A field guide for

On-Farm Research

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with special reference to improvement of cropping systems and techniques in West and Central Africa

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Foreword

For several years, scientists at IITA's Farming Systems Program have cooperated with their colleagues in national agricultural institutions in West and Central Africa in an effort to develop viable on-farm research strategies and approaches that are relevant to their conditions. This volume of On-Farm Research Guidelines, prepared by Drs. H.J.W. Mutsaers, N.M. Fisher, W.O. Vogel, and M.C. Palada, is based primarily on the knowledge and experience gained from several workshops, training courses, and on-farm exploratory surveys jointly organized by IITA and its national collaborators. It contains practical guidelines for conducting exploratory surveys, collection and analysis of physical and socio-economic data, identification of OFR sites and design of on-farm trials. It is to be used as a field manual for OFR workers.

The authors are aware of the knowledge gaps existing in this volume and further improvement and revision will be made in the future as more OFR results are obtained.

We wish to thank the many scientists from national research centers, international organizations and IITA, who contributed to this manual through their participation in our training workshops as resource persons, in particular Drs. G.O.I. Abalu, Susan Almy, M. Ashraf, P. Ay, M. Diomandé, P.T. Fotzo, Martha Gaudreau, J.C. Jones, Susan Poats, W.R. Schmehl and K.G. Steiner; and as participants, in particular the team leaders, Drs. K. Adri, I. Binneweg, L. Diehl, B. Gmakagni, D. Miller, S.O. Odurukwe, J. Olukosi, B.A. Olunuga and M.O. Omidiji.

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Finally, we wish to acknowledge the contributions of Dr. C. H.H. ter Kuile, who initiated various OFR projects at IITA during his tenure as the Director of the Farming Systems Program. We are grateful to the Ford Foundation for financing the publication of this manual and to the Institute of Agricultural Research (IAR) at Zaria, Nigeria for making the Institute's OFR experiences available to us.

Mrs. Amy Chouinard and Alison Fong Weingartner are greatly acknowledged for thoroughly editing the manuscript and Mr. Abel O. Iyun is highly commended for processing and reprocessing the text countless times.

A. S. R. Juo
Director
Farming Systems Program
February, 1986

Annex 1: Review of basic economic principles

Annex 2: Some statistical techniques

References

Chapter 1

On-farm Research: Objectives and concepts

Chapter 1

On-farm Research: Objectives and concepts

Chapter I: On-farm Research: Objectives and concepts

Introduction

The objective of On-Farm Research (OFR) is to identify, in cooperation with farmers, acceptable new farming practices and materials that will improve the farmers' system and raise its productivity in a sustained way.

This requires testing of innovations under farmers' conditions with close monitoring of their profitability and acceptability, rejection of what is not appropriate, modification of what is modifiable and addition of new technologies in the light of previous results. In other words, OFR is a continuous process with each phase built upon the experiences of previous phases.

For an innovation to be adopted by farmers, it must solve some of their constraints without creating new ones of the same magnitude, or it must tap some of their unused resources. An adequate choice of innovations therefore requires good knowledge of farmers' conditions and of the farming system they practise.

The farm as a system

Representing the farm* as a system is a tool; it helps one to structure thinking, to identify major resource flows and to understand the interrelationships between elements. The goal is to develop an understanding of how the farmer makes his decisions.

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*In West African usage the word "farm" often refers to a single (cultivated) field. In this document "farm" is used in the standard English sense, meaning all the land exploited by a farm household, while for a single patch of (cultivated) land the word "field" is used.

Every system is an orderly arrangement of parts that operate together to achieve an objective. A farming system is the result of all the decisions made to devote a set of resources to a set of activities or enterprises to produce output that supports the farm family (Figure 1). The farm family tries to meet subsistence requirements, producing its preferred foods for consumption and cash as well as to increase its income over time. It pursues these goals and avoids risks that endanger them.

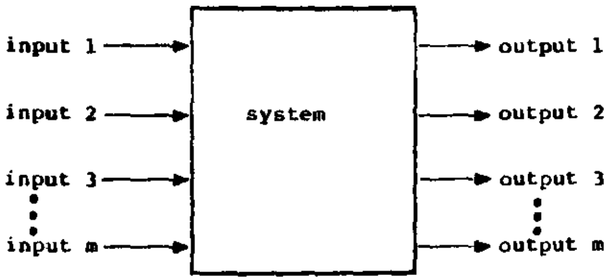


Fig. 1. System with inputs and outputs.

To describe a system, one needs to know its boundaries. Everything outside the boundaries is called the environment of the system. Although the environment influences the system, its influences are beyond the control of the farm family. That is, the influences are external or exogenous to the system. The decision-makers in the farm family observe and monitor the external influences and consider their effects, attempting, over time, to gain control over some of them, to make them internal or endogenous to the system.

The environment of the farming system has two dimensions: material and human (Figure 2). The material environment consists of physical and biological elements, including rainfall, temperature, solar radiation, topography and soil. The biological elements consist of natural vegetation, plant as well as animal pests and diseases. The physical and biological elements determine what crops can be grown in an area, given a suitable human environment.

The human environment consists of economic, institutional and social elements. Economic elements include the economic policy of the country or region. This policy determines quantities as well as absolute and relative prices of inputs and outputs and influences the availability of physical infrastructure such as transportation, water supply, health services, and facilities for marketing, processing and storage.

Institutional elements are the laws of the area; credit and marketing conditions; contractual arrangements; extension services; and property rights to land, water, trees, pasture, as well as seed distribution, quality control of inputs and outputs, grading and measuring systems, educational institutions and taxation.

The social elements include culture and customs within a community. They strongly influence the access that members have to inputs. They determine who does what and, thus, the distribution of labor by age and gender within the household.

In general, the human environment determines access to factors of production and output. It also sets the price (absolute and relative) and can make or break production.

By following major production activities, a key food crop, a cash crop and a livestock activity over a whole production cycle, one can identify resources that are scarce at specific times. For crops, the production cycle extends from land preparation to consumption or sale.

Crop production involves a series of steps. The farmer:

Makes an inventory of available resources, deciding how much cash to allocate to each production process;

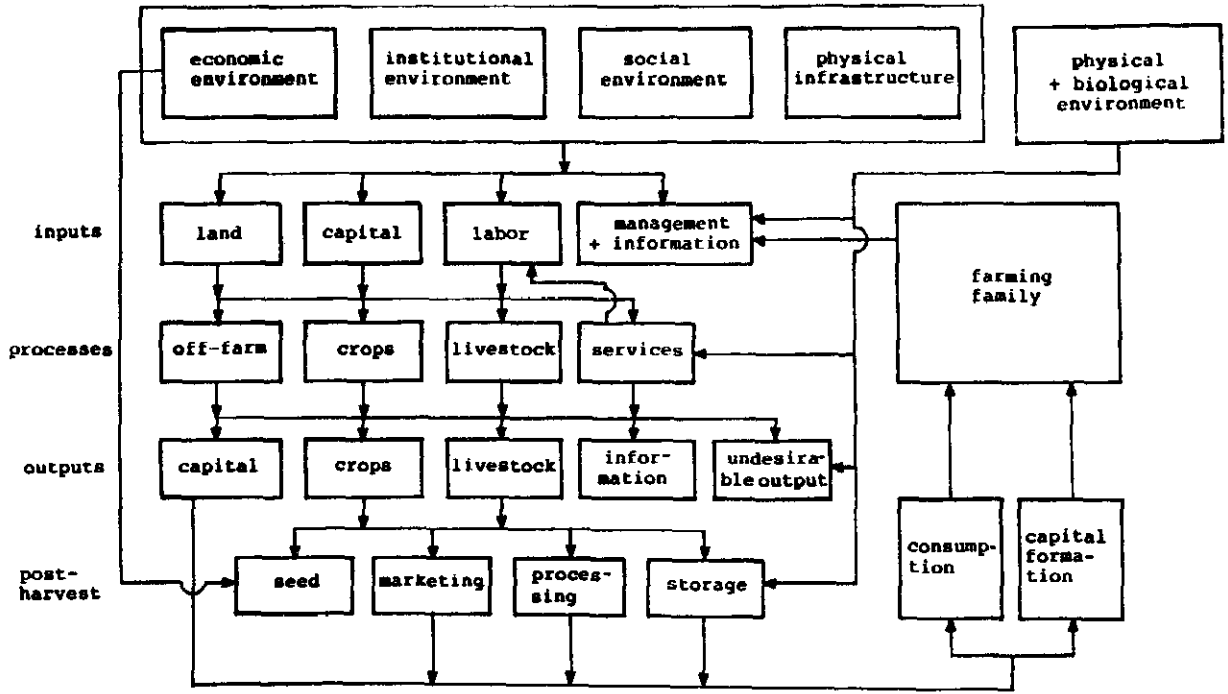


Fig. 2. Farming system for one crop year. (Relationships between subsystems and feedback have been ignored).

Carries out the sequence of operations to produce the output, which may flow over an extended period; and then

Decides how to use the output. It may be consumed or sold directly, processed and stored for later consumption or sale, kept for seed, fed to animals or used in other production processes. A part of the output may be available for capital formation. It may be invested in education or recreation or on the farm.

Farmers have developed courses of action to cope with regularly occurring changes and unexpected disturbances in their system. This is called a monitoring and control system. They monitor, for example, the fertility of the soil and select crops accordingly; they take contingency measures when rodents attack crops. Similarly, they monitor market prices, deciding whether to sell immediately or build additional storage facilities. Such control systems have been developed over time and information and experience are added continuously. A description of the farming system is incomplete without this indigenous knowledge.

The OFR process

Research under farmers' conditions starts with the collection of data on the system and its environment.

Some OFR projects put considerable effort in gathering detailed information before venturing into field testing. We recommend limiting the initial data collection to the minimum needed to make a first choice of innovations for testing:

- A study of existing sources of information and
- An informal exploratory survey.

The purpose is to analyze the major physical and biological elements of the system, to understand the goals of the farmer, to determine the major factors that influence his or her decisions and to describe the resource flows and how they relate to each other. This is sufficient for the identification of important constraints and underused resources — the basis for on-farm testing. Gaps can be filled as they become apparent during testing. Any time a major constraint emerges — for example storage or processing of certain crops — it merits attention in "special studies".

Careful testing of innovations with close farmer cooperation is the main course on the OFR menu. Obviously, the aim is to jointly identify innovations that farmers can readily adopt.

Monitoring the degree of adoption — the only valid proof of success — is part of the OFR process, but education for mass adoption is beyond the scope of OFR, belonging in the domain of extension.

In a nutshell, OFR embraces (Figure 3):

- Choice of the research area;
- Initial collection of data through the study of existing sources and exploratory surveys;
- Choice or design of innovations for testing;
- On-farm testing and evaluation, including monitoring of adoption, and
- Special studies.

This field guide describes procedures for on-farm research, worked out by IITA in close cooperation with several national OFR teams in West Africa. The guide follows the step-by-step evolution of such a program. It begins with the

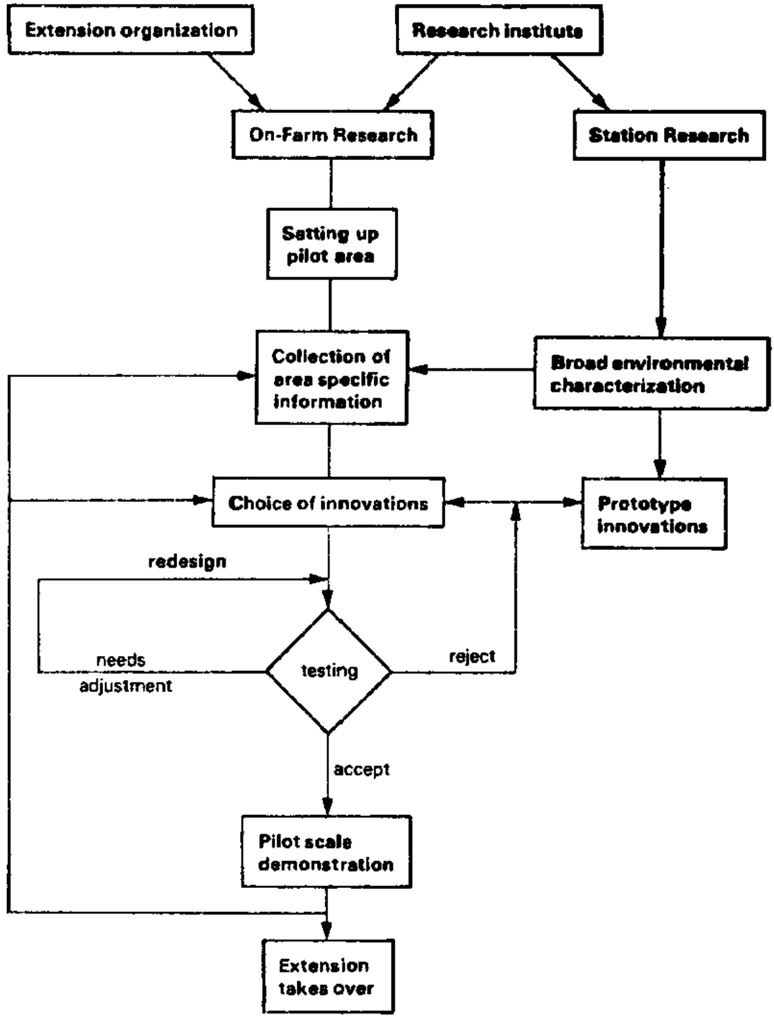


Fig.3. Flowchart of OFR activities and their inter-relations.

formation of an OFR team after which it assumes the reader is a member of the team, providing explanations and then simple instructions. The style is less cumbersome than a series of "shoulds" and "musts" but does not imply that these guidelines are the final word. The document covers the choice of a pilot research area (Chapter II), moves to the collection of initial information (Chapter III) through the characterization of the area (Chapter IV). The final section is the choice of innovations and the techniques of on-farm testing, evaluation and monitoring of adoption by farmers (Chapter V).

Chapter II

The OFR team and the research area

Chapter II: The OFR team and the research area

Introduction

On-farm research is a team activity that can be effective only if it is continual. It does not end with the adoption by farmers of one or a few innovations but continues to generate new ideas and pick up new technologies for testing.

Research at field stations and on farms forms a continuum, with the former developing new technologies and the latter testing them under farmers' conditions, feeding back the results to the station and stimulating station researchers to address new problems (Figure 3).

An OFR team should therefore be an integral part of a research institution. The creation of independent OFR teams without institute backing is not recommended.

An institute that opts for an OFR program must be willing to assign a core team of scientists to the task. They should be permanent but not necessarily involved full time in on-farm testing. In fact, the team members, in particular the agronomist, can contribute more if they maintain some on-station work in support of the on-farm activities.

The OFR team

The OFR team should comprise scientists, field assistants and extension agents (Figure 4). Our recommendation is that the core include at least two experienced research officers - an agronomist and an agricultural economist, with field assistants trained in implementing trials and collecting agronomic and economic data. The field assistants should reside in the research area, and the scientists must be close enough to visit the sites at least every two weeks to supervise the research. The field team should preferably be headed by a junior researcher, perhaps a first-degree holder. Researchers in other disciplines (from the team's institution or elsewhere such as universities) should be invited to participate when needed; for example, soil scientists and sociologists can provide crucial input for the exploratory survey and design of trials.

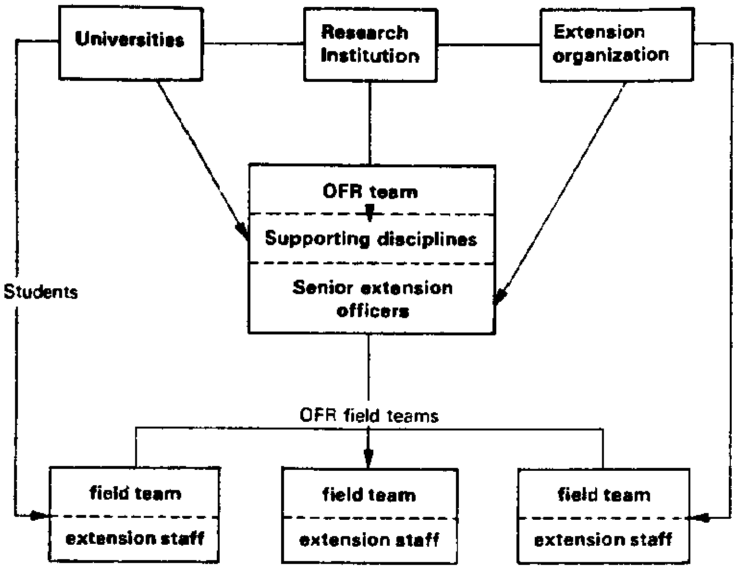


Fig. 4. Organizational structure of OFR

The team, by the nature of its work, enters the territory that has traditionally been that of the extension service. Tasks overlap; the extension agents have much to offer OFR from their experience in the community. Eventually they will be responsible for dissemination of successful innovations. Thus, one or two local extension agents should be associated with the field team. Although they have other priorities and will not be as involved as the research assistants, they should participate in the exploratory survey, trial design, supervision and monitoring, farmers' field days, etc.

The chief extension officer, who supervises the local extension agents, must be kept regularly informed by the scientists about the program's progress, or even better, be a member of the supervisory team.

The target area and the pilot research area

Because of the intensive nature of OFR, the area covered by the field team must be manageable and representative of a larger area, sometimes called the extrapolation or the target area for which the research results will be relevant (Figure 5).

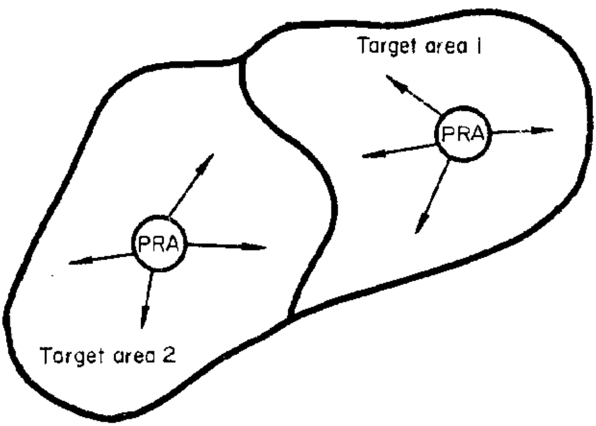


Fig.5. Target areas with their representative pilot research area (PRA). Arrows indicate assumed applicability of the results.

Choice of the target area

Many criteria can be listed for the choice of a target area; a few apply to all OFR. Look for a target area that reflects:

Your research institute's mandate - the crop, region or ecologic area that is the focus of the institute;

- The government's development priorities - for example, "problem areas" or "high potential areas";

- A single or homogeneous ecological zone (i.e. differences in climate, soil associations and vegetation should be minor), without large differences in population density, ethnic group or farming system.

To choose the target area, study soil maps, climatic charts and other geographical documents and conduct a reconnaissance tour.

Choice of a representative pilot area

In conventional multilocation and demonstration trials, the experimental sites are distributed across the target area. Because of the intensive nature of OFR, the amount of travel resulting from this procedure would be prohibitive. Carefully choose one or a few compact pilot areas that can be considered as a model for the target area as a whole (Figure 5).

Choose a pilot area that:

- Incorporates all the microvariability of the target area, such as differences in access and distance to roads and markets, small-scale soil variations, population density, etc.;

- Is manageable during the testing phase (not more than 10-15 km can be traveled daily by field staff on bicycles or mobylettes and acceptable living quarters must be available for field assistants);

- Is close enough to the research station so that the scientists can visit frequently to monitor the on-farm tests.

Chapter III

The collection of initial information on the research area

Chapter III: The collection of initial information on the research area

Introduction and note of caution

The aim of collecting initial information is to provide a basis for defining research priorities. As a team, become familiar with the farming system and agree on the major constraints to production and the underutilized resources. Identify groups of farmers who face the same constraints or surpluses. With this knowledge, a first set of trials and other studies can be designed.

Data collection is done in two phases:

. An analysis of the existing base data, and

. An exploratory survey.

Good base data are often available on the physical and sometimes on the socio-economic environment, but good written descriptions of the farming systems are rare. Besides, reading about an area can never be a substitute for direct observation and interviews, which bring to life the problems farmers face and the opportunities there are for improvement. Finally, the team-building element of an exploratory survey is valuable and justifies the investment in time and energy.

The results of base data analysis and the exploratory survey are written up in an "area report", which consists of a descriptive and an analytic part (Table 1). The descriptive part deals with the farming system and its physical, biological and socio-economic environment and the analytic part consists of an analysis of constraints and opportunities identified in the farming systems and a typology of farms and fields.

Chapter IV of this field guide gives extensive guidelines and descriptive techniques for writing the area report. Before setting out on the field survey, become familiar with the contents of that chapter.

In Chapter IV we have attempted to cover as many analytical techniques as possible, that may be useful during and after an exploratory survey, without assuming that a team will be able to use all of them. It depends on the available data and expertise of the team which analyses will be carried out and which will not.

In many cases a team will decide that a more detailed study is needed on certain topics and for such studies the descriptive techniques will hopefully prove useful as well.

As an example of an "incomplete" survey report which followed this Field Guide but only used part of its contents, the reader is referred to Mutsaers et al. (1986).

Collection and interpretation of base data

Before the exploratory survey, work with the other team members to analyze the base data. Digest and discuss the information, and draw up some preliminary hypotheses. Prepare a preliminary report, using the setup recommended for the final version (Table 1). This will serve as the framework to which the results of the exploratory survey will be added.

For base data, search:

- Meteorology bulletins or records;
- Soil maps, relief maps (consult soil/land survey laboratories or development projects);
- Publications of the national statistical bureau;

Table 1. Suggested contents of the report on the pilot research area

General features of the area

Maps, administrative divisions, area, population, settlement pattern, ethnic groups, traditional hierarchy, religions.

The physical and biological environment

Climate
Evapotranspiration, rainfall regime, median and quartiles of rainfall, critical periods, temperature, humidity.

Vegetation

Land, soil and water
Land form, land types and associated soils with frequency of occurrence, texture and color of top soil, soil depth, hardpans, water table heights, water storage capacity, chemical fertility.

The human environment and the physical infrastructure

Economic environment
Imports of capital goods, foodstuffs; agricultural exports: exchange rate policy, employment opportunities: urban migration.

Institutional environment and services
Credit facilities: input supply services; extension services· marketing facilities: farmers' organizations.

Social environment
Land tenure system, labor distribution by gender· community help: festivities.

Physical infrastructure
Road conditions, availability of transport, markets, large-scale storage, schools, water supply, electricity, medical services.

Farming systems

Cropping patterns and land use
Crops, cropping patterns and crop associations; utilization of land types; fallow; cropping patterns and fertility; products collected from the bush.

Crop varieties
Characteristics of varieties.

Cropping operations and crop calendar
Land preparation, planting, crop densities, weeding, manuring, harvesting, cropping calendars.

Inputs and yields
Source of seed and planting material; use of fertilizer and agro-chemicals; tools· crop yields.

Crop disorders
Pests, diseases, weeds and their control; nutrient deficiencies.

Post-harvest activities and consumption
Storage, processing, marketing, prices of farm products, nutritional habits, consumption.

Livestock

Factors of production

Land
Ownership and access to land, farm sizes.

Capital, capital goods and capital formation
Sources and utilization of cash; prices and purchase of inputs; cash flow profile; investment.

Labor
Labor profile, division of labor, sources and cost of labor.

Management and information
Educational level, farm management systems.

Decision-making and production choices

Gender roles in decision making; production choices (food, cash crops, livestock, non-farming activities).

Analysis of farmers' conditions

Typology of farms and fields

Constraints and opportunities

- Regional project reports;
- Local government offices;
- University students' village studies (B.Sc, M.Sc theses), and
- Written or verbal information from extension services, agro-service centers etc.

Study and discuss the preliminary report thoroughly as a team before the field survey. Agree on the logistics of the survey and choose representative villages for the survey. Team members who are familiar with the area (extension agents) can contribute much to the discussions.

The exploratory survey

At first sight, land use in West African farming seems impossibly complex, defies description, much less analysis, and may seem too disordered to allow for improvements that seek to make the most of indigenous cropping patterns rather than replacing them. Those who have taken part in exploratory surveys have always found that land use systems that seem impossibly complex gradually take shape, become subject to analysis and reveal previously unsuspected wisdom on the part of the farmers who collectively contribute to them.

Through the exploratory survey the team tries to understand the system, its constraints and potentials in an intensive, informal way, combining field observations and farmer interviews. The exploratory survey concept was introduced by Byerlee, Collinson et al. (1980) in Eastern Africa and by Hildebrand (1981) - who called it a sondeo - in Latin America. We have drawn extensively from these published sources.

A single survey allows only an incomplete assessment of a farming system, but from it you can frame a first set of objectives for field testing and further studies, which is its main purpose. Subsequent intensive contacts with farmers involved in the testing will improve your insights into the farming system.

The exploratory survey is a critical phase in OFR and all the team members participate. Consider inviting a few additional persons with specific expertise, such as a pedologist, sociologist etc. The survey team should comprise:

. The core team of scientists and some from other disciplines, e.g. a soil scientist and a rural sociologist;

. The field assistants who will be responsible for the trials in the survey area;

. The local extension agents; and

. A "critical outsider" from a national or international institute with experience in exploratory surveying. This last person is particularly useful to a team with no previous experience.

Ensure that the team includes at least one woman, for whom it will be easier to obtain information about the tasks and resources of women.

A broadly trained crop protectionist with local experience is a great asset in an exploratory survey team, either as a visitor or full-time member. Otherwise, the agronomist will need to be acquainted with the symptoms of the pests and diseases likely to be encountered.

A total of 10 days for the survey is adequate. The best period is in the middle of the first growing season, when the crops are well established.

The exploratory survey combines field observations and individual and group interviews. Most of the time is spent visiting farmers' fields, but the field visits are preceded and followed by a group meeting with farmers in the village.

The village meetings can be held with the full team, but the team is often too unwieldy for efficient field visits and interviews with individual farmers. For the field visits, split up into subgroups of at the most three members and rotate every other day.

Each subteam needs at least one person who speaks the local language, preferably one of the team members (extension agent) or a local person with at least a few years of secondary school education. Avoid formal questionnaires but use a checklist to keep track of the topics that have not been covered (Table 2).

For recording physical information on individual fields, use a simple data sheet (Figure

Table 2. Checklist of information to be collected during the field survey

	Field visit	Group discussion
General features of the area		
Ethnic groups, traditional hierarchy, religions		x
The physical and biological environment		
Climate		
Farmers' perception of rainfall and consequences for cropping	x	x
Vegetation		
Vegetation type (data sheet)		
Land, soil and water		
Land form, land types, soils (data sheet)		
Soil fertility	x	
Seasonal availability of water		x
The human environment		
Economic environment		
Availability and origin of items not produced locally (market visits)		
Urban migration		x
Institutional environment and services		
Availability and prices of capital goods, inputs (ask traders, distribution centers, etc.)		
Availability and organization of credit		x
Access to extension and input delivery systems		x
Farmers' organizations		x
Social environment		
Access to land and tenurial arrangements	x	x
Division of labor by age and gender		x
Health conditions		x
Festivities		x
Physical infrastructure		
Accessibility, availability of transport		x
Location, frequency, role of markets		x
Large-scale storage facilities		x
Schools, water supply, electricity, medical services		x
The farming system		
Cropping patterns and land use		
Crops, cropping patterns, crop associations	x	x

Differences in cropping pattern among fields/ land types; reasons	x	
Ownership of crops within same field	x	
Criteria for choosing/abandoning field	x	
Duration and utilization of fallow	x	x
Products collected from the bush		x
Obsolete, new crops, reasons		x
Other changes in farming practices over the last 40 years (ask old folk)		x
Crop varieties		
Crop varieties and their characteristics	x	
Cropping operations and crop calendar		
Plant spacing and arrangement	x	
Time and method of land preparation, planting, weeding, harvesting	x	
Inputs and yield		
Sources and maintenance of seeds/planting material	x	
Use of organic, inorganic fertilizers, household refuse, agro-chemicals	x	x
Farm implements	x	
Estimates of yields	x	
Crop disorders		
Weeds, time and method of control	x	
Pests and diseases and their control	x	
Nutrient deficiencies	x	
Post-harvest activities and consumption		
Storage facilities (household and community)	x	
Utilization of crops, proportions marketed and consumed	x	
Processing of crops and food by the farm household or community	x	
Prices of farm products	x	x
Consumption patterns and food preferences; sorts of purchased food		x
Water and fuel requirements and sources		x
Utilization of crop residues and by-products	x	
Livestock		
Livestock systems; species, husbandry, feeding pattern, interaction with cropping	x	x
Factors of production		
Land		
Availability of land	x	x

Number, size and location of fields per household	x	
Accessibility of fields	x	
Capital, capital goods and capital formation		
Sources and principal usages of cash	x	
Labor		
Sources and cost of labor, family and hired	x	
Distribution of labor, peaks, slack periods and bottlenecks	x	x
Management and information		
Educational level of farmers	x	
Decision making and production choices		
Gender roles in these		x

6) and complete it in the field. Without it, discussions often stray into general topics and bypass vital information. Carry field notebooks, soil augers, magnifying glasses and sample bags for plants and soil.

In spite of the informal nature of the survey, adhere to fairly strict rules of operation. The team leader - usually either the agronomist or the economist - introduces the team in the village, decides the subteams for the field visits, organizes reporting etc.

General tour of the area

On the first survey day, take a general tour of the area, with frequent stops and special attention to landscape features, soils, crop combinations. If possible invite a pedologist to guide you through the research area to point out relations between topography, soil and land use. Visit all the survey villages, and explain the purpose of the coming survey to the village leaders. Stress that the team wants to meet a cross-section of the farming population, including women. Discourage the leaders from preselecting farmers. Request that you be allowed to meet with the community and ask for volunteers to accompany you to their fields and to answer your questions.

Fig. 6. Field data sheet for recording technical information on visited fields

Record No:

Recorder:

Date: Field Name:

Farmer's name/age/gender: Crops owned by: Man/Woman

Distance from village:

Village:

1. Vegetation type (circle): dense forest, sparse forest, savanna

2. Crops (note early and late season crops, associations etc. in Tables below)

Crops planted this year (both seasons if appropriate)

Species	Date of Planting	Date of Harvest	Inputs used

Crops planted since last fallow (start with last year)

Species	Date of Planting	Date of Harvest	Inputs used

Future crops and fallow

Species	Date of Planting	Date of Harvest	Inputs to be used

3. Duration last fallow: Yrs
Duration next fallow: Yrs

4. Major weeds:

5. Draw outline and pace the field, indicate crop arrangements and spacings

6. Place in the topography (circle):

Plain- crest -upper slope-middle slope-lower slope-valley bottom

7. Percentage slope: %

8. Soil

	Textural class[1]	Color	Gravel	Hardpan/rock
Top.soil (0-20 cm)			Yes/No	Yes/No
Subsoil (20-50 cm)			Yes/No	Yes/No

[1] S = Sandy; L = Loamy; C = Clayey.

9. Comments/Notes:

Field visits, interviews

The field visits and interviews last for 8-9 days. Upon arrival in a village, meet with the village head and farmers, again explain the purpose of the visit and ask some general questions about major crops and cropping patterns. The meeting should not last for more than an hour.

Split into subteams (two or three members each) and start the field visits, each subteam accompanied by two or three farmers. After the field visits, reassemble in the village and discuss the findings with interested farmers, including those whose fields were visited.

Spend two successive days in every village. During the first day the sample of farmers tends to be biased in favor of more prosperous and influential ones and the team gets a distorted picture as to availability of land, duration of fallow, importance of cash crops, etc.

On the second day this picture can be corrected and the participation, particularly of women, may increase.

Observations and recording

The checklist forms the basis for the collection of information and each section corresponds with a chapter in the final report. Use it as a record of what is discussed rather than a prescription. Move through the subjects in any order you feel appropriate. Keep interviews as informal and natural as possible. At the end of the discussion, quickly scan the list for major topics that have been missed.

Complete a separate data sheet for each field visited. From these sheets you will be able to identify the major cropping patterns and sequences and a possible relation with soil or land types.

Certain topics are better discussed during the group meetings in the village than during the individual field visits. Group interviews are an efficient means of obtaining information about the general cropping sequences and practices and the time that each task requires. Interview farmers - for example women - who are expected to differ from their counterparts as to constraints; attempt to find out how much of the population they represent.

Some hints are given below to guide your observations and interviews.

Climate and vegetation. It is difficult to give precise questions to find out farmers' perception of rainfall. Questions should relate to constraints on cropping (short season, dry spells, late start?). One question that is always relevant is "Was last year a good season; why or why not?". Farmers may distinguish between seasons that were good for some crops but not for others.

Attempt to find out how farmers adjust cropping to rainfall, what they consider as adequate rainfall to start planting, what they do in case of an initial crop failure caused by drought etc.

A question about long-term trends in rainfall almost always gets the reply that the rains are not as good as formerly. Farmers may have an objective basis for this belief: where intensive cultivation and the physical conditions of the soil have led to more runoff and reduced water retention, the available moisture may well have decreased, while measured rainfall has not.

Land, soil and water. Crops are good indicators of soil conditions. In cocoa-growing areas of the Alfisol belt, plantations are found on the fertile, medium textured deep soils, which are generally in flat parts of the topography or on plateaus. Plantains also indicate favorable soil conditions in humid and subhumid areas. They tend to disappear when land is overexploited unless farmers take special measures such as mulching or manuring (some countries in East Africa and Cameroun). Cocoyams (Colocasia esculenta) are often grown in soils that are temporarily waterlogged, that is, mainly lower slopes and valley bottoms.

The position of a field along the slope and slope degree are easily assessed. For the position in the topography, use a sufficiently large scale and do not consider minor humps as separate toposequences: a catena or toposequence will typically cover in the order of 500-1000 m on the horizontal scale. The degree of slope in combination with the textural class indicates erosion risk.

Texture, color and the presence of root restricting layers can be assessed with a soil auger (screw, bucket, "Dutch" auger) if the soil is not too dry and hard, provided the team agronomist has some experience in "feeling" soil texture of moistened samples.

