||  ||  ||  ||    ||  ||  ||  ||

                              B  C  A  D
                              ||  ||  ||  ||
```

where || represents 3 columns or rows of accession.

The actual field plot arrangement, with three columns of each accession for the first two blocks could be as follows:

<-------BLOCK 1---------> <-------BLOCK 2-------->

a a a	c c c	b b b	d d d	a a a	b b b	d d d	c c c
a a a	c c c	b b b	d d d	a a a	b b b	d d d	c c c
a a a	c c c	b b b	d d d	a a a	b b b	d d d	c c c

a a a	c c c	b b b	d d d	a a a	b b b	d d d	c c c
a a a	c c c	b b b	d d d	a a a	b b b	d d d	c c c
a a a	c c c	b b b	d d d	a a a	b b b	d d d	c c c

The total source of variation may be categorized as differences between blocks, differences between treatments, and interaction between blocks and treatments. The latter is usually taken as the error term for testing differences in treatments.

The Randomized Complete Block Design (RCB) is the most commonly used, particularly because of its flexibility and robustness. However, it becomes less efficient as the number of treatments increases, mainly because block size increases in proportion to the number of treatments. This makes it difficult to maintain the homogeneity within a block.

In RCB, missing plots (values) leading to unbalanced designs were problematic at one time. However, this is not much of a problem now due to the availability of improved estimation methods, for example, the use of generalized linear models. For situation with less than three missing values, one can still use the traditional computational procedure of RCB design.

<u>Latin Square Design (LS)</u>

The Randomised Complete Block design is useful for eliminating the contribution of one source of variation only. In contrast, the Latin Square Design can handle two sources of variations among experimental units. In Latin Square Design, every treatment ocurs only once in each row and each column. In the previous example,cropping history was the only source of variation in four large blocks. Supposing in addition to this we have a fertility gradient at right angle to the "cropping history" as shown below:

CROPPING HISTORY ↓ FERTILITY GRADIENT →

One may tackle this problem by using a Latin Square Design. Each treatment (in this case, the *Gliricidia* accessions) is applied in "each" cropping history as well as in "each" fertility gradient. In our example, restriction on space allows us to have a maximum of only 16 plots, when, say, 64 might have been ideal. The randomization process has to be performed in such a way that each accession appears once, and only once, in each row (cropping history) and in each column (fertility gradient). The layout will be as follows:

CROPPING HISTORY	FERTILITY GRADIENT 1	2	3	4
Fallow	A	C	B	D
Maize	B	D	A	C
Gmelina	C	B	D	A

The four blocks correspond to the four different cropping histories. The Latin Square (LS) design thus minimises the effect of differences in fertility status within each block. The total sources of variation are made up of row, column, treatment differences, and experimental error.

For field trials, the plot layout must be a square. This condition imposes a severe restriction on the site as well as on the number of treatments that can be handled at any one time. However, the principle can be extended to animal experimentation where a physically square arrangement does not necessarily exist. For instance, if the intention is to assess the nutritional effects of the accessions when fed to animals, the latter could be divided into four age and four size classes. The LS arrangement will thus be used to ensure that each age class and size class receives one and only one of each accession type.

The LS design can be replicated leading to what is commonly referred to as "Replicated Latin Squares". These Latin squares may be linked as shown below:

CROPPING HISTORY	FERTILITY GRADIENT							
	A	C	B	D	D	A	C	B
	C	B	D	A	A	B	D	C
	B	D	A	C	C	D	B	A
	D	A	C	B	B	C	A	D

In the case of the above, the two squares have the same set of rows (cropping histories), leading to an increased degree of freedom for the error term.

The rows are said to be linked. If, on the other hand, the rows are not linked, "Rows Within Squares" variability replaces the ordinary "Row" source of variation.

An additional restriction (source of variation) imposed on a basic LS design would lead to what is called "Graeco-Latin Square Design".

7.4.3 Incomplete Block Designs

One precondition for both the RCB and LS designs is that all treatments must appear in all blocks and all rows (For RCB) or columns (For LS). Sometimes with large number of treatments (say 20 accessions), each requiring relatively large plot sizes, this condition may not be practicable. Latin Square and RCB then fail to reduce the effect of heterogeneity(s). The designs in which the block phenomenon is followed but the condition of having all the treatments in all blocks is not met, are called Incomplete Block designs. In Incomplete Block situations, the use of several small blocks with fewer treatments results in gains in precision but at the expense of a loss of information on comparisons within blocks. The analysis of data for incomplete block designs is more complex than RCB and LS. Thus where computation facilities are limited, incomplete block designs should be considered a last resort.

Among incomplete block designs, lattice designs are commonly used in species and variety testing. These are more complex designs beyond the scope of this paper, but covered in a number of text books cited at the end of this paper. It is always advisable to consult a statistician when using incomplete block designs.

7.5 EXPERIMENTAL DESIGNS: MULTI-FACTOR EXPERIMENTS

We have so far concentrated on only one factor (i.e., one accession or other treatment). However, more than one factor will often need to be studied simultaneously. Such experiments are known as factorial experiments. The treatments in factorial experiments consist of two or more levels of the two or more factors of production.

7.5.1 Factorial Treatments

Suppose we are interested in studying the yield of an agricultural crop in an alley farm where four different leguminous tree species and three cultural methods are of interest. The leguminous tree species could be *Acacia* sp., *Cassia* sp., *Leucaena* sp., and *Gliricidia* sp.

The cultural treatment could include two weedings, one weeding and no weeding; the agricultural crop is maize planted between hedgerows of the same tree species. For a complete factorial set of treatments, each level of each factor must occur together with each level of every other factor. Thus in the present case we ensure that each cultural method is applied to each tree species. Since there are 4 species and 3 cultural methods, the total number of treatments will equal 12. In reality, what we have here is 12 treatments, with one treatment being made up of 2 factors having 4 and 3 levels, respectively. One might say, in this case, the factors are crossed.

This is not an "experimental design" but rather a "treatment design," because the 12 treatment combinations could be applied to any of the designs discussed previously. If we take the simplest design, the unrestricted randomized design, and four replications, then the conduct of an experiment with 4 leguminous species and 3 cultural methods will imply the randomization of "12 treatments" in 48 plots. If it is a Block design, we will have to ensure that each of the 12 treatments appears in all the blocks.

The advantages of the factorial arrangement are many. One major advantage is the reduction in the number of experiments, and a second the possibility of studying the interactions among the various factors. A significant interaction implies that changes in one factor may be dependent on the level of the other factor. If this happens, interpretation of the results has to be done cautiously to avoid inaccurate general statements on the individual factors.

7.5.2 Nested Treatments/Nested Designs

The situation discussed above can be extended to two or more locations, and the results combined using the Combined Analysis Procedure. However, it does at times happen that species may be location specific, in which case the 4 leguminous tree species utilised in a particular location may not be suitable at other locations. One approach would then be to use 4 different species in each location. Or, a particular tree species may not appear in all the locations. This structure of treatments falls under the category of Nested Designs (or better, Nested Treatments). The tree species are said to be nested in locations, not crossed as in factorial treatment. It is necessary to emphasize that this nested-treatment arrangement can be applied to any of the basic designs, such as CRD, RCB and LS.

7.5.3 Nested-Factorial Treatments

This type of treatment arrangement is followed when some factors in the same experiment are crossed (as in factorial treatment) while others are nested. For instance, if we impose three fertilizer levels to the trees nested in the example above a nested-factorial treatment arrangement is obtained — provided the same fertiliser levels are used for all trees and locations.

7.5.4 Split-Plot Arrangement

Split-plot experiments are factorial experiments in which the levels of one factor, for example tree species, are assigned at random to large plots. The large plots are then divided into small plots known as "sub-plots" or "split plots", and the levels of the second factor, say cultural practices, are assigned at random to small plots within the large plots.

This arrangement is often useful when we wish to combine certain treatments (as in factorial and nested), some of which require larger plots than others for practical and administrative convenience. Examples are situations requiring spraying insecticides, irrigation, tillage trials, etc. Usually, the treatment on which maximum information is desired is placed in the split-plot or in the smallest plot.

It is important to emphasize that the split-plot is not a design as such but rather refers to the manner in which treatments are allocated to the plots. A split-plot arrangement in an RCB design will usually have two error terms — one for testing the treatments in large plots (not efficient) and the other for the sub-plot treatments and interactions (very efficient).

A split plot design can be further extended to accomodate a third factor through division of each sub-plot into sub-sub-plots. This is then called a split-split-plot arrangement.

7.5.5 Multi-Factor, Incomplete Block Designs

Although factorial experiments provide opportunities to examine interactions among various factors, they are difficult to conduct when the number of factors and their levels are many. Consider a situation involving 3 factors, each of which has 4 levels, making a total of 4^3 or 64 treatment combinations. The conduct of this experiment will require very large blocks if we employ randomised block design. Obviously in field plot experimentation this could be a major defect.

To overcome this difficulty, fractional factorial or confounding designs can be used. In a fractional factorial design, only a fraction of the complete set of factorial treatment combinations is included. Here the main focus is on selecting and testing only those treatment combinations which are more important. The fractional factorial design is used in exploratory trials, where the main objective is to examine the interaction between factors. In a confounding design all the treatment combinations of the factors and levels under study are tested with blocks containing less than the full replications of the treatment combinations.

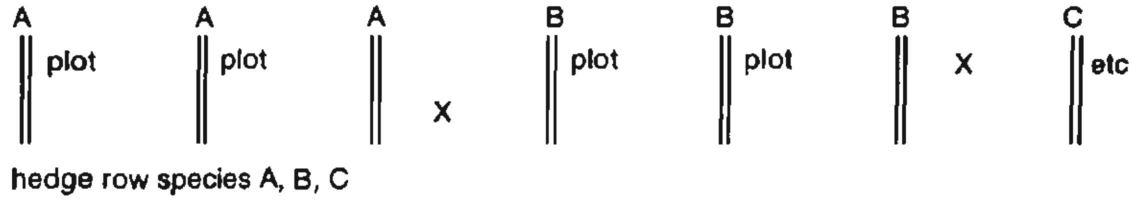
The two procedures do not allow equal evaluation of all the effects and interactions. Depending on what is being confounded, some effects may not be estimated at all. This problem can be resolved through a conscious and objective selection of the input variables. With the limited number of variables in alley farming research,the need for confounding may not be as great as the need for fractional replications and or balanced incomplete blocks. To use the fractional factorial or confounding designs, the assistance of a statistician is a must.

7.6 NOTES ON LAYING OUT FIELD PLOTS

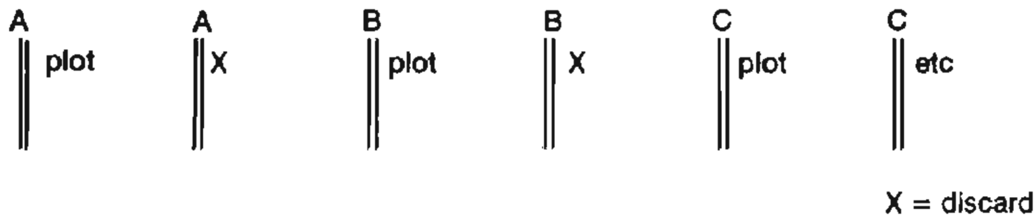
7.6.1 Discards and Sample Units

As in any field crop experiment, not all the areas in alley farming experimental plots need to be observed during data collection. If we are comparing two or more hedgerow species for their effectiveness in enhancing soil fertility, the following possibilities in layout, subject to land restriction, could arise:

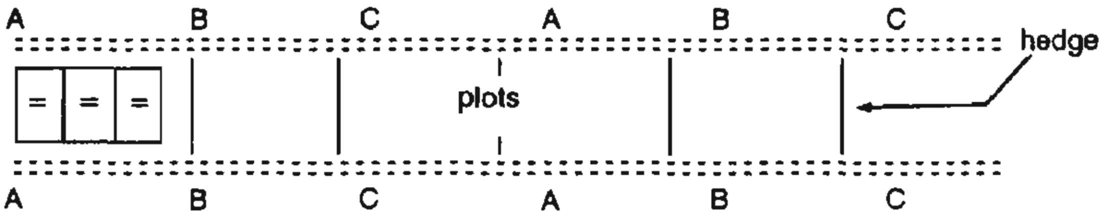
(i)



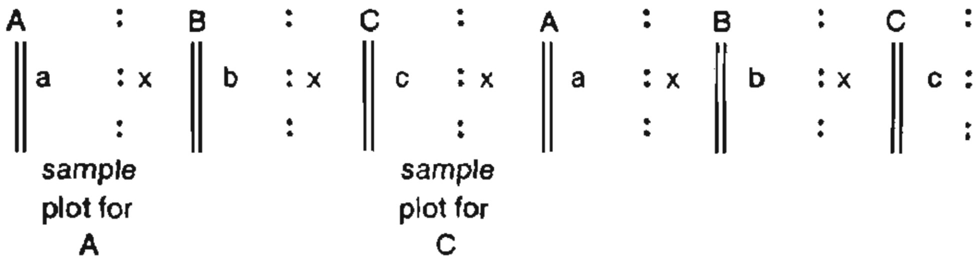
(ii)



(iii)



(iv)



The arrangement in (i) provides two plots for each hedgerow species for soil nutrient or crop yield studies. One whole plot is discarded between the last row of a species and the first row of another species. If land is not limiting, this arrangement is ideal. Some practitioners will even go further to sample or observe the area surrounding only the middle hedgerow, i.e., one half-plot to the left and one half-plot to the right of the middle hedgerow of the same species.