Do not conduct systematic soil sampling during the exploratory survey, but consider taking a few samples of representative soils and have them analyzed.

The human environment and the physical infrastructure. Ask about credit opportunities and the existence of cooperatives. Frequently farmers form local credit cooperatives. Information on the minimum contribution and terms of payment is important.

If possible, obtain information about private money lenders. Also, informal money lending within the family is common. Be aware that information on the latter sources of credit is difficult to gather.

Physical inputs may be supplied by private companies or individuals or government agencies. Make an inventory of the available physical inputs. For machinery, record the location of the supply sources. This inventory includes make, size and age. Inquire about availability of spare parts, the hectarage covered on the average per year or per season, and the downtime due to repairs.

Find out who can own land and whether newcomers to the village can obtain land. In some societies, both men and women inherit land; in other societies only the man. Sometimes the right to farm the land does not include the right to plant trees. In most cases, the village chief allocates land to newcomers; however, the land may be far from the village or of low quality.

Distribution of labor by age and gender within families is always influenced by customs. Ask questions like: Do men and women within a family farm together or independently? Are men and women within the family expected to perform different tasks? What are these tasks and how time consuming are they? Who is responsible for providing the family with food? Who markets the output and who keeps the cash?

Cropping patterns and land use. The team agronomist's prime responsibility is to provide a good description of land use. Of course, insights gained and shared by other team members are vital. The key to unraveling the seeming confusion is to identify the principal cropping patterns and sequences of the study area. Be parsimonious in distinguishing different patterns. It is common to find four or five for the main upland outfields plus perhaps one or two more special patterns associated with distinct land types such as valley bottoms or with homestead gardens. What at first sight may seem to be a separate pattern is often a variant of a general type.

Try to develop an eye for the landscape and to identify soil types associated with different positions in the topography. Be alert for differences in land use associated with toposequence position; for example, in the better Alfisol areas of the forest zone, cocoa may be found in flat or plateau positions on deep soils of medium texture, arable crops on the slopes and cocoyam (Colocasia esculenta) where waterlogging occurs on lower slopes and in valley bottoms. Valley bottoms that do not dry out too rapidly in the dry season may also be used for off-season cropping with maize or vegetables. In the savanna areas yams or other crops may be grown in valley bottoms on large mounds or beds. Rice may also be grown on lower slopes and valley bottoms.

Don't place too much emphasis on minor crops or on minor variations in spatial arrangement. Try to identify the main species and ask the farmer about their relative importance. If, for instance, he or she refers to the plot as a yam plot, that usually means that yam is considered as the main crop. The principal cropping patterns rarely have more than three major crops; two is the most common. Minor crops will then be added and each field may contain a different selection. It is difficult to define exactly what are minor crops but they are usually present at low densities or added late in the season to fill gaps in the stand. The staple food crops are never minor crops in any cropping pattern. Except in the home garden, vegetables are often, but not always, minor crops. They can be a major crop if grown for sale. Crops used to delineate field boundaries can be viewed as minor.

Don't assume that the only components of the cropping pattern are the ones you see on the ground at the time of the visit; look for residues and ask whether the farmer has already harvested or plans to plant anything else this season. The field data sheet covers this.

Try to find out from farmers the extent to which an observed cropping pattern was planned or was formed as a reaction to events early in the season. The failure to establish an early crop because of pest, drought, rainwash or the lack of labor, draft animals or tractors can lead to unplanned changes or compensations to other plots within the same farm. In the event of a loss of stand short of total failure, an extra species may be introduced as a gap-filler. Such contingency cropping illustrates the farmers' strategies to offset risk but, unless elicited in interviews, can cause confusion in identifying the main cropping patterns.

Minor crops are also mainly a matter of observation, followed by relevant questions such as "Do you always sow okra in your maize field?". You may find that some of these crops are primarily the wife's responsibility and this is all useful information.

The question "Why did you choose this cropping pattern for this plot?" is always relevant and the answer will give insight into the cropping patterns considered appropriate for different land types or for different phases in the rotation. Follow it up by tracing the cropping patterns that were grown on the fields in earlier years, back to the last fallow or for about five years in permanently cropped land. Continue by asking what the farmer plans to plant next year and how much longer he or she expects to use the field before fallow. How long will it be fallow? Who will use the plot after the fallow? Again the data sheet (Figure 6) covers most of this.

Try and visit a number of plots with different cropping patterns in proportion to their importance. Sometimes farmers give useful qualitative information about other plots but semi-quantitative observations are more satisfactory, with the agronomist visually confirming the farmers' descriptions.

Crop varieties. Question individuals about the variety of each component preferred for each cropping pattern (sometimes important but not always so). For instance, vigorous varieties may be preferred for sole cropping if they would be too aggressive in mixtures. Ask the farmer to show you any different varieties grown, to tell you how to recognize them and to explain any special ways of using the varieties in the crop mixtures. Questions about utilization of the product from the different varieties may also arise naturally at this point.

Cropping operations and crop calendars. For each cropping pattern identified, obtain more information on the cropping techniques, varieties etc. Investigate the range of sowing and harvest dates for each component and its relation to operations carried out on earlier-sown components; for instance, the second crop may be sown during or immediately after weeding of the first (data sheet). Sowing and harvest dates can be estimated by visual observation of the crops and confirmed by the farmer. (But don't ask "You sowed this crop in June, didn't you?"; better simply "When did you sow this?"). He or she is likely to reply with a time period, "4 weeks ago", or in relation to an event, "after the third rain" or "before a particular festival", and it is up to the team with the help of a local interpreter to translate the information into their own terms.

Attempt to determine the dates of all other operations such as weeding, harvesting and crop-specific operations such as yam staking and protection practices. Find out what criterion the farmer used to decide when to start the operation (rainfall event, degree of weediness etc.).

Look into the range of stand densities of each component, the number of plants per stand or per heap and the spacing of the components relative to each other and to the heaps or ridges. Stand densities and spatial arrangements are primarily a matter for observation and estimation by the agronomist who should have practised estimating ridge or row widths, stand spacings and the distances between heaps. Pacing is the simplest technique and the agronomist should know his or her pace-length and shoe-length. Count about 20 heaps, ridges or stands and pace out the distance from the first to the last. Do it in two directions. Record these data on the data sheet. Questions naturally follow such as "Why do you use such big heaps in this field?"; "Why is this crop sown at the side of the ridge?". Try to avoid the impression that you are accusing the farmer of ignoring an extension recommendation. Make it clear you are planning to test different practices and are looking for the reasons for the ones being used.

Inputs and yields. Try to find out how much manure and fertilizer is being used: the types, and approximate quantities, techniques and date of application (data sheet).

Carefully assess the tools and techniques used in each operation. Record as much information as possible about the person(s) normally doing each task (sex, age, relationship to farmer). Attempt to get some indication of the labor requirement per hectare or for a typical plot size. Also ask about fees for labor, noting any differences by operation. Find out whether laborers are given meals as part of the wage.

Describe and photograph each tool and item of equipment. Ask a farmer to demonstrate its use and report the technique as accurately as possible. Be on the lookout for special techniques to deal with specific weeds or other crop-protection problems, techniques to provide trellises for climbing crops and to minimize labor inputs. Find out why the farmer does or does not use these techniques.

Sometimes yields can be estimated visually if an agronomist can see the crop in the field just before harvest. If not, then the farmer can be asked what yields are expected from the crops. Get estimates of the capacities by weight of the units (bags, bundles, calabashes etc.) familiar to the farmer. To estimate plot size, draw a rough sketch, pace off the dimensions in two directions and mark them on the sketch (data sheet). Then, estimate the dimensions of the rectangle that would have an area equal to the sketched plot. Multiply the rectangle dimensions in metres and divide by 10,000 to obtain the plot area in hectares. However crude these estimates, they are likely to be better than estimates from official monitoring services. The exception to this is crops marketed only through official channels for which the best estimate obviously comes from the local buying office.

Post-harvest activities and consumption. Pay special attention to the post-harvest activities such as seed preservation, marketing, processing and storage. Describe individual and community storage methods. Find out the allowable storage period, problems with storage and insects, and techniques used to minimize losses.

Livestock. Small ruminants and chickens are almost universally kept by African farmers. Note the number of animals owned by a household, the source of feed and provisions to avoid damage to crops (e.g. unplanted buffer zones around villages, village regulations, tethering, etc.). Is the dung utilized? Who is responsible for feeding?

For large animals, two types of livestock-crop interaction may be identified in West Africa; in the first, the livestock are peripheral to the cropping and are mostly owned or at least herded by members of an ethnic group other than the crop farmers.

In the second type, cattle are central to the village economy and usually are owned by the farmers themselves, though often only by the rich ones. Traditional pastoralists who have settled in recent years commonly practise this type of farming.

Peripheral livestock systems. Questions that are appropriate for the farmer include:

- Do the herders restrain or remove their livestock during the cropping seasons? What are the locally recognized signals for the beginning and end of the cropping period?

- Do the herds use any crop residues left on the field during the dry season? Does this cause problems of grazing to the late crops such as cotton? Do farmers harvest and carry home residues such as groundnut and cowpea haulm? If so, for what do they use the residues? Is fencing necessary for crops during the dry season?

- Do the farmers invite herders to keep cattle on their fields overnight? Are they expected to pay for the dung that accumulates?

- Are there any conventions governing the grazing of fallow land?

- Is it common for farmers to trade with herders? What commodities are traded? Are payments made in cash or kind?

Centralized livestock systems. For systems in which livestock are central, relevant questions include: Are the cattle herded and by whom, where are they corraled, do they get supplementary feed and, if so, what? Ascertaining who owns the cattle may be impossible because farmers are reluctant to state how many they own. There are good historic reasons for this, dating from the colonial practice of taxing cattle.

Draft animals. In some areas, animals (camels, bulls, oxen, donkeys) are used for transport and, less commonly, for tillage. Look into patterns of ownership and hiring and the charges levied. Photograph and describe tillage tools and carts. Ask about dry season feeding and be on the lookout for opportunities to introduce improvements at the beginning of the rains when the animals are likely to be in poor condition.

In areas where animal draft could be introduced or extended, explore the availability of animals and of credit to enable farmers to purchase them. Keep in mind the skills needed by handlers to train the animals.

Factors of production. Ask farmers about the number of cropped fields they have and which crops they grow on each to estimate the size of their holding and the importance of the different cropping patterns.

Other questions are: Could you expand your farm? (An exploratory survey in northern Ghana showed that the group of farmers interviewed on the first day could expand. The second day group could not. The chief had invited his friends, the well-to-do farmers the first day. The team had, however, insisted on seeing a group of small farmers the following day.) Has the fallow period always been ... years, or has it become shorter? A shorter fallow period indicates that land supply is declining. There may still not be a shortage; however, maintaining fertile soil may be a problem.

Observation can support the answers obtained from farmers. Weedy fields typically indicate that land is not constraining expansion. Another indicator is grazing habits. When goats and sheep are tethered or penned and feed is collected for the animals, land is usually short.

Assess the available infrastructure, goods available in the market, nutritional status of the people, especially women and children, as well as clothing, wrist watches, bicycles, motor bikes and cars. The home economist who visits the women should note the presence of durable consumer goods in the houses, clocks, radios, kitchen utensils etc. A good indicator is the condition of houses. New construction, cement floors and corrugated iron roofs indicate prosperity.

If exchange labor is common, ask whether a farmer can count on it or whether he or she asks neighbors to help only for special tasks such as land clearing or house construction or under certain conditions such as illness.

Daily roundup discussions

Each day after returning to the base, discuss the day's findings, using the checklist to note topics that were insufficiently covered. Keep notes of the discussions. Assign sections of the checklist to different team members to record the team's observations on those subjects. Use recording sheets, a separate one for each survey day. This will greatly simplify final reporting. The rapporteurs will later have responsibility for drafting the corresponding chapters of the final area report.

Visits to markets and traders

Data of a general nature may be collected from other sources such as local traders and transporters, local markets, agro-service centers (types and volumes of marketed produce, items produced locally and imported, available inputs, prices etc.). Part of the team may set aside one day for this. Ask traders about the origin of items not grown in the area, and find out whether farmers have given up growing certain crops because of competition from imported items.

Brainstorming

When the survey is about half way, spend a day discussing land use, cropping patterns and cropping techniques, and on constraints and potential for improvement, without worrying too much at this stage about details. Define different "target groups" of farmers and different land and soil types with their specific cropping patterns. Such target groups and land types may later require different innovations.

During the remainder of the survey, test assumptions and hypotheses so that you focus on "addressable" problems and opportunities.

Analysis of farmers' conditions

Immediately after the survey, analyze the findings in a few roundup meetings and draft:

- a typology of farms and field: classify the farms, perhaps according to size, degree of market orientation, etc. — whatever criteria delineate the farm types or field types that require different innovations.

- an analysis of constraints and opportunities: identify and list elements in the farming system and the environment that limit productivity and for which solutions may be sought. Also describe features of the system that may be better exploited to increase productivity.

Writing the area report

In the next chapter guidelines are given for writing the area report, illustrated with examples. Table 1 shows suggested contents of the area report, and Chapter IV explains how to interpret the data for each subject. You may find this chapter at times too ambitious. We wish to stress again that it gives the maximum and you may have to settle for far less than that. If the data are not available, do not try to write more than you actually know and leave the gaps for further studies during the testing phase.

Complete the draft of the report before designing on-farm trials (Chapter V).

Chapter IV

Guidelines for the description of the pilot research area

Chapter IV: Guidelines for the description of the pilot research area

General features of the area

When writing the report, begin with a brief general description; including:

- Location and size of the area, maps. A simple map of the country and the relevant section of a detailed topographic map (e.g., 1:100,000), with the boundaries of the research area, its size and the location of the sample villages indicated.

- Administrative divisions. The lower and higher administrative units to which the research area belongs, with administrative centers (use maps!).

- Population, settlement pattern. Total population of the area, size distribution of settlements (villages and hamlets), location of settlements relative to roads.

- Ethnic groups, traditional hierarchy and religions.

The physical and biological environment

Climate

When describing the climate, aim to:

- Understand why farmers have adopted the crops, cropping patterns and seasonal working patterns observed in the exploratory survey.

- Suggest improved cropping patterns or new crops or varieties for testing.

The historic climate is relevant to the first objective but the future climate is more relevant to the second. Climatologists have always assumed that the best available guide to the future climate is the historic climate, but climatic change does take place. In the southern savannas and forests of West Africa, the rainfall has changed little over a time-scale of interest for OFR; however, in the northern savannas and Sahel ecologies, rainfall has tended to decline over the last 20 years. Unfortunately, we do not know whether this decline will continue. Still, the trend warrants testing of innovations that have a smaller rather than greater water requirement than existing cropping patterns and this is certainly the direction in which farmers are already adapting their systems.

The most important elements in characterizing the climate of the research area are the components of the water balance, namely rainfall and potential evapotranspiration. Other subsidiary elements are temperature, daylength and insolation.

Potential evapotranspiration. The amount of water exchanged with the air by a green, actively growing, well-watered grass sward that completely covers the ground (potential evapotranspiration, PET or E_t) is quite an adequate estimate of water requirements for optimal crop growth. This value shows much less variation in space and time than does rainfall. Use an average monthly value from a weather station at similar latitude and altitude to the research area even if it is at some distance.

E_t is assumed to be related in a simple manner with potential evaporation (E_o), defined as the rate of evaporation from a large open water surface, expressed in mm per month or per day. When consulting published sources, ascertain whether the estimate given is of E_t or E_o. If it is E_o, then multiply by 0.8 or 0.9 to obtain an adequate estimate of E_t in the rainy season.

Many West African countries now have published estimates of potential evaporation (E_o) for a number of weather stations. Check in the libraries of research institutes and agricultural faculties. Find out how the values were estimated. The more sophisticated methods (e.g. Penman) involve complex calculations and require data that are not generally available. Most often the estimates will be based on US Weather Bureau Class A pan evaporation.

At first sight, pan evaporation seems a direct estimate of E_o but because of the pan's small area, edge effects and uncertainties from exposure to wind, it is far short of ideal. Even when pan data are available, an estimate from one of the simpler methods using radiation, temperature, windspeed and humidity data from a weather station may be preferable. The FAO publication by Doorenbos and Pruitt (1975) gives full details of the methods available, the limitations of each and the weather data required for each.

The Blaney and Criddle method as modified by Doorenbos and Pruitt requires only mean temperature data for each month, together with some qualitative estimate (low, medium or high) for relative humidity, cloud cover and daytime windspeed. The Blaney and Criddle factor (f) is given by:

$$f = p(0.46t + 8.13) \text{ mm/day}$$

where "t" is the mean temperature for the month in ^oC and "p" is the mean daily percentage of annual daytime hours (0.27 throughout the year at the equator; varies from 0.26 in December/January to 0.29 in June/July at 10 0^oN and from 0.25 to 0.30 at 20^oN). Generally, where humidities are low or medium this factor overestimates E_t at low values (<3 mm/day) and underestimates it at high values, especially when windspeed or radiation are high. Under high humidity, that is during the rainy season, E_t can be taken as about 0.75f.

Doorenbos and Pruitt also give conversion factors for use with US Weather Bureau Class A pans, which vary from 0.4 under low humidity, strong winds and with no irrigated crop upwind of the pan to 0.85 for high humidities, light winds and when the pan is surrounded by a well-watered crop or grass.

If no better source is available, an estimate, suitable only for use in West Africa and at sites lower than 1000 m is given in Table 3. The potential evapotranspiration may be assumed to fall in a gentle curve (cf. Figures 8 and 9) from the peak tabulated for March to the minimum tabulated for August. It will then rise again toward the March peak.

Table 3. Approximate potential evapotranspiration (mm/10 days) at five different latitudes in West Africa for the peak month (March) and the lowest month (August)

Latitude (°N)	March	August
6	47	27
8	50	30
10	54	33
12	59	36
14	65	39

Not to be used outside West Africa or for sites more than 1000 m above sea level.

Rainfall. A first orientation can be obtained from a map showing mean annual rainfall (Figure 7), but a more detailed analysis is needed to relate cropping patterns to rainfall. In particular, the length of the dry season and the reliability of rainfall according to season are important. Much depends on the source of rainfall data. The ideal is to have daily records that have been collected for at least 15 years by a rainfall station within the research area.

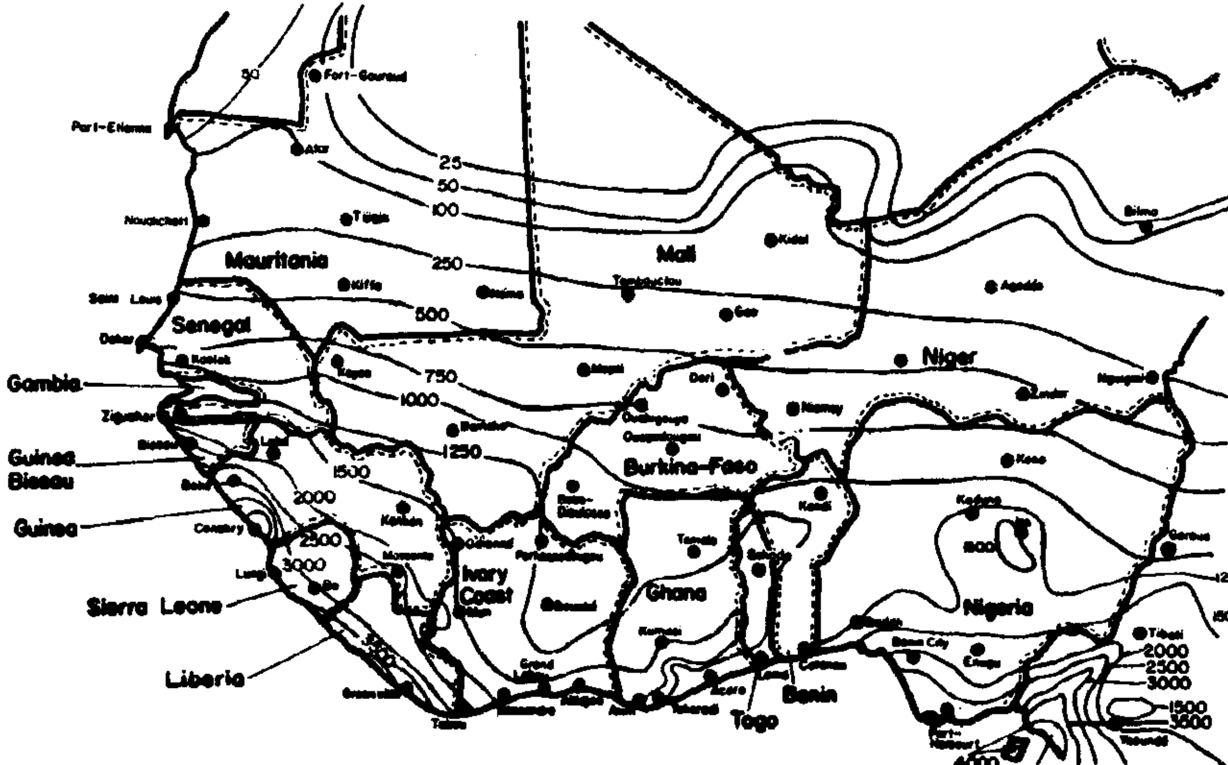


Fig. 7. Isohyets (Lines of equal mean annual rainfall) for West Africa (adapted from OAU/STRC, 1966).

A month is a long time in the life of a crop and recommendations for the timing of farm operations usually have to be more precise than merely specifying the month. Reduce daily rainfall figures to totals for periods shorter than a month: 10 days is a reasonable compromise between precision in describing seasonal trends and statistical complexity.

For convenience, divide each month into three periods: days 1 to 10, 11 to 20 and 21 to the end of the month. The last period varies from 8-11 days but is here described as a 10-day period. The rainfall figures can thus be shown in a table of 36 x n 10-day rainfall totals where there are 36 10-day periods in each of n years for which records are available. If gaps in the record exist, affecting more than three 10-day periods in any one year, omit all records for that year. Where three or fewer gaps exist, enter a symbol such as ? (not "0" or "-" which could be mistaken for zero) and, when calculating means, medians or quartiles, use a value of n that represents the

Table 4. Rainfall totals (mm/10 days) for Ibadan in March and April

	March			April		
Year	1-10	11-20	21-31	1-10	11-20	21-30
1953	2	20	15	3	24	8
54	6	95	148	25	43	91
55	10	58	21	53	49	18
56	47	74	49	61	45	13
57	27	81	27	92	11	25
58	57	1	72	26	63	3
59	13	12	26	16	41	54
1960	0	78	4	22	48	56
61	0	8	15	43	126	56
62	28	90	6	38	78	2
63	39	0	9	51	60	5
64	0	30	52	14	101	83
55	23	15	39	0	42	56
66	1	48	111	4	78	69
67	2	0	63	0	43	24
68	2	24	45	5	100	65
69	6	30	61	71	73	30
1970	95	20	15	2	141	11
71	16	30	135	16	21	46
72	24	20	10	50	55	28
73	0	24	28	67	18	25

number of annual records available for that particular 10-day period (Table 4). Where the dry season is long, it may not be necessary to tabulate the 10-day periods that almost invariably have zero rainfall.

From the table, find the median (see section on ranking method) estimate of the "average" rainfall. (For periods shorter than a month, the arithmetic mean is not a good estimate of average rainfall. Particularly at the beginning and end of West African rainfall seasons, the statistical distribution of the 10-day rainfall totals is skewed so the mean rainfall is an overestimate of what is exceeded in 50% of the years.)

Many more or less complex statistical techniques exist for estimating medians and probability limits in skewed data but none of these is at all satisfactory where more than 10% of years have zero rainfall in a 10-day period. Use the ranking method described in the next section: the estimates are adequate, zeros pose no problem and even a pocket calculator is not essential. Medians do have one drawback: they are not additive; that is, the sum of the three 10-day medians does not equal the median for the month. This is of no importance for any of the techniques described in this manual but could become important if the medians were subsequently used for calculation of a water balance in the "average" year. Where computers and programming expertise are available, use the more sophisticated method of Mutsaers (1979).

Ranking method for estimates of medians and quartiles. Arrange the data for each 10-day period in order of magnitude (Table 5). The simplest way to do this is to take a sheet of unlined scrap paper and write in the data year by year at the position in a column where it is estimated to fall, with small values at the top and large ones at the bottom and with zeros included; then copy them into a ranked table (Table 5). From the ranked data for each 10-day period, extract:

- The value at (n+1)/4, lower quartile, exceeded in 75% of years;
- The value at 2(n+1)/4, median, exceeded in 50% of years;
- The value at 3(n+1)/4, upper quartile, exceeded in 25% of years.

When (n+1) is an exact multiple of 4, the actual rainfall falling on the appropriate rank is taken as the quartile or median value; otherwise an interpolation is made between the rainfall values immediately preceding and immediately following the indicated value. Suppose n=21, as in Table 5, then:

$$(n+1)/4 = 5.5$$

$$2(n+1)/4 = 11.0$$

$$3(n+1)/4 = 16.5$$

and the appropriate lower quartile is given by:

$$r5 + 0.5(r6-r5),$$

the median by

$$r11$$

and the upper quartile by

$$r16 + 0.5(r17-r16)$$

where r5 is the 10-day rainfall occupying the 5th position in the ranked column (Table 5) and so on. Remember that where there are missing data, n should take the value of the number of years with complete data for the 10-day period in question.

Other confidence limits can also be estimated from the ranked data; for instance the 90% and 10% expectations would be given by the values at (n+1)/10 and at 9(n+1)/10 respectively. Estimates of extreme occurrences are however not reliable if n is less than 30. When presenting and interpreting the data, state and consider the exact confidence interval displayed.

Table 5. Ranked rainfall totals (mm/10 days) at Ibadan (1953 to 1973)

	March			April		
Rank	1-10	11-20	21-31	1-10	11-20	21-30
1	0	0	4	0	11	2
2	0	0	6	0	18	3
3	0	1	9	2	21	5
4	0	8	10	3	24	8
5	1	12	15	4	41	11
6	2	15	15	5	42	13
7	2	20	15	14	43	18
8	2	20	21	16	43	24
9	6	20	26	16	45	25
10	6	24	27	22	48	25
11	10	24	28	25	49	28
12	13	30	39	26	55	30
13	16	30	45	38	60	46
14	23	30	49	43	63	54
15	24	48	52	51	73	56
16	27	58	61	53	78	56
17	28	74	63	58	78	56
18	39	78	72	61	100	65
19	47	81	111	67	101	69
20	57	90	135	71	126	83
21	95	95	148	92	141	91
rank						
Low qu. 5.5	1.5	13.5	15.0	4.5	41.5	12.0
Median 11.0	10.0	24.0	28.0	25.0	49.0	28.0
Up. qu. 16.5	27.5	66.0	62.0	55.5	78.0	56.0

Preparation and interpretation of the rainfall diagram. The ranking process yields three summary statistics, the median and two quartiles for each 10-day period in the season when rain is expected. These can be presented graphically (Figure 8), with an estimate of potential evapotranspiration (E_t) being superimposed. Take care with the units; if they are in mm per month they need to be divided by 3.0 to superimpose on rainfalls for 10 days. As we have said, the mean evapotranspiration is all that is needed and even 3-4 years' data are adequate. When the median rainfall exceeds E_t, there is a good chance that crops will not suffer water stress. At the beginning and end of their growth periods, crops require less water than E_t: $^1/_3$ E_t (or 0.4 E_o) is sometimes used to represent potential evapotranspiration of bare soil or young crops (Figure 12). If the lower quartile falls below E_t, crops will probably suffer at that time if they are at full leaf canopy or a sensitive stage of growth. Remember to study the dry spells in the rainfall data when specific crop improvements or new introductions are proposed for testing. Upper quartile values greatly in excess of 2 E_t indicate the possibility of flooding in lowland sites and water-logging, leaching and accelerated soil erosion on upland sites. Fungal diseases or spoilage of ripening crops may also occur at times of excessive rainfall.

How do diagrams such as Figures 8 and 9 help in the understanding and design of cropping systems?

The seasonal trend for rainfall throughout West Africa has either one or two peaks. In the one-peak category, as at Samaru (Figure 9), median rainfall rises to a peak, usually in August or September and then falls rapidly. Double (sequential) cropping of unirrigated uplands is generally not possible in such a regime. Reliable rainfall for germination and establishment can be expected beginning 20 May and will exceed the crops' requirements until 20 September. Since excess rainfall sufficient to recharge the soil moisture usually occurs in August and early September, 40-100 mm of water, depending on soil depth and texture, representing 20-50 days' water supply, is available from store so that the ideal crop would reach physiologic maturity about 10 October in a shallow light soil or 10 November in a deep heavy one. It would thus have a total duration of 140-170 days to physiologic maturity.

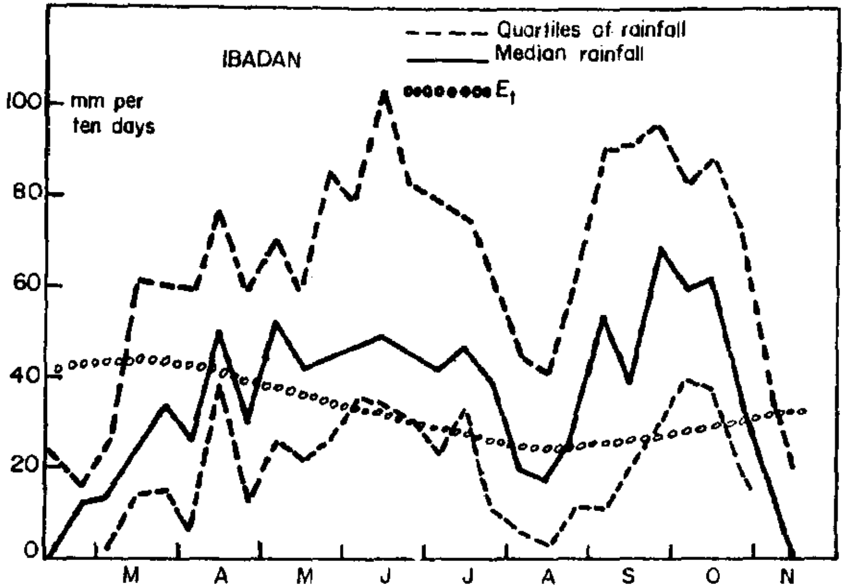


Fig. 8 Rainfall and evapotranspiration at Ibadan, Nigeria. 1953-1973 rainfall data.

mm per ten days

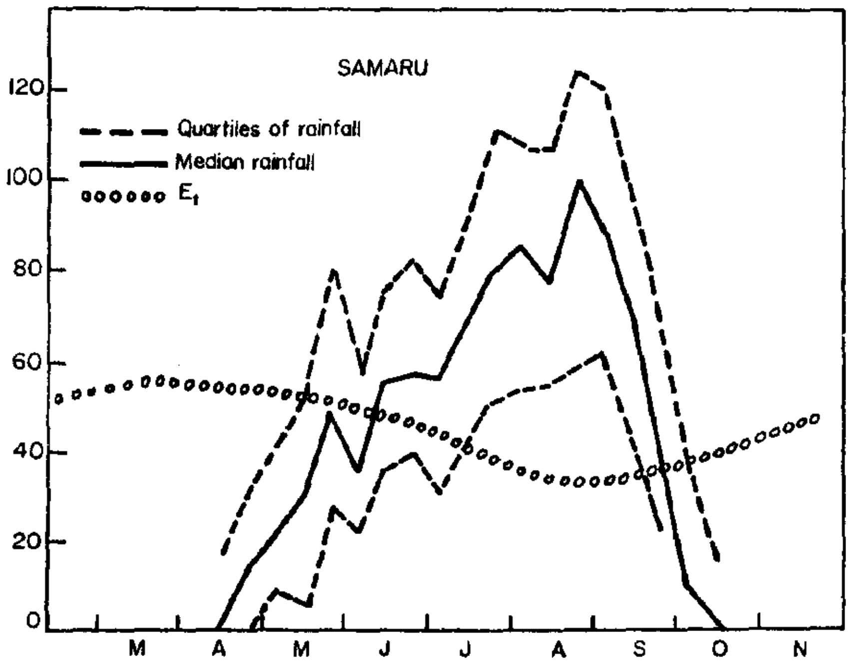


Fig. 9. Rainfall and evapotranspiration at Samaru, Nigeria. 1928-1984 rainfall data.

In practice, farmers have realized that few such ideal crops exist and that a crop mixture or relay cropping strategy is more appropriate for realizing the potential set by the rainfall regime.

In the two-peak category, represented by Ibadan (Figure 8), the option of double cropping is available and the dry period in August may be of advantage in reducing spoilage of the ripening first crop. This could be planted by 10 April, earlier in favorable years and reach physiologic maturity around 10 August, giving a duration of 120 days. It would run the risk of dry spells at almost any time except during June and if it were a crop with marked sensitivity to water stress at a particular stage of growth, it would be wise to ensure that this stage occurred in June. The rainfall is likely to be sufficient for a second crop to be sown immediately after harvest, about 20 August, and it should be physiologically mature about 10 November to 10 December, depending on soil type and should therefore be of 80-110 days' duration. Although double cropping is technically possible, farmers generally use a complex cropping strategy involving a combination of mixed and sequential cropping, which is probably less risky than two crops grown in sequence. It is neither likely nor desirable that these complex cropping patterns be totally replaced by two sole crops. A very common basic mixture in the two-peak rainfall belt of West Africa is early-season maize interplanted with cassava. Well established cassava is more tolerant of poor late-season rain than maize or cowpea and the maize+cassava cropping pattern is therefore appropriate.

In research areas of the size that can be handled by OFR teams, one rainfall station with records over at least 15 years inside or just outside the study area would usually be adequate for initial characterization. In later years, analysis of other data can be added. Occasionally, especially in hilly areas, one rainfall station may be inadequate even for initial characterization. In such cases, search for two stations, one of which should be drier and one rather wetter than the average for the research area. In later reports, identify the climatic limitations of innovations that prove successful in on-farm testing. Use the techniques described earlier to delineate zones well outside the original OFR area for the guidance of extension workers.

Making the best use of inadequate rainfall data. Frequently, rainfall data are not available or they do not span 15 years. Rainfall records of a less "official" nature may be available outside a central records library. Likely sources are extension offices, schools, large-scale farms or plantations and mission stations. Sometimes, you can interpolate between two rainfall stations outside the area but do so with care in hilly country. For the initial characterization, data for both stations could be presented with the statement that the best available guess is that rainfall in the study area is somewhere between the two. Where data for less than 15 years are available, don't try to estimate confidence limits but show the mean (here, better than the median) with a note to the effect that it is based on only a few years.

If there is a rainfall station outside the study area but close enough to have similar annual fluctuations, assess whether the years for which data are available within the study area were unusually wet or dry and adjust the mean for the research area:

$$\underline{r}' = \underline{r} \times \underline{d}1/\underline{d}2$$

where $\underline{r}'$ is the adjusted mean for any 10-day period, $\underline{r}$ is the unadjusted value from the data available, $\underline{d}1$ is the long-term mean for the 10-day period at a distant station and $\underline{d}2$ is the mean at the distant station for those years in which data are available within the research area. Avoid adjusting confidence limits in this way; the records of the distant station give some indication of variability and could be included in the report as the best available.

Where daily rainfall records are not available, monthly rainfall is certainly better than nothing though it will not give as good an indication of the occurrence of dry spells or the precise length of the season. It can be presented as medians and quartiles by the ranking methods suggested for 10-day periods. Skewness is much less of a problem for monthly rainfall totals than for 10-day totals so confidence limits based on the normal distribution are acceptable.

Farmer perceptions of the rainfall and climatic change. Analyze the findings from farmer interviews. Include a description of how they perceive rainfall, how it limits their cropping possibilities, how they decide when the rains are sufficient for planting, what strategies they adopt in bad years, whether they believe the rainfall to be as good as when they were young and if not, what adjustments they have made in their cropping pattern.

Other climatic factors. After rainfall, temperature is the most important climatic variable for crops. Temperature variation is much less localized than rainfall, and usually the research station would have a temperature regime similar to that of the research area. Local temperature data are likely to be more difficult to obtain than data for rainfall, but five years' data are adequate to give a good mean since the temperature is not as variable as rainfall. To allow for a difference in altitude, extrapolate from data for a not-too-distant weather station by assuming a decrease of 0.55 C degrees for every 100 m increase in altitude.

Daily insolation affects crops, especially tropical cereals, which are capable of responding to high light intensities. Fortunately, it rarely needs to be considered on a local basis. Generally the total amount of sunshine increases with distance from the equator because there is less cloud cover at higher latitudes.

Many crops grown at latitudes of more than 5^{o} from the equator are sensitive to daylength in their flowering behavior. However, screening in research stations at similar latitudes to that of the research area should ensure adaptability. If such information is not available, we recommend on-station testing, particularly for exotic varieties of photosensitive crops (especially legumes), before use in on-farm trials.

Vegetation

Although vegetational zones have provided the traditional basis for delineating ecologies in West Africa, they would probably never have been used if rainfall data had been available when modern agricultural development efforts began. Vegetation is a useful guide if expertly interpreted but is often misleading. Remember that vegetation maps have largely been based on foresters' assessment of the "climax" and, for their models, they searched for sites that were undisturbed by felling and cultivation. Today these sites are more or less limited to forest reserves. The secondary vegetation in areas of bush fallow is much less fully developed than in the traditional descriptions. These differences can give the impression that a highly cultivated area is drier than it really is and also that the ecology is deteriorating more rapidly than is really the case.

The factor that determines vegetation on most soil types is the duration of the dry season. A short dry season allows even the tallest trees to maintain turgor and eliminates the possibility of fire in the undergrowth. When dry seasons are long, forest trees cannot survive and even the short savanna species can survive only if they are fire tolerant. The grasses whose aboveground parts die back each year gradually become competitive with the trees, and this competition increases the fire hazard. The elimination of woody vegetation however, reduces the hazard of tsetse-borne disease in livestock and therefore allows grazing of the grass to such an extent that, in the Sudan savanna, fire tolerance is secondary to palatability and tolerance of grazing.

Despite the near disappearance of the vegetation as traditionally described, some generalizations can be made about conditions prevailing in each zone of vegetation as mapped and widely used in agricultural planning:

In the forest, mean annual rainfall exceeds 1300 mm, distributed with two peaks and falling at any time between March and November. Oil palm (Elaeis guineensis), kola (Cola nitida) and silk cotton (Ceiba pentandra) often remain standing in cleared land and the umbrella tree (Musanga cecropioides) often dominates the early regrowth.

In the derived savanna and savanna-forest mosaic, found in areas with about 1300 mm mean annual rainfall, forest outlayers persist on sites less prone to fire while the savanna areas are similar to the southern Guinea savanna.

In the southern Guinea savanna, mean annual rainfall ranges from 1100 to 1300 mm and falls from April to October. This zone is transitional, with the two rainfall peaks tending to coalesce. Vegetation is fire-tolerant; locust bean (Parkia clappertoniana) is preserved in cultivation, Lophira lanceolata and Daniellia oliveri trees and tall grasses of the genera Hyparrhenia, Andropogon or Pennisetum dominate the fallows.

- In the northern Guinea savanna, mean annual rainfall is from 800 to 1100 mm and falls from May to October. Locust bean and shea butter (Butyrospermum parkii) trees are preserved in cultivation and Isoberlina doka is common in the fallows. The tall grasses are found but are often heavily grazed.

- In the Sudan savanna, 500-800 mm falls from June to September. Locust bean and baobab (Andansonia digitata) are left standing, and uncultivated land is often dominated by Acacia and Combretum thornbush. The species of grass from the genera Eragrostis, Cenchrus and Pennisetum are short and, because of the grazing pressure, are rarely allowed to develop.

- In the Sahel with less than 500 mm mean average rainfall, the season is short; in some years rain may be confined to July and August. There are few trees; Acacia thornbush and very short grasses dominate the uncultivated land.

Superimposed are the effects of:

- Topography, where valleys usually support richer vegetation than do the water-shedding uplands;

- Soil type, where the soils with better water retention favor richer vegetation; and

- Farming intensity, where frequent cutting tends to eliminate trees except species such as oil palm, shea butter and locust bean that are deliberately preserved because of their economic value. It favors the herbaceous species such as Imperata in derived savanna and Eupatorium in forest ecologies. These weeds recover rapidly after disturbance.

These local variations are paramount in descriptions for OFR. Therefore, report what you see rather than what the maps tell you. Requesting a botanist to join the team for a few days is one way to identify some of the species. If that is not possible, simply describe the physiognomy of the vegetation: the height and density of the trees, the presence or absence of scrub (bushes) and the luxuriance of the herbaceous layer. This description will provide a guide primarily to differences in cropping intensity within the area, with rich fallow vegetation usually implying less frequent cultivation rather than soil differences. Confirm suspected differences in the soil by taking auger samples. A more-or-less treeless, grass-dominated vegetation sometimes indicates seasonal waterlogging or a high water table, and very sparse vegetation indicates shallow soils where an iron pan or other rock formation comes close to the surface. To the unpractised eye, natural vegetation seldom reflects the influence of lesser impedances such as gravel layers.

As with climate, add notes about farmers' perceptions of the vegetation and particularly the signs they look for in fallow vegetation. Also pertinent are recollections by elderly farmers of the vegetation in their childhood.

Land, soil and water

Soil conditions are key determinants of a farming system. They influence the system and intensity of cropping, the need for fallowing, the species and varieties of crops that can be grown and the risk of drought stress. First, assess the range of soil conditions in the area both from published sources and from field observations during the exploratory survey. Ensure that the description answers such questions as: Is there an erosion risk? How much water can be stored; is there a drought risk? Are nutrient deficiencies or toxicities to be expected? Which crops are suitable?

Integrate the information from soil maps, observations, and chemical analysis.

Interpretation of data. For a general idea, consult a small-scale soil map that shows the dominant soil order, suborder or great group level, but keep in mind that they do not show local variations such as alluvial soils along rivers and other small-scale variations. For more detailed information in a given area (i.e. at soil family or soil series level), large-scale maps at 1:50,000 or 1:5,000 are required.

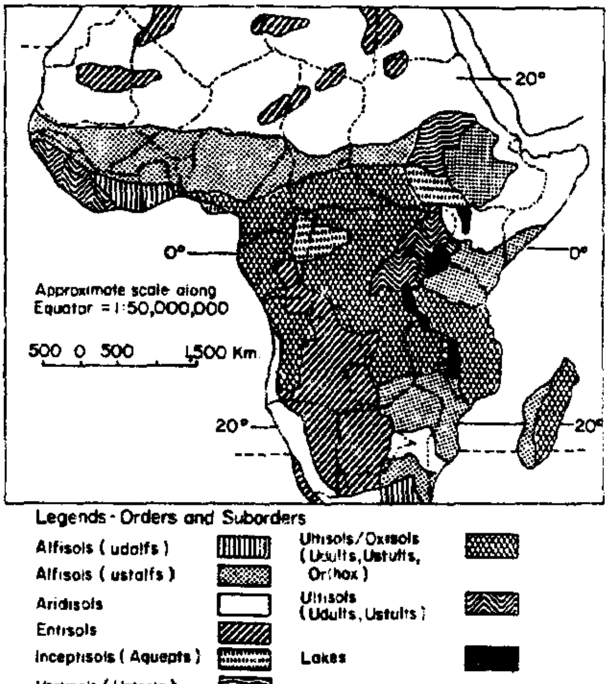


Fig.10. Soils of tropical Africa (Adapted from Aubert and Tavania, 1972 by Kang and Osiname, 1985).

For example, in West Africa south of the Sahel, the area with wet-dry climates practically coincides with the Alfisol zone. A simplified

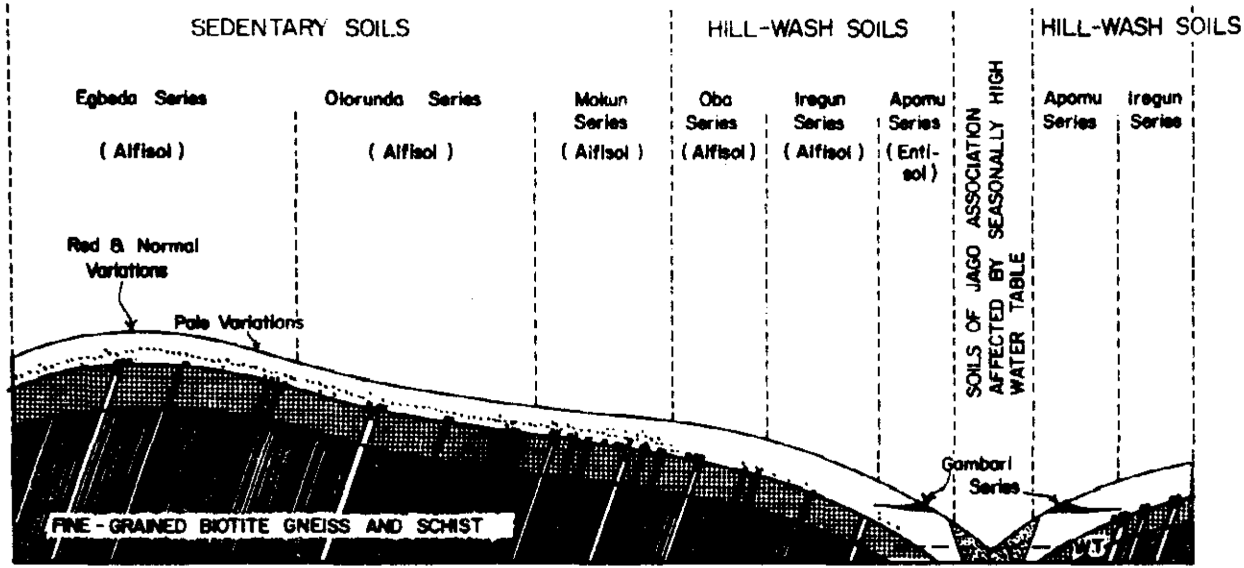


Fig.11(a). Topographical sequence of soil series in an Alfisol landscape ("Egbeda-association", note nature of parent rock). Adapted from Smyth and Montgomery, 1962.

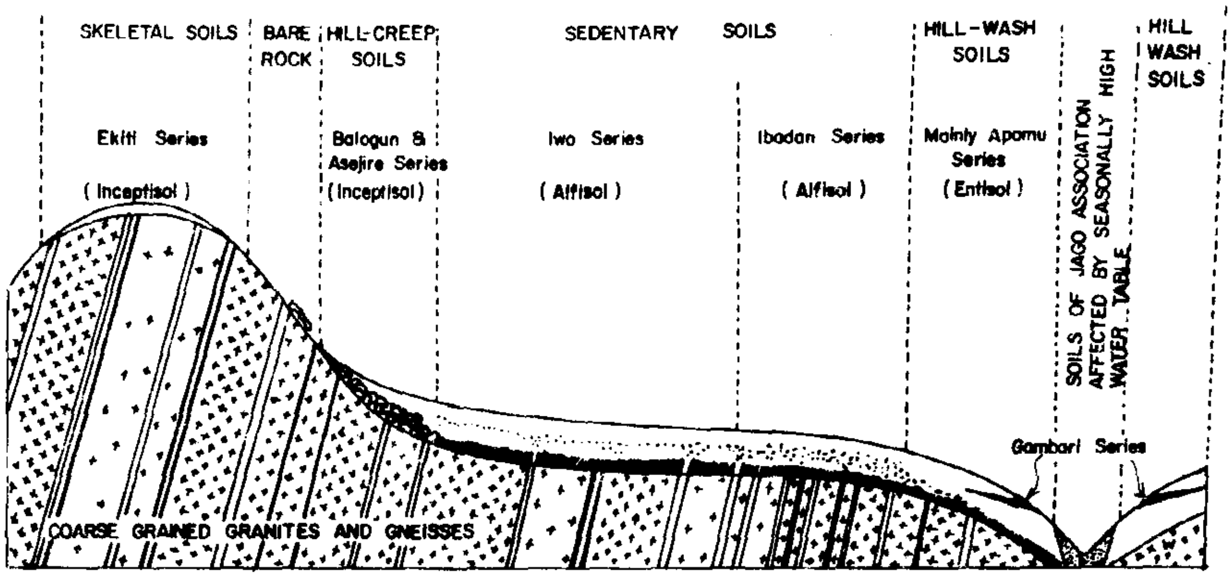


Fig.11(b) Topographical sequence of soil series in an Alfisol landscape ("Iwo-association", note nature of parent rock). Adapted from Smyth and Montgomery, 1962.

U.S. Soil Taxonomy map of Africa (Figure 10, Table 6) does not show the fairly extensive Vertisol areas occurring in Benin Republic, Togo (Depression de la Lama), Ghana (Accra plain) and around Lake Chad. Even where Alfisols are dominant, several other soil orders are always associated with them in a toposequence (Figures 11a,b).

The Alfisol (and Ultisol), mainly derived from "sedentary" material from the underlying rock, are in relatively flat positions. The topsoil is generally sandy, whereas the subsoil contains a clayey layer (Table 6). Entisols and Inceptisols are "young" soils, found particularly on slopes and in valley bottoms and have derived from colluvium washed down the slope or from alluvial material. These soils are usually light but in valley bottoms range from sandy to very clayey.

To make an initial assessment, supplement the broad characterizations with additional information, using the Fertility Capability Soil Classification approach (FCC) (Buol and Couto, 1981). FCC is a convenient notation system for soil limitations, based on commonly measured soil parameters, and guidelines for their interpretation. A soil is represented by two sets of notations:

- A characterization of topsoil (0-20 cm) and subsoil (20-50 cm) texture; and

- "Condition modifiers" that indicate limitations, mainly in fertility.

The system has been adapted to conditions in tropical Africa by Juo (1979). We will use this notation system as far as possible. For a more extensive treatment, see Juo (1980), Juo and Sanchez (1985).

From the field data sheet (Figure 6) used in the exploratory survey, extract information on texture of topsoil and subsoil, color, presence of

Table 6. Major soil orders in Africa according to the U.S. Soil Taxonomy, correspondence with other classifications and broad characteristics

Soil order	Ecology/distribution	Corresponding units FAO/UNESCO	Corresponding units INRA/ORSTOM	Soil characteristics
Oxisols	Mainly humid/ subhumid climates, "stable" landscape	Ferralsols	Sols ferralitiques fortement desatures	Strongly weathered; uniform; deep and porous
Ultisols	Mainly humid climates, less stable landscapes	Acrisols, Dystric Nitosols	Sols ferralitiques moyennement desatures	Coarse to medium surface layer, clayey B-horizon; exchangeable base saturation <50%; generally acidic (pH<5)
Alfisols	Wet-dry climates, savanna and forest-savanna transition zone of West and Central Africa	Luvisols, Eutric Nitosols	Sols ferrugineux tropicaux	As Ultisols, but with base saturation >50%; in transition zone with quartz gravel; in savanna with plinthite and hardened, laterite; pH 5.5-7.0
Entisols and Inceptisols	Occur in association with other orders in both savanna and forest areas in various slope positions (colluvium), in valley bottoms and river flood plains (alluvium)	Fluvisols, Regosols, Arenosols Cambisols, Gleysols	Regosols and various others	Young soils mainly derived from recent alluvial or colluvial material.
Vertisols	Alluvial plains in Guinea and Sudan savanna; alternately inundated and dry conditions; Lake Chad flood plain, East-West depression in Benin, Togo (Depression de la Lama), Ghana (Accra plain)	Vertisols	Vertisols	Dark, heavy cracking clays, montmorillonite; very hard in dry season, sticky in wet season

gravel and hardpan, the position along the slope and the slope percentage.

Use the simple textural class division as employed for FCC. This system represents the textural class of topsoil (0-20 cm) and subsoil (20-50 cm) by one capital letter each, as follows:

S = sandy soil (>85% sand);

L = loamy soil (<35% clay);

C = clayey soil (>35% clay); and

R = quartz or ironstone gravels or other root-restricting layers in the top 20-50 cm.

Thus, SLR means a "sandy" topsoil overlying a "loamy" subsoil and a root-restricting layer within 20-50 cm. This somewhat crude classification can be interpreted according to Sanchez et al. (1982) and linked with available water content (AWC) (Table 7). Indicative ranges of AWC in mm/50cm are S 30-50, L 40-60 and C 30-70. These ranges are for sedentary upland soils in the humid and subhumid tropics and were derived from data compiled by Lal (1979) and Mansfield (1979). Soils derived from recent volcanic material (e.g. Andepts), Vertisols and some alluvial soils do not fall into this category and will have an AWC higher than 70 mm/50 cm.

Table 7. Textural classes in FCC and indicative available water content (AWC)

FCC texture class		Interpretation	Indicative AWC mm/50 cm
S		High infiltration rate, low water-holding capacity	30-50
L		Medium infiltration rate, medium water-holding capacity	40-60
C	-Oxisols	High infiltration rate, low water-holding capacity	30-50
	-Most others	Low infiltration rate, medium to high water-holding capacity	50-70
SC, LC, xxR (light textured soil, overlaying heavier subsoil or presence of hardpan)		Susceptible to erosion exposing subsoil	

Soils with a low organic matter content (<1% C) will be at the low end of the range for their class and those with a high content (>1.5% C) at the higher end. Coarse materials (gravel, concretions) will reduce AWC in exact proportion to their volume in the soil. Finally, any impediment to root growth will limit AWC to the layer above that impediment. Such impediments can be an ironstone pan, a very coarse (gravelly, lateritic) layer, etc.

With this information, make a rough estimate of the water storage capacity of the soil. If available water is less than 50 mm, add the letter "w" to the FCC characterization, indicating drought sensitivity. An estimate of AWC together with the rainfall analysis allows a good first approximation of drought risk.

Consider, for example, a soil with loamy texture in top- and subsoil, medium organic matter content in the topsoil, and low content in the subsoil, a gravel percentage of 15% in both and a root impediment at 40cm. This is not uncommon in the West African Guinea savanna. The top 20 cm of soil can store about 20 mm of water and the next 20 cm about 16 mm (Table 7), a total of 36 mm. The gravel reduces AWC by the same percentage and the total storage capacity thus equals about 30 mm.

For example, in Nyankpala, northern Ghana, this soil can store sufficient water for about 5-6 days of full evapotranspiration (Steiner, 1984) (Figure 12). The rainfall distribution for the area (Figure 12) shows that in practically every 10-day period, fewer than 25 mm is recorded in one out of four years. This amount is sufficient for less than five days at full E_t. When fully recharged, the soil can supply the deficit; otherwise drought stress occurs. Drought stress can be expected regularly up to mid-August and sensitive crops like maize cannot be grown profitably in this soil.

Soils with a light topsoil overlying heavier subsoil or an impermeable or compacted layer are sensitive to erosion, particularly when slopes

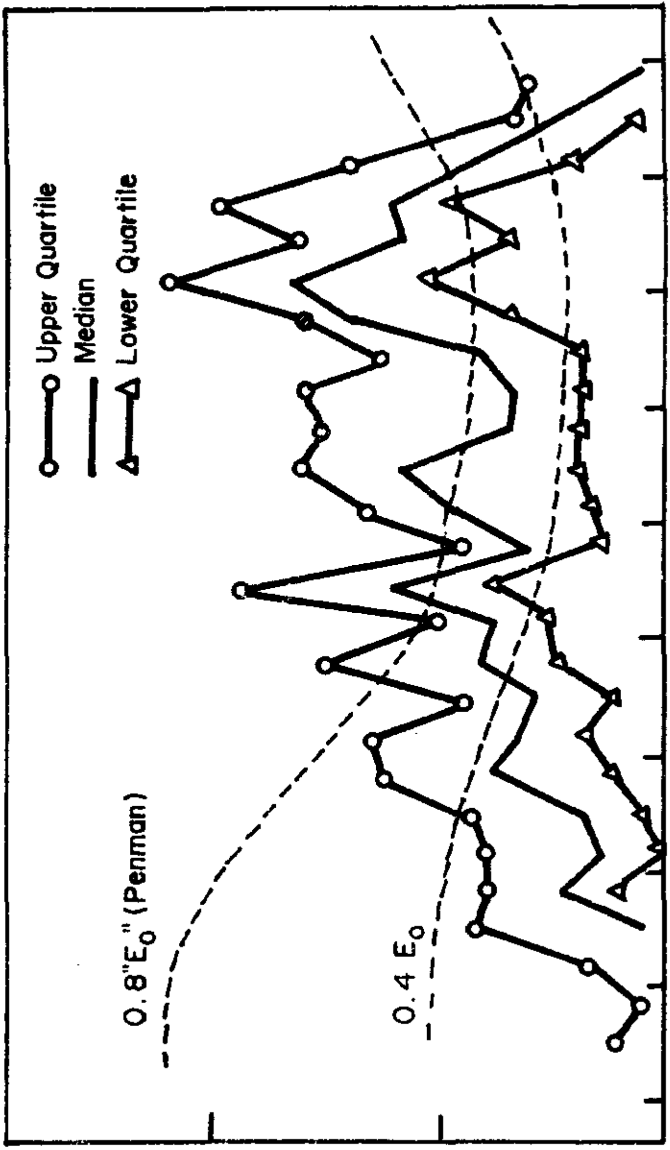


Fig.12. Rainfall and evapotranspiration at Nyankpala, Ghana 1953-1982 rainfall data (Steiner, 1984)

exceed 5%. The revised FCC system adds the modifier "r" to such soils, indicating erosion risk.

Chemical soil analysis. Search for chemical soil analyses in other sources and fit them into the FCC notation for a concise picture of limitations. A set of modifiers is added to the textural classes to indicate the soil chemical limitations. Whenever a limiting condition occurs, the corresponding lower-case letter is added to the FCC code. We give only those that can be readily derived from a standard analysis (Table 8). For a more complete treatment, see Juo (1980). Examples appear at the end of this section.

Table 8. Some chemical and physical soil properties and their interpretation under the modified FCC system for Africa (Juo, 1979)

	Limitations for cropping	
Routine analyses	Modifier	Criteria
Mechanical analysis	(') (")	(Gravel): a prime (') denotes 15-35% gravel; two primes (") denotes >35% gravel
	i	(P-fixation): may occur in Oxisols with clay content >35%
	r	(Erosion): SL, LC, XxR soils
Available water content	w	(low available water reserve): <50 mm/50 cm soil depth
pH (H_2O)	h	(Acidic): pH <5.0 (to be used if data on Al-saturation are not available)
	m	(Mn toxicity): pH <5 for soils derived from high-Mn parent rock
Effective CEC (exchangeable cations + total acidity)	e	(Low cation exchange capacity): Effective CEC of topsoil <4 meq/100g soil.
NH_4OAc exchangeable cations	k	(Low K availability): exchangeable K <0.15 meq/100 g
KCl extractable Al	h	(Acidic): 10-45% Al-saturation of effective CEC within 50 cm
	a	(Al toxicity): >45% Al-saturation
Micronutrients	t	(Secondary and micronutrient deficiency): see text

Nutrient deficiencies and toxicities. Most soils in Africa are deficient in nitrogen for cereals and root crops, except in newly cleared forest fields. After 2-3 years of cropping, nitrogen deficiency appears in forest soils too and continues to increase.

Phosphorus deficiency is also common, particularly in the savanna but it can be corrected by low to moderate doses of P fertilizer (e.g. 30 to 60 kg P_2O_5/ha). IITA soil analyses give the available P by Bray-1 extractant; by this method, 15 ppm is considered critical for maize and soybeans in most Alfisols in the forest and savanna regions. The critical level is 5-7 ppm for most other crops.

Some soils in Africa also are low in K reserves, but most soils contain adequate available K in the surface soil if they have not been intensively cropped (Juo and Grimme, 1980). Potassium problems can be expected under intensive land use with application of moderate to high rates of N and P. FCC gives criteria for K sufficiency based on soil tests (Table 8).

Secondary and micronutrient deficiencies may occur under certain soil conditions (Figures 13 and 14) and may develop with high intensity cropping. Magnesium, sulfur and zinc deficiencies often occur in sandy savanna soils. The critical level for exchangeable Mg is 0.20 meq/100g (Kang, 1980). Boron deficiency has been reported both for forest (in oil palm and cocoa) and savanna soils (particularly in cotton). Iron toxicity often occurs in flooded rice and manganese and aluminium toxicity in acidic upland soils, the former on soils derived from Mn rich parent rock (Kang and Osiname, 1985). Suspect secondary or micronutrient deficiencies ("t" in the FCC notation) when yields are low and do not respond to applications of major nutrients.

Observed nutrient deficiencies and toxicities can be listed in the area report, as well as expected deficiencies under intensive land use.

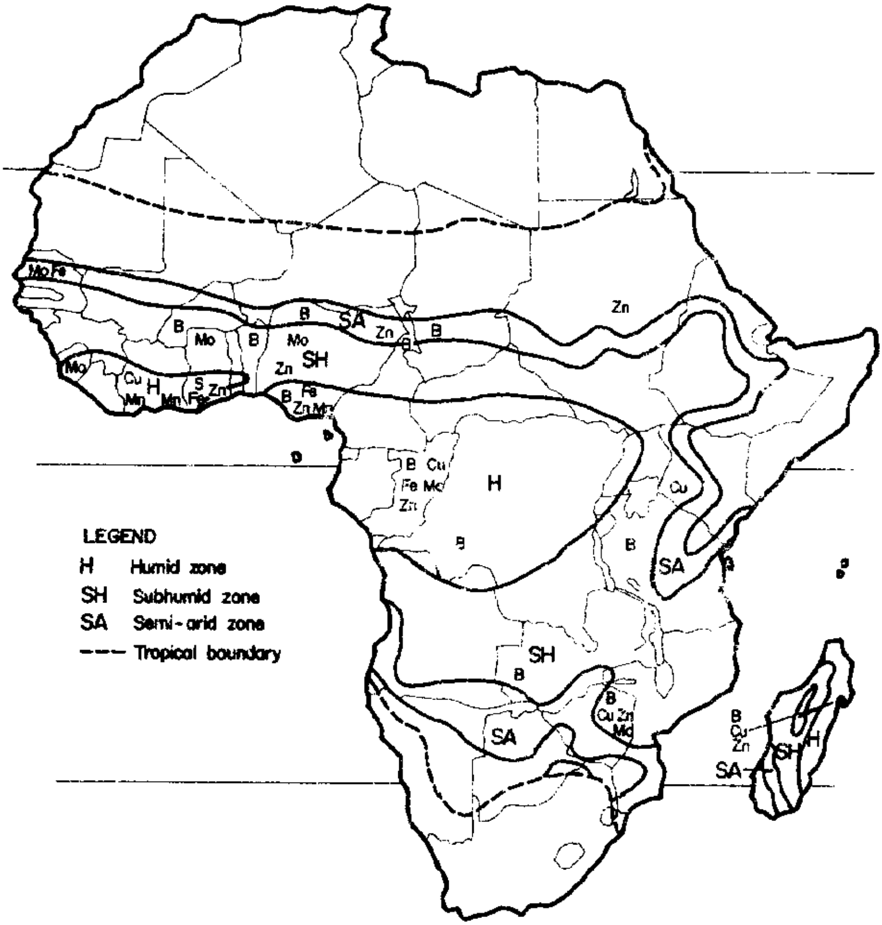


Fig.13. Location of micronutrient deficiencies in tropical Africa (Agroecological zones adapted from Dudal, 1980). From Kang and Osiname, 1985.

Suitability for cropping. Textbooks almost invariably state that the preferred soil for any crop is deep, loamy, well drained with a high base status; in other words, "any crop prefers a good soil". This is true but not very helpful and crops do differ in sensitivity to adverse soil conditions (Table 9). Match the crops to the physical and chemical data about the soil before making recommendations for testing.

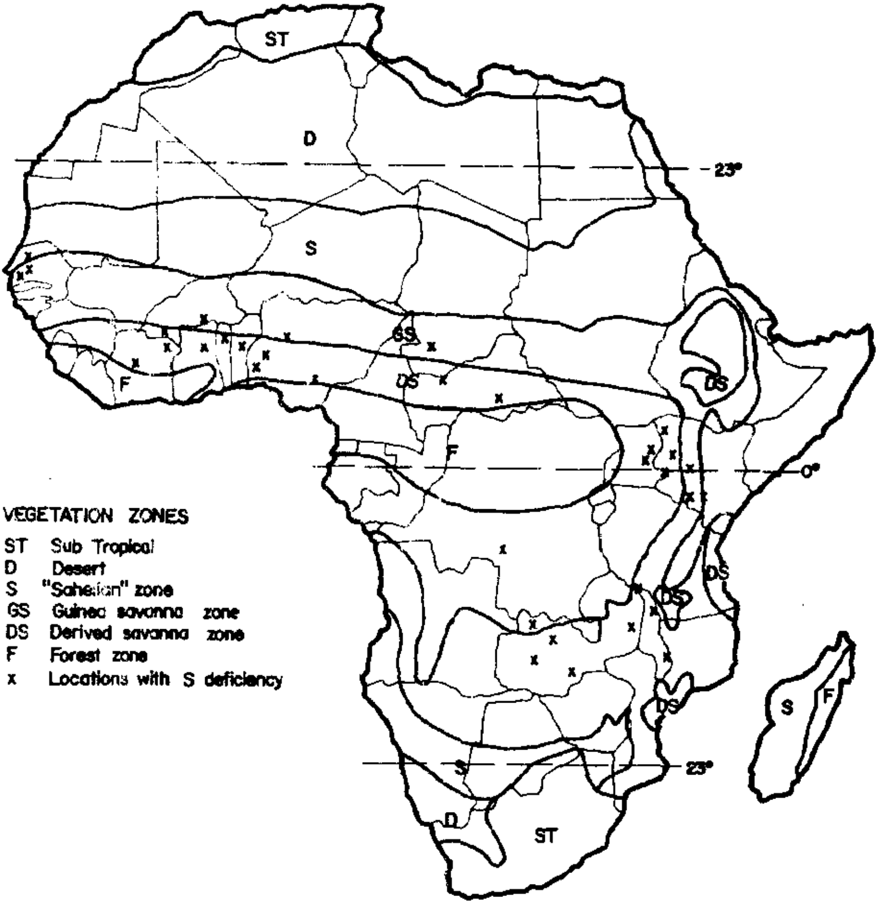


Fig.14. Location of sulphur deficient areas in tropical Africa (Kang, 1980).

An example. An exploratory survey was carried out in the forest-savanna transition zone of southwestern Nigeria. The area is of rolling to undulating topography, Alfisols (Ustalfs) being the dominant soils in the upland with coarse textured Entisols in slope positions (Ustorthents) and in the small U-shaped valleys (Tropaquents). A 1:250,000 soil map from the early 1960s showed that the pilot area included a zone of generally coarse soils ("Iwo association") and a zone of

Table 9. Tentative classification of some crops according to their sensitivity to adverse soil conditions

Species	Acidity Al-toxicity	Low P-status	Drought
Maize	-	--	--
Upland rice	+	o	--
Sorghum	-	+	+
Millet	-	+	+
Cowpea	+	o	+
Groundnut	+	-	-
Soybean	-	--	-
Phaseolus	-	--	-
Pigeon pea	+	-	++
Yams	+	+	-
Cassava	++	++	++
Sweet potato	o	+	o
Cocoa	-	+	-
Coffee	++	+	o
Citrus	+	+	-
Bananas/plantain	+	+	-

*-, -- = Sensitive, very sensitive; o = average;
+, ++ = Tolerant, very tolerant.

heavier soils ("Egbeda association") (Smyth and Montgomery, 1962). In the former area, although forest patches occurred, the development of savanna from human intervention was more pronounced than in the latter.

In the "savanna zone", arable cropping (mainly maize + cassava) generally took place on middle and lower slopes. Practically all fields visited had sandy surface soils with medium and sometimes shallow depth and small amounts of gravel (<10%) within 50 cm. Slopes generally did not exceed 5%. Erosion risk was expected to be moderate but would probably be appreciable with mechanized tillage.

Drought risk was important, the soils having an AWC of less than 50 mm in the top 50 cm. According to the rainfall pattern for the area (Ibadan data, Figure 8), the first rainy season was adequate for maize growing. In the second season in one out of 4-5 years, planting could not take place until after 1 September (1/3 E_t exceeded) while the probability of rain after 1 November was low. Maize growing on light soils in the second season would be risky, therefore, particularly with the 4-month varieties common in the area.