For the assessment of the hedgerows themselves, the middle hedgerow constitutes an ideal sampling unit. However, in most practical situations, particularly where the hedgerow species are spaced widely apart from each other, examination of all hedgerows may be acceptable.

Arrangements (ii) and (iii) have been found useful when land is particularly limiting. In situation (iii), the area to sample lies between the two rows as marked in treatment A.

The arrangement in (iv) is not recommended, but has been used under serious land limitation and species availability situations. The sample plots are half-plots. For consistency, either the right-hand or left-hand side of the hedgerow should always be chosen. Remember that the hedgerow species at the edges cannot be studied reliably. Given enough replications, these could be ignored. If the interest is in the yield of the hedge crop itself, then the arrangement in (iv) is very much appropriate, with the sampling unit being the inner rows of the hedges. This implies ideally a minimum of three rows per species for effective assessment.

The areas marked "x" in the illustrations are usually planted with the agricultural crops, but not assessed. Unplanted gaps are not recommended as they are likely to aggravate the edge effects.

7.6.2 Soil Heterogeneity

For long-term experiments involving perennial crops such as hedgerow species, agronomists have recognised the need to establish the nature and extent of soil heterogeneity through "blank" trials, before the conduct of the actual trial. This involves the planting of a bulk crop on the experimental field and monitoring its performance. On the other hand, if one is familiar with the cropping history of an area, this could be considered accordingly while laying out the trial so as to eliminate the delay in planting trials. When planting on farmer's plots the knowledge base of the farmer should not be ignored.

7.6.3 Plot Orientation

Irregularly sloped areas should be avoided, but there is no objection to the use of area with a near constant slope provided the plots run up and down the slope. The same principle applies on a fertility gradient. For trials on terraces, one should ensure that all the treatments (except in incomplete block situations) appear on the same terrace, so that a terrace could be regarded as a block (Rao and Roger, 1990).

7.6.4 Plot Shape and Size

In alley farming, plot shapes are more likely to be square or rectangular than any other shape. A square plot exposes the least number of plants to the edge effect. Avoid circular plots; on sloping grounds, circular plots tend to be ellipses.

As regards plot size, plots that are too small yield unreliable results. On the other hand, excessively large plots waste time and resources.

7.6.5 Selection of Experimental Site

The most important factor in selecting an experimental site is its representativeness of the area. It should be of appropriate shape and size for the conduct of the experiment. The land and soil characteristics as well as past cultural practices should be known as far as possible. It should have an access to a road and be distant from environmental modifiers.

7.6.6 Guidelines in Recording Data

Record only as much data as you can analyse and interpret. Use metric units to record the data. Always note the date of data collection. Use standard procedures for recording the data.

7.7 ON-FARM ALLEY TRIALS

On-farm research, whether managed by the researcher or the farmer, requires simplicity in design. Sometimes this simplicity requirement may be due to limited resources such as land, or subject materials (treatments). However, it is more often due to the fact that complexity in design renders the management and data collection burdensome, especially for the farmer.

The statistical implications also encourage simplicity. If the treatments are not kept to a basic minimum of two or three, the whole experiment, with or without replications, cannot be carried out on one smallholder's property. This would require the use of several farmers plots, either as replicates or single plots. This could result in increased variability and might make it impossible to compare effectively some treatments and/or farmers.

The following four possibilities may exist in the availability of experimental plots on farmers fields:

- Farmers' plot sizes unlimited;
- Farmers' plots as replicates;
- Farmers' plots inadequate for complete replicates;

- Farmers plots as single experimental plots.

7.7.1 Farmers' Plot Sizes Unlimited

This is a happy situation in which a complete trial is performed on each of the farmers' property. The unlimited nature of the available area would enable the use of all the treatments and the relevant replications on the same farmer's fields. The complete experiment is thus performed at each site. Any of the basic designs can be applied here, depending on the nature of the land and treatments being tested. These trials are time-consuming and are mostly researcher-managed. The obvious limitation is that only a small number of such farmers' plots would be available for experimentations.

7.7.2 Farmers' Plots as Replicates

This situation arises when the farmers plots are large enough to accommodate all the treatments, but not large enough to allow for replications. The fact that replications are not possible in this situation implies that the usual Completely Randomised Design (CRD) will not be applicable. What is more likely to be feasible is the Randomised Complete Block Design (RCB) in which a farmer's plot will be regarded as a block receiving all the treatments. This is illustrated below for four treatments (A, B, C, D).

(i)	Farmer 1	A	B	D	C
	Farmer 2	B	A	D	C
	Farmer 3	C	D	A	B

The arrangement in (i) is a typical complete block layout. The minimum replications is only three farmers, but this can be increased depending on the availability of resources and time. We will, in the case of design (i), assume uniformity in land and other considerations *within* each farmers plot, but will allow for heterogeneity *between* the farmers plots. In a classical block arrangement, we often conclude that the block design is justified when the analysis indicates significant differences between blocks. This is not a necessity in the on-farm situation. The use of the farmers plots is to ensure reasonable replications (unless clearly observed differences are known to exist). The analysis however does not exclude comparisons between the farmers (i.e., between blocks).