In the "Egbeda zone," valleys were found to be wider, slopes more gentle and soils heavier. Savannification was less extensive. Well-developed perennial crops were found (cocoa, coffee, plantains), and soils were less sensitive to drought.

Table 10. Results of soil analyses in five fields sampled in an OFR pilot area, Ijaiye/Imini, southwestern Nigeria (Kosaki and Mutsaers, unpublished results)

Sample	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	C (%)	P Bray-1 (ppm)	Exchangeable cations (meq/100 g) Ca	Mg	K	ECEC meq/100 g
1	0-20	90	6	4	5.5	0.96	3.9	0.90	0.06	0.20	1.45
	40-50	88	10	2	5.2	0.25	1.8	0.66	0.36	0.09	1.45
	80-90	82	6	12	5.2	0.32	0.9	1.14	0.57	0.09	2.23
2	0-20	82	14	4	5.7	1.22	3.9	2.45	0.64	0.23	3.75
	40-50	86	10	4	5.4	0.14	2.6	0.63	0.33	0.12	1.24
	60-70	92	4	5	5.2	0.34	1.5	0.48	0.35	0.10	1.39
3a	-40--20	86	10	5	5.8	1.09	8.9	1.58	0.50	0.28	2.56
	10-20	88	8	5	5.6	0.28	1.8	0.87	0.31	0.10	1.49
	50-60	84	6	11	5.5	0.28	0.9	1.23	0.48	0.13	2.12
3b	-40--20	82	16	3	5.6	0.85	3.6	1.55	0.64	0.10	2.78
	40-50	84	12	5	5.5	0.20	1.7	0.69	0.43	0.08	1.44
	70-80	82	10	9	5.4	0.60	1.0	0.93	0.65	0.10	2.00
4	0-20	72	18	11	6.7	2.32	17.1	6.35	1.01	0.37	7.93
	40-50	66	10	25	5.5	0.80	2.7	5.76	0.87	0.32	7.38
5	-10-0	80	12	9	6.3	1.84	6.0	2.18	0.62	0.35	3.49
	0-20	80	14	7	7.2	0.87	9.3	6.35	0.82	0.21	7.57
	60-70	78	10	13	5.3	0.33	1.8	0.75	0.70	0.18	2.26

A pedologist was invited after the survey to evaluate a few "representative" fields (Tables 10

Table 11. Preliminary soil classification and present land use of five fields sampled in an OFR pilot area, Ijaiye/Imini, southwestern Nigeria

Field	Position, Slope %	Surrounding vegetation	Tentative Soil series	Tentative ST Classification (great group)	FCC notation	Present use, Comments
1	Hill crest 1%	Grass savanna	Ekiti	Oxic Ustropept	SSet(?)w	3 Maize+cassava crops-fallow
2	Lower slope 10%	Grass savanna	Apomu	Typic Ustorthent	LSew	Cassava; sequence unknown
3a	Upper slope 4%	Shrub savanna	Ekiti/ Ibadan?	Typic Ustorthent	SSew	Early maize - maize+cassava - yams - fallow "good yam field"
3b	Middle slope 7%	Shrub savanna	Iregun	Oxic Haplustalf	LLekw	Same field as 3a
4	Upper slope 2%	Secondary forest	Egbeda	Oxic Haplustalf	LL	Cassava + good Horn plantains; sequence unknown
5	Middle slope 4%	Secondary forest	Egbeda	Oxic Haplustalf	LL	2 maize+cassava crops, plantain borders, no foreseeable fallow

and 11). The results of soil samples largely explain the differences in general aspect of the two zones. The savanna fields had sandy, drought-prone soils with low effective cation exchange capacity (ECEC), P-status and organic matter content. These soils would not be able to support intensive cropping without substantial fertilization. Secondary and micronutrient problems might also develop. The food crop fields in the forested area (4 and 5 in Tables 10 and 11) were on excellent soil that would probably support good yields for a number of years even without fertilizer.

The human environment and the physical infrastructure

The characterization of land, soil and water provides some indication of what crops could be grown and which animals could be reared. The next step is to describe the human environment and physical infrastructure, which together determine what options farmers are able to select. Search secondary sources to supplement the information gathered in interviews about how farmers adjust to conditions.

Economic environment

The economic environment determines quantities as well as absolute and relative prices of inputs and outputs. Find out the policies governing imports and exports, foreign exchange and marketing as well as subsidies.

Consult national or regional statistics for information on imports of tractors, spare parts, fertilizers as well as insecticides and herbicides. Likewise, gather information on food imports, drawing on international and national sources. Imports of food are common in most countries. In general, imports depress prices of locally produced foods. If, for example, rice is imported, the price of locally produced rice is lower than it would otherwise be. Furthermore, the price of maize, cassava flour or whatever else is eaten as a source of calories is depressed. The imported items take away a share from the domestic market. From the information obtained in the market and in the exploratory survey, elaborate the effects of exports and imports on local production.

Export policies sometimes artificially raise prices of crops. A country may attempt to export as much oil palm, groundnut, coffee, tea, cocoa, cotton and tobacco as possible, to earn foreign currency. Obtain information on these policies from country studies done by international organizations.

Another policy tool that influences domestic prices is the manipulation of the exchange rate. An indicator of such policies is the existence of a black market, usually for US dollars.

Suppose a country, say Alphaland, fixes the exchange rate. The central bank buys and sells, say, 1 Alpha for 1 US dollar. However, buyers of US dollars are willing to pay 4 Alpha for 1 US dollar. What are the effects on agriculture? Importers have to pay only one-fourth the amount for US dollars that they would be willing to pay. Thus, imported items are made artificially cheap. This is a subsidy to farmers. Farmers are thus encouraged to use, for example, cheap fertilizer; however, they are also encouraged to replace draft animals by tractors. Farmers who produce export items are adversely affected. Their products are sold in the world market for US dollars. If the Alpha rate were not fixed, they would receive 4 Alpha. The central bank however, pays them only 1 Alpha. This is a strong disincentive to produce for export. Farmers may avoid selling export crops to domestic government agencies by resorting to smuggling, especially in regions that border countries that do not manipulate their exchange rate.

Information on exchange-rate policy can be obtained from country studies. A good indicator is export statistics of goods that are produced exclusively for export.

Another government policy is procurement of food items. Farmers may be forced to sell a certain quantity of output to government agencies at lower than market prices. Products most commonly affected by this policy are staples needed to feed the urban population.

From the data about labor and education gathered in the village, analyze the labor market, especially as it is affected by economic policy. Efforts to develop the industrial sector or the exploitation of minerals lead to higher wage rates in these sectors and to massive rural-urban migration. Often the active farming population is older and less educated than average. Also, the children are often left in the villages, so the dependency ratio is high.

Institutional environment and services

The institutional environment affects input and output through the availability of and rules and regulations on credit, capital goods and marketing of certain products. In many cases it is the absence rather than the existence of institutions that is important.

Usually three sources of credit are available to farmers -- government agencies such as cooperatives or agricultural credit banks, private cooperatives and private money lenders. Access to credit is often reduced because in many countries land does not serve as collateral. Farmers do not have a clearly defined title to land. Also, the costs of debt collection from small farmers are high. This discourages private lending institutions from building credit institutions. In many countries, government agencies are supposed to fill the gap. Credit as well as capital goods are made available to farmer cooperatives. The agencies often require farmers to form cooperatives to obtain access to subsidized inputs. Explore the institutional setup of such arrangements, including the fee charged, acceptable collateral and terms of repayment. Information on quantities and prices of inputs delivered to farmers can be gathered from government sources or the cooperative. Describe the allocation of government and other inputs; detail terms of payment for credit arrangements.

In southwestern Nigeria, for example, the government agency allocated tractors on a first-come, first-served basis. To avoid unnecessary driving, the government personnel served all the farmers in the neighborhood of the one who had signed up first regardless of when they had signed up. The terms were strictly cash. The demand for tractor services exceeded supply while other machinery stood idle.

For agro-chemicals and seed, find out the type and quantity available. Government-operated suppliers are usually willing to provide information on sale figures. They are a good indicator of the technology used by farmers. Investigate terms of payment, the overall supply and demand, and timeliness of supplies. For all inputs, record prices. In many cases, government suppliers charge lower prices than private companies or individuals. Confirm all information with farmers.

Of particular importance is the experience of farmers with the quality of purchased seed. Quality control of seed supply may be vital for the introduction of new varieties. The successful introduction of hybrid maize in Kenya was largely possible because farmers could purchase a product of assured quality in small quantities anywhere in the country. Other necessary inputs were also made available.

Presence or absence of extension services are important for the transfer of new technologies.

Investigate the numbers and quality of human resources as well as means of transportation of the extension service.

Marketing boards have been established in many countries to handle export cash crops. Carefully investigate the functioning of such boards, since not only can they be a means of taxing producers but also of stabilizing prices and incomes to farmers. The boards can also be useful in introducing new varieties of some crops. They are often used as suppliers of physical inputs as well as credit institutions.

Social environment

The social environment includes culture and customs within a region or community. Property rights for example, are usually regulated by custom and they may even differ in neighboring villages.

Elaborate grazing rights, rights to trees and rights to harvest. Consider commissioning a special study on property rights, especially before proposing interventions that require long-term investments. Recognize that women may require different innovations and inputs from men.

In southwestern Nigeria, male and female family members both inherit land and manage their own farms. Women tend to have smaller farms and to apply less fertilizer than do the men. Likewise, they have less time to devote to farming and have to rely more on hired labor because they are expected to do all household chores. They rear the children, cook food, fetch water and firewood, although they receive some help from their children. They buy their husband's produce and acquire cash from marketing and processing (primarily oil palm and cassava). Compared with other social settings, these women are highly independent economically. The men are obliged to provide food, whereas in many other areas the women have this responsibility. Take the time to discern such relationships because they can be profoundly affected by changes in the farming system. For instance, women and children may become malnourished when a cash crop is introduced.

Also, note other sources of family labor or community help. In some societies family members living in town or neighbors are obliged to help with certain field operations, for which they receive food from the farm.

The cash flow is strongly influenced by community and family festivities and by payment of school fees. Religious festivals as well as weddings and funerals may require substantial cash outlays.

Physical infrastructure

To describe the physical infrastructure, begin by reporting on the existence and condition of roads as well as the availability of cars and trucks. Try and provide some idea of cost of transport including not only the method but the time involved. In general, costs increase with the bulkiness of the product.

Describe markets, their location, their organization and the services they provide, including how frequently market days are held, what items are sold, whether they are sold wholesale or retail, whether a standardized weighing and measuring system exists and how products are graded. Later, during on-farm testing, obtain more detailed information on price levels and their fluctuations.

Report on processing and storage facilities and techniques because they determine the availability and, hence, the price fluctuations of perishable products. Note whether government provides storage space or other services such as spraying against insects and indicate which farmers can take advantage of these services.

Present information about access to schools, water supply, electricity, medical services, etc., which not only raise the standard of living but also improve productivity — for instance, freeing women to pursue activities other than fetching water. Schools can be a vehicle for technology transfer, especially if the curriculum includes agricultural education. Collaborate with schools if possible since they house the country's future farmers.

Farming systems

Cropping patterns and land use

Report cropping patterns and sequences. "Pattern" is the set of crops — mixed or in sequence — planted in a particular field in a full growing season; "sequence" is the succession of patterns in the same field in successive years. Detail the planting and harvest dates of each component, their spatial relationships and the minor crops. Supplement descriptions with a diagram (Figure 15), (Okigbo, 1978). Use the same time scale (horizontal axis) as for the rainfall diagram, which can be traced onto transparent paper and used as an overlay for the cropping pattern diagrams.

Zandstra et al. (1981) suggest a descriptive convention using "+" to denote species in mixture, planted more or less at the same time, "/" to denote an additional crop interplanted later (relay crop) and "-" to denote a sequence. Thus millet+sorghum/ cowpea (Figure 15) indicates a mixture with millet and sorghum with cowpea intersown later but before millet harvest. (Maize-cowpea) +cassava indicates that maize and cowpea are in sequence and cassava is mixed with both. The spatial relationships can also be described diagrammatically (Figure 16).

Describe the minor crops associated with each major cropping pattern. State which minor crops

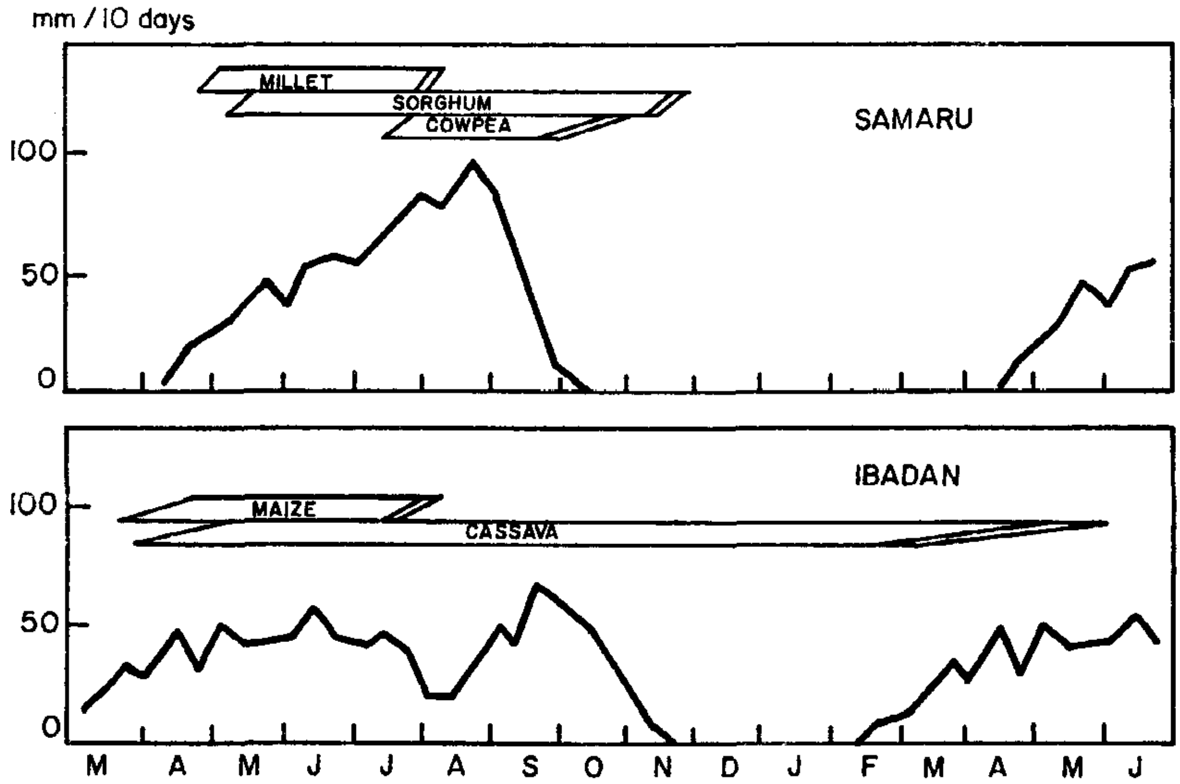


Fig. 15. Diagram showing (mixed) cropping patterns in relation to the rainfall regime.

were observed and the approximate frequencies and densities. The report might read something like: "Cucurbits, mainly pumpkins, may be found in about 40% of yam+rice plots at one or two plants per heap; 60% of yam+rice also had legumes, mainly groundnut, and maize occurred in about 30% of plots, usually with one plant per heap."

Examine each cropping pattern and sequence in relation to the rainfall diagram to answer questions such as: To what extent does the pattern maximize the use of the rainfall pattern? Are there opportunities for introducing another crop, especially if an earlier variety of an existing crop can be substituted?

The set of cropping patterns and sequences used by a farmer in his or her different fields and the fallow constitute the cropping system. Distinguish between different land types within the farm and the annual sequence of farm operations, the tools and techniques that are used and any measures taken to improve or maintain fertility or control pests, diseases or weeds.

The land use describes the relative importance of each cropping pattern in any one year and also includes the type of fallow vegetation and how it is used, the use of land for grazing, for perennial crops, for fuelwood, hunting, roads, pathways and cattle routes, villages and compounds and for religious purposes (sacred groves).

The exploratory survey should have provided enough information to give some indication of the relative importance of each cropping pattern both in terms of land use (approximate proportion of cropped area) and in terms of its value in proportion to the produce of all the cropped area. This distinction is important when high value crops such as yam are found; for instance, a small land area with a cropping pattern dominated by yam might contribute more in both cash value and food calories than a larger land area with only

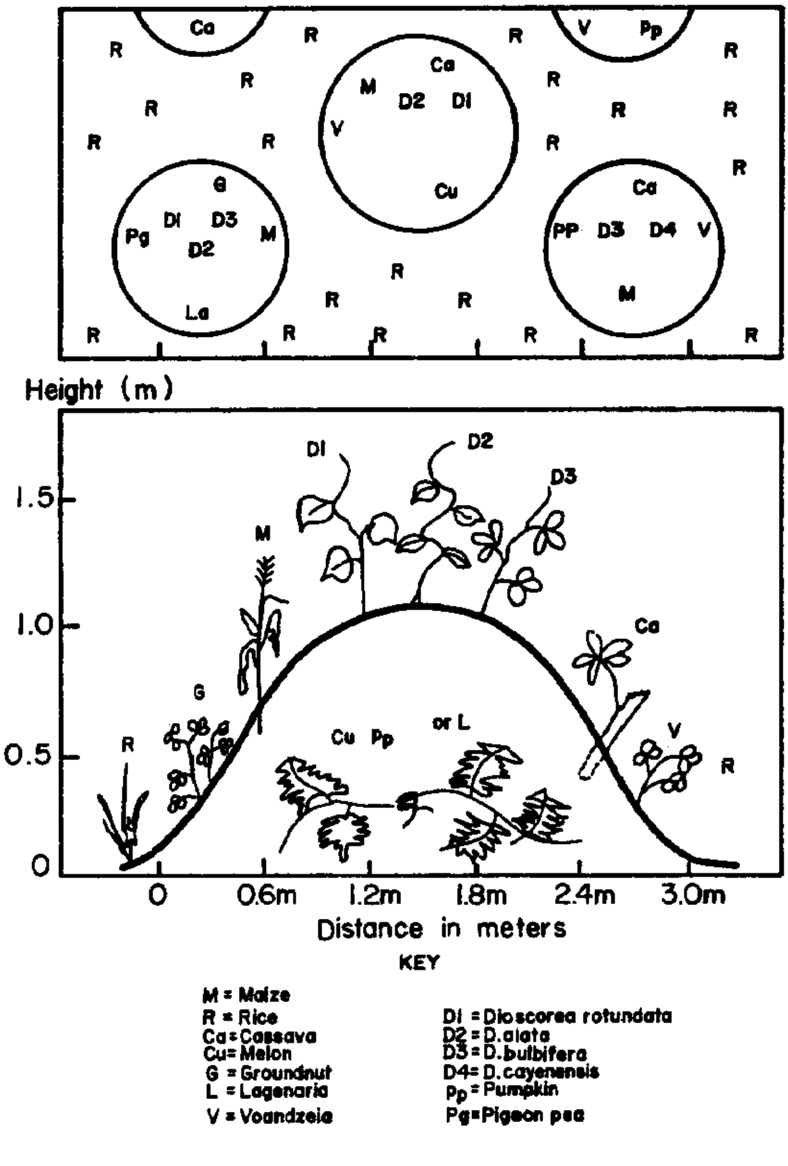


Fig.16. Spatial relationships of crops on and between mounds in Southeastern Nigeria (From Okigbo and Greenland, 1976)

cereals. Estimate the relative values contributed by the various cropping patterns, using yield figures from the exploratory survey. Also, report the approximate proportions of cultivated land, fallowed land and various categories of uncultivated land, grazing and forest reserves, rock and ironpan outcrops, swamps, steep slopes, etc.). Report the type of fallow (forest, woody savanna or herbaceous). If identified, report the dominant fallow species. If necessary, subdivide the area to reflect differences in population density, topography or proximity to roads and markets and show associated differences in cropping intensity or type of fallow in the sketch map of the area. This might be useful later in defining recommendation zones. Work with the other members of the team to reach a consensus and to answer questions such as:

- Is the present cropping intensity capable of being sustained with present technologies and, if not, what innovations might be brought to assist in maintaining fertility? If the land is already cropped every year, are yields maintained?

- Are certain cropping patterns associated with particular land types? If so, why?

Crop varieties

Record crop varieties, their characteristics and different uses.

Cropping operations and crop calendar

For each cropping pattern the different operations should be briefly described, with the timing and inputs and tools (photographs, diagrams) used, for example, land preparation, planting, staking, weeding, applying fertilizer with rates, pest control, harvesting, carrying the produce from the field.

An agricultural engineer with an interest in small equipment can provide useful input in describing and analyzing farm operations. Ideally he or she would have joined the team for a few days in the field and part of the team discussion at that time would have centered on farm operations. He or she might suggest innovations to alleviate labor bottlenecks.

Table 12. Crop calendar for the millet+sorghum/cowpea cropping pattern near Samaru (see Figure 15)

Date of beginning	Operation	Labor per typical plot of 0.5 ha: Adult days	Labor per typical plot of 0.5 ha: Child days	Tool used	Notes
20 April	Land partly prepared & millet sown	2	4	Large hoe	Needs rain to wet 75 mm soil depth
15 May	Land prepared & sorghum sown	10	5	Large hoe	Needs rain to continue
10 June	First weeding & fertilization	17	0	Small hoe	Depends on weed cover
15 July	Second weeding & cowpea sown	15	5	Small hoe	Depends on weed cover
20 Aug	Millet cut down	2	0	Cut-lass	Millet must be ripe
25 Aug	Millet heads removed, carried home	2	4	Sickle	Millet must dry
1 Sept	Weeded by remoulding ridges	15	0	Large hoe	Millet must be harvested
10 Nov	First cowpea harvest	4	10	Hand	Pods must be dry
20 Nov	Sorghum cut down	2	0	Small hoe	Sorghum must be ripe
25 Nov	Sorghum heads removed, carried home	2	6	Sickle	Sorghum must be dry
30 Nov	Second cowpea harvest; haulm carried home	6	10	Hand/ cutlass	Pods must be dry

Note: Dates and labor requirements are very approximate. Women do not usually do farm work in Hausaland; an additional column would be required in societies where they do.

From the information obtained, draw up a crop calendar for each important cropping pattern (Table 12). Draft a calendar for each cropping pattern fairly soon after identifying the patterns and then in questions to farmers and field observations, focus on those aspects about which you do not have enough information. Even if the work is too ambitious for the exploratory survey, ensure that you obtain the dates of operations. This information can be used to draw up a qualitative crop calendar (Figure 17) as an alternative to the quantitative one of Table 12.

When the crop calendar for each cropping pattern has been drawn up, do a simple whole-farm labor profile (Table 13). At Samaru, labor bottlenecks on a farm might occur in June (first weeding), July (second weeding) and in late November (sorghum and cowpea harvest). Opportunities for additional crops are in early August and late September and early October.

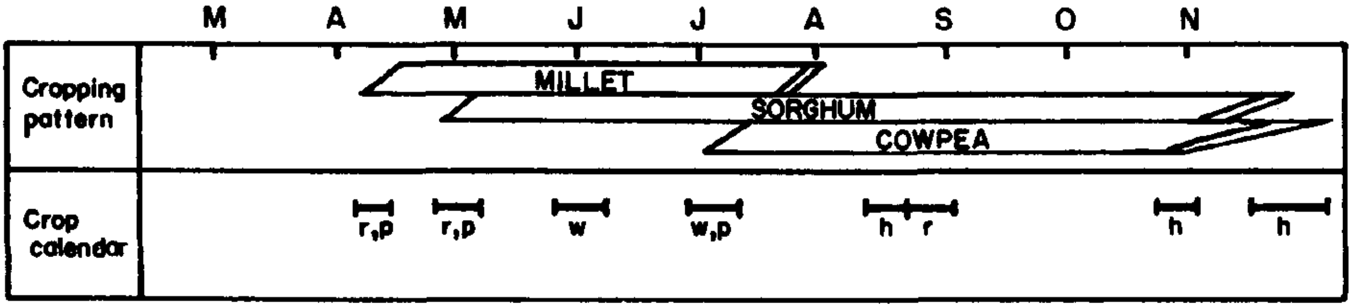
Again, when quantitative data are lacking, combine the qualitative calendars (Figure 17) for each pattern into one figure and visually assess the occurrence of labor bottlenecks and slack periods.

Finally note the farmers' perceptions: at what times of the year do they find it most difficult to keep up with the operations or to hire the labor needed? What operations do they find most irksome? Are there times of year when they are less busy?

The data can now be analyzed to answer questions such as:

- When do the labor bottlenecks occur on a whole-farm basis? Can any innovations be suggested to help?

- When are the slack periods and can any new enterprise be suggested for which the labor



r = land preparation, tillage.
w = weeding.
p = planting.
h = harvesting.

Fig. 17. Millet + Sorghum / Cowpea pattern (Samaru) and its qualitative crop calendar

Table 13. Simplified labor profile for a hypothetical farm near Samaru

	millet+sorghum/ cowpea 0.5 ha	sorghum+ groundnut 0.5 ha	Maize/ cowpea 0.3 ha	Labor demand work days per farm
21-30 April	3 Partly prepare land & sow millet			3
1-10 May		15 Prepare land, sow crops		15
11-21 May	12 Prepare land, & sow sorghum			12
21-31 May			10 Prepare land & sow maize	10
1-10 June		15 First weeding		15
11-20 June	15 First weeding			15
21-30 June			10 First weeding	10
1-10 July		15 Second weeding		15
11-20 July	17 Second weeding, sow cowpea			17
21-31 July			12 Second weeding, sow cowpea	12
1-10 Aug				0
11-20 Aug				0
21-31 Aug	7 Harvest millet			7
1-10 Sept	15 Remould ridges		4 Harvest maize	19
11-20 Sept				0
21-30 Sept				0
1-10 Oct		5 Lift groundnut		5
11-20 Oct				0
21-31 Oct		10 Pick groundnut	8 Harvest cowpea	18
1-10 Nov	8 Harvest cowpea			8
11-20 Nov				0
21-30 Nov	6 Harvest sorghum		7 Harvest cowpea	13
1-10 Dec	10 Harvest cowpea	5 Harvest sorghum		15

Note: The operation is entered in the period in which it should be carried out and the estimated work days are given for the actual plot size on the hypothetical farm. The labor demand is the sum for all the cropping patterns in each 10-day period.

The figures need interpreting with care, for instance the non-urgent operations of maize harvest and ridge remoulding in 1-10 September do not really represent a bottleneck when followed by two very slack periods.

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requirements would mainly fall in these slack periods?

- More generally, what innovation could most easily be introduced to raise the output of each cropping pattern?

Inputs and yields

Record the source of seed and planting material. Note whether organic or inorganic fertilizer and agro-chemicals are used and on which crops. Observe and photograph farm tools. Finally, record your estimates of crop yields. Reliable estimates are hard to obtain from an exploratory survey alone and you should not pretend that they are more than intelligent guesses.

Crop disorders

Report the important pests and diseases. Give some indication of their relative importance and whether farmers recognize the symptoms of each disorder and practise any measures to reduce crop losses (roguing, adjusting sowing dates).

Obvious opportunities for on-farm testing arise in areas of crop spraying and introduction of resistant or tolerant varieties. Consult breeders and entomologists/pathologists for assistance.

Seldom do scientists realize just how much traditional cropping patterns have evolved to escape or resist the local pest and disease problems. Even the farmers may not be aware of why their ancestors have long since abandoned certain cropping possibilities or varieties. The latent pest and disease problems only become apparent when a new variety or technique is tested, or perhaps even only when it is adopted on a wide scale. Some disorder may appear, to which the local varieties are tolerant or resistant, or by which they have not been affected because of local production methods. A good example is the lax-headed, late sorghums of the Guinea savanna: they largely escape the head bug and grain mould problems of the new compact-headed, early varieties. None of these latent problems may show up in the exploratory survey, but they might explain some aspects of the cropping patterns or farming practices. If the possibility exists, report it because it may become relevant in the testing phase.

Post-harvest activities and consumption

Improvement in post-harvest activities may be proposed for its own sake or it may be necessary to make a new production technology acceptable to farmers. This would be the case, for instance, if larger volumes of produce result from an agronomic improvement; the yields have to be stored or processed and marketed. Consult specialists like seed technologists, marketing economists, food technologists, home economists, nutritionists and storage technologists.

Storage and seed preservation. Storage serves two purposes: to ensure food supply over a long period and to even out fluctuations. Compared with other products, grain is easy to store. Most farmers own grain storage facilities; however, the storage qualities of grains and varieties differ substantially, and storage problems vary greatly over the season.

In southwestern Nigeria, for example, the first part of the rainy season is dependable and gives a good maize crop. However, the dry spell between the two rainy seasons is unreliable, crops may be difficult to dry and unsuitable for storage. If prices fall to low levels, the benefits of a bumper crop will be wiped out. Second-season maize production is risky because the rains are unreliable at the end of the second rainy season. However, second-season maize can usually be stored without problems. These facts are reflected in the market. The price of first-season maize is low at harvest and may remain low because of the poor quality of the grain. The price of second-season maize is higher and more stable.

Among the root and tuber crops, yams are the easiest to store after harvest, and many cassava varieties can be left in the soil for extended periods.

Note how farmers select and store seed and planting material and indicate whether any such materials are purchased. The introduction of new varieties may be hindered or facilitated by the methods the farmers use. Typically farmers keep their own supply of food crop planting material. Grains are dried and stored over the fireplace to prevent insect infestation. Seed of new crops or varieties sometimes cannot be stored by this method. Soybean seed, for example, has a low germination percentage after storage at normal tropical temperatures. Consider methods to improve seed growing and selection to maintain the purity of new varieties. Successful introduction of hybrid maize depends on the availability of quality seed. If farmers buy seed or obtain it from a specific supplier, then the introduction of improved varieties is simplified. For example, new cotton varieties are easy to introduce since farmers have to sell their produce to ginneries and obtain their seed from them.

Processing and marketing. Make note of when activities such as cassava processing, yam flour making, parboiling of rice and oil extraction from palm or groundnut are carried out. Report who does the processing, when, what techniques and equipment are used and how they could be improved. Also, report when, where and by whom crops are marketed. Processing increases storability, allows for marketing over a longer time period and thus increases profitability.

Keep in mind the qualities required for processing. For example the ease with which cassava can be peeled and grated and the cyanide removed are important. Describe also the time needed for cooking (and thus fuel requirements) as well as color and taste.

Processing and marketing are often gender specific tasks, and whoever controls these activities earns the income they generate. This has an impact not only on the adoption of technologies but also on the welfare within the family. In southwestern Nigeria, for example, women control the processing as well as the marketing of food crops such as cassava and cash crops like oil palm. The women buy crops from their husbands and process and market them. Men and women keep separate accounts. It is thus in the interest of both men and women to adopt more productive technologies.

In other societies women do the field work and are expected to provide food for themselves and their children. The husband markets the cash crops and keeps the money. In such a system, men are interested in adopting new technologies for cash crops, but women cannot maintain food production if they have to devote additional time to cash crops. The husband benefits at the expense of the rest of the family.

Consumption, nutrition. Include a short section on the preferences for certain foods, their quality and the timing of consumption. Report how much of the farm output is consumed immediately, including information about how food is distributed within the family and who prepares it, how much is processed or stored and consumed later. Note which products are converted to cash to be spent on food or non-food consumer goods. Is part of the cash saved and invested?

In developing countries the share of income spent on food often approaches 100%. Since the amount of labor a person can provide depends on food consumption and labor is the most important input for small farmers, issues related to food consumption need to be elaborated in the report.

If possible, assess the risk of food shortage during the hungry season before the new harvest. Note the farmers' attempts to balance their diets - for example, spreading out planting time or planting crops like cassava that can be left in the ground until needed for consumption. Spell out the sources of protein consumed, including when small ruminants and other animals are consumed or sold.

In some societies, children are not given meat, and beans are a cash crop. Increasing the productivity of these commodities does not improve the diet of children, at least not directly.

Briefly describe the incidence of endemic and seasonal health problems. As most are related to inadequate water supply, they can be expected to increase when water is short, that is, at the end of the dry season. Malaria is also more widespread at that time of the year. Improved health may be a prerequisite for increased production.

Livestock

This manual is not intended for use by teams whose primary emphasis is livestock improvement, and, therefore, our aim is to help workers report and analyze the interactions that exist in their study area between crops and livestock and the consequences for the cropping system.

Report whether the livestock is "peripheral" to the cropping system, that is, herded and owned by other ethnic groups (for example, Fulani pastoralists), or central to the village economy and owned and managed by the farmers themselves. Describe how, where, and by whom livestock are herded at each season of the year, whether additional feeding is practised (dry season), whether the animals are used for farm operations such as hauling and tillage, what rates and charges are levied by livestock owners for use of their animals as draft power. Concentrate on constraints imposed by livestock on cropping land at certain times of year and on the opportunities that might exist for better use of manure or animal draft.

Factors of production

Land

Clearly delineate access to and availability of land; don't rely on observations alone because they can be misleading. For example, in southwestern Nigeria, goats and sheep graze freely around the village and all villagers confirmed that they could expand their farm land if more labor were available. In northern Ghana however, where cattle, goats and sheep also graze freely, the rich farmers simply had not yet given up their traditional grazing rights. The small farmers were already short of fertile land.

Access to land was used as one criterion to form target groups in southwestern Nigeria. One group of farmers had access to land in the savanna so they could farm more land with tractors, and earn higher incomes. Another group farmed in the forest. The fields were less accessible, tractors could not be used, and transport of inputs and outputs is costly. This limited farm size and income.

Farm size is an indicator of income and can be used to delineate target groups. Obtaining exact data on farm size, however, is not usually possible. Farmers may not be willing to reveal such information. To establish ranges, use the information about how many fields farmers cultivate, where they are located and whether they are larger or smaller than others that have been observed.

Capital, capital goods and capital formation

During the process of development, farmers usually move from subsistence to commercial farming. They become more dependent on marketing systems over time. In writing the report, consider two groups of capital inputs -- physical inputs such as machinery, agro-chemicals and seed, and monetary inputs such as credit and cash.

Cash is needed for domestic consumption of food and non-food items, purchase of farm inputs, taxes and fees, etc. It is obtained through savings from the previous season or year, sales from storage or present production, off-farm income and credit. Although farmers' cash income may exceed expenditures for the total year, the occurrence of seasonal cash shortages is common. Cash shortages limit production directly and indirectly by making it impossible to purchase inputs and by modifying the crop production choices. Also, they may force farmers to sell crops earlier than they otherwise would.

Attempt to construct a rough cash-flow profile to identify seasonal shortages, incorporating information on festivities, timing of input purchases and fees. Draw on notes from interviews on cropping patterns, storage and average sales. List the months, give sales a plus and purchases a minus sign. In interviews in southwestern Nigeria, many farmers said that they did not hire tractors or more labor and did not buy fertilizer because no money was available when needed. Some indicated that they hired a contractor for harvesting cassava because they needed cash but would have preferred harvesting and processing it themselves. Sales from storage were also made because cash was needed.

Later, establish a more accurate cash flow profile from the crop budgets assembled during on-farm testing.

Whatever portion of the farm output is not consumed can be invested. How much capital is invested in agriculture depends on the opportunities that farmers have to invest elsewhere. Economic policy has a great influence on how profitability of agriculture compares with other sectors. For good reasons farmers are not willing to furnish information about their investment capability. For the report, analyze indicators of the welfare of a community - for example, the presence of modern conveniences.

Labor

From the information and observations about labor, identify periods of shortage and slack labor. Note the sources of labor supply - family, hired and exchange labor. Consider whether the farm can be considered a family farm. For example, in southwestern Nigeria husband and wife (wives) farm independently; their farms had to be considered separately. Also, outline what is considered as family because access to family labor is regulated by custom.

Comment on gender and age in the distribution of labor, keeping in mind variations over the year, such as increases in child labor during school holidays. Give approximations of the work children perform in the fields and, if husband and wife farm independently, the share of children's work for each parent's fields.

Elaborate the activities of both the women and the men. Women in most societies do all household chores, may not engage in heavy field work or certain tasks, may do the transporting and may specialize in processing and trading. They may have to hire labor more often than men with similar sized farms, or operate smaller farms.

Use the information gathered about hired labor to discern the times that family labor is short or when farmers have cash-flow problems. In southwestern Nigeria farmers typically hire labor for land clearing, heap making, weeding and harvesting. When asked for which tasks they would hire labor if given the money, most farmers answered "weeding" and then "land clearing". In a bimodal rainfall regime, contract harvesting at the end of the first season serves two purposes, providing cash needed to purchase inputs for the second season and alleviating the demand for family labor.

Give a per-hectare figure of the cash costs. Note whether hired labor is paid daily and on the basis of area, or on the basis of the number of heaps made, etc. Provide examples of amounts paid, according to the type of bush cleared, weed infestation observed, etc. If the laborers are given a meal, include cost in the cash wage. Don't be surprised if the wage rate fluctuates over the year and varies substantially within a small region. The farmers' assessment of the labor situation should be checked against the cropping calendar. By using the rough profile of the demand for labor and comparing it with information about the average supply of labor you can discover and report opportunities for supplementary activities.

Management and information

Describe the level of management of the farmers and their access to information. Keep in mind that farmers are good managers but cannot adopt a new technology unless they have adequate resources (including information). Low educational level is often related to income because better education means better access to information and a greater ability to use the information. The incentive to gather information and to adopt new technologies often corresponds to the size of the farm. Thus, describe the level of education in the target groups. It is especially important when the new technology is a whole package.

Decision-making and production choices

Identify the decision makers for different activities, production processes and enterprises. Note whether the farm family or members within the family are considered the decision making unit or decision maker. In southwestern Nigeria, where both the husband and the wife farm their own plots, decisions are not made independently because the activities of the husband as provider of food for the family relate to the processing and marketing done by women. Thus the wife strongly influences how much and what is grown and how much is processed or stored. The contribution of the wife to family consumption is, in turn, influenced by the quantity the husband produces.

Delineate the activities and decision-making for cropping, livestock rearing, services and off-farm activities. Divide the crop activities into those for food crops and those for cash crops. (Traditionally those crops that were grown only for sale were considered cash crops, for example, cotton, tobacco, cocoa, coffee and tea. With increasing commercialization of agriculture a growing portion of food crops also is produced for sale, especially the portion left after food requirements are satisfied. Even crops that were once considered subsistence crops are now grown for sale. Cassava, for example, is the major staple of the rapidly growing urban centers and is grown commercially.)

In describing the decision-making for livestock enterprises, consider the incidence of animal diseases and note cultural significances. For example, raising cattle is restricted to the more open savanna free from the tsetse fly, which is the vector of sleeping sickness. Some cultures have evolved around the herding of cattle and crop activities are not even considered or play a minor role. In the areas where cattle cannot be kept, goats and sheep dominate. Raising of pigs may be restricted by religion.

Determine how decisions are made about service activities. Describe the services, some of which are provided by buildings and equipment and flow over an extended time. For example, note who controls storage facilities or sprayers and who provides upkeep. Decisions about services must be elaborated because the time and money required by these activities increase with growing technical standards. Most household activities fall into the category of services as well.

Include information about off-farm activities, the types and the times of the year when they are undertaken. Many off-farm activities are only done during the off season or after the farm chores have been completed. They supplement farm income. When they interfere with field operations this may indicate that the farmer's resource base is too small or that returns to off-farm work are higher than for farm work.

Attempt to explain individual decision-making in terms of economic principles (Annex I). The amount of resources the farmer allocates to each activity is influenced by the goals of food production, generation of cash income and risk avoidance. Report cultural, climatic and socio-economic contributors to decision-making.

If, for example, farmers expect a drought to occur every other year and sorghum is the grain that is the most drought tolerant and can be stored for two years, farmers may allocate as much land for sorghum as is needed to produce enough for the family for two years. However, if weather conditions are favorable the farmer may be able to produce more food by planting a higher yielding crop, say maize. The logical cropping pattern is thus to intercrop sorghum with maize. Profitability may thus be a decision criterion for the allocation of the remaining labor, land and capital. The more unreliable the natural environment the more important the goal of a secure supply of food.

Decisions are also influenced by customs. For example, in the yam-growing area of Nigeria where yam has strong cultural significance, farmers grow the crop for home consumption although it demands high inputs of scarce labor.

If labor is in short supply at certain times of the year, the farmer will attempt to obtain the highest returns to this scarce factor. If land is available in an area, livestock (e.g. goats and sheep) production will not be integrated with crop production. Rather they will be allowed to graze freely since feeding animals requires labor.

Report decisions about income, whether it is consumed in kind, converted to cash and then spent on consumption, or retained for investment. Give some indication of decision-making as it affects how much of every product is used in post-harvest activities. Do not overlook decisions about outputs such as crop residues or products that need disposal.

Analysis of farmers' conditions

The purpose of the description discussed in the previous sections is to lay the foundation for a sensible experimental program. The information should allow you to design trials that are consistent with the physical and socio-economic environment and that have some chance of improving the existing farming system.

First, however, you need to define "target groups", that is, groups of farmers facing similar physical and socio-economic conditions. Then, you must identify the major constraints and opportunities in the farming system that can be addressed by innovations to be tested under farmers' conditions.

Typology of farms and fields

Describe the criteria by which farms or farming households are to be grouped. Some commonly used criteria are:

- Access to land, labor or credit;

- Degree of mechanization;

- Market orientation, and

- Part-time versus full-time farming.

Additional criteria may emerge from the exploratory survey. For example, in southwestern Nigeria, women who owned and operated farms were one group, men another, with subgroups being those who specialized in "savanna" farming and those who farmed the forest.

An individual farming family will often have access to different land types, for example, plateau, sloping land, valley bottom land, which may be utilized in different ways. In the West African cocoa belt, cocoa is often found on plateau land and food crops on plateaus and slopes, whereas valley bottoms are used for off-season cropping or not at all. In an OFR project in Niger State, Nigeria (Ashraf et al., 1985) a distinction was made between valley bottoms or fadamas (rice soils), lower slopes with good soils (yam soils), middle slopes (cassava soils) and drought-prone upper slopes and crests (sorghum soils). Farmers differed as to their access to or use of different land types and they were grouped into those with rice-based, yam-based, cassava-based or cereal-based systems, according to which system was dominant in their farm.

Do not attempt too elaborate groupings based on the exploratory survey alone as the quantitative data required will not come out of such surveys. In fact, the groupings made in the Niger State project came out of additional studies, the exploratory survey only distinguishing between upland and fadama land types and associated cropping systems.

Different technologies may be appropriate for different groups of farmers and for different land types within farms, or, if the same innovation is proposed for different target groups, it may give different results among the groups. Design a simple matrix of "target systems" resulting from groupings across and within farms (Table 14).

Table 14. A simple matrix of target systems*

	Farmer categories	
	Semi-commercial	Subsistence
Land type	partial mechanization	manual
Upland	xx	xxxx
Valley bottom	x	x

*Number of crosses indicates relative importance of different systems.

Such a matrix should be useful either for choosing group-specific innovations for testing or for stratification of the trial innovation.

Constraints and opportunities

Carefully examine what you feel are constraints — those elements in the farming systems and their environment that limit the systems' productivity. Also attempt to focus on opportunities — features of the system that may be better exploited to increase productivity. What is meant by opportunities is best explained in an example.

In the forest-savanna transition zone of central Ivory Coast (Daoukro/M'Bahiakro area), cocoa used to be an important cash crop. During the short second rainy season (bimodal rainfall), farmers tended the cocoa (and yam) plantation and rarely planted arable crops. The recent decline of cocoa growing seriously limited cash-earning possibilities and labor appeared to be underutilized in the short rainy season.

The need for new cash-earning possibilities and the slack labor period in the short rainy season, together, represented an opportunity which could be exploited, for example, for the introduction of a new crop for the second season.

For the analysis of constraints and opportunities we propose a step-by-step approach. The first step would be to prepare a fairly comprehensive list using various categories (e.g. Table 15). Review all the aspects of the farming system and farmers' conditions.

Table 15. Categories of constraints and underutilized opportunities

1. Physical environment
   - Climate
   - Soils
2. Human environment and physical infrastructure
   - Marketing
   - Transportation
3. Farming Systems
   - Cropping patterns, fallow
   - Cropping operations
   - Inputs and yields
   - Crop disorders
   - Storage, processing, consumption
4. Factors of production
   - Land
   - Labor
   - Capital and capital goods
   - Management

Next, weed out the list and retain the major constraints and opportunities, ranked by degree of limitation they exercise on farmers' productivity.

This can be done separately for constraints and opportunities that are amenable to technical solutions ("addressable") and those that are not (non-addressable). The table of ranked constraints can be matched with solutions farmers themselves have found. This combination provides a good summary of the survey findings and shows the limitations under which farmers operate (Table 16). The ranked constraints and underutilized opportunities will be the basis for the choice of innovations for an on-farm testing program and for additional data collection if such appears necessary. This will be taken up in the next chapter.

Table 16. Ranked major constraints and underutilized opportunities with farmers' solutions; Ijaiye area, southwestern Nigeria (Palada et al., 1985)

Constraints and opportunities	Farmers' solutions
Addressable	
Low inherent soil fertility and inadequate fertility maintenance	Use of fertilizer, fallow, cassava "semi-fallow", mounding (?)
Shortage of labor for land preparation and weeding	Hire labor, limit cropped area, substitute less labor-requiring crops for yam, use herbicides, exchange labor
Erratic late-season rains and nonadapted crops and varieties, resulting in frequent crop failure in late season	Intercropping, growing of early maturing vegetables, limited maize growing
Buildup of weeds over the years (forest and savanna) and predominance of "difficult" (grassy) weeds in savanna	Tractor ploughing (savanna), herbicides (limited), early weeding
Grasshoppers on cassava	Choice of variety ('ege dudu'), destroying of breeding sites with gammalin 20 (extent?)
Maize streak	Not perceived by farmers as serious problem
Low yield potential of local crop varieties*	

Underutilization of valley bottoms*	
Disappearance of cowpeas because of pest complex	Buy cowpeas on the market
<u>Non-addressable</u>	
Lack of cash and credit	Formation of cooperatives, sale of land, off-farm enterprise, adjust harvest of cassava to cash needs, remittance by absent family members, sale of livestock
Inadequate inputs supply and extension services	Buy inputs (fertilizer) piecemeal in odd places

*Constraints with an asterisk are uncertain and more information is needed.

Chapter V
On-Farm Experimentation

Chapter V: On-farm Experimentation

Choice of innovations

Addressing constraints and opportunities

Consider whether innovations are available or can be developed to alleviate a constraint or exploit an opportunity. It could be a new crop or cropping pattern, a fertilizer, a new variety, a labor-saving machine (for example in field preparation or crop processing) or a crop protection chemical.

Expand the summary table of the previous chapter to include innovations to be studied on farm or on station and any additional studies that are considered necessary for a better understanding. An example from an exploratory survey in Nyankpala, Ghana (Steiner, 1984) is shown in Table 17.

A proportion of the constraints and opportunities will prove to be non-addressable within the time and mandate of the OFR team. This is to say that solutions may require government action. An example of a non-addressable constraint is the tendency of a proportion of the crop land to flood unpredictably. An example of a non-addressable opportunity might be a dry-season labor surplus. The team may not see an innovation ready for on-farm testing that would address these but they could make recommendations to the appropriate authorities, for instance by suggesting a flood control scheme or a labor-intensive industry for processing agricultural products during the dry season. A copy of the exploratory survey report could accompany the recommendation and a letter, should draw the attention of the recipient to the relevant sections of the report.

A constraint may be temporarily non-addressable but station research might provide a solution in 5-10 years. An example might be a

Table 17. Constraints and opportunities and ways of addressing them; Nyankpala, Ghana. (Adapted from Steiner, 1984)

Constraints and opportunities	Farmers' solutions	On-farm testing	On-Station testing and additional studies
Addressable			
Declining soil fertility caused by reduced fallow periods; shortage of fertilizer	-Decrease yam growing -Rotational kraaling of cattle (compound farms)	-Interplant pigeon pea for 1-2 years fallow -Cassava+legume break crop -Sole groundnut alternating with maize+sorghum mix	-Screen species for alley cropping -Take inventory of indigenous legumes for fallow or alley cropping
Frequent dry spells made worse by low water retention of soils	-Staggered planting -mixtures with drought tolerant crops	-Tied ridges and contour ploughing -substitute early millet for maize	-Plant very late maturing maize to avoid stress per[illegible]od (does it exist?)
Conflict between livestock and cropping	-Plant later around compounds -Tether small ruminants -Seasonal selling of animals? -Herd cattle	-Enclose and feed small ruminants	

Inefficient use of draft bullocks			-Investigate scope for improvement of bullock/driver training
Underutilized soil resources: compounds and valley bottoms		-Dry season gardening in valley bottoms -Development of compound farming combined with animal management	-Take inventory of valley bottoms
Labor shortage for land clearing and weeding	Plough with tractors and bullocks -Diversify cropping (staggered planting, late compound farming?)		
<u>Non-addressable</u>[1)]			
Inadequate support services (marketing, prices, extension, credit)			
Scarcity of productive land			

1) Workshop participants did not further elaborate on the non-addressable constraints.

pest or disease problem for which no genetic resistance or chemical control is currently available. Inform the directors of appropriate research institutes about the constraints and opportunities and provide an estimate of the relevant quantities such as the crop losses being sustained in the research area. At the same time, exploit personal contacts within the research services.

Choosing innovations for on-farm testing

The addressable constraints or opportunities are the ones for which solutions can be sought in on-farm trials in the season following the exploratory survey. Usually the brainstorming sessions during and after the exploratory survey will generate more suggestions than could possibly be handled effectively in the first year of trials. The need therefore arises to place priorities on the constraints and opportunities that are to be addressed and on the innovations addressed to each. Sometimes a complex innovation such as a change of cropping pattern addresses more than one constraint or opportunity and merits a higher priority than it would be assigned on the basis of a single constraint or opportunity. Look for not more than three innovations to be tried in year 1. Otherwise, the tasks for enumerators and supervisors will be too great. Innovations will be held in reserve in case one or more innovations perform so badly in trials that they have to be dropped or so well that they can be passed to the extension service after only 1-2 years in trials.

Necessary criteria. The innovation must of course address constraints or exploit opportunities that actually exist in the localities in which it is to be tested. It must be simple enough that ordinary extension personnel can be trained to demonstrate it and ordinary farmers to operate it.

The innovation must be economically viable at the yield levels that farmers may be expected to achieve and at prices and costs prevailing in the villages.

Desirable criteria. The seasonal labor requirements should complement rather than compete with other farm operations. The innovation should not require resources (capital outlay, expert maintenance or service facilities) that are not available to ordinary farmers in their villages.

The innovation should not be more prone to weather, pest and disease or other risk factors than the existing production practices.

Other criteria may be added; for instance the avoidance of difficult-to-obtain inputs (foreign exchange cost) may be a criterion, or compatibility with the livestock-herding conventions prevailing in the study area.

These criteria consciously seek to replace the one that has determined the choice of innovations for on-farm testing in the past: the interest of a research team in promoting an innovation that it has developed in the research station.

Only rarely will any one of the proposed innovations fulfill all of these criteria. The desirable criteria could be overridden if the innovation were good enough in other respects to justify, for instance, the use of hired labor, backup credit, a crop insurance scheme or fencing.

How each innovation rates in respect to all the criteria is uncertain until the end of the testing phase, but innovations that clearly fail in one of the necessary criteria or score generally badly in the desirable ones can be assigned low priority. A useful technique in deciding among innovations is a decision table.

The decision table. For example, a decision table was designed to deal with poor soil fertility at Nyankpala in Ghana (Table 18). The decline in fertility resulted from reduced fallow periods and the uncertain availability of fertilizer because of the country's foreign exchange problems. This constraint was particularly binding on maize yields. Assuming that expanded fertilizer use was politically unacceptable, the team suggested three innovations for relieving the constraint (See Table 18).

Table 18. Decision table for possible innovations to address the soil fertility constraint at Nyankpala, Ghana

Innovation	How does the innovation rate for:					
	Necessary Criteria		Desirable Criteria			
	Simple enough?	Economic?	Labor use and timing	Capital inputs	Risk	Live stock
Sole groundnut	++?	+	-	+	++	++
Cover cropping	+	+?	+	+	++	-?
Cassava break	++	+?	+?	+	++	+

++ Very favorable
+ Favorable
- Unfavorable
-- Very unfavorable
? Uncertain

N.B. An innovation that does not or only slightly increases capital inputs would be favorable (+); in that respect, one that reduces the need for capital is very favorable (++).

. Sole cropping of groundnut, which had been shown on the experiment station to give good yields of maize in the following year. Farmers already grew groundnuts but in mixture with maize and sorghum, which was shown on the experiment station to give poor yields next year.

. Cover cropping with pigeon pea: rows of pigeon pea, planted at the beginning of the season and intercropped with the farmer's normal mixtures. The pigeon pea grows up after the crops, persists for a subsequent full season and is then cut back at the beginning of the next season and provides mulch for the new crop.

. Cassava or cassava+legume break crop. Farmers believed that cassava gave good yields of cereals in a subsequent year but no information was available from trials. The only innovation was to grow the cassava without cereals admixed to ascertain whether this would improve cereal yields after a one- to two-year break.

Groundnut and cassava were rated better for simplicity than pigeon pea because they were already familiar to farmers. The query for groundnuts was whether farmers would be prepared to grow it as a sole crop. Some economic analysis of groundnuts could be undertaken with the data from a 2-year groundnut-cereal rotation on the research station; cassava was already established and therefore presumably economically viable. No economic assessment could be made for the other innovations.

The pigeon pea as a cover crop would not produce substantial consumable products and would, therefore, only be economic if it supported higher yields in subsequent crops. Sole groundnut would need to be sown and weeded at the same time as the other crops and so had poor labor timing. Later sowing might be permissible but was considered doubtful. Cover cropping was rated better in this respect because fewer pigeon pea stands had to be established. It was thought, but not known, that cassava might be fairly tolerant of late planting or weeding and therefore could be grown in a way that would not conflict with labor requirements.

None of the technologies required much in the way of capital resources but the legumes would probably need phosphate fertilizer. Groundnut and cassava as already established crops were known to be free of risk. While there was no reason to suppose that pigeon pea would be risky, no local information was available on this. Whether the cover crop could be protected from livestock roaming free in the dry season was not clear, but groundnut did not have this problem because it would be harvested before the dry season and could provide haulm for dry-season feeding.

Thus, sole groundnut seemed to have more chance of success in on-farm trials than the pigeon pea cover crop. In addition, the uncertainties for it are related to farmer reaction, which can only be tested on-farm. The queries on the other two innovations, some relating to purely technical questions, suggest that further experiment station trials or a limited number of researcher-managed, on-farm trials would be appropriate. Note that the question marks in a decision table sometimes suggest treatments for on-farm trials: for instance, would a later planted cassava with a better labor profile be as effective as early planted cassava? All proposals require trials of at least two years.

This example addresses only one of the constraints identified at Nyankpala. Often a team will wish to consider addressing more than one constraint and the decision table should then be expanded.

Quantification of some of the decision criteria

To answer some of the questions posed by the criteria, use farm-level yield data if available in partial budgeting (See section on economic analysis). Beware, however, of comparing yields from research stations or closely supervised demonstrations with those from farmers' fields as determined during the exploratory survey.

The simple farm-scale labor profile (Chapter IV) is the basis against which to compare the labor requirement of the proposed innovation. Ideally, the innovation requires labor at a time when existing farm operations are not pressing or reduces the labor requirement at one of the peak times. Farmers will rarely accept any innovation that demands priority for labor allocation over their staple food crops.

Estimate the capital costs for each proposed innovation: the cost of any equipment (tillage tool, planter, sprayer etc.) amortized over a realistic period and the annual cost of purchased consumables (hybrid seed, fertilizer, spray chemicals). Is this cost likely to be covered by an increase in marketable output? Is there a reasonable prospect that the necessary inputs will actually be available at the assumed price after the research team withdraws? Do the farmers have either savings or a source of credit sufficient to meet the outlays?

Weather risks. Weather risks can be quantified if the daily or 10-day rainfall totals and mean temperatures are available for the study area. First, find out from an expert or from the literature what weather events can be particularly damaging to a specific crop that is to be introduced or improved. For example dry weather cannot be tolerated by maize at silking (no fertilization); by groundnut at pegging (no soil penetration); or by other legumes at or just after flowering (flower or pod abortion). Wet weather cannot be tolerated by Pennisetum millet at anthesis (pollination minimal) or by sorghum at flowering (grain is spoiled). Cold weather when sorghum is flowering hinders fertilization, and hot weather or low humidity at maize silking can dehydrate the pollen or silks. The root crops such as yam and cassava may not have susceptible growth stages, but their yield will reflect weather conditions throughout the growth period. Express each of the weather hazards as a simple event to be searched for in the weather data. Examples are:

- Two consecutive 10-day periods with a total of less than 30 mm rainfall between 50 and 80 days from the anticipated date of sowing maize; and

- Three consecutive days with recorded rainfall after the anticipated flowering date of sorghum.

Scan the appropriate months of rainfall data to assess the probability of the event occurring (i/n where "i" is the number of years in which the event occurred in "n" years of available records). On the basis of this, decide whether to go ahead with testing the innovation.

A simple weather hazard analysis (Table 19) would show, for example, the frequency of occurrence of periods of three or more consecutive days of rain at the time when sorghum might be in head at Samaru in northern Nigeria. Such a wet spell might lead to fungal spoilage of the grain. Wet spells beginning 21-30 September are rather frequent but there is much less risk after 1 October. Early maturing sorghums should probably not be sown so early that they head before 1 October; unfortunately, later sowing could lead to problems of drought in a year when the rains finished early. Fisher (1984) gives a full discussion of this problem.

Favor testing of less water-demanding innovations in the dry savannas and Sahel where rainfall has been declining.

Table 19. The occurrence of wet spells (3 or more consecutive days with recorded rainfall) between 20 September and 20 October at Samaru (1928-82)

Period	No. of years	Probability
21-30 Sep	16	0.29
1-10 Oct	4	0.07
11-20 Oct	1	0.02

Innovations for household activities other than cropping

We have tended to assume that this manual will mainly be used by on-farm researchers whose primary mandate is improvement of cropping systems. However, constraints or opportunities identified during the survey could easily indicate that the most appropriate innovations are in an area not directly related to cropping, for instance in fuel supplies, product storage or marketing, food processing, animal production or house building. Decide whether the mandate for the research is broad enough to allow testing of innovations in these fields. If so, seek help from someone with experience in extending this type of innovation at the village level. Although the next section of this manual is written on the assumption that the innovations to be tested will be applied to the cropping subsystem, we think certain principles are still applicable for other innovations:

- The comparison of the innovation with a sample of existing village practice;

- The annual evaluation of performance and acceptability and possible changes in the innovation or format of the trials in the light of that evaluation.

Design of on-farm trials

The word "design" in the context of on-farm trials is used broadly to mean:

- The choice of representative villages and farms for siting of trials;

- The selection of treatments to be compared in the trial;

- The choice of the number of replicates and of the distribution of these replicates within and between farms;

- The choice of the most appropriate experimental design; and

- The size of plot (in the statistical sense) to be used.

The selection of treatments

As with any experimental design, the choice of treatment must follow from the objectives of the trial, so spell out exactly what the hypotheses are. For example, the three innovations in the previous section were all aimed at alleviating a soil-fertility constraint but the hypotheses for trials to test these three innovations would be rather different.

Sole groundnut:

H1. The benefits of sole groundnut for a subsequent cereal crop as found on the research station will also be obtained on farmers' fields.

H2. Farmers will be prepared to grow sole groundnut if hypothesis H1 is demonstrated to be true.

Cover cropping with pigeon pea:

H1. Pigeon pea cover cropping will improve the yields of subsequent crops sufficiently to outweigh the losses caused by competition from pigeon pea in the current year.

H2. Farmers will accept the labor and cash costs of growing pigeon pea if H1 is demonstrated to be true.

Cassava break crop:

H1. Yields of cereals (next year) after cassava, grown without cereals admixed (this year), will be better than after cropping patterns that include cereals.

H2. Farmers will accept the practice of growing cassava without cereals admixed if H1 is demonstrated to be true.

To primary hypotheses, add subsidiary hypotheses to narrow down the choice of treatments. For instance, in the sole groundnut innovation:

H3. Phosphate fertilizer will improve the yield and subsequent benefits of sole groundnut.

H4. Farmers will use phosphate fertilizer if H3 is demonstrated to be true.

In each case, the hypotheses can be divided into those that concern technical questions and those that concern feedback on farmers' opinions.

Another example will bring out the reasoning leading to a choice of treatments. Maize streak disease can devastate yields, especially with second season maize in bimodal rainfall regimes. When introduction of a streak resistant variety is the objective, the hypotheses could be:

H1. Growing a streak-resistant variety instead of a traditional one will improve farmers' maize yields.

H2. Farmers will accept the variety if H1 is true and the associated crops are not adversely affected.

A trial to test these hypotheses will consist of two or more treatments, one with the traditional variety, one or more with the streak resistant variety(ies), in each case planted in the farmer's usual pattern. If maize is grown in more than one pattern, a separate trial for each pattern can be conducted. Plant breeders often insist that their varieties be tested according to a package of recommended practices which may include sole cropping, fertilizer dose etc. However, this does not follow from the above hypotheses.

The treatments must fit the farmers' cropping pattern and sequence. Stating that a treatment consists of a certain fertilizer rate on maize is not adequate if maize is grown in more than one pattern and in fields at different stages of occupation. For example, maize in a recently cleared forest field often shows no or minor response to N fertilizer, and fertilizer may be more attractive after a few years of cropping.

The reasoning is similar for new or improved cropping patterns. Carefully consider how a new crop (e.g. sole groundnuts) fits best into the farmers' usual cropping sequence.

Types of on-farm trials

The range of possible trial types is large and we will first try to bring some order in this multitude.

On-farm trials can be grouped according to several criteria:

. **According to the type of innovations being tested**

- Improvement of crops and cropping techniques in existing cropping patterns;

- Improved or new cropping patterns and new crops; and

- Soil, vegetation and water-management practices.

. **According to the state of knowledge**

- Exploratory trials;

- Verification trials; and
- Pre-extension trials.

. **According to the degree of farmer involvement**

- Researcher managed, researcher executed;
- Researcher managed, farmer executed; and
- Farmer managed, farmer executed.

This discussion of on-farm trials is mainly based on type of innovation with some indication of how the design and the degree of farmers' involvement are influenced by the state of knowledge. In general, as the knowledge expands, the range of treatments or levels will narrow, and the complexity of the trials decreases. The number of replicates or farmers and the degree of farmer involvement will increase in the same direction. Farmer involvement will be treated in more detail later.

Improvement of crops and cropping techniques in existing cropping patterns. Just as the cropping pattern was the basic unit of description in the exploratory survey, so it remains the basic unit of experimentation. A sole crop or sequence of two sole crops can constitute a cropping pattern, but in most of West Africa cropping is mixed or relayed. The control in on-farm experimentation is the farmer's existing cropping pattern and the field operations normally associated with it.

Innovations that may be considered for introduction in existing patterns are improved varieties for the crops in the pattern, a better fertilizer rate and time of application, improved weed control etc. The pattern itself remains basically the same.

The simplest case occurs when there is one overwhelming problem for which a straightforward solution is available, for example, a major disease of one of the component crops for which resistance has been developed. A simple on-farm trial can be designed with variety as the only variable. Compare one or more resistant varieties with the traditional one(s) in a randomized complete block design with one or a few replicates per farm (replication will be discussed in a later section). Such a simple trial can go straight to a large number of farmers and the farmers can manage the trials.

In the early stages of an OFR program, however, the team may wish to answer more than one question at the same time. Low fertility is almost invariably diagnosed as a constraint and fertilizer responses in farmers' fields are often not known. Consider combining the variety test with a few levels of fertilizer in an "exploratory" trial.

Resist the temptation to make exploratory trials too complicated. For example, don't attempt to set up exploratory trials with varieties, fertilizer rates and various densities of the component crops in a multi-factorial arrangement. Such trials should be left to research scientists. Carefully define priorities and only design simple exploratory trials with a limited number of variables and levels. (If necessary, reduce the number of plots per farmer by using a confounded factorial design.)

In general, give low priority to modifying plant densities. Evidence is that farmers plant at densities that suit their management and input levels (Kang and Wilson, 1981; Mutsaers et al., 1981). In other words, the farmers have probably arrived at the best densities for their system. Higher densities will only be required at substantially higher fertilizer rates. Similarly, limit the fertilizer treatments, even if no actual responses to nutrients are known for farmers' conditions. Consult specialists on soil fertility;

often they can advise on the best ratios between the major nutrients. Use formulations of compound fertilizer that are readily available on the market.

In an OFR project in southwestern Nigeria (Palada and Vogel, 1986), improved varieties were available for two traditional crops -- maize and cassava -- and compound fertilizer 15-15-15 and calcium ammonium nitrate were more or less readily available on the Nigerian market. The team tested both new varieties and a few levels of fertilizer applied to the maize in an exploratory trial (Table 20). The trial was a split-plot design with varietal combinations as main plots and fertilizer rates as subplot treatments.

Table 20. Exploratory trial with improved varieties and fertilizer rates in farmers' maize and cassava intercrop, southwestern Nigeria

	Variety		
Main treatment	Maize		Cassava
1	Farmers'		Farmers'
2	Improved		Farmers'
3	Improved		Improved
	Fertilizer (kg/ha)		
Subplot treatment	N	P_2O_5	K_2O
1	0	0	0
2	45	45	45
3	90	45	45

An assumption, implicit in the choice of the fertilizer treatments, was that nitrogen application alone is unwise on these soils. Otherwise, an additional treatment could have been 45 kg N and zero P and K.

If little is known about the soils and fertilizers are readily available, a mini-factorial

Table 21. Example of a "minifactorial" arrangement of fertilizer rates

Treatment	Application rates, kg/ha		
	N	P	K
1	0	0	0
2	45	0	0
3	45	45	0
4	45	45	45
5	90	45	0
6	90	45	45

arrangement (Table 21) of fertilizer doses could be considered. Some previous knowledge is assumed in the choice of treatments in Table 21, for instance that P and K applications are not useful in the absence of N. If nothing at all is known about fertilizer responses, a confounded factorial arrangement may have to be considered. In any case, consult with a soil expert and a statistician when choosing the fertilizer combinations.

Such trials or, perhaps, previous work should lead to a preliminary choice of innovations to be tested on a wider scale, with more farmer involvement. To clarify how each element of the package contributes to improvement, use a stepwise or add-on trial (Mutsaers, 1984).

For example, suppose three innovations make up the "full package":

- Medium fertilizer rate, 300 kg/ha of 15-15-15;
- Improved maize variety; and
- Improved cassava variety.

Suppose also that from earlier experiences the returns from the innovations are expected to be in

Table 22. Treatments in a stepwise trial with fertilizer and improved varieties for a maize and cassava pattern

	Fertilizer	Variety		
Treatment	level	Maize	Cassava	Note
A	Farmers'	Farmers'	Farmers'	Baseline
B	Farmers'	Improved	Farmers'	Step 1
C	Improved	Improved	Farmers'	Step 2
D	Improved	Improved	Improved	Package

the order: maize variety > fertilizer > cassava variety. Then, a stepwise trial would incorporate four treatments, each treatment being a step on the way to the full package of innovations (Table 22).

If the order is right, each treatment is a feasible option on the way to adoption of the full package. If the order is wrong, the analysis and the farmers are likely to say so. This stepwise approach has major advantages over alternative factorial or "all minus one" designs that invariably involve some treatment combinations that can be seen to be inappropriate even before they are tested.