In illustration (ii) below, we assume a situation similar to (i) except that each farmer's plot can be stratified into four units according to, say, soil type, crop type, management practices, etc. (a, b, c, d). We have assumed that *four* such farmers with ***all*** the four classifications (strata) are available. Although not easily identifiable, this arrangement is in fact a Latin Square. Notice that each treatment appears once and only once in each stratum and in each farmer's plots. The LS design can be seen more clearly below in (iii).

A, B, C, D = Species or accession
a, b, c, d = Clarification variable (e.g. soil types)

(ii)

Farmer 1	a	b	c	d
	A	B	C	D
Farmer 2	b	a	c	d
	A	D	B	C
Farmer 3	c	d	a	b
	D	A	B	C
Farmer 4	b	c	a	d
	D	A	C	B

(iii)

	Strata			
	a	b	c	d
Farmer 1	A	B	C	D
Farmer 2	D	A	B	C
Farmer 3	B	C	D	A
Farmer 4	C	D	A	B

Layout (ii) assumes a different ordering of the classification variable (a, b, c, d) for each farmer's plots. This is more likely than the hypothetical standard ordering given in (iii).

7.7.3 Farmers' Plots Inadequate for Complete Replicates

We consider a situation in which the subject materials (treatments) are not in limited supply, but plot size considerations do not allow for the allocation of all treatments in the same farmer's plot. We might thus wish to deny some farmers' plots certain treatments. This would mean an incomplete block design. A valid statistical design results if *pairs* of treatments appear the same number of times. The only issue worth determining here is the number of farmers plots required to ensure this requirement.

If we assume each farmer's plot can accommodate a maximum of three treatments, then:

- For 4 treatments, we will need 4 farms;
- For 5 treatments, we will need 10 farms;
- For 6 treatments, we will need 20 farms;
- For 7 treatments, we will need 35 farms;
- For 10 treatments, we will need 120 farms.

In general, for t treatments and a block size of b (number of experimental plots on farmers field), the number of farmers for a balanced incomplete block arrangement is

$$tCb = \frac{t!}{(t-b)!\,b!} = (t(t-1)\,(t-2)\ldots(t-b+1)/b!)$$

For this arrangement, it is important to keep the number of treatments to the basic minimum. A maximum of 5 treatments requiring 10 farmers should be more than adequate. An example of a possible treatment combination (not necessarily layout) for (i) is given as follows:

Farmer 1	A	B	C
Farmer 2	A	B	D
Farmer 3	A	C	D
Farmer 4	B	C	D

We note that pairs AB, AC, BD, etc., occur the same number of times, that is twice. For the field layout, each set of treatment will be randomised within each farm.

7.7.4 Farmers Plots as Single Experimental Plots

We consider two possibilities:

(i) Farmers plots identical

(ii) Farmer's plots variable

In experimentation, as already pointed out, we are interested in observing the effects of treatments when applied to identical units. Thus in situation (i) we would simply assign the treatments to the farmers' plots as illustrated for a hypothetical set of 3 treatments (A, B, C) and 12 farmers, as follows:

Farmer 1	A	Farmer	7	A
Farmer 2	B	Farmer	8	C
Farmer 3	A	Farmer	9	C
Farmer 4	C	Farmer	10	B
Farmer 5	B	Farmer	11	B
Farmer 6	A	Farmer	12	C

However, if instead of assuming identical farmers' plots, we recognise that some plots have identical traits different from others, then we would group the similar farmers separately and apply the treatment accordingly. This is situation (ii), and could be illustrated as follows:

Group 1 Degraded soil, maize as only previous crop			Group 2 Degraded Soil, maize & cassava previous crop			Group 3 Fertile soil, maize as only previous crop		
Farmer	1	A	Farmer	3	A	Farmer	2	B
Farmer	4	B	Farmer	5	C	Farmer	9	A
Farmer	8	C	Farmer	6	B	Farmer	10	D
Farmer	12	D	Farmer	7	D	Farmer	11	C

These layouts can also be modified as in split-plot arrangements.

7.8 SUMMARY

Basic principles for the design and layout of alley farming trials have been outlined and illustrated. These should not be taken as a complete presentation. Neither does the paper cover all possible field plot designs.

It is important to mention that appropriate experimental designs are the first step in the conduct of successful experiments. Accordingly, whenever we are not sure of the appropriateness of a design with regard to a particular scientific objective or to the availability of physical resources, we must consult a statistician.

While simplicity should be the watchword in deciding the design and layout for an alley farming trial, the basic requirements of randomization, replication and blocking should not be overlooked. The study of many factor and levels simultaneously, will necessarily lead to the use of complex designs for which assistance from a statistician is a must.

7.8.1 Summary of Important Points on Statistical Methodologies

1. Alley farming trials are long term, due to the inclusion of woody species, and therefore require special caution in their designs.
2. Seven steps in experimentation are:
   - define the problem
   - identify objectives and develop a hypothesis
   - design and conduct experiments to test the hypothesis
   - collect data
   - analyse data
   - interpret data and
   - draw conclusion about the hypothesis.
3. The definition of the problem and objectives of the experiments determine the type of data to be collected in a trial.
4. Data screening aims at identifying representative data for the population. Data is transformed to suit to appropriate statistical procedures. The ranking of data and the reduction or increase of all data are examples of data coding.
5. Variables refer to characteristics that will be measured for treatment effects in a trial.
6. The procedures used in data analysis depend on the objectives and methods of data collection.

7.8.2 Summary of Important Points on Experimental Design

1. Monitoring of the effects of certain inputs on a subject matter is known as **experimentation**.

2. The allocation of treatments to an experimental unit or plot is referred to as an **experimental design**.

3. A **plot** is the smallest unit of land receiving a treatment.

4. **The treatment** is the material being forced on the subject and whose effect is to be studied.

5. **Experimental error** is a measure of the difference between two units treated alike.

6. **Replication** is the number of times a complete set of treatments is repeated in an experiment.

7. **Randomisation** refers to the allocation of treatments to plots in such a way that within a specific experimental design, units are not discriminated for or against.

8. **A block** is a large area or several identical units receiving all or most of the treatments.

9. Issues to consider in selecting an experimental design include the choice of dependent and independent variables, the availability of subject material, data collection procedures and timing.

10. In a **single-factor** experiment, only one factor varies while others are kept constant.

11. Experimental designs can be broadly classified as:
    - complete block
    - incomplete block

12. Three important basic designs in the group of complete block designs are:

- Completely Randomised (CRD)
- Randomised Complete Block (RCBD)
- Latin Square (LS)

13. **Completely Randomized Design** offers an equal chance of receiving a treatment by each experimental unit. However, it is appropriate only for experiments with homogenous experimental units.

14. **Randomized Complete Block Design** is characterized by the presence of equally sized blocks, each containing all of the treatments. It reduces the error of one source of variation among experimental units. It is one of the most popular designs for agricultural experimentation, but becomes less efficient with large number of treatments.

15. **Latin Square Design** is capable of handling two known sources of variations among experimental units. In this design every treatment occurs only once in each row and each column.

16. **Incomplete block designs** are those in which each block does not contain all the treatments. These designs are used to accommodate large number of treatments.

17. Experiments in which two or more factors vary simultaneously are known as **multi-factor or factorial experiments.**

18. The major advantage of a factorial experiment is that it offers an opportunity to examine interactions among various factors.

19. In factorial experiments, factorial treatments can be tested using any one of the basic designs used for single factor experiments.

20. The commonly used designs for factorial treatments other than the CRD, RCBD and LS are:
    - Complete Block
        - Nested
        - Split plot
    - Incomplete Block
        - fractional factorial

confounded

7.8.3 Summary of Important Points on Field Layout and On-Farm Trials

1. Use of appropriate sampling units is essential for the valid statistical analysis of the data.

2. Knowledge of soil heterogeneity is a prerequisite for the field plot layout of an experiment.

3. Irregularly sloped areas should be avoided for alley farming trials. On terraced land, a terrace may be treated as a block.

4. Rectangular and square plots are preferred for field experimentation. Plots that are too small yield unreliable results and too large plots waste time and resources.

5. An experimental site should be accessable, located away from environmental modifiers, representative of the area, and consistant with experimental design.

6. Use standard procedures for recording date.

7. For on-farm trials, one should use simple designs only.

8. The availability of experimental plots on farmers' fields could be visualised as follows:

   - farmers' plot sizes unlimited
   - farmers' plots as replicates
   - farmers' plots not complete replicates
   - farmers' plots as single experimental plots

10 Use conventional designs if availability of land in farmers' field is unlimited. If not ,consider possibilities for incomplete block arrangement, including the possible use of a farmer's plot as a single treatment unit.

7.9 FEEDBACK EXERCISES: (Find out the answers from the text)

1 Write the first four steps in a 7-step procedure for scientific experimentation.

1. ______________________
2. ______________________
3. ______________________
4. ______________________

2. Circle **T** for true and **F** for false.

a. The merit of any data depends much on the accuracy with which it is collected and not so much on its representativeness of the population.

T **F**

b. The "test of outliers and spurious observations" relates to data transformation.

T **F**

c. The coding of data is carried out for equalisation of variances or normalisation of observations.

T **F**

d. By "variable" we mean the observational parameters to compare the treatment effects.

T **F**

e. Data analysis depends on objectives and methods of data collection.

T **F**

3. Column 1, given below, lists certain terminologies used in connection with experimental design. Match each with its explanation in column 2.

1. experimental error
2. plot
3. experiment design
4. replication
5. blocking
6. treatment

a: rules for assigning treatments to experimental plots

b: difference between two plots treated alike

c: the unit on which random assignment of treatment is made

d: material being forced on the subject

e: repetition of some treatments on several plots

f: a large area or several identical units receives most or all treatments

4. Tick the correct answer(s).

a. What is a factorial experiment?

- it has many levels of the single factor treatments
- it tests two or more factors simultaneously, each one at one level
- it tests two or more factors at the same time, with two or more levels
- it is also called multi-factor experiment

b. A Randomized Complete Block Design is characterised by:

- treatments assigned at random to an experimental unit
- treatments assigned at random to experimental units within a block
- appropriateness only for experiments with homogenous experimental units
- arrangement of blocks in a square

- reduction experimental error by elimination of a known source of error among experimental units

5 a Write one major advantage of the Latin Square design over the Randomised Complete Block Design and one distinguishing feature of its layout.

Advantage____

Distinguishing feature of layout ______________________________

____

b. What is the most important advantage of a factorial experiment over a single factor experiment?

____

c. In a split plot design, there are main plots and sub-plots. To which one of these you will allocate the treatments requiring higher precision?

____

d. How does a split-split-plot design differ from a split-plot design?

____

6. a. Define sampling unit and discard plot.

____

____

b. List two main considerations in locating sampling units in alley farming trials.

a. ____________

b. ____________

c. Tick the correct answer(s). Why are blank trials conducted before initiating an actual trial?

- to homogenise the experimental area
- to study the performance of test crops
- to study the extent and pattern of soil heterogeneity
- to treat the soil with a fertility restoring crop

d. List 4 important factors in selecting an appropriate experimental site.

1. ____________________
2 ____________________
3. ____________________
4 ____________________

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TECHNICAL PAPER 8

Examples of Experimental Designs for Alley Farming Trials

8.0 Performance Objectives

8.1 Introduction

8.2 Examples of Experimental Designs

1: Fallow management in alley farming

2: Screening of multipurpose trees in different intra-row spacings for alley farming.

3: Screening of *Gliricidia* collections across a range of environmental and edaphic conditions in West Africa.

4: Assessment of effects of feed supplementation from different legume trees.

5: Comparison of the effectiveness of 3 leguminous tree crops in soil fertility maintenance and in sustainability of crop production.

6: Efficiency of selected multipurpose tree species in alley farming on soil fertility regeneration and agricultural crop yield.

7: Alley farming trials concerning both soil fertility and animal production.

8: Evaluation of species mixture in alley trials.

9: Effect of tree density on water relations of trees in alley farming systems in the dry areas.

10: Evaluation of the negative effects of fodder uptake on agricultural crop yield.

11: Light interception and its effect on crop yield in alley farms.

12: Effect of lime and manure application on the growth of hedgerow species in strongly acidic (p^H 3.5-5) soil.

13: Integration of short grazed fallows in rotation within *Leucaena* alleys and their effects on soil fertility and crop yield.

14: Pattern of N build-up in the pens of sheep receiving different feed supplementations of alley shrubs.

15: Manurial value of manure dug out from pens receiving known levels of leguminous fodder supplements.