The simplest analysis of market values or yields is:

A vs B effect of maize variety;

B vs C effect of fertilizer in presence of improved maize variety, and

C vs D effect of cassava variety in presence of fertilizer and improved maize.

Any number (n) of innovations can be used to give (n+1) treatments per replicate and n non-orthogonal contrasts. For example, an additional treatment E could be considered, consisting of a higher maize density with improved varieties and fertilizer.

An interesting and rather more sensitive analysis is available for market value but would not make much sense for individual crop yields unless all the innovations were applied to one crop. View the treatments as a series of equally spaced steps between the baseline and the package as represented by the number of innovations included: 0, 1, 2, and 3 for A, B, C, and D respectively. This means that each additional innovation is expected to contribute positively to the market value. This "model" is analogous to that of a factorial trial with different levels of fertilizer. Apply the same analysis using orthogonal polynomials, as explained in statistical textbooks, for instance in Snedecor and Cochran (1967). The interpretation, however, is rather different:

- A negative linear component indicates that the innovations are reducing market value. If significant, the trend calls for a completely different set of innovations.
- A positive and statistically significant linear trend indicates that market value is responding to the innovations. If the quadratic and higher trends were not significant, the value contributed by each successive innovation would be statistically indistinguishable.
- Significant linear and negative quadratic trends indicate decreasing returns to successive innovations (ordering of the innovations was correct). A positive quadratic component, whether significant or not, suggests that the initial order was incorrect or that the innovations had strong, positive interactions. For example, if the new maize variety better expresses its yield potential at higher fertilizer doses, the

returns for the first step could be negligible, whereas those for the second step would be large.

- A significant quadratic trend in the absence of a positive and significant linear trend or any significance in the levels of polynomial higher than quadratic would be difficult to interpret but probably would indicate that the ordering was wrong.

The interpretation is valid only if the ordering of the treatments is predetermined. It would not be valid to arrange the means in ascending order and then do the analysis. A worked example is given in Annex II.

The add-on trial, repeated over a few years and modified if necessary, will lead to a final ordering of the components with each additional component making a positive contribution to market value. It may also lead to deletion of components that are not sufficiently profitable or are rejected by farmers for other reasons. The package may even become reduced to a single new component.

The well-tested package can then be distributed to larger numbers of farmers, but don't limit the trial to a comparison of the farmers' practice and the "full package" alone. Include some intermediate steps to show the options. At this stage, however, consider having the farmers managing the trials themselves; and the size of a plot should be no less than 500 m^2.

If new components, such as a recently released variety, some secondary or micronutrients or even different application rates of fertilizer have to be tested for the package, accommodate them as a superimposed trial (Zandstra et al., 1981). In such a trial, a portion of the plot testing the full package is used for the layout of a few small

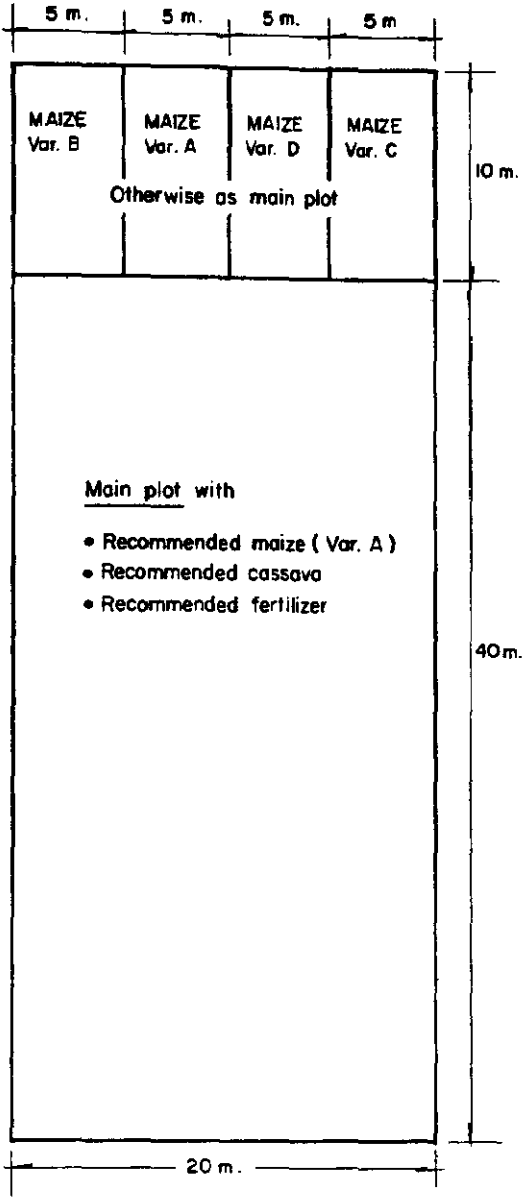

Fig.18. Field layout of a superimposed trial design.

experimental plots, managed by the researchers (Figure 18). For example, a plot of 40 x 20 m assigned to the "full package" (improved maize and cassava varieties with the recommended fertilizer rate) incorporates subplots of 5 x 10 m that include later improvements, such as one or two maize varieties or a micronutrient; these treatments are randomized separately on each farm. Replication of the subplot treatments is between farms. Economic analysis for the packages is done on the 800 m^2 main plots. Another use of superimposed trials (Dr. K. Sayre, pers. comm., 1983) is to monitor changes of the response to some factor, such as fertilizer, over time by repeating the same treatments in the same plots over several years. Such changes would indicate that other factors are becoming limiting (micronutrients) or that acidification is occurring.

When new components or different rates of inputs are tested in this way, be on the lookout for interactions between crops: a good variety should not only yield well but also should not be too competitive with the other crops; fertilizer is of no use if it stimulates one crop and suppresses another.

New cropping patterns and sequences and new crops. Introducing new patterns and sequences is somewhat more complex than adding fertilizer or substituting one variety for another. New cropping patterns might be required when you are planning to:

- Introduce a new crop;
- Introduce new varieties with growth durations that differ from traditional ones;
- Better exploit the rainfall regime or fill a labor opportunity; and
- Accommodate new inputs such as herbicides or pesticides that require a simpler crop

association than the farmers have been practising.

Search for innovations that are readily extended to farmers; this generally means avoid advocating sole cropping except where some outstanding technical development really cannot be used in mixed crops. Carefully consider what the farmers are normally doing -- this is the check for your trials. Measuring the profitability of a new pattern means comparing it with an existing one. Profitability in farming systems is always relative to what farmers are already doing.

Take care that the trials are carried out in a field that a farmer would use for the check pattern. This is no vain warning, because farmers sometimes try to locate uncertain innovations in harmless places, for example, a field that they did not intend to use otherwise. The farmer should be asked to make available a few plots within a field he has allocated to the check pattern.

The simplest case is the introduction of a new crop in the farmers' system. Answer four questions before designing a trial:

. Which of the farmers' crops is the new crop intended to replace, or will the new crop compete with?

. Is the new crop to be grown in mixtures with or relayed with existing crops? If yes, which crops?

. In which season is the crop to be planted?

. In which phase of the occupational period is the crop to be grown?

For example, in the forest-savanna transition of southwestern Nigeria, a soybean breeder and agronomist recommended growing soybeans in the

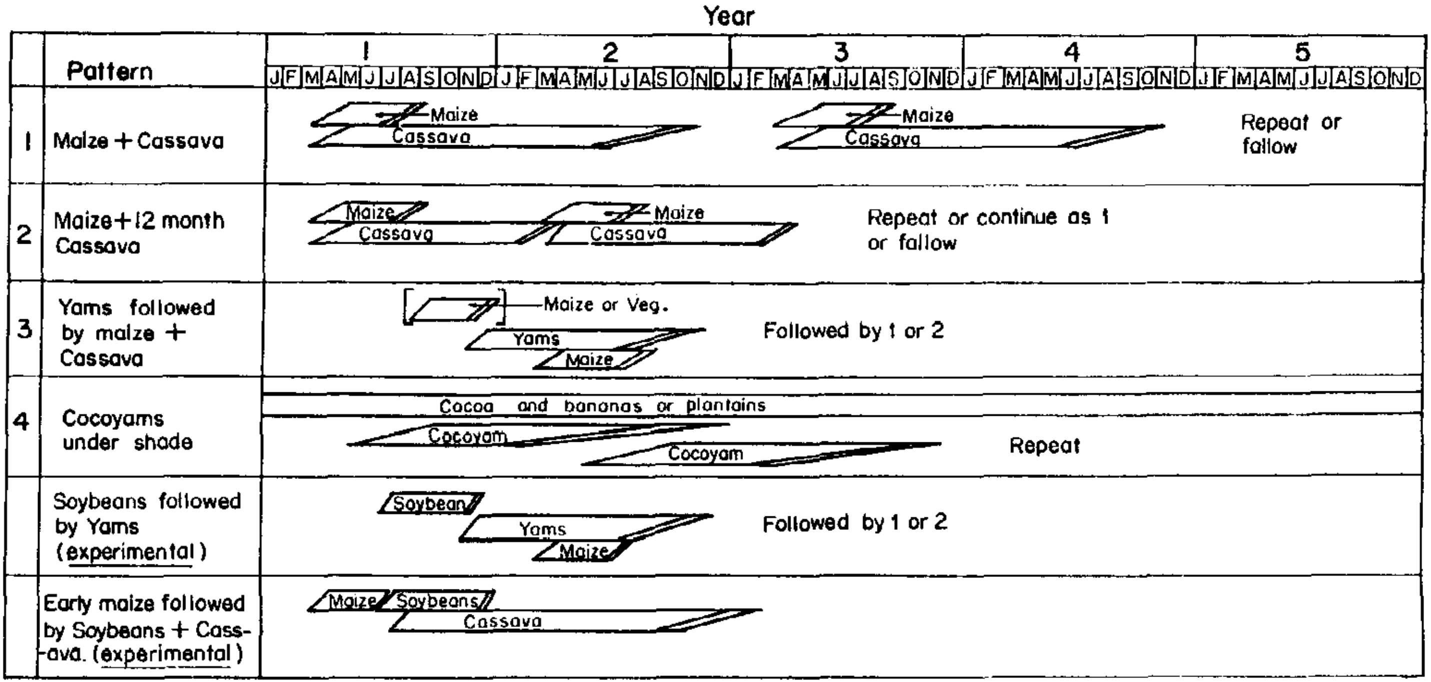

Fig.19. Common cropping patterns in the Ayepe pilot area, southwestern Nigeria and two experimental patterns with soybeans.

second rainy season (bimodal rainfall). However, the growth cycle of the available varieties is too long and the crop has to be planted around mid-July, before the short dry season.

Two options could be considered (Figure 19):

- Sole cropped early maize, followed by soybeans possibly intercropped with cassava.

- In replacement of late maize and/or vegetables, grown before yam. Yam heaps could be prepared in July after fallow; then soybeans with or without vegetables would be planted immediately and the yams planted after the rains (November/December).

In this case, two separate trials would be appropriate (Table 23); both are exploratory trials to assess whether soybeans can be grown with crops in the farmers' usual pattern. The treatments are only fully comparable in terms of monetary yields. The sole crop treatment is included because farmers may accept a monoculture of a new and unknown crop as sole crop. In the second trial, the effect of the treatments on the following yam crop is most important and should be carefully evaluated.

These trials are designed to determine the best cropping pattern for the new crop, although many other factors influence the way the crop performs -- for example, need for or reaction to inputs, the growth of the associated crops, etc. First address the major issue and find the best pattern without inputs beyond what farmers normally use. If you feel that the new crop would fail without specific inputs, then consider crop and input indivisible (for example, in southwestern Nigeria, cowpeas and pest control).

From the results of the trials, order the different patterns, for example by cash return. After 1 or maybe 2 years of testing discard the

Table 23: Possible treatments for exploratory trials with soybeans in two "slots" of a cropping system

Treatment	Crop combination
Soybeans after early maize	
1	Early maize - (cassava + soybeans)
2	Early maize - soybeans
3 (check)	Early maize + cassava
Soybeans as pre-yam crop	
1	(Vegetables + soybeans)/yams
2	Sole soybeans/yams
3 (Check)	(Maize + vegetables)/yams

poorest pattern(s) and begin wider testing of the best ones, if any. Ask farmers to manage the trials on plots of 500-1000 m^2 so that the patterns can be evaluated by an economist. Consider superimposing treatments, such as crop varieties or fertilizer on a subset of fields — four or five 50 m^2 plots with the different options available for varieties, fertilizer rates or crop protection practices.

Whether the superimposed treatments are researcher- or farmer-managed (depending on the complexity), ask the farmer to comment on them as well as on the pattern plots.

As another example, in Nyankpala, Ghana, planting groundnuts alone alternately with the usual maize + sorghum + groundnuts was proposed mainly to improve the cereal yields every other year. The trial therefore, would simply compare the farmers' pattern and the new pattern (sole groundnuts every second year). As groundnuts do not cover the full growing season, a third pattern could be considered: groundnuts followed by a second crop.

Finally groundnuts could benefit from phosphate fertilizer and, considering the rather simple design, this factor could be included straight away. The trial has to run over a number of years to assess the residual effect on the following crop.

The sole crop in this case was proposed for a specific purpose (to enhance the yield of the succeeding cereal). Do not promote sole crops simply because a new variety, such as hybrid maize, yields best when cropped alone with high inputs. Often sole cropping is not the most suitable for farmers or even the most profitable despite high yields. If you are determined to put sole cropping to a test, design a stepwise trial (Table 24). The control treatment is the farmers' crop association; the other treatments add successive components of the intended package, starting with the new variety, followed by more fertilizer, and finally the total system for the sole crop.

Table 24. Stepwise trial to test a package that includes sole cropping of maize

Treatment	Maize variety	Fertilizer	Practice	Note
A	Farmers'	Farmers'	Mixed	Baseline, mixed maize
B	Improved	Farmers'	Mixed	Mixed maize
C	Improved	Improved	Mixed	Mixed maize
D	Improved	Improved	Sole	Sole maize at high density

On an area basis, the rates of fertilizer recommended for sole crops may be excessive if applied to farmers' mixtures, so calculate the fertilizer rates on a per-plant basis.

This design is more meaningful than the widely used 2^2 factorial ("diamond trial"), with fertilizer and variety as factors, such that the sole crop and high density are used in all treatments. The "control" (farmers' variety without fertilizer grown as a sole crop at high density) for the factorial design bears no relation to what farmers are actually doing.

Managing soil, vegetation and water. Some innovations address the growing medium rather than the farmers' crops or cropping patterns although they may limit the choice of crops or patterns. Management practices that are designed to improve the soil, fallow or availability of water fall into this category.

Take, for example, the innovation in which rows of pigeon peas are interplanted in the farmers' crop association in the last year of cropping before fallow. After harvest of the crops, the pigeon peas remain as a planted fallow for the duration of the farmers' normal fallow. After 1 or 2 years the land is cleared again for cropping and the pigeon pea is used as mulch.

In the last year of cropping, the pigeon pea may compete with the crops, but the pattern as such is not affected. Also, after the fallow, the crops normally planted would be used. This innovation, thus, operates on the fallow and does not affect the cropping pattern. The analysis considers the effect (negative?) on the crop into which pigeon pea is relayed and the effect (positive?) on the post-fallow crops.

The innovation is straightforward and the design can be simple, consisting of the farmers' practice and the pigeon pea fallow only. Within farmers' fields, two fairly large plots (500 m^2 or more) would be demarcated -- one for pigeon peas and one for the farmers' system (the control).

A more complex innovation is alley cropping, where crops are grown between hedges of a leguminous tree species. The objective is to eliminate or reduce the need for fallowing, the trimmings of the hedges cycling nutrients from the subsoil and the roots contributing biologically fixed nitrogen. The farmers' cropping pattern need not be changed (Table 25). Ideally the alleys are planted with the first crop after the fallow, but farmers are sometimes reluctant to make their best land available for trials. If you attempt such an innovation, at least avoid planting the hedges in the last cropping year. Expect the trial to run over a considerable number of years because the benefits build gradually. Carefully observe whether the plots with alleys can be indeed continuously cropped while the non-alley plots are left fallow.

Table 25. Evolution of an on-farm trial with alley cropping

	Year				
Treatment	0	1	2	....	k
Farmers'	Fallow	Farmers'	Farmers'	Farmers'	Fallow
Farmers' + alley	Fallow	Farmers' + alley	Farmers' + alley	Farmers' + alley	Farmers' + alley

Ensure that alley plots are not smaller than 500 m^2; otherwise the farmer may lose interest when the rest of the field is in fallow. Also, large plots are needed for economic analysis and observations on labor use.

Monitor labor requirements closely. Although alley cropping does not require a change in cropping pattern, the innovation does involve fairly important changes in practices: the hedges have to be cut back at the end of the dry season and pruned regularly during the growing season. Both activities compete for labor otherwise engaged — in weeding and land preparation, respectively. Keep in mind that practices, especially when they involve increases in labor, can be more difficult to change than crops.

An innovation like minimum tillage does require changes of cropping patterns and practices, but reduces labor requirements. The "ideal" package for minimum tillage consists of:

- No tillage or tillage of the plant rows only;
- Weed control by herbicides;
- An "adapted" cropping pattern, e.g. maize followed by cowpeas; and
- Planting with adapted equipment, e.g. rolling injection planter.

This full package is complex and unlikely to be adopted by peasant farmers.

Take a careful look at the package to see whether it can be built up in a stepwise manner. Focus on the major components of the system: tillage method, weed control and planting method (Table 26). Each "system plot" can be subdivided for testing a few different cropping patterns, for example, the farmers' usual pattern and one that is known to respond well to minimum tillage, such as maize, followed by a grain legume. Eliminate the inappropriate treatments before involving farmers in management of trials.

Table 26. Stepwise trial of minimum tillage

Treatment	Tillage method	Weed control	Planting method	Note
A	Farmers'	Manual	Manual	Baseline
B	Minimum	Slash	Manual	
C	Minimum	Herbicide	Manual	
D	Minimum	Herbicide	Rolling injection (grains)	Package

A few other innovations that deal with the medium include:

- Leguminous cover crops planted during fallow to suppress difficult weeds (Imperata); and

- Tied ridges in the savanna for water conservation.

Farmer involvement in on-farm trials

On-farm trials range between those designed solely to test technical hypotheses and those designed mainly to get farmer feedback. The degree of farmer involvement will vary accordingly.

Researcher-managed, researcher-executed trials. When purely technical hypotheses are to be tested under representative physical conditions, the researcher or enumerator decides how the crop will be managed and either directs or executes all the operations. The researcher simply "hires" a plot of land and labor, paying in cash or kind. The feedback on how the technique fits into the farmers' system is minimal, but the farmers see the trial and may offer useful opinions. The reasons for not carrying out such trials on the research station could be several:

- The basal fertility of the research station has diverged from that of the farms because of differences in cropping history and fertilizer policy;

- The system of land preparation or the spectrum of weed species is different; or

- The land type is not represented on the research station.

Researcher-managed, farmer-executed trials. In contrast, exploratory trials are generally managed by the researcher and executed by the farmer. The operations and their timing may not be technically precise, but the feedback is substantial, for example, on how much training farmers need to operate new equipment and to apply correct quantities of new material; on whether some unforeseen labor or capital inputs are required, and on which treatments can be eliminated.

Farmer-managed, farmer-executed trials. Feedback is maximized when the researcher simply marks out the plots, ensures that the farmer understands what is to be done in each one, and monitors the activities. All management decisions are made by the farmer so the variation between plots is likely to be large.

These distinctions are not absolute! For instance, a researcher may maintain control over one operation such as herbicide application in an otherwise farmer-managed trial. The guiding principle is that no innovation is proven until it has worked to the satisfaction of both researcher and farmer in a farmer-managed, farmer-executed trial. Often trials will gradually progress to become more farmer-managed, but some innovations can go straight into farmer-managed trials, while others need to be moved more cautiously. Researcher-managed trials with annual crops should not be longer than 1-2 years. If in doubt about the farmers' ability to handle an innovation try it on a small scale of, say, five farmers and compensate them if necessary rather than continuing in doubt. Rethink whatever is causing the doubts about putting the innovation into the hands of farmers. Can it be simplified?

The appropriate statistical design

As one moves through the spectrum of management and execution from researcher to farmer, the permissible complexity and the replications per farm both decrease sharply.

The principles of designing researcher-managed trials are not greatly different from those for trials on the research station except that distance, field size, input costs and technical expertise may be more limiting. Multi-factorial trials can be run if farmers can be found to supply the land. By confounding unimportant interactions a reduction of the number of plots per field is often possible. A statistician or at least a textbook should be consulted. Replicating the trials between farms gives better representation of the target soils than does conventional replication within sites, but a good compromise would be some of each.

For farmer-managed trials, six plots per farmer is a maximum; three or four is much safer. This means that replication must be between farms and that, given a control, only two to five innovative treatments are possible. Even then, these must be simple to understand and apply. The randomized complete block design is almost inevitable, with one block per farmer.

Plot size. For researcher-managed trials, the criteria for choosing plot size are usually similar to those operating on the research station. Much depends on the type of treatments and the observations that are required. When yield alone is measured, plots can be from 30 to 100 m^2, according to the type of crops (small grain crops at the low end and mixed crops of, for example, maize + cassava at the high end of the scale).

For researcher-managed, farmer-executed trials and usually for farmer-managed trials, costs and labor, for instance, in weed control trials, are to be evaluated and are difficult to measure on plots smaller than 500 m^2. Simply divide the farmer's field into as many equal sized plots as the number of treatments to be tested. Carefully measure the plots and convert all data to a per-hectare basis before statistical analysis.

Number of replicates. The number of replicates depends on the precision required. Generally, better representation of the environment is achieved by having trials spread over a number of farms but a more sensitive statistical analysis is gained from within-farm replication. Little is gained by more than two replicates per farm and for farmer-managed trials, we recommend a single replicate per farm.

Consider how many replicates are needed to give adequate statistical precision, bearing in mind that variation is likely to be high and an equal number of replicates is required for each target group.

First, in the analysis of variance the number of degrees of freedom of the error term should be at least 15. With five treatments, this condition requires five replicates as a minimum.

The following reasoning (Cochran and Cox, 1957) will generally call for a number of replicates exceeding this limit.

Assume that the expected difference between the variables X1 and X2 (yield, monetary yield, etc.) is non-zero, that there is a real difference between treatments 1 and 2. If the difference exceeds a certain preset limit we want to be reasonably sure to detect it. In other words, we want a high probability, say 80%, that our statistical analysis will reject the null-hypothesis ("there is no treatment difference") if the real difference exceeds a certain limit. When this is worked out statistically for a t-test at 95% confidence level, the number of replicates required is:

$$k = 17.5\ (CV/f)^2$$

where k = number of replicates; CV = coefficient of variation; f = difference between treatment means the researcher wants to be able to detect, as a percentage of the trial mean.

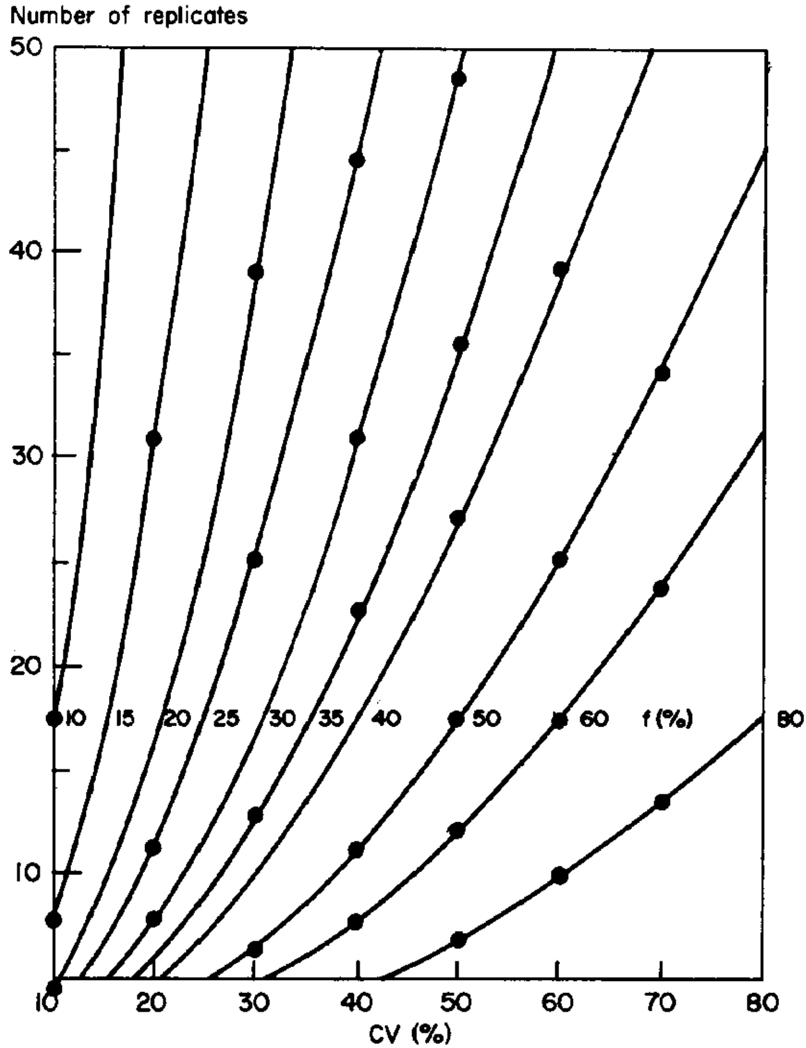

Fig. 20. Nomogram relating required number of replicates to coefficient of variation (cv) at different levels of true treatment difference that it is desired to detect (f).

The number of replicates (within or across farmers' fields or both) can be read from a nomogram based on the expression (Figure 20).

As an example, consider a trial that is expected (based on earlier experience) to have a CV of 25%. If researchers want to be 80% sure to detect treatment differences that exceed 40% of the trial mean, they need a minimum of seven replicates.

When treatments are few, the number of replicates required for at least 15 degrees of freedom for the error term in the ANOVA is sometimes higher than that indicated by the nomogram. The highest number of the two indicated should be taken.

The number of replicates needed to detect differences in treatment increases steeply with CV, and therefore, from researcher-managed to farmer-managed trials.

If you are not sure whether an innovation will work under farmer management, try it first with a few farmers and then run a full-scale trial the next year. Even with researcher-managed trials this is a wise strategy, particularly if an innovation has not previously been tested under farmers' conditions.

Choice of farmers and fields. Villages and farmers within villages should be as representative of the target group as possible. In particular, choose farmers who correspond to the age, wealth and sex of farmers in the study area, but avoid inaccessible farms. The same applies to land types and any other grouping that is relevant. For example, in a bush fallow system, trials of fertilizer rates may have to be carried out in fields at different stages of utilization (e.g. immediately after fallow and after a few years of cropping).

In the early phases of a testing program it will rarely be possible to achieve ideal representation of farmers.

Unscheduled variation between farms. Variation between farms can be caused by different plant densities, spatial arrangements and interplanting of minor crops. Although the best technical information is obtained when one eliminates all variation other than the treatments, the best feedback from farmers (and the most reliable indicator of adoption) is obtained from trials in which farmers are free to make and implement decisions. In researcher-managed trials, where replicates are few and technical information is the aim, standardize the nontreatment conditions, perhaps by using average densities observed in the area and planting minor crops uniformly over all treatments and at low densities.

In farmer-managed trials, where the aim is to have farmers assess an innovation, standardizing the trial conditions is artificial and often impossible. Be as flexible as possible and use statistical techniques to adjust for unscheduled variations. Some techniques are discussed in the section on statistical analysis.

Management, monitoring and evaluation

Management of enumerators and trials

Selection and training of field staff is perhaps the most difficult and yet most necessary component of good on-farm experimentation. Enumerators should live in the target villages and must be prepared to be available whenever they are needed rather than working office hours. They must be competent in both English and the local language, with knowledge about the locality and a sympathetic personality. Former extension staff or people with agricultural training do not necessarily make good enumerators because they may have been trained to regard indigenous farming methods as primitive and the opinions of traditional farmers as worthless. In areas where women are active on the farms, recruit some women enumerators.

Successful experiments are those in which the enumerator undergoes in-service training with the researcher. The researcher carefully explains the objective of each trial in the program and exactly how each is to be laid out and monitored. The enumerator must understand the distinction between researcher- and farmer-managed trials and that for researcher-managed trials, he or she has some obligation to persuade the farmer to follow the instructions exactly whereas for farmer-managed trials, the aim is reliable monitoring. Having taught this principle, the researcher must act consistently and not blame (or seem to blame) enumerators for unscheduled departures in farmer-managed trials.

Field record sheets and farmer questionnaires must be designed by the researcher in consultation with enumerators who must be trained to use them. Ask one enumerator to translate the questionnaire into the local language and another, independently, to translate it back. Then meet with both to discuss where the inaccuracies have arisen.

For farmer-managed trials with illiterate farmers, color-coding of the plots is essential. Each of the pegs demarcating a plot is painted in a clearly distinguishable color. Bags of seed and fertilizer and the bag into which the produce will be harvested are marked with the appropriate color. The researcher or enumerator explains to the farmer exactly what is to be done on each plot and tries to explain that the plots should differ only in the intended treatment. The enumerator should always be within reach to answer the farmers' questions or refresh their memory. While monitoring trials, enumerators may remind farmers about particular operations but should not seem to be demanding that they be done.

The purpose of monitoring and evaluation is to find out how innovations perform on farmers' fields, with farmers managing them and whether or not the innovations are, or can be made, acceptable to farmers.

Also the data each year are reviewed so the research team can decide which trials to continue, which to drop and whether the design or operational procedures need to be modified. New trials are also considered. This annual exercise is undertaken after the results for each trial are available and before the next season's planting, so time is always pressing and the temptation is to perform an abbreviated analysis. However, every 2-3 years, set aside time for a full analysis, and write up the results for a wider audience.

Table 27. Checklist of information to be collected at different stages of testing of innovations [a)]

Part I. Information to be collected when selecting farmers and fields, probably by an enumerator except 5, which needs an agronomist or soil scientist.

1. Name and approximate age of the farmer. Time for which he or she has lived in the village. Ethnic allegiance, educational level, gender and status in the household (e.g. head, first wife, unmarried son, etc.).
2. Size and structure of the family and especially the labor force by age and gender.
3. Approximate size and location of fields other than the trial site. Land type and planned cropping pattern of each field in the year of the trial.
4. Soil sample(s) from the trial site for routine laboratory analysis. (Subdivide if differences in slope, drainage, proximity of trees, etc.).
5. Field description of the trial site: soil texture to auger depth, drainage, depth, position in toposequence, land type, land history (duration of last fallow; cropping patterns since last fallow, fertilizer and manure applied since last fallow [or last 3 years in permanently cropped land]).

Part II. Information to be collected during the growing season by enumerators who are supervised and frequently advised by senior personnel in the project.

6. Daily rainfall in each research village.

7. Dates of all operations, time spent on each plot and types of labor (man, woman or child; family, exchange or hired). Tractor or draft animal time when appropriate. Farmer's estimate of cost per work day of hired labor at that time of year. (Enumerator either observes the operations or visits regularly and asks the farmer to recall the date and times spent on operations).

8. Emergence counts of each crop in each plot. Exact dimensions of each experimental plot. (Enumerator to count and measure.)

9. Names of all varieties planted including local names where appropriate. Amounts of all material inputs used by plot (seed, fertilizer, crop protection chemical). (Not always easy; farmers may divert fertilizer to other fields. If it happens, then try to ascertain actual quantities applied to research plot). Farmer's estimate of cost of each item if purchased without help (record units).

10. Scores of weed infestation by plot at weekly intervals (general weediness and specific problems if present).

11. Scores of specific pests and diseases by plot at weekly intervals as they occur.

12. Scores of crop vigor by plot for each crop at weekly intervals.

13. Dates of flowering of each crop by plot, dates of physiological maturity where this can be easily assessed.

Part III. Information to be collected at harvest of each crop. The enumerator should be present if possible. Weigh and count all produce by plot; if piecemeal harvesting is the normal practice, then take samples. Use the same sampling procedure in every plot on one farm and record it clearly.

14. Stand or plant count by plot of crops to be harvested, lodging count if appropriate, counts of barren or diseased plants.

15. Number of units (maize ears, sorghum heads, yam tubers etc.) by plot and by grade (ware and seed, filled heads and partially filled heads, etc.).

16. Weight of product by plot and grade (product = crop as carried from the field, i.e., often unthreshed).

17. Drying and threshing percentage of a small subsample from each plot and grade (buy it and carry to the lab if necessary).

18. Labor inputs for harvesting by labor type (see 7 above) and by plot. Farmer's estimate of daily wage rate at the time.

Part IV. Information to be collected at the interview with the farmers at the end of the season. A questionnaire is essential for enumerators.

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19. Farmer's perception of the yield of improved and conventional plots.

20. Farmer's perception of the quality of the improved and conventional product (color, cooking quality, processability, taste, storability, etc.).

21. Farmer's estimate of the market price of the improved product at the time of harvest and at the seasonal peak. Prices of the conventional product at the same times. (Use units understood by the farmer, e.g., bags, calabashes).

22. Farmer's perception of the effectiveness of an innovation (herbicide, insecticide, fertilizer, new cropping pattern).

23. Farmer's intention to use or abandon the innovation next year. For a "package", this question should be broken down to include each element of the package.

24. Farmer's comments on other matters.

Part V. Information to be collected when farms are visited during the season following that in which trials were held.

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25. Farmer's adoption or discontinuance of the innovation. Confirm by observation, and tackle each element of a package separately.

26. Reasons for decision (adoption or not). If yes, repeat 19 to 22 in the checklist.

27. Adoption's effects on the farming system (change in cropping pattern, adjustment of farm size, change in labor use etc.).

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[a] The information in this checklist may not be relevant or sufficient for all innovations. Draw on it for questionnaires and record books.

For every trial:

- Describe cooperating farmers and their fields (part I of the checklist of Table 27);

- Monitor all field operations, regularly discussing the progress with enumerators who are collecting the information (parts II and III of the checklist);

- Carry out informal interviews with the farmers; and

- Prepare enumerators to administer closed-sequence questionnaires to farmers at the end of the season (part IV of the checklist).