16: Effect of hedgerow species on surface soil physical properties.

17: Growth of alley shrub in farmers' fields.

18: Evaluation of an alley cropping species, *Calliandra Calothyrsus* on an Oxic Paleustalf.

19: Effect of alley crop combinations on sequentially cropped maize and cowpea.

8.3 References

8.0 PERFORMANCE OBJECTIVE

Technical paper 8 is intended to enable you to:

o Describe examples of experimental designs being followed in on-going alley farming field trials.

TECHNICAL PAPER 8:

Examples of Experimental Designs for Alley Farming Trials

Sagary Nokoe

8.1 INTRODUCTION

This paper provides the interested reader with a set of examples of experimental designs for various types of alley farming trials. The examples are drawn from actual on-going or proposed field trials. They cover basic designs which appear to have universal acceptability for alley farming experiments.

The basic principles for the design and layout of alley farming trials are covered in the previous paper (Technical Paper 7). The standard design recommendations for AFNETA collaborative research projects are available from the network coordination unit.

8.2 EXAMPLES OF EXPERIMENTAL DESIGNS

EXAMPLE 1: Fallow management in alley farming.

<u>Treatment:</u> A - 4 year cropping/2 year unmanaged fallow
B - 4 year cropping/2 year managed fallow
C - 4 year alley cropping/2 year unmanaged fallow
D - 4 year alley cropping/2 year managed fallow

<u>Intercrop:</u> Maize

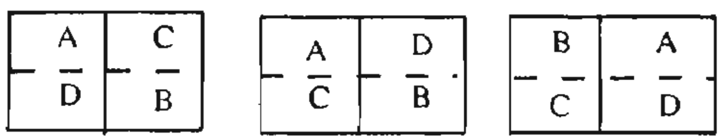
<u>Notes:</u>

(1) Treatment combinations will allow comparison of normal cropping with alley cropping at the end of or at any time during the 4-year period, as well as monitoring of the effect of fallow management and its interaction with cropping.

(ii) Design can be Randomized Complete Block (RCB) with a minimum of 3 replications.

(iii) Assessment can be in terms of changes in soil fertility status, crop yield/economic returns, etc.

(iv) Possible layout



(v) On farmers' plots, the design can be modified slightly as indicated in the layout below:

Normal Cropping   Alley Cropping

With each farmer as a replicate, this can be considered a split-plot arrangement, with type of cropping as the main-plot and management practice in the sub-plot.

EXAMPLE 2: Screening of multi-purpose trees in different intra-row spacings for alley farming.

Treatments: Two factors (Tree Species and Spacing) are involved:

Factor A Tree Species

A1: *Acacia albida*
A2: *A. manginum*
A3: *Azadirachta indica*
A4: *Albizia lebbeck*
A5: *Leucaena leucocephala*
A6: *Gliricidia sepium*

Factor B Intra-row spacing

B1: 50 cm
B2: 100 cm
B3: 150 cm
B4: 200 cm

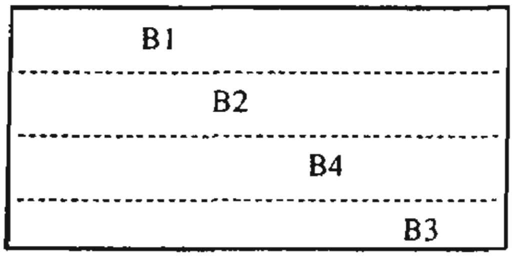
Notes: (i) Possible design: m a split plot (with species in main plots and intra-row espacement in sub-plots) in an RCB design with 3 replications. If the levels of Factor B differ from species to species (which is a possibility), this would lead to a nested design with intra-row spacing nested in the plots containing the trees.

(ii) A possible layout for one replicate could be:

REP 1:

Factor B within A					

Factor A:



A. manginum

EXAMPLE 3: Screening of *Gliricidia* collections across a range of environmental and edaphic conditions in West Africa.

<u>Treatments:</u> 12 different accessions (ILG50 - ILG61)

<u>Design:</u> 3 x 4 rectangular lattice in three replicates, for 5 locations (triple rectangular lattice).

<u>Possible layout at each location</u>:

Block	Group X			Group Y			Group Z		
(i)	5	4	6	2	5	12	4	3	11
(ii)	1	2	3	9	3	6	2	9	10
(iii)	10	11	12	4	7	10	6	8	12
(iv)	7	8	9	1	8	11	5	7	1

EXAMPLE 4: Assessment of effects of feed supplementation from different legume trees.

Treatment: Four treatments corresponding to 4 feed rations formulated as follows:

1. Normal ration (ALP)
2. ALP + *Gliricidia sepium* (800 gm DM/animal/day)
3. ALP + *Leucaena sp.* (800 gm DM/animal/day)
4. ALP + *Flemingia sp.* (800 gm DM/animal/day)

Procedure:

(a) Select 20 animals; usually they will be of different weights or ages. Divide animals into, for example, 5 weight groups of equal sizes, and ensure that each weight group receives all treatments. The design is thus identical to a block design with 5 replicates per treatment.

(b) Alternatively, allocate the 4 treatments randomly to the 20 animals, ensuring 5 replicates per treatment. This can then be considered as unrestricted randomized design. However, considering differences in weights and the possibility of unbalanced mean weight among treatment groups, the method of Covariance Analysis with initial animal weights as covariate should be used. The analysis of covariance is an extremely valuable statistical technique for increasing precision.

EXAMPLE 5: Comparison of the effectiveness of 3 leguminous tree crops in soil fertility maintenance and in sustainability of crop production.

Treatments: Two factors are involved in this example, namely, tree species and fertilization:

Tree species - *Azadirachta indica*, *Leucaena* sp., *Gliricidia* sp.

Fertilization - NPK 45 kg/ha, No fertilization

Design possibilities:

(i) For on-farm, farmer-managed trials, the ideal design is split-plot with fertilization in the main plot.

(ii) For research-plot trials, factorial arrangement in a block design allows equal evaluation of both factors. However, if interest lies more on one factor than the other, then the split-plot arrangement is recommended, with the more important factor in the split or smallest plot.

(iii) The factorial arrangement in a Randomized Complete Block (RCB) is used to demonstrate the analysis of variance outline.

EXAMPLE 6: Efficiency of selected multipurpose tree species in alley farming on soil fertility regeneration and agricultural crop yield.

Treatments:

A. Alley farming with Species A

B. Alley farming with Species B

C. Alley farming with Species C

D. Non-alley farming

Notes: (i) A Latin-Square arrangement is most suitable

(ii) Possible layout could be as follows:

A 50*	B 12	C 18	D 92
B 63	C 4	D 52	A 8
C 12	D 72	A 35	B 83
D 21	A 25	B 32	C 62

The data concerning treatment combinations could be observed from a known variable.

* *Numerical figures represent hypothetical data after 4 years of trial.*

EXAMPLE 7: Alley farming trials concerning both soil fertility and animal production.

Treatments: Three pruning regimes are planned, as follows:

1. Zero mulching/3 prunings for feeding.
2. 1 mulching/2 prunings for feeding.
3. 2 mulching/1 pruning for feeding.
4. 3 mulching/0 pruning for feeding

Assessment considerations:

(i) Dependent variables cover both the effects of mulching on soil and the effect of feeding animals with prunings, assuming the same amount of prunings are made on each occasion.

(ii) If soil fertility is assessed indirectly on the basis of agricultural crop yield, then an economic analysis (with revenue, for example, as the dependent variable) that combines both crop and animal productivity will be desirable. The analysis can also be performed separately for crop and livestock components. In the case of crop analysis, such separation will allow assessment of the effects on crop yield of removing prunings.

(iii) A block design is appropriate especially if trials are carried out on farmers plots, in which case a farmer's plot may be considered as a replicate. If several species are being evaluated a split-plot arrangement should be considered.

EXAMPLE 8: Evaluation of species mixture in alley trials.

Treatment: This type of experiment could involve 3 species and 23 factorial arrangement in a block design.

Factors: Species A at 0, 1 levels
Species B at 0, 1 levels
Species C at 0, 1 levels

Treatment Combinations:

A0B0C0	=	(1)	control
A1B0C0	=	(a)	
A1B0C0	=	(ac)	
A1B1C0	=	(ab)	
A0B0C1	=	(c)	
A0B1C1	=	(bc)	
A0B1C0	=	(b)	
A1B1C1	=	(abc)	

Procedure: Randomize treatment combinations in blocks, and analyze results with 7 degrees of freedom (df) per treatment. The treatment source of variation is further split into:

Factors A, B, C, each with 1 df
Interactions AB, AC, BC, each with 1 df
Interaction ABC with 1 df

EXAMPLE 9: Effect of tree density on water relations of trees in alley farming systems in the dry areas.

Treatments: A single tree species is investigated at different densities.

Tree density A
Tree density B
Tree density C
Tree density D
Tree density E

Design considerations are as for Example 6. Given more than one species, a split-plot may be considered.

EXAMPLE 10: Evaluation of the negative effects of fodder uptake on agricultural crop yield.

Treatments:

A - No fodder removed

B - 20% fodder removed

C - 40% fodder removed

D - 60% fodder removed

E - 80% fodder removed

F - 100% fodder removed

Design: Any of the basic designs may be used, depending on land availability.

Notes:

(i) Observe crop yield periodically and analyze according to design used. A block design or an ordinary randomized design could be appropriate.

(ii) Alternatively, the trend in the effect of fodder reduction on crop yield can be investigated using single degree of freedom orthogonal polynomials. The relevant data would be percentage losses in yield from the previous cropping season, during which no fodder was removed from any plot.

(iii) During analysis, check whether the trend in percentage losses over increasing removal of fodder is linear, quadratic, etc.

EXAMPLE 11: Light interception and its effect on crop yield in alley farms.

Treatments: Three factors are involved:

Factor H- Hedgerow shrubs at 5 levels

H1 : *Acioa*

H2 : *Alchornea*

H3 : *Gliricidia*

H4 : *Leucaena*

H5 : NIL (as control)

Factor S- Interhedgerow spacing at 2 levels

S1 : Spacing 2m

S2 : Spacing 4m

Factor F- Fertilization at 2 levels

F1 : 45-20-20 N-P-K kg/ha

F2 : 90-40-40 N-P-K kg/ha

Intercrop: Maize

Observations: Incident solar radiation of maize leaves at known height

(i) Height at which solar radiation values are taken (Hc)

(ii) Corresponding shrub height at time of solar observation (Hh)

(iii) Height/distance index ({Hh - Hc}/S)

(iv) Crop (maize) yield.

Design: Split-plot with Factor H in main plot, and a crossed (factorial combination of Factor S and Factor F in the 4 sub-plots.

Analyses: (i) Analysis of variance with the split-plot breakdown

(ii) Linear or non-linear regression relating:

- % incident light to height/distance index
- Crop yield to % incident light
- Crop yield to dry pruning biomas

EXAMPLE 12: Effect of lime and manure application on the growth of hedgerow species in strongly acidic (pH 3.5-5) soil.

Treatments: Three factors are involved:

Factor S- Shrub species at 4 levels

S1 : *Sesbania*

S2 : *Calliandra*

S3 : *Leucaena*

S4 : *Markhamia*

Factor L- Liming at 2 levels

L1 : 0 t/ha

L2 : 10/ha

Factor M- Manure at 3 levels

M1 : 0 t/ha

M2 : 5 t/ha and M_3 : 10t/ha

Design: Split-split plot arrangement. Factor S is the main plot, with each plots divided into 2 sub-plots. Three months after establishment the sub-plots received the 2 levels of Factor L respectively. Each sub-plot is further divided into 3(sub-sub) plots to which levels of Factor M are allocated randomly.

Observations:

(i) Height growth of shrubs at predetermined intervals

(ii) A derived variable known as the Lime Response Index (LRI)

Definition: $LRI = \frac{HML\ (8) - HWL\ (8)}{HWL\ (3)}$

Where HML (8) = the mean height of shrubs receiving liming at 8 months after planting (MAP)

HWL (8) = the mean height of shrubs without liming at 8 MAP

HWL (3) = the mean height of shrubs without liming at 3 MAP.

(Source: Yamoah, Grosz and Nizeyimana, 1989)

EXAMPLE 13: Integration of short grazed fallows in rotation within *Leucaena* alleys and their effects on soil fertility and crop yield.