In the early stages of an on-farm research project, contact farmers and interview them informally to pinpoint flaws in questionnaires, choices of innovations, and trials. Record the farmers' views in a notebook or in the logbook for the trial. Later, enumerators can take on most of the interviewing, using closed-sequence questions that can be analyzed by computer. In the advanced stages of testing an innovation, larger numbers of farmers are involved, and researchers cannot regularly interview all of them. Therefore, the emphasis shifts from informal interviewing by the researcher to questionnaire interviews (Table 28) by the enumerators.

Table 28. Example of closed sequence questions

Do you consider the quality of the introduced maize variety to be:

i. better than the local? _____

ii. as good as the local? _____

iii. worse than the local? _____ (tick one)

If better than the local, is:

i. the color more acceptable? _____

ii. the food from it better tasting? _____

iii. there some other reason? _____

Specify: ____________________

If worse than the local, is:

i. the color less acceptable? _____

ii. the food from it less tasty? _____

iii. there some other reason? _____

Specify: ____________________

Design record sheets and questionnaires for enumerators to use in their weekly farm visits to record emergence and stand counts, vigor and disease scores, etc. Farmers are asked to recall and report dates and times spent on each operation. The arrangements for recording the harvest of the trials are much more difficult, and the details are best left to individual farmers and enumerators. If harvest is a once-only, rapid operation, the best solution is to ask the farmer to summon the enumerator to weigh and subsample the produce while it is still in the field, indeed while still on the plot from which it was harvested. If this is not possible, the farmer should be asked to keep the produce in color-coded bags or bundles in a special place until the enumerator can weigh it. Sometimes, with piece-meal harvest of crops, the yield will have to be estimated from farmers' recall. Have enumerators record when figures are estimates rather than measurements, and be sure that the estimates are realistic. The end-of-season interview should be carried out at a time when no one feels hurried. Be present for a proportion of the interviews, especially when using inexperienced enumerators.

To supervise the enumerators, look at the record sheets and completed questionnaires whenever visiting a farm. Check that the records are consistent with what is on the ground and what the farmers say and do. It is much easier to correct errors and misunderstandings at this stage than at the end of the season. If given tactfully, criticisms help enumerators improve their skills.

Statistical analysis

The statistical principles of on-farm trials do not differ from those of station trials, but some features that influence the analyses are more common in on-farm trials than in station work.

Which variable to analyze? In mixed cropping, the market value (gross return) of the whole cropping pattern, including "unscheduled" minor crops, is the principal focus of analysis. For each plot on each farm, sum up the yield and commodity price for each crop species. Using market value allows you to judge the effect of an innovation on the entire cropping pattern. Also look at effects on yields of each crop independently.

Since we do not generally grow the sole crops, there will be no basis for using the land equivalent ratio but grain equivalents or total calories or protein are possible alternatives to market value.

Accounting for differences in treatment effects between farms. In many on-farm trials, particularly those with much farmer involvement, no within-farm replication is used and a farm constitutes one replicate or block. In station trials, differences among blocks are of little interest and only serve to account for physical variation in the experimental field, but in on-farm trials, differences between "blocks" occur because of soil fertility, management practices, such as timeliness of weeding, plant arrangements, etc. These differences influence the expression of the treatments: a new variety may do much better than a traditional one under good management but not so under poor management. In statistical terms, we expect an interaction between management level and treatments. In fact, information about these interactions is the key to assessing the innovations.

As a first approach, tabulate the number of farmers who had increased yields associated with an improved variety or practice. Suppose a simple variety trial included 20 farmers comparing three new varieties with their local one (Table 29).

On the basis of the means, one variety (C) looks best, but farm by farm, the data indicate that it had very high yields on a few farms. Many farmers got better results with a different varie-

Table 29. The yields of four maize varieties in on-farm trials and the number of farmers who got better yields from the improved variety than from the local one

Variety	Yield kg/ha	Farmers on whose farm the variety outyielded the local	
		Number	Percentage
Local	853	-	-
A	1064	15	75
B	872	9	45
C	1235	12	60
SE	45.0		

ty (A). The final choice depends on the farmers' reactions as found in the end-of-season questionnaires. In a rate-of-fertilizer trial, tabulate the number of farmers for whom each successive increment in fertilizer gave an improved yield.

Where tabulations suggest that the distributions by farm are of interest, prepare histograms of frequency distribution for each variety or other innovation. Choose an interval that divides the results for the control into about four classes and then, for comparison, use the same interval to divide the results for the innovations (Figure 21).

Or, for a more quantitative approach, assume that the quality of management, fertility level, etc. are reflected in the overall mean yield of the replicate in a particular farm. Then, calculate how the treatments interact with the mean yield (Morris, 1981). This is in essence the same as the "stability analysis" proposed by Hildebrand (1984). Graphically represent the relation between average yield and treatments to clarify the differences among farmers (Annex II).

One can use any other measured quantity in the same way, such as weediness of the fields, planting dates, planting density, etc. Such

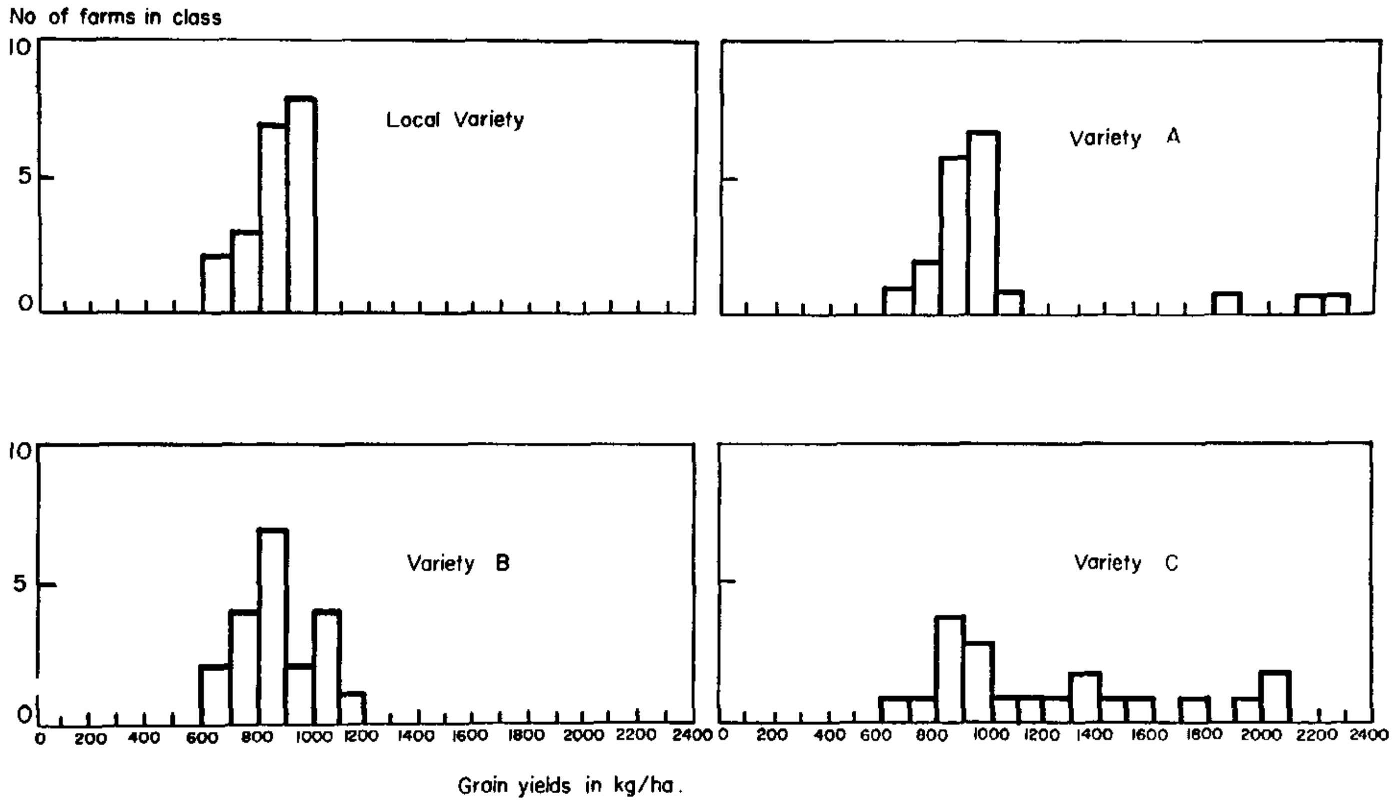

Fig. 21. Histograms of the distribution of yields of 4 varieties on 20 farms arranged in class intervals of 100kg/ha.

quantities sometimes reveal the causes of variation in treatment effects between farms and help in formulating recommendations. Consult a statistician to help with this analysis.

Economic analysis

A popular and powerful tool for economic analysis is partial budgeting. As the name indicates, the technique employs only a portion of the information required for a whole budget analysis; it is simple but applicable only to a limited number of problems, when the changes called for by the innovation are relatively small. It measures changes in income and returns to limited resources, provides a limited assessment of risk, and suggests a range of prices or costs at which a technology becomes profitable, that is, sensitivity analysis.

Partial budgeting. The aim of partial budgeting is to estimate the change that will occur in farm profit or loss from some change in the farm plan (Boehlje and Eidman, 1984, p. 237). Partial budgets do not calculate the total income and expenses for each of two plans but list only those items of income and expense that change. The goal is to estimate the difference in profit or loss expected from the plans or technologies (Table 30).

First select a plan as the basis for comparison and use it to establish the items to be compared. Then decide the time and location for which to compare the alternatives. For example, to compare no fertilizer use versus fertilizer use on plots of maize, you could use planting as the starting point (assuming that land preparation is the same for both treatments) and the date of harvest as the end point.

Having determined the time span you can list all the operations that occur during the period, for example, planting, tilling, weeding, thinning,

Table 30. Partial budgeting format (Boehlje and Eidman, 1984, p. 237).

1. **Additional income**: list the items of income from the alternative plan that will not be received from the base plan.

2. **Reduced expenses**: list the items of expense for the base plan that will be avoided with the alternative plan.

3. **Subtotal**: 1 + 2.

4. **Reduced income**: list the items of income from the base plan that will not be received from the alternative.

5. **Additional expenses**: list the items of expense from the alternative plan that are not required with the base plan.

6. **Subtotal**: 4 + 5.

7. **Difference**: 3 - 6: A positive (negative) difference indicates that the net income of the alternative exceeds (is less than) the net income of the base plan by the amount shown.

application of herbicides, pesticides and fertilizer. Check whether the quantities of the factors of production -- purchased inputs, equipment, labor and capital -- differ between the two treatments. List income derived from the enterprise -- cobs harvested green, grain, stover, etc. -- and again check for differences (Table 31).

Table 31. Checklist for costs and benefits of the base and alternative plans in partial budgeting

Costs

1. Identify all operations that will be performed differently from variety to variety or treatment to treatment, including:

   . Land preparation;
   . Planting (density, technique, seed);
   . Weeding/cultivating;
   . Thinning; and
   . Application of pesticides, herbicides and fertilizer

2. For each operation, note the inputs that differ and estimate the quantities required: chemicals, labor, equipment, capital.

3. Determine the "field price" of:

   . Purchased inputs
     - retail price for the appropriate size of package and
     - transport or other costs

- Equipment
  - retail price;
  - average years of life;
  - hectares cropped by average farmer in area; and
  - inputs required to operate the equipment (batteries, gasoline)

- Labor
  - agricultural wage during the relevant season;
  - full employment or slack employment period; and
  - other costs of hiring labor e.g. transportation, meals

- Capital
  - loan rate;
  - fees to be paid; and
  - insurance

4. Identify all costs to be paid from harvest to marketing the crop:

   - Shelling/threshing;
   - Bagging;
   - Storage; and
   - Transportation

Benefits

1. Identify all series of potential benefits that vary from treatment to treatment or variety to variety:
   - Grain;
   - (For maize) cobs harvested green;
   - Fodder; and
   - Residue for livestock bedding

2. Determine the market price for all benefits or estimate a value that could be obtained if the item were sold. Record quality discounts.

Analysis

1. Calculate per-unit costs; and
2. Subtract the costs from the market price.

The next step is to convert the identified quantities into costs and revenues. The farmer's field is the reference location, so calculate the value of all inputs and outputs as they are ready to be used or sold in the field (i.e. establish the "field price" of inputs and outputs). To the market price of, say, fertilizer, add transport costs from the market to the field. If the standing crop is sold to a contractor, then the contractor bears the costs of marketing and handling so the price he or she pays will take these costs into consideration. Use exact values for items that are purchased or sold, and assign a monetary value for all other inputs.

Table 32. Yields (t/ha) of maize grain (14% moisture) from plants fertilized with four levels of nitrogen and three levels of phosphorus in eight trials (figures are average of three replications) (Perrin et al., 1976)

Trial		Fertilizer treatment (kg/ha)											
	N:	0	50	100	150	0	50	100	150	0	50	100	150
	P_2O_5:	0	0	0	0	25	25	25	25	50	50	50	50
1st year													
1		0.40	1.24	3.63	3.76	0.79	2.58	4.23	4.72	1.67	2.51	3.28	3.66
2		1.53	2.60	5.14	5.32	1.67	3.79	5.10	6.83	1.41	4.13	5.89	6.27
3		4.15	4.86	4.80	4.87	4.44	5.00	4.97	5.28	5.12	5.66	6.36	6.62
4		2.42	3.82	5.23	4.48	2.36	4.54	6.26	7.17	1.61	4.41	5.38	6.58
2nd year													
5		1.64	1.92	2.08	2.19	2.04	3.21	3.12	2.93	1.44	3.44	3.32	3.62
6		1.61	2.94	4.14	4.34	1.81	3.92	3.61	3.81	1.18	3.89	5.38	4.92
7		4.74	5.41	4.29	4.92	4.91	5.22	5.38	5.14	5.10	4.88	4.54	5.28
8		1.21	2.33	1.97	2.23	1.53	2.78	2.49	2.80	1.37	3.51	3.75	4.35
Average		2.21	3.14	3.91	4.01	2.44	3.88	4.40	4.84	2.36	4.05	4.74	5.16

For inputs that are not purchased or outputs that are not sold, employ the opportunity cost, which is the value of any resource in its best alternative use.

Consider the opportunity cost of the farmer's time. If a farmer has a job off the farm and has to give it up temporarily to weed the maize field, then the opportunity cost of the time weeding maize is the wages that would have been earned on the job instead. In many cases, a market exists for the inputs and outputs that the farmer does not purchase or sell. Use the market price when available, and estimate the other opportunity costs.

The analysis can be applied to recommending rates of fertilizer. Suppose we have identified an agroclimatic zone and a group of farmers whose farms and practices are similar. We have conducted fertilizer trials on four farms over two years, and have data on the response of a new maize variety to nitrogen for three levels of phosphorus (Table 32, Figure 22).

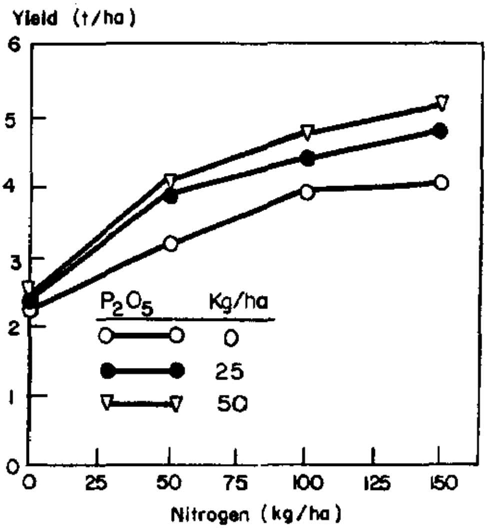

Fig. 22. Average yield response to nitrogen (Perrin et al. 1976, p. 10).

Table 33. Partial budget analysis of fertilizer treatments as derived from average yields of maize in eight trials (Dillon and Hardaker, 1980)

	Budget element		Fertilizer treatment (kg/ha)											
		N:	0	50	100	150	0	50	100	150	0	50	100	150
		P_2O_5:	0	0	0	0	25	25	25	25	50	50	50	50
1	Average yield (t/ha)		2.21	3.14	3.91	4.01	2.44	3.88	4.40	4.84	2.36	4.05	4.74	5.16
2	Net yield (t/ha)		1.99	2.83	3.52	3.61	2.20	3.49	3.96	4.36	2.12	3.64	4.27	4.64
3	Gross field benefit ($/ha @ $1000/t)		1990	2830	3520	3610	2200	3490	3960	4360	2120	3640	4270	4640
4	Nitrogen ($8/kg N)		0	400	800	1200	0	400	800	1200	0	400	800	1200
5	Phosphate ($10/kg P_2O_5)		0	0	0	0	250	250	250	250	500	500	500	500
6	Variable money costs ($/ha) (4 + 5)		0	400	800	1200	250	650	1050	1450	500	900	1300	1700
7	Number of applications		0	1	2	2	1	1	2	2	1	1	2	2
8	Cost per application (2 work-days @ $25)		50	50	50	50	50	50	50	50	50	50	50	50
9	Opportunity cost ($/ha) (7 x 8)		0	50	100	100	50	50	100	100	50	50	100	100
10	Total variable costs ($/ha) (6 + 9)		0	450	900	1300	300	700	1150	1550	550	950	1400	1800
11	Net benefit ($/ha) (3 - 10)		1990	2380	2620	2310	1900	2790	2810	2810	1570	2690	2870	2640

The next step is to convert the physical data into monetary values for the partial budget analysis (Table 33). The contractor who harvests the maize is not interested in the yields the researcher measured. He or she needs to offset costs in harvesting and transportation as well as spoilage. Let us assume the contractor discounts yields by 10% and pays $1000 per tonne. From these benefits, all the costs that vary with treatment have to be subtracted. The analysis shows that an application of 100 kg of nitrogen and 50 kg of phosphorus yields the highest net returns per hectare. Should this be the recommended rate of fertilizer? Not necessarily, because no consideration has yet been given to capital scarcity, yield uncertainty and risk aversion.

Capital scarcity. When recommending inputs such as fertilizer, consider the costs of the capital to buy the inputs. The cost of capital is direct if the farmer has to borrow money; it is indirect if the capital is available but could be invested in some other enterprise. The cost for capital in developing countries is high. In general, the rate of return on working capital over the cropping season should be at least 40%.

To proceed, plot the net benefits per hectare against the variable costs (Figure 23). Some treatments are clearly "dominated", that is, for the same variable costs they yield lower net returns. Connect the points with the highest net returns per variable cost to form a net benefit curve.

Average versus marginal analysis. Then, for the highest net return calculate the average rate of return on investment [($2870-$1990)/$1400 = 63%]. If this figure exceeds the target of 40%, the innovation deserves further analysis. However, it is not ready to be recommended because the judgment so far has been based on an average figure.

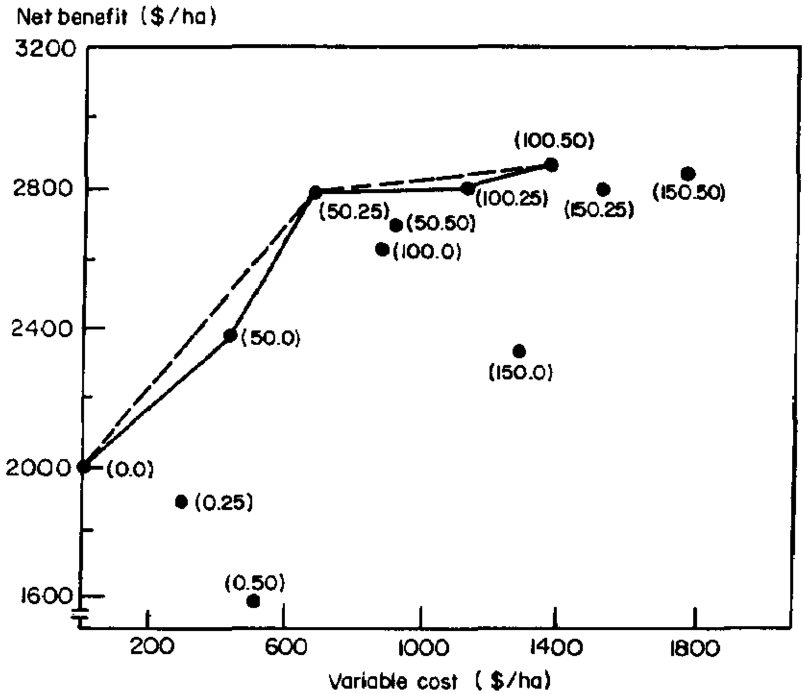

Fig. 23. Net benefit curve for fertilizer trials. Numbers in parentheses represent kg/ha of N and P_2O_5 respectively (Perrin et al. 1976, p. 16).

To decide on an investment, people normally ask: what is the return to the additional amount of capital I wish to invest? Economists call this the marginal rate of return to investment.

For example, an application of 50 kg of nitrogen and no phosphorus (50,0) rather than no fertilizer may add costs of \$450, whereas the additional net returns are \$2380 - \$1990 = 390. The marginal rate of return is 390/450 = 87%. For 50 kg of nitrogen and 25 kg of phosphorus, the added investment is \$250 (700-450), and the marginal net benefit is \$410 (\$2790-2380). The marginal rate of return is 410/250 or 164%. The marginal rates of return to 100 kg of nitrogen and 25 or 50 kg of phosphorus are 4% and 24% respectively. Thus, the recommended rate of fertilizer is 50 kg of nitrogen and 25 kg of phosphorus (50, 25). But what about the risk of failure?

Variability of net returns. Risk, especially for small farmers, is paramount. In an agricultural setting there are two sources of risk, variability in prices and variability in yield. The effects of the latter can be assessed by minimum return analysis, those of the former, by sensitivity analysis.

As its name indicates, minimum return analysis means looking at the minimal or worst returns in yields. Yields vary because of differences in space, time and management levels. Look at the net benefit for each site based on constant prices (Table 33); then examine the worst 25% or so of the outcomes of the trials (Table 34). If the recommendation derived from marginal analysis shows outcomes that are lower than those for current practices, reconsider the recommendation. If the outcomes are higher, have some confidence in the recommendation (for example, the recommended fertilizer level leads to a high average of the two worst outcomes). But supplement the analysis with a careful look at prices.

Table 34. Minimum returns from 12 alternative fertilizer investments (Dillon and Hardaker, 1980, p 99)

Fertilizer treatment (kg/ha)	Net benefit: Worst	Second worst	Average of worst two observations
(0,0)	360	1090	725
(50,0)	670	1280	975
(100,0)	870	970	920
(150,0)	670	710	690
(0,25)	1080	1200	1140
(50,25)	1620	1800	1710
(100,25)	1090	1660	1375
(150,25)	970	1090	1030
(0,50)	510	680	595
(50,50)	1310	2150	1730
(100,50)	1550	1590	1570
(150,50)	1460	1490	1475

Sensitivity analysis. Prices vary from year to year. Also, some items in the partial budgets are estimates. Use sensitivity analysis to assess the range of prices for which recommendation would not change.

Suppose that output prices fluctuate widely from year to year. Farmers are expected to use more inputs when output prices are high. Also, if prices fall below a critical level there is no incentive to use additional inputs. In the case of recommended rates for fertilizer, the relevant questions are: What is the lowest output price level that will induce farmers to apply fertilizer? At which price level would the recommendation change -- for example, from 50 kg N, 25 kg P to 100 kg N, 50 kg P? Note that the farmer will not consider the rate of 100 kg N, 25 kg P. If the output price is high enough that this rate becomes profitable, the rate of 100 kg N, 50 kg P would also be profitable.

The relevant question thus becomes: At which output price is the marginal rate of return for the step from 50 kg N, 25 kg P to 100 kg N, 50 kg P at least 40 percent?

The calculation would be

$$[(4.27P_u - 1400)-(3.96P_u-1150)]/(1400-1150) = 40$$

Therefore, P_u = 1129, where P_u is the top of the price range that is suitable for a recommended rate of 50 kg N and 25 kg P. Thus, if the price of maize rises above $1129 per tonne we should recommend 100 kg N and 50 kg P. The calculation for no fertilizer use would be

$$(3.49\ P_1 - 700 - 1.99\ P_1)/700 = 40$$

Therefore, P_1 = 653, where P_1 is the price below which no fertilizer should be recommended. Or to state it differently: If prices stay in the range of $653 and $1129 per tonne we can be confident that the recommendation is correct. Using the same procedure we can establish ranges for prices of inputs.

Summary. Partial budgeting is appropriate for assessing technologies that involve small changes. The key steps in data collection are:

- Define a target group or area;
- Define a time and a location for which alternatives are to be compared;
- Identify all variable inputs that are affected by the choice of alternatives;
- Select a series of relevant input levels;
- Conduct on-farm trials covering a sufficiently large area to capture yield variations within a year; and
- Repeat trials over years to capture yield variability over time.

Farmer assessment

Few workers, so far, have reported quantitatively on farmers' reactions to innovations in their trials but for the farmers, not just the yields decide whether an innovation is adopted. Prepare a table (Table 35) to incorporate information derived from part IV of the checklist for monitoring on-farm trials. For example, in a comparison of three improved and a local maize variety (Table 31), farmers' perceptions of yields were in fair agreement with the measured yields. They were not too impressed with the quality of the improved varieties, commonly criticizing both flavor and color of variety A. Most farmers thought that varieties A and C would fetch similar or lower prices than the local but one farmer thought that B might sell for a higher price. Variety C was the one that most farmers expressed

Table 35. Farmer assessments of three improved maize varieties compared with a local control

	% of respondents choosing variety:			
	Number of responses analyzed	A	B	C
Farmers who believed variety:				
Yielded more than local	18	56	11	44
Had better quality than local	15	27	40	30
Didn't have color as good as local	15	67	7	7
Didn't taste as good as local	10	40	10	10
Farmers' estimate of market price:				
Better	17	0	6	0
Same		41	82	71
Less		59	12	29
Farmers who intend to use it next year:	18	11	22	39
Other matters commented on:				
More susceptible to lodging	10	0	100	0

interest in growing next year. The only other comment forthcoming was on B's poor resistance to lodging.

If at all possible, revisit each cooperating farmer during the season after that in which trials were placed to see whether he or she has adopted the innovation tested. Some questions that can be asked are shown in part V of the checklist.

Annex 1

Review of basic economic principles

Annex 1: Review of basic economic principles

Physical scientists who are working with farmers to help overcome problems of the physical and biological environment sometimes forget the economic and social factors that influence farmers' decisions. An example of what can happen as a result was given during a workshop about on-farm research at Nyankpala, Ghana (Steiner, 1984a).

Maize breeders and agronomists in Malawi developed a technical package to increase maize production in the early 1980s. The recommendations were to plant a new variety as a sole crop and to apply a high level of nitrogen fertilizer to it. To promote the package, the government gave farmers free seed and the required amount of fertilizer at a subsidized price. Farmers took the seed and gave it to their wives to cook (fortunately it was not treated with chemicals). They continued to intercrop their maize with other crops, and they distributed the fertilizer over all fields.

This review is an attempt to explain some of the reasoning behind their -- and other farmers' -- actions. Farmers have an intuitive grasp of basic economic principles, and much more formal expositions of this subject can be found in the standard literature (Doll and Orazem, 1978; Boehlje and Eidman, 1984).

Inputs can be applied in various amounts. A field can be weeded only once, twice or every week; one, two, 10 or more bags of fertilizer can be applied. The question for the farmer is how much of a variable input should be applied. An answer to this question can be obtained by an investigation of the production function or response curve.

The production function or response curve

Production functions portray an input-output relationship. They describe the rate at which resources are transformed into products. To demonstrate basic decision rules it is assumed that all input factors except one are held at the same level. The response to a variable factor can be charted on a graph whereby output (Y) is shown on the vertical axis and variable input (X) on the horizontal axis (Figure 1.1). Two concepts help to determine the amount of input a farmer should use, **the Marginal physical product** (MPP) and the **Average physical product** (APP). The MPP is the change in output resulting from a unit change in variable input, change in Y/change in X, or dy/dx.

For the first step (Figure 1.2), for example, output rises from zero to about four (i.e. the MPP is four); for the second step output increases from four to 12. Thus, the additional output for one additional unit of input is eight. As input continues to increase, MPP increases and then declines. Beyond a certain level, additional units of input may even cause output to decline. The initial phase of increasing MPP may not exist for all inputs, but the MPP will always eventually decline. This is known as **the law of diminishing returns**: if increasing amounts of one input are added to production while all other inputs are held constant, the amount of output added per unit of variable input will eventually decrease.

When the total amount of output, Y, is divided by the total amount of input, X, the result is APP — how much output, on average, is produced per unit of input. Thus APP is a measure of technical efficiency.

Efficiency can be measured for any point on a response curve; it is equal to the tangent of the angle under the line joining the origin and a point on the curve (Figure 1.3). This angle becomes larger until the line from the origin to a point on the curve is tangential to the curve. Beyond that point, efficiency declines again.

Suppose that a farmer has only one enterprise or activity, for example, he or she grows maize on

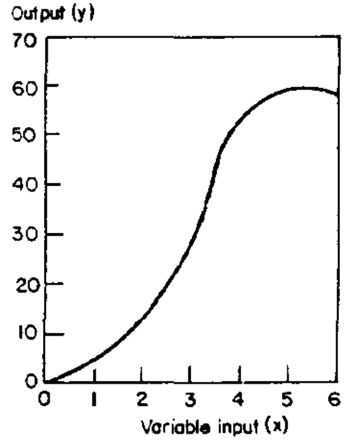

Fig.I.1. Response curve indicating increase in output as a reflection of increases in a single input.

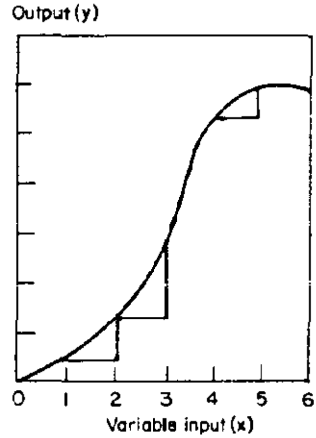

Fig.I.2. Increments in output eventually decrease with additional increases in a single input.

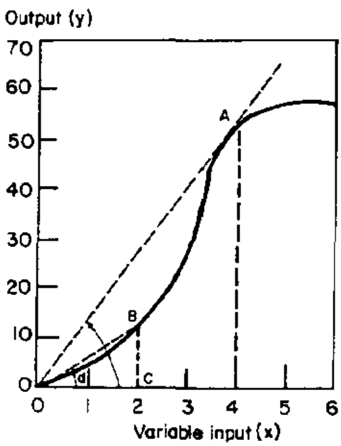

Fig.I.3. The technical efficiency is equal to the distance from O to the Y-coordinate divided by the distance from O to the X coordinate (angle a in the triangle OBC) Efficiency declines at A.

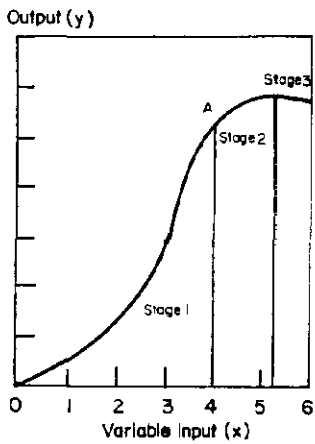

Fig.I.4. Three stages of the production function with stage 2 being the level at which farmers attempt to operate.

one field. How much of an input, say nitrogen fertilizer, should be applied? An indirect way to answer this question is to find the level of fertilizer application that is definitely reasonable and the level beyond which application is unreasonable.

Farmers will never apply fertilizer beyond the level at which output is maximum, since additional fertilizer causes output to fall (i.e. MPP is negative). The range beyond maximum output is called stage III of the production function (Figure 1.4). Also farmers always attempt to reach the maximum technical efficiency of an input. Thus the range of the production function where efficiency is still rising, stage I of the production function, can also be ruled out. Farmers wish to operate between the point of maximum technical efficiency of input, where APP is maximum, and the point of maximum output, where MPP = 0. This is stage II of the production function.

The information provided by physical scientists can be used to narrow the range of rational behavior to stage II but farmers want researchers to be more specific. Additional assumptions and information are required to locate a point within stage II. This is where economics comes in.

A standard assumption is that farmers wish to maximize profit and that they can purchase as much input as they wish. To find maximum profit, one needs to collect information on costs of the input and prices of output because a farmer will compare the value of the additional unit of output with the costs of the additional unit of input. As a measure of the value of additional output, the marginal physical product can be multiplied by its market price, MPP*Py. This value is called **marginal revenue** (MR). The costs of an additional unit of input are called **marginal** cost (MC). As long as MR exceeds MC, it pays to apply more of the input. When MR equals MC, the additional costs are recovered, but the use of more input becomes uneconomical.

The profit-maximizing rule is: apply the variable input until MR = MC. But this point varies with changing input and output prices. As farmers cannot anticipate at planting time what the final output and its price will be, they have to use their judgment.

Input efficiency is a technical concept, and is based on an average. The farmer looks at the economics and employs the concept of a margin. At the beginning of stage II the additional revenue generated by the input still exceeds the additional costs. Clearly, the farmer should apply more input but at maximum output marginal costs generally exceeds MR. So the farmer seldom produces maximum output. The one exception is when an input is free.

Most often, especially in developing countries, farmers cannot purchase as much input as they wish. Profit must be maximized under an input constraint, but the economic reasoning is the same.

The farmer will not be able to realize the point where MR equals MC but will remain at a point on the function where MR exceeds MC. This point may very well lie in stage I.

The question then becomes: is there a level at which it is unprofitable to use the variable input? At low levels of input, the output may respond negligibly to the input such that MC > MR. The threshold of profitability cannot be determined from physical data alone; economic analysis is required.

In summary, variable input can be profitably used where MR exceeds MC. Along the production function, an input is never economical in stage III, as output declines with additional input. If an input can be purchased in unlimited quantities, the most profitable point of production lies in stage II where MR = MC. If the input is limited it is profitable as long as MR is greater than MC in stage I or stage II.

The equal marginal returns principle

Farmers usually have several enterprises and limited inputs. Still, they wish to maximize returns to their resources. How should the resources be allocated to the various enterprises?