<u>Treatments</u>: Cropping systems at 5 levels:

C1 : Continuous cropping without trees (control)

C2 : Continuous cropping in *Leucaena* alleys

C3 : Grazed fallow/cropping rotation in *Leucaena* alleys

C4 : Cropping/grazed fallow rotation in *Leucaena* alleys

C5 : Continuous alley grazing in *Leucaena* alleys.

Duration of experiment is 4 years, with rotation in C3 and C4 effected every 2 years.

<u>Intercrop</u>: Maize

<u>Design</u>: Randomized block design

<u>Observations</u>:

(i) Chemical analyses of soil samples at beginning of trial and before each first season crop.

(ii) Dry matter and nitrogen content values from prunings of *Leucaena* hedgerows.

(iii) Maize crop yield

(Source: Atta-Krah, 1990).

EXAMPLE 14: Pattern of N build-up in the pens of sheep receiving different feed supplementations of alley shrubs.

Treatments: Diet supplement at 4 levels

D1 : 200 g dry matter (DM)/head/day of mixed (1 : 1 w/w ratio) of *Leucaena* and *Gliricidia* forage

D2 : 400 g DM/head/day

D3 : 800 g DM/head/day

D4 : 1200 g DM/head/day

Design: Completely randomized, with 40 pregnant West African Dwarf sheep randomly allocated to the 4 diet supplementations (10 pens per diet treatment). All animals receive *ad libitum* chopped *Panicum maximum* grass plus 50 g of sun-dried cassava peel as basal diet. Each pen also has 5 kg of wood shavings spread on top of litter at 4 weeks.

Observation: Random samples of wood shavings, analyzed for N at 2, 4, and 5 weeks after the sheep have been placed in the pens.

(Source: Cobbina, Atta-Krah, and Kang, 1989)

EXAMPLE 15: Manurial value of manure dug out from pens receiving known levels of leguminous fodder supplements (Extension of example 14).

Treatments: Two factors involved

Factor D- 5 levels of diet supplement (as in example 15) for 5 week-period.

D1 : Pen with 200 g/DM/Head/day

D2 : Pen with 400 g/DM/head/day

D3 : Pen with 800 g/DM/head/day

D4 : Pen with 1200 g/DM/head/day

D5 : Control (raw wood shavings)

Factor S- Manure rates at 3 levels

S1 : 4 g/kg soil

S2 : 8 g/kg soil

S3 : 12 g/kg soil

Design: Completely Randomized (CRD) or Randomized Complete Block (RCB) design with 5 x 3 factorial arrangment of treatments. Each treatment is replicated 3 times. The choice as to CRD or RCB depends on the arrangement of pots in the greenhouse. In each pot, maize is planted.

Observations:

(i) Maize shoot dry matter yield

(ii) Soil chemical analyses(pre- and post-trial)

(Source: Cobbina, Atta-Krah and Kang, 1989)

EXAMPLE 16: Effect of hedgerow species on surface soil physical properties.

Treatment: Hedgerow species at 5 levels

S1 : *Leucaena leucocephala*

S2 : *Gliricidia sepium*

S3 : *Alchorneaa cordifolia*

S4 : *Acioa barteri*

S5 : Control (no hedgerow species)

Intercrop: Sequential cropping of maize (main season crop) and cowpea (minor season crop)

Design: Randomised complete block with 3 replications (blocks). Inter-hedgerow spacing is 4 m.

Observations:

(i) Crop yield

(ii) Soil physical properties (bulk density, pore size, water infiltration etc.) at predetermined intervals.

(Source: Hulugalle and Kang, 1990)

EXAMPLE 17: Growth of alley shrubs in farmers' fields

Treatments: Alley shrubs at 3 levels

S1: *Leucaena leucocephala* var K28

S2: *Gliricidia sepium* local variety

S3: No alley shrub (control)

Design: Eight farmers plots are selected within a known area. Each farm constitutes a block, with 3 plots receiving randomly either S1, S2, or S3. This results in a completely randomized design with 8 replications (the replicates being the farmers)

Observations:

(i) Soil chemical characters based on sample from each plot (before and during trial)

(ii) Shrub height growth at pre-determined periods.

(Source: Cobbina, Kang and Atta-Krah, 1989)

EXAMPLE 18: **Evaluation of an alley cropping species, *Calliandra calothyrsus* (Meissn.) on an Oxic Paleustalf.**

Treatments: Treatments comprise combinations of two factors as follows:

Factor N — Rate of N applications at 3 levels

N1: 0 N

N2: 45 N in kg/ha

N3: 90 N in kg/ha

Factor P — Prunings management at 2 levels

P1: Prunings removed (-PR)

P2: Prunings retained (+PR)

Intercrop: Maize

Design: (i) In Layout 1, randomization is such that all N levels are in each row. The +PR or -PR factor is randomly allocated such that in the third row no combination from the first row is repeated! This arrangement is not recommended.

(ii) In Layout 2, randomization of the N levels is made on row plots which have either +PR or -PR. This is a split-plot arrangement with PR in main plots and N in the sub-plots. This design is preferred to Layout 1.

(iii) In Layout 3, treatment arrangement is factorial (3 x 2). The design is simply the Randomized Block, and is much preferred to Layout 1 and Layout 2. Its preference over Layout 2 is due to the fact that both PR and N levels can be evaluated equally.

(V = the middle row which is planted with same maize crop as in the alleys but receives no treatment)

Observations:

(i) Crop yield,

(ii) Soil chemical content.

(Source: Gichuru and Kang, 1989)

EXAMPLE 19: Effect of alley crop combinations on sequentially cropped maize and cowpea.

Treatment: Species combinations as follows:

	Acioa barteri	*Leucaena leucocephala*
T1:	0%	0%
T2:	0%	100%
T3:	25%	75%
T4:	50%	50%
T5:	75%	25%
T6:	100%	0%

Design: Randomized Complete Block plots are split at the cropping stage into 2 equal parts and receive 0 and 60 kg N/ha. This later modification changes the design to a split-plot.

(Source: Siaw, Kang, and Okali - In press).

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ISBN 978–131–075–8

Printed at ILCA, Addis Ababa, Ethiopia