The rule to allocate a limited amount of available input to multiple outputs is referred to as **the equal marginal returns principle.** Stated simply, the principle is that the returns from a limited resource are maximized when the input is allocated to its most profitable uses and the value added by the last unit of the resource is the same in each of its alternative uses.

Take southwestern Nigeria as an example. Here, labor at weeding time is scarce and land is abundant (Palada et al., 1985). Suppose a farmer grows one crop on two identical fields. The response curves for the fields are identical. Multiplying each level of output by its price and subtracting the costs of labor indicates net returns (Figure 1.5). Suppose the farmer has 20 days of labor available at weeding time. At planting time he or she has to decide whether to plant two fields or only one. The farmer reasons that by applying the first 10 days of labor to the first field, he or she can increase returns from zero to 50 units. The remaining 10 days if also applied to the first field, will increase returns by 30 units from 50 to 80. However, if applied to the second field, the 10 days of labor would mean additional returns of 50 with a total of 100 instead of 80. Consequently, he or she will distribute the scarce labor at weeding time over the two fields.

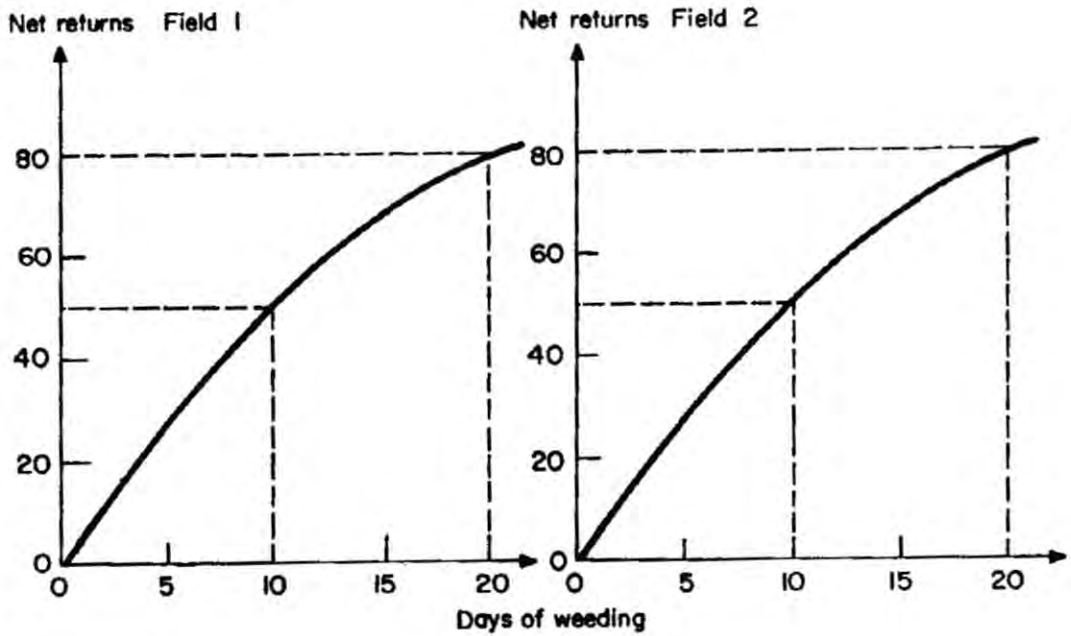

Fig.1.5. Net returns per day of weeding.

Suppose now that the fields differ, that the crops respond differently to weeding and that output prices differ. Let the net returns for each additional 5 workdays be 50, 40, 30, 20 and 10 units on the first field and 25, 15, 10 and 5 on the second field. The farmer maximizes returns to labor by working on the first field for 15 days and for 5 days on the second.

Since the labor yields different returns from the two fields, it can be considered as being two different inputs, say labor 1 and labor 2 and they can be ranked by value. Labor 1 is more valuable than labor 2 since five more units of labor 1 increase net returns by more than five more units of labor 2. In other words, returns to scarce resources are maximized when they are allocated to the most profitable uses and the value added by the last unit of each resource is the same in each of their alternative uses.

The implications of the principle of equal marginal returns are often visible in the way people farm. In southwestern Nigeria, farm size is limited by labor. Farmers attempt to be on that part of the response curve where returns per unit of labor are highest. They crop as much land as possible. Doing so, their weeding is "poor" but economical. Weedy fields thus may indicate that labor rather than land is the constraint. Where land is scarce, farmers will most likely have only one field and then, of course, use all the labor there.

In many areas fertilizer is in short supply. Farmers apply fertilizer to the crop that responds best to it, usually maize. They rarely apply the quantity recommended to them as "optimal", choosing instead, to spread the amount they can obtain over a larger area.

The principle has implications for trial design, so explore carefully the response curve of crops to scarce inputs. For nitrogen use on

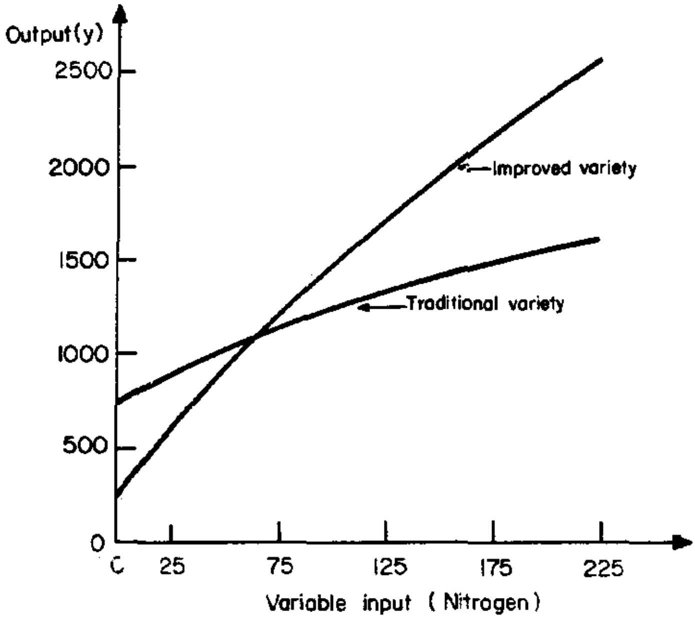

Fig.16. Hypothetical response of two varieties to nitrogen fertilizer.

maize, a traditional variety could be compared with an improved variety and the recommendations for low levels of fertilizer may be different from those at higher levels. Suppose the response curve of the improved variety lies below that of the local variety at low levels of N (Figure 1.6). At high levels, however, yields of the improved variety exceed those of the traditional one. A poor farmer who has no access to fertilizer is better off planting the traditional variety, while a richer farmer who can purchase fertilizer should adopt the new variety.

The product-product frontier

Suppose a farmer has a field that could be planted to maize or cassava. It could be divided into a maize and a cassava plot or it could be intercropped. The farmer also faces the question: How much of each product should be produced? The concept of the product-product frontier helps to answer this question.

The **product-product frontier** is a technical relationship depicting the maximum amount of one product, Y_1, that can be produced for alternative levels of a second product, Y_2, with a specified set of resources. Thus, the product-product frontier shows the maximum quantities of output that a farmer can produce with the resources available.

For simplicity, assume that production costs are the same for both crops. Prices of output, are, however, different. Suppose an experiment with cassava and maize as sole crops has shown that when the populations of the plants are increased both crops have diminishing returns. Suppose that intercropping and substituting maize for cassava increases maize yields but only at the

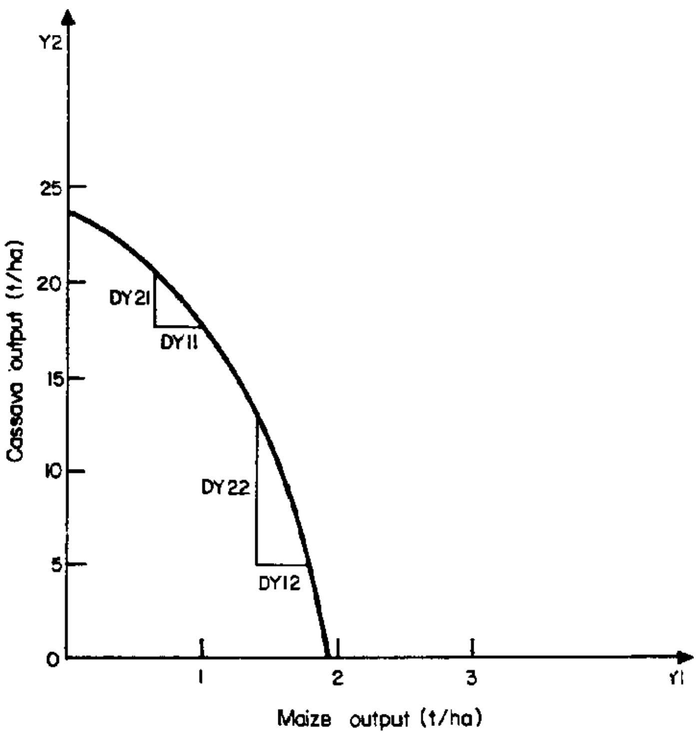

Fig. 1.7. Product-Product Frontier for Competitive Enterprises.

expense of cassava yield. The relationship between the cassava and the maize is called competitive (Figure 1.7). Let cassava output be called Y_2 and maize output Y_1. From sole cassava, a maximum of Y_{20} can be obtained (Figure 1.7). As the cassava population is reduced, cassava yields diminish but maize output increases. Let the change in cassava output be DY_2, the change in maize output be DY_1. As maize is substituted for cassava the additional output of maize per unit of cassava is high initially but becomes smaller and smaller because of the law of diminishing returns.

Suppose the farmer grows both crops for cash, what should be the most profitable plant populations for cassava and maize? The additional revenue from maize is the increase in maize output times its price, $DY_1 * PY_1$. The loss in cassava revenue is the reduced cassava output times its price, $DY_2 * PY_2$. As long as the additional revenue exceeds the reduction, the farmer will continue to increase maize output. Maximum returns will be obtained where additional maize revenue just equals reduced revenue from cassava, $DY_2 * PY_2 = DY_1 * PY_1$, or $DY_2/DY_1 = PY_1/PY_2$. When the price of maize increases relative to the cassava price the farmer will increase the maize plant population in his or her field. In contrast to these competitive enterprises are supplementary and complementary enterprises (Figures 1.8 and 1.9).

Supplementary enterprises

In the previous section, the plant densities of cassava and maize were such that cassava output could only be increased at the expense of maize output and vice versa. However, maize plants can be increased to a certain level without negative effect on cassava yield. Maize makes more efficient use of nitrogen so that total output could be increased. The enterprises are called supplementary until crops compete for a scarce factor, sunlight for example (Figure 1.8).

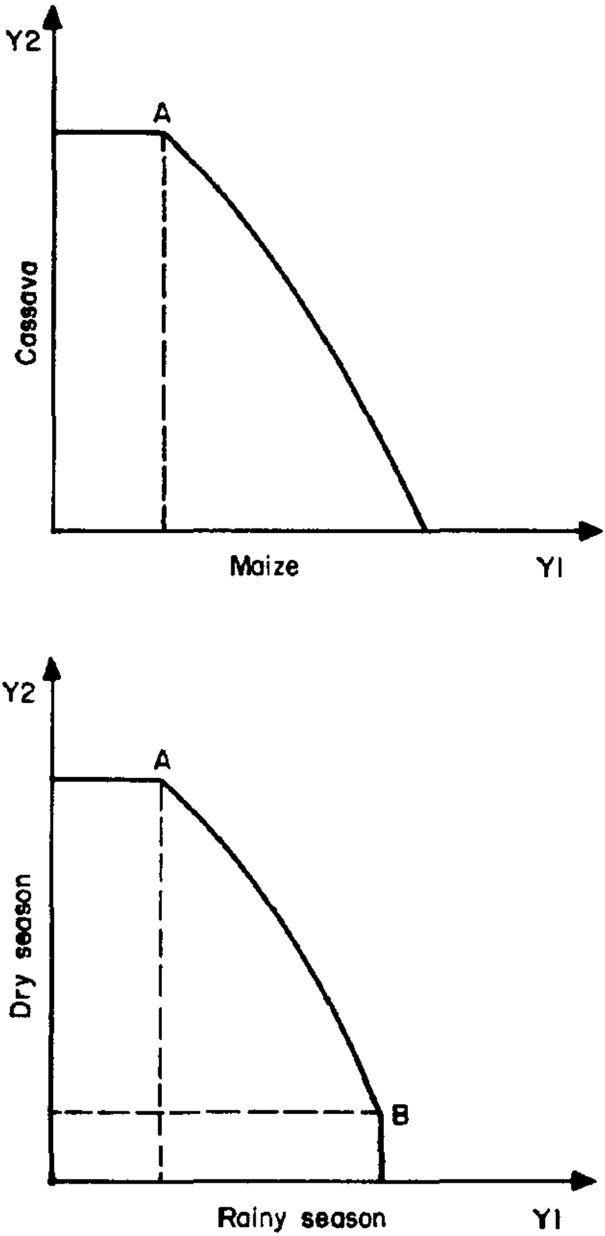

Fig. 1.8. Supplementary Enterprise(s)

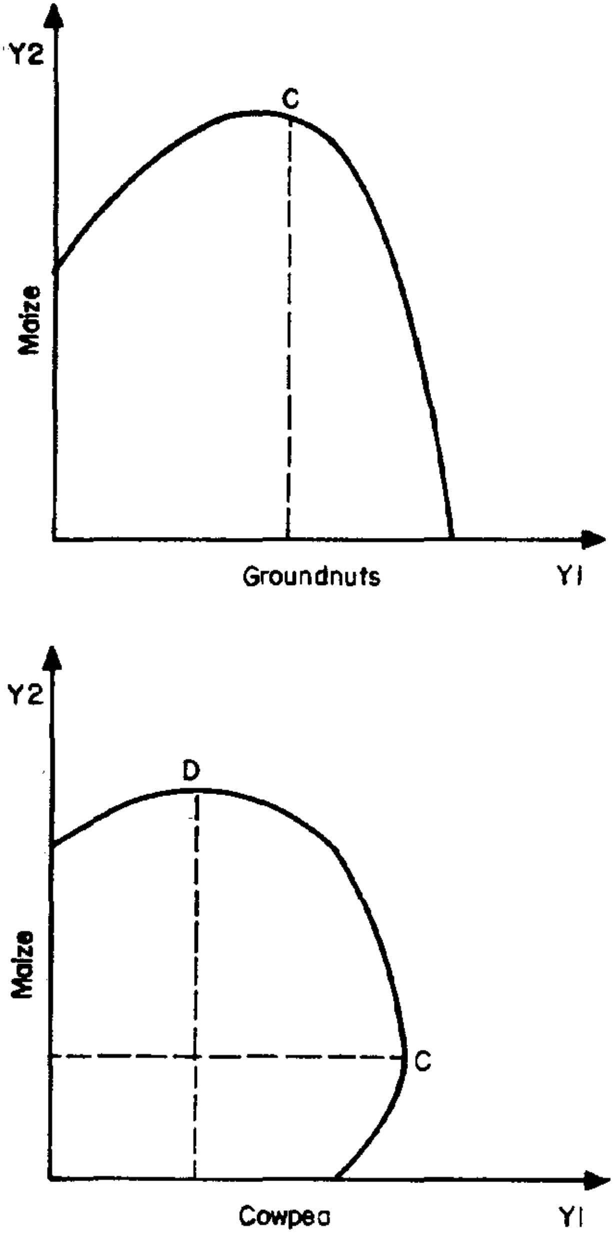

Fig. 1.9. Complementary Enterprise(s)

A farmer could cultivate valley bottoms during the dry season, make handicrafts for sale and work part of the time off the farm. These enterprises are supplementary. Each activity may be increased without reducing the other until they compete for available time.

Complementary enterprises

Enterprises are complementary when increasing the output of one increases the output from another with no increase in resources. A typical example is intercropping with nitrogen-fixing legumes (e.g. intercropping of maize with groundnuts). Groundnuts complement maize as do cowpeas. An experiment in southwestern Nigeria showed that maize, in turn, reduces damage to cowpeas by Maruca (M. testulalis) (Steiner, 1984b). Again, the crops compete at some levels (at C and D in Figure 1.9).

Enterprises may even be supplementary and complementary. In northern Nigeria, the Fulani graze their cattle in the harvested fields. This makes use of crop residues in the off season and is a supplementary enterprise. They are required to tie up the cattle so that the manure is left in the field to complement the crops.

The reason that farmers operate enterprises and follow certain cropping patterns is that they are attempting to maximize the benefits from the supplementary and complementary relationships. Understand these relationships; determine which enterprises compete with one another for which resource(s) and whether a new technology increases the competition. A new technology can be introduced only when it either supplements or complements the traditional enterprise or when the returns to scarce resources are at least as great as they were with the traditional technology.

Risk

Small farmers are averse to risk, and the degree of the aversion increases the closer they are to subsistence. Small farmers can produce only small surpluses. In many climates storage is difficult, and a crop failure almost certainly leads to starvation if not death. Even if surpluses are available in other parts of the country, they are difficult to transport into disaster areas and their prices will be high. Smallholders try to avoid the hazards by placing first priority on food crops. They mix crops that yield well but demand much water with those that are low yielding but drought resistant. Maize/sorghum or maize/cowpea are common crop mixtures.

For small farmers risk can be measured by the variance of yields; for commercial farmers by the variance of net returns. A simple way to conceptualize risk is to specify a disaster level. For example, take the food requirements for a family. Then, from time-series data, determine how often yields or net returns fall below this level. Suppose a farmer crops one hectare. He or she can either grow maize or cowpeas or both. The farmer knows that on the average a normal year is followed by a bad, a good and a normal year. The cycle then repeats itself. For simplicity, assume that the nutritional value of the crops is the same and that the farmer needs 250 units/year.

The variability of maize yields is high, and every four years the crop fails almost completely (Table 1.1). Average yields of cowpea are only a third of the average maize yield, but the variability is small.

The farmer would, of course, like to capitalize on the high yields but to avoid disaster, intercrops the two, trading high average yields for food security. If the farmer plants either maize or cowpeas alone, the total yield would fall 20% below disaster level. Intercropping makes use of the complementarity between the crops. Although the plant population is assumed to be 50%, yields decline less. The farmer is still unable to grow

Table 1.1 Imaginary yields of maize and cowpeas, alone and together, in good, bad and normal years

	Sole Crop		Intercrop	
Year	Maize	Cowpea	Maize	Cowpea
Normal	1000	300	550	175
Bad	200	200	100	125
Good	1400	400	800	225
Normal	1000	300	550	175
Total	3600	1200	2000	700
Average	900	300	500	175

sufficient food, but the shortage is less severe (Figure 1.10).

Risk-averse behavior has obvious implications for trial design and recommendations. Explore risk by repeating experiments over a number of years on farmers' fields. Also, conduct trials over a range of environments to experience the different sources of risk such as rainfall, insects as well as other pests. An observation of zero yield may be of no value for agronomists but contributes to economic evaluation. Risk can be compounded. For example, new varieties usually yield better than traditional varieties, but the variability of yield also increases, especially when fertilizer is a required input. Since fertilizer requires cash outlays the farmer faces the potential not only for crop failure but also for financial loss. So base recommendations on yield or net return plus risk analysis.

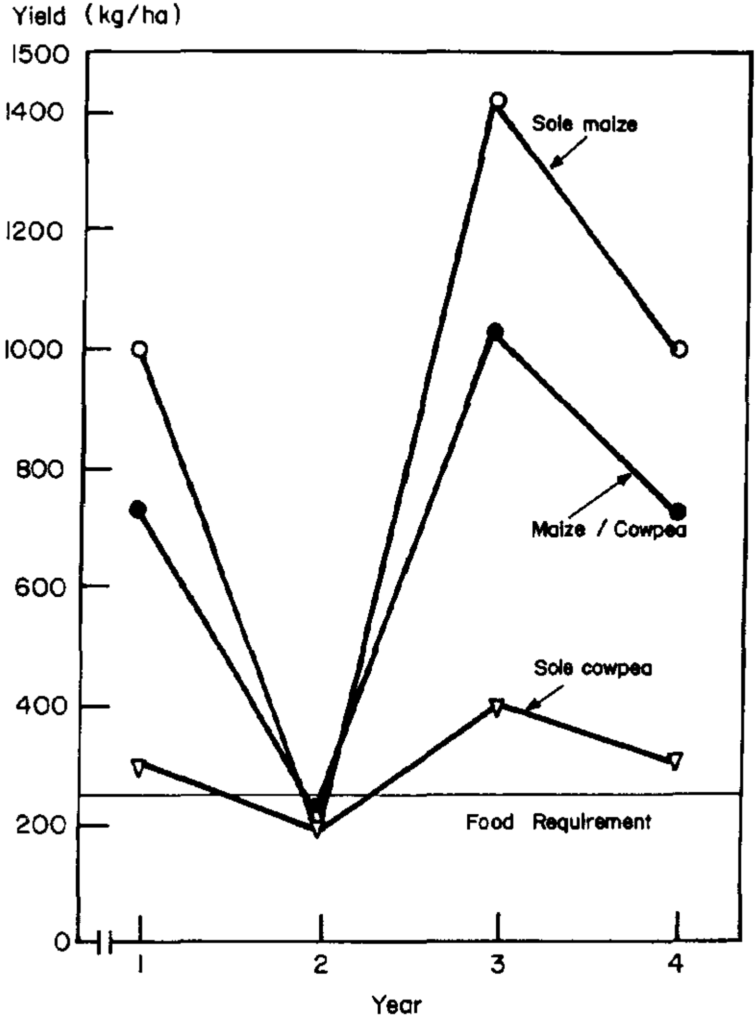

Fig.I.10. Farmers often plant a high yielding, water-demanding crop like maize with a low yielding, drought-resistant crop like cowpeas to ensure their food supply, even though it means sacrificing some returns in good years. Figure shows hypothetical relationship between years and crop yields.

Annex 2
Some statistical techniques

Annex 2: Some statistical techniques

In Chapter IV we referred to two analytical techniques which will be described here in detail.

1. The analysis of stepwise trials by orthogonal polynomials

In the example of the stepwise maize + cassava trial given in Chapter IV, the treatments were as follows (Table 2.1):

Table 2.1 Treatments in a stepwise trial with fertilizer and improved varieties for a maize and cassava pattern

Treatment	Fertilizer level	Variety Maize	Variety Cassava	Note
A	Farmers'	Farmers'	Farmers'	Baseline
B	Farmers'	Improved	Farmers'	Step 1
C	Improved	Improved	Farmers'	Step 2
D	Improved	Improved	Improved	Package

Suppose that the treatment means for this trial, replicated five times expressed in $/ha were: 301, 363, 384 and 408 for A, B, C and D respectively and with a standard error of 72.8 $/ha which would represent a realistic 20% coefficient of variation.

If the treatments were not structured, a standard analysis of variance (ANOVA) would have given the following results (Table 2.2).

The conclusion would be that there are no treatment differences. The usual Newman-Keuls test for differences among all treatment combinations (Snedecor and Cochran, 1967) also shows no significant differences, the minimum significant differences between the extremes being $136.70.

Table 2.2 Standard ANOVA for the maize + cassava trial

	d.f	SS	MS	F
Mean	1	2649920		
Farms	4			
Treatments	3	31530	6306	1.190 n.s
Error	12		EMS = 5300	
Total	20			

Now, using our predetermined order of the treatments, we assume that each successive treatment makes a positive contribution to the monetary yield. This is similar to an expected increase in yield by each additional dose of fertilizer in a fertilizer rate trial. Therefore, we use orthogonal polynomials to test for linear and higher order trends among the treatments. The calculations are as follows:

Linear component =
(-3 x 301) + (-1 x 363) + (1 x 384) + (3 x 408) = 342

$$\text{Linear SS} = \frac{5 \times 342^2}{20} = 29{,}241$$

The coefficients for mutiplying the treatment means and the divisor (20) for the sum of squares (SS) are from Table 2.3 and the multiplier (5) is the number of replicates.

Quadratic component =
(1 x 301) + (-1 x 363) + (-1 x 384) + (1 x 408) = -38

$$\text{Quadratic SS} = \frac{5 \times -38^2}{4} = 1{,}805$$

Cubic component =
(-1 x 301) + (3 x 363) + (-3 x 384) + (1 x 408) = 44

$$\text{Cubic SS} = \frac{5 \times 44^2}{20} = 484$$

With an EMS of 5300 (20% CV) with 12 degrees of freedom, the F values are 5.52, 0.34 and 0.09 and the linear effect is significant with a positive component. The conclusions would be that our innovations have improved the market value but that we do not have enough information to distinguish among them. The negative quadratic component weakly confirms our ordering of the innovations.

Table 2.3 Coefficients and divisors for the analysis of data by orthogonal polynomials.

Number of treatments		Coefficients					Divisor
3	Linear	-1	0	+1			2
	Quadratic	+1	-2	+1			6
4	Linear	-3	-1	+1	+3		20
	Quadratic	+1	-1	-1	+1		4
	Cubic	-1	+3	-3	+1		20
5	Linear	-2	-1	0	+1	+2	10
	Quadratic	+2	-1	-2	-1	+2	14
	Cubic	-1	+2	0	-2	+1	10
	Quartic	+1	-4	+6	-4	+1	70

A full table of coefficients for orthogonal polynomials is given in most statistical textbooks, for instance on page 351 of Snedecor and Cochran (1967). Table 2.3 will be sufficient for most on-farm purposes.

The approach with polynomials makes rather strong assumptions about the ordering and may therefore be objected to. A similar but more conservative approach is based on meaningful contrasts between the treatments, without assuming equidistant steps. (Thanks are due to Mr Peter Walker for suggesting this approach).

The important contrasts are:

1. between treatment 1 (the baseline) and all the others

2. between step 1 on the one hand and steps 2 and 3 on the other

3. between step 2 and 3.

The only difference in the analysis with the one using polynomials is the coefficients and divisors used in the calculations. They are given in Table 2.4.

Table 2.4 Coefficients and divisors for the analysis of the data by contrasts between treatments (4 treatments).

Contrasts	Coefficients				Divisor
1 vs (2, 3, 4)	-3	+1	+1	+1	12
2 vs (3, 4)	0	-2	+1	+1	6
3 vs (4)	0	0	-1	+1	2

The calculations are as follows:

First contrast =

(-3 x 301)+(1 x 363)+(1 x 384)+(1 x 408) = 252

$$SS = \frac{5 \times 252^2}{12} = 26,460$$

Second contrast =

(-2 x 363)+(1 x 384)+(1 x 408) = 66

$$SS = \frac{5 \times 66^2}{6} = 3,630$$

Third contrast =

(-1 x 384)+(1 x 408) = 24

$$SS = \frac{5 \times 24^2}{2} = 1,440$$

The F values are 4.99, 0.68 and 0.27. The conclusions are as follows: Our innovations have improved the market value but the fertilizer and the improved cassava variety did not give a significant additional improvement over the improved maize variety. (The absence particularly of a fertilizer response would require explanation and indicates the need for further research.)

2. Accounting for between farm variability

Coefficients of variation are often very high in on-farm trials for several reasons such as:

- high local variability between plots within fields; and

- variability of treatment effects between fields due to differences in cropping history, soil quality, quality of field maintenance etc.

Table 2.5 Yield data (tons/ha) of 3 rice varieties and ANOVA, Bida, Nigeria (Palada and Vogel, 1986)

Variety	Farms 1	2	3	4	5	6	7	8	9	10	11	12	V	V
Local	3.08	3.16	2.74	3.60	2.74	2.31	2.99	1.94	2.46	1.33	0.99	0.60	27.94	2.33
ITA 306	3.74	4.15	5.32	2.62	4.89	5.26	4.38	1.74	3.20	2.92	1.60	0.63	40.45	3.37
FARO 29	2.56	3.73	1.94	1.96	2.64	5.22	2.78	2.43	2.78	1.81	2.79	0.77	31.11	2.59
Σr	9.38	11.04	10.01	8.18	10.27	12.79	10.15	6.11	8.44	6.06	5.38	1.70	99.5	
$\bar{r}(=e_i)$	3.13	3.68	3.33	2.73	3.42	4.26	3.38	2.04	2.81	2.02	1.79	0.57		2.76

ANOVA

	d.f.	SS	MS	F
Mean	1	275.01		
Replicates	11	33.65		
Varieties	2	7.05	3.525	4.96**
Error	22	15.65	0.711	
Total	36	331.36		

CV = 30.6%

The field team should collect information on the differences between fields in order to explain differences in response to the treatments. Fertilizer response could, for instance, depend on the degree of weed infestation of the field.

It can often be assumed that the mean yield over all treatments in a given field reflects the accumulated effects of several of these factors. The mean yield in each field is then used as a separate covariable and the regression of yields for each treatment separately is calculated. This can tell us whether particular treatments are more sensitive to site than others, i.e. wether there is interaction between treatments and sites, without the need for replication within sites.

As an example, Table 2.5 gives the yields of 3 rice varieties in 12 farmers' fields in the Bida area, Nigeria (Palada and Vogel, 1986) and the standard ANOVA. The variety effect is very significant but one would like to know whether varietal performance varies with farmers' or field conditions. The very high CV value also points to an additional source of variation that is not accounted for in the standard ANOVA.

Using the average yield for each farm as a compound "index" for the "environment" we proceed as follows:

1. Calculate sum of squares (SS) for regression on the "environmental index" (e_i) for each variety separately:

$$SS = S^2 y_i e_i / S e_i e_i$$

$$= (\Sigma y_i e_i - \Sigma y_i \Sigma e_i / n)^2 / (\Sigma e^2{}_i - (\Sigma e_i)^2 / n)$$

For the local variety:

$$SS = (85.21 - 27.94 \times 33.17/12)^2 / (102.82 - 33.17^2/12) = 5.72$$

Variety 2:

$$SS = (127.45 - 40.45 \times 33.17/12)^2/(102.82 - 33.17^2/12) = 21.97$$

Variety 3:

$$SS = (95.90 - 31.11 \times 33.17/12)^2/(102.82 - 33.17^2/12) = 8.82$$

2. The SS due to differences in regression equals the sum of the individual regression SS minus a correction factor. This correction factor is calculated by regressing all varieties together on the environmental index, giving:

SS correction =

$$(308.56 - 99.5 \times 99.5/36)^2/(3 \times 102.82 - 99.5^2/36)$$

$$= 33.65$$

(The correction factor is equal to the SS for farms.)

SS due to differences in regression thus equals

$$36.51 - 33.65 = 2.86.$$

3. The full ANOVA Table now becomes as shown in Table 2.6.

The conclusion is that there is no significant difference in the varieties' reaction to our environmental index. The CV is still high indicating a high variability of plots within fields.

It is always wise to record any differences between farms during the season that could later

Table 2.6 ANOVA for data of Table 2.5, with regression on environmental index

	df	SS	MS	F
Mean	1	275.01		
Farms	11	33.65		
Varieties	2	7.05	3.525	5.512**
Differences in regression on environmental index	2	2.86	1.43	2.236n.s.
Error	20	12.79	0.6395	
Total	36	331.36		

CV = 29.0%

explain the differences in treatment effects. Possible factors are soil type, previous cropping history, degree of weediness, in this case also the occurrence of iron toxicity etc.

These factors, quantified in an appropriate manner (e.g. scores for weediness on a scale of 0-5) can be used in the analysis in exactly the same way as the "environmental index".

When a significant difference is found, it is illuminating to draw the calculated regression line of each treatment against the chosen variable (such as the environmental index). This is done for the present trial in Figure 2.1, although there was no significant effect. The slope of the line is calculated from:

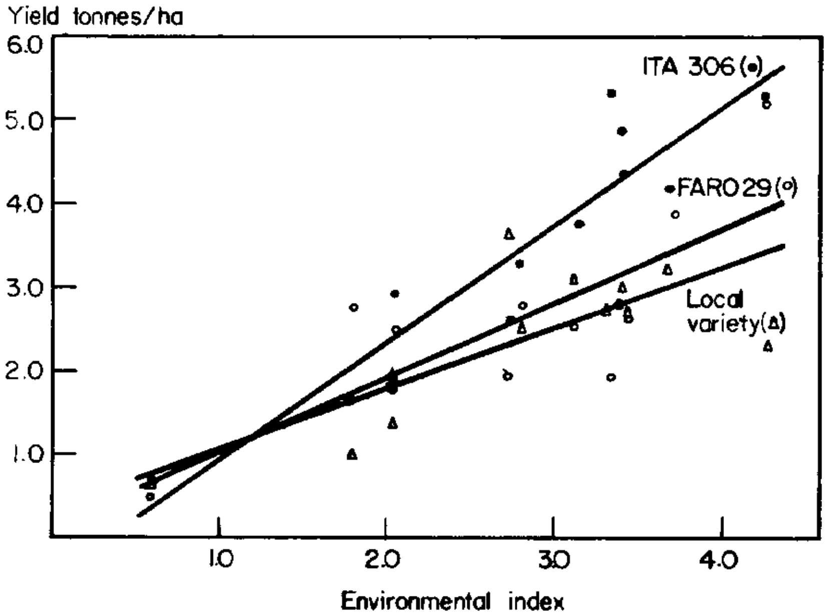

Fig. 2.1. Regression of the yields of three rice varieties on the environmental index.

$$b = Sy_i e_i / Se_i e_i$$

$$= (\Sigma y_i e_i - \Sigma y_i \Sigma e_i / n) / (\Sigma e^2_i - (\Sigma e_i)^2 / n)$$

The slopes for the 3 varieties equal 0.72; 1.40 and 0.89.

The intercepts equal $\bar{y}$ – be (0.34; –0.49 and 0.13 respectively).

The regression lines are thus as follows:

Local variety: y = 0.34 + 0.72 e

ITA 306 : y = –0.49 + 1.40 e

FARO 29 : y = 0.13 + 0.89 e

A treatment or variety with a small slope is called stable, that is, it varies little across farms and vice versa. The analysis is therefore often called "stability analysis" (Hildebrand, 1985). It is not wise to draw these graphs unless significant effects have been identified in the ANOVA: an effect may be suggested that actually cannot be substantiated by the data.

